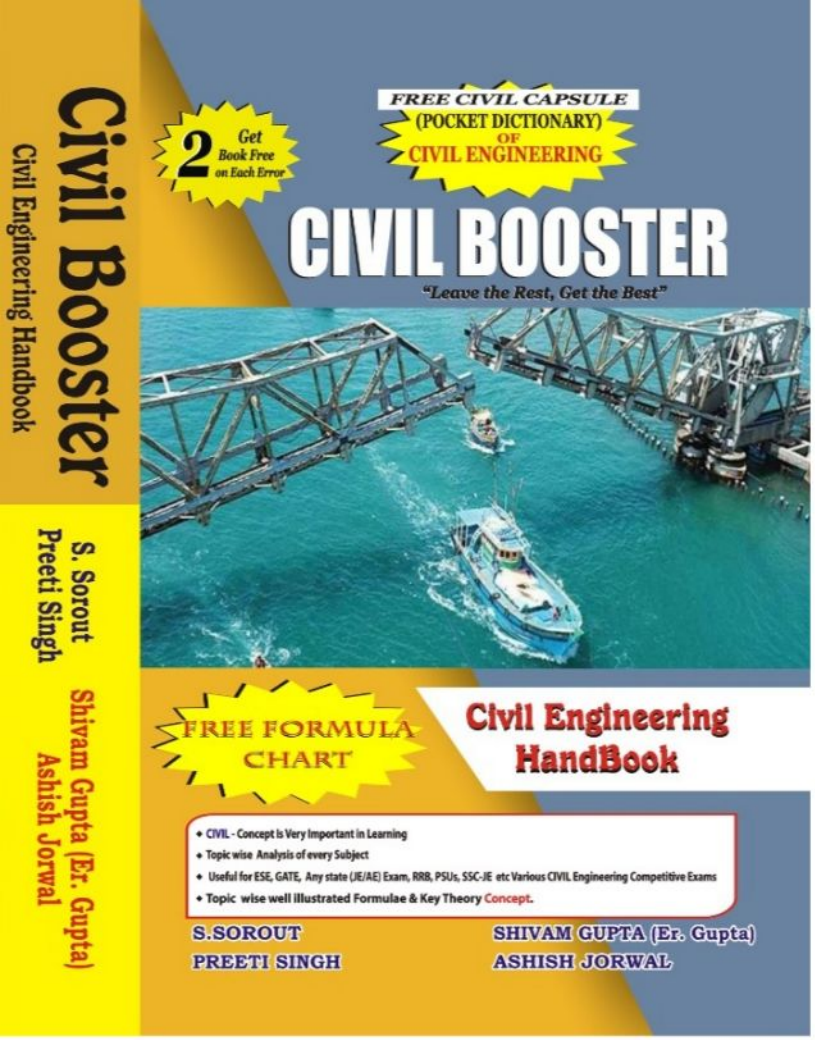
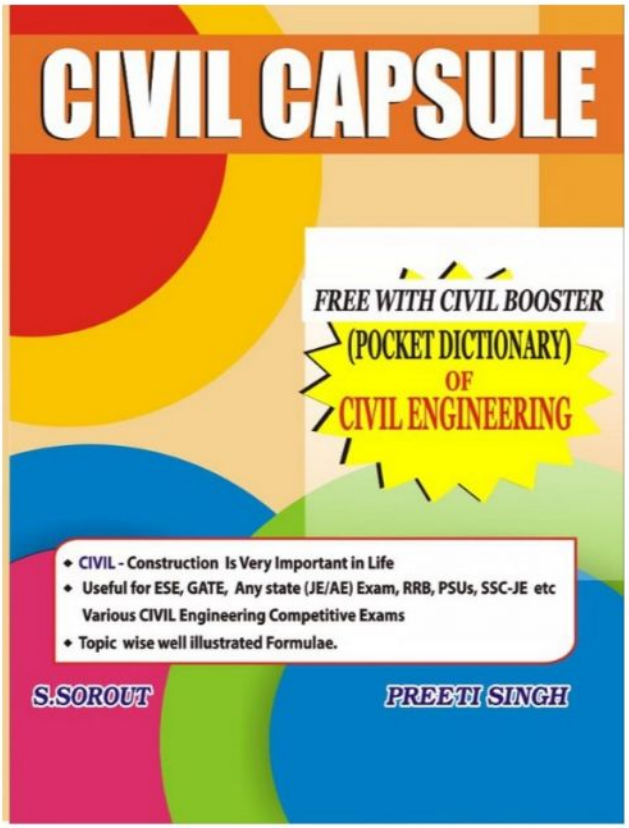
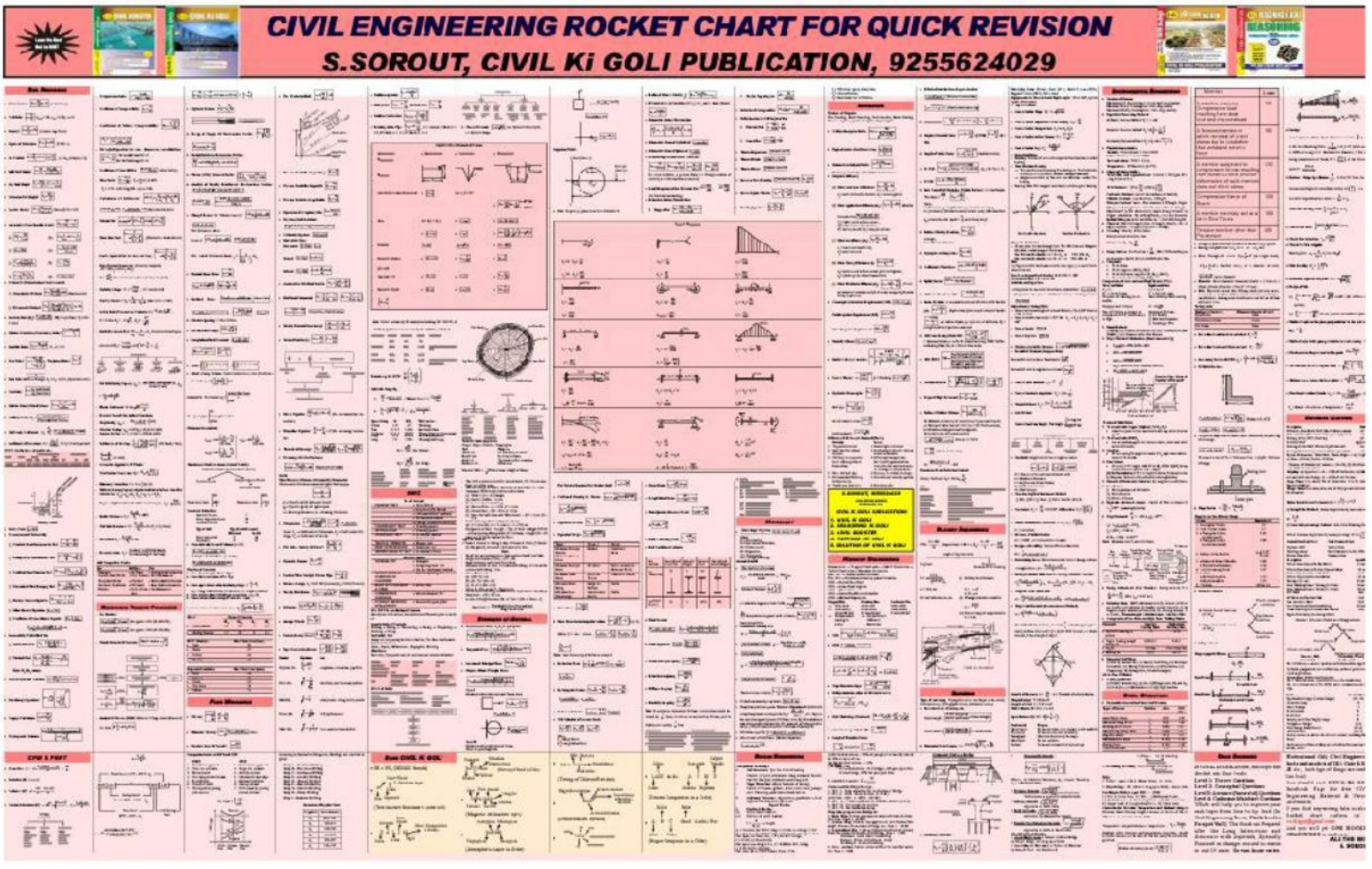




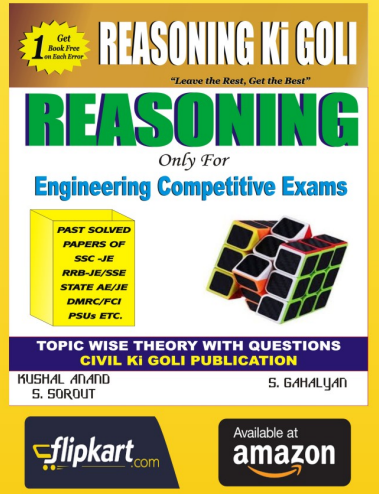
Best Civil Engineering Handbook Civil Booster (with Chart, Pocket Dictionary) Very useful for ESE, GATE, AE, JE, PSU's Exams



GOAL OF THIS BOOK

PAPER WISE ANALYSIS WILL HELP YOU TO UNDERSTAND THE IMPORTANCY OF EACH SUBJECT







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2. Electrical Engineering Rocket Chart
3. Mechanical Engineering Pocket Dictionary
4. Electrical Engineering Pocket Dictionary

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MRP 495/-

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Civil Booster

Civil Engineering Handbook

S. Sorout
Preeti Singh

VIVEK SHARMA
M K SHARMA

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(POCKET DICTIONARY)
OF
CIVIL ENGINEERING

CIVIL BOOSTER

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Free formula Chart

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- CIVIL - Concept Is Very Important in Learning
- Topic wise Analysis of every Subject
- Useful for ESE, GATE, Any state (JE/AE) Exam, RRB, PSUs, SSC-JE etc Various CIVIL Engineering Competitive Exams
- Topic wise well illustrated Formulae & Key Theory Concept.

S.SOROUT
PREETI SINGH

VIVEK SHARMA
M K SHARMA

CIVIL BOOSTER
(A HAND BOOK OF CIVIL ENGINEERING)

by

PREETI SINGH

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PREFACE

It is an immense pleasure to present the **CIVIL BOOSTER (A Hand Book of CIVIL Engineering)** in the hand of young Engineers. After B. Tech/Diploma, An Engineer has to appear in competitive examinations for good job and has to answer objective type questions. So, this book has come out after long observation and detailed interaction with the students preparing for various Engineering exams. This book contain Topic wise theory which is completely as per previous year of GATE, ESE, SSC-JE, PSUs and Various State Papers. Today competitive environment, in-depth Knowledge, qualitative guidance, time mangement and good source of study is required to achieve Goals. It will help you in the quick revision of CIVIL Engineering Subjects.

I am thankful to my **Teachers (Sh. Arpan Manchanda, Mohd. Shabbir, Sh. Navin Sharma, Sh. Prabhu-Dayal Hans & Sh. Ramesh Chand Dagar) & Students** who encouraged me to write this book.

I have true desire of serving to society and Nation by way of making easy path of the education for People of India. You should visit the **CIVIL Ki GOLI** You-Tube channel for better use of this book.

Every care has been taken to bring an Error free book. However, if you find any wrong Data in it, Inform us at civilkigoli@gmail.com.You will get **two book free on each error.** I will be highly obliged if you message/ mail your feedback or suggestion on civilkigoli@gmail.com.

Date: March 2021 **Preeti Singh**

Contents

Competitive Exam: Quick Review **(A-I)**

(A) ESE Previous Years Cut off
(B) SSC-JE Previous Years Cut off
(C) GATE Previous Years Cut off
(C) SSC-JE Previous Years Appeared Condidate Details
(D) ESE & SSC-JE Previous Years Vacancy Details
(E) Today's Increasing Competion Review
(F) GATE Previous Years Subject-Wise Analysis
(G) ESE Previous Years Subject-Wise Analysis
(H) SSC JE Previous Years Subject-Wise Analysis
(I) **HOW TO GET FREE BOOK ON EACH ERROR**

UNIT 1: Building Material Construction **(1-91)**

1. Important Indian Standard Codes 1-1
2. Cement 2-11
3. Concrete 3-31
4. Timber 32-41
5. Aggregates 42-46
6. Bricks 47-53
7. Brick Masonry 54-56
8. Mortar & Lime 57-59
9. STONE 60-64

ADVANCE TOPICS

10. Door , Window & Roof 65-70
11. Stair Case 71-72
12. Floors 73-73
13. Steel & Glass 74-77
14. Paint & Varnish 78-81
15. Building Maintenance Engineering 82-85
16. Building Laws 86-91

UNIT 2: Estimation-Costing **(92-113)**

1. Basic Measurement & Work 92-94
2. Valuation 95-101

3.	Estimation and Area Types	102-106
4.	Material Calculation & other miscellaneous topics	107-113

UNIT 3: Soil Mechanics (114-196)

1.	Soil Origin & Its Properties	114-121
2.	Index Properties of Soil	122-128
3.	Classification of Soil	129-131
4.	Clay Mineral & Soil Structure	132-133
5.	Compaction of Soil	134-136
6.	Compressibility and Consolidation	137-141
7.	Effective Stress, Capillarity and Permeability	142-146
8.	Seepage Through Soil	147-148
9.	Shear Strength of Soil	149-155
10.	Earth pressure and Retaining walls	156-163
11.	Shallow Foundation	164-175
12.	Deep Foundation	176-184

ADVANCE TOPICS

13.	Vertical Stressess	185-187
14.	Stability of slopes	188-190
15.	Soil Exploration	191-193
16.	Expansive Soil	194-195
17.	Soil Stabilization	196-196

UNIT 4: Solid Mechanics (197-254)

1.	Properties of Material	197-211
2.	Shear Force & Bending Moment	212-216
3.	Deflection of Beams	217-222
4.	Principal Stress & Principal Strain	223-226
5.	Theories of Failure	227-230
6.	Bending Stress	231-234
7.	Shear Stress	235-238
8.	Combined Stress	239-241
9.	Columns	242-244

ADVANCE TOPICS

10.	Springs	245-247
11.	Torsion of Circular Shaft	248-251
12.	Thick & Thin Cylinder/Sphere	252-254

UNIT 5: Navigation Channel Harbour Dock (255-263)

1. Navigation Channel 255-257
2. Harbour 258-259
3. Breakwaters 260-261
4. Dock 262-263

UNIT 6: Reinforcement Cement Concrete (264-325)

1. Basic of RCC 264-272
2. Limit State Method & Beam 273-280
3. Codal Provisions for Beam and Slab 281-287
4. Shear 288-293
5. Bond and Anchorage 294-297
6. Torsion 298-299
7. Column 300-304
8. Wall & Footing 305-310
9. Pre-Stressed Concrete Basic 311-313
10. IS Code Recommendations for Pre-Stressed Concrete 314-316
11. Analysis of Pre-Stress And Bending Stresses 317-319
12. Losses & Deflection in Pre-Stress Concrete 320-325

UNIT 7: Earthquake (326-334)

UNIT 8: Fluid Mechanics (335-395)

1. Properties of Fluid 335-341
2. Pressure and its Measurement 342-345
3. Hydrostatic–Forces 346-348
4. Buoyancy and Floatation 349-351
5. Liquid in Relative Equilibrium 352-354
6. Fluid Kinematics 355-359
7. Fluid Dynamics 360-365
8. Momentum Equation and Application 366-367
9. Weir and Notches 368-373
10. Laminar Flow 374-376
11. Turbulent Flow 377-379
12. Boundary Layer Thickness 380-384
13. Dimensional Analysis and Model Studies 385-388
14. Flow Through Pipes 389-395

UNIT 9: Hydraulic Machine (396-414)

1. Turbines 396-405
2. Hydraulic Pumps 406-414

UNIT 10: Open Channel Flow (415-426)

1. Introduction 415-417
2. Uniform – Flow 418-420
3. Energy-Depth Relationship 421-422
4. Gradually Varied Flow 423-423
5. Rapid Varied Flow 424-426

UNIT 11: Surveying (427-484)

1. Fundamentals of Surveying 427-432
2. Linear Measurement 433-438
3. Compass- Surveying 439-443
4. Theodolite 444-446
5. Traversing 447-450
6. Levelling 451-455
7. Techeometry 456-458
8. Plane-Table Surveying 459-461
9. Contouring 462-463
10. Curves 464-466

ADVANCE TOPICS

11. Field Astronomy 467-470
12. Measurement of Area and Volume 471-474
13. Photogrammetry 475-480
14. Theory of Errors 481-484

UNIT 12: Hydrology (485-510)

1. Introduction 485-486
2. Precipitation and Measurement 487-492
3. Abstractions from Precipitation 493-495
4. Stream Flow Measurement 496-497
5. Runoff & Drought 498-501
6. Hydrograph 502-504
7. Floods & Flood Routing 505-510

UNIT 13: Irrigation (511-540)

1.	Irrigation & Methods	511-514
2.	Soil-moisture Plant Relationship	515-518
3.	Water Requirement of Crops	519-523
4.	Canal-Design	524-528
5.	Earthen-Dams	529-529
6.	Canal-Irrigation	530-530
7.	Water-Logging	531-533
8.	Gravity Dams	534-537
9.	Spillway	538-540

UNIT 14: Environmental Engineering (541-629)

1.	Water Demand, Source & Conveyance	541-550
2.	Quality Parameters of Water	551-558
3.	Treatment of Water	559-575
4.	Distribution System	576-581
5.	Waste Water Characteristics	582-586
6.	Disposal of Sewage Waste	587-590
7.	Design of Sewerage System and Sewer Appurtenances	591-598
8.	Sewage Treatment	599-613
9.	Solid Waste Management	614-616
10.	Air Pollution	617-625
11.	Noise Pollution	626-629

UNIT 15: Highway Engineering (630-694)

1.	Introduction	630-632
2.	Geometric Design	633-638
3.	Horizontal Alignment	639-644
4.	Vertical Alignment	645-647
5.	Traffic Engineering Studies	648-655
6.	Traffic Control Regulation	656-663
7.	Highway Material	664-674
8.	Pavement Design	675-679
9.	Flexible Pavement Design	680-684
10.	Design of Rigid Pavement	685-690
11.	Highway Maintenance	691-694

UNIT 16: Airport engineering (695-705)

1. Introduction 695-697
2. Airport Planning 698-698
3. Runway Design 699-701
4. Airport Capacity 702-702
5. Taxiway Design 703-705

UNIT 17: Tunnel Engineering (706-718)

UNIT 18: Bridge Engineering (719-730)

UNIT 19: Railway Engineering (731-751)

1. Basic of Railway and Rail Joints 731-733
2. Sleepers and Track Fasteners 734-735
3. Ballast and Track Alignment 736-737
4. Track Stress and Creep 738-739
5. Geometric Design of the track 740-744
6. Points and Cross 745-748
7. Railway Station and Station Yard 749-749
8. Signalling and control Systems 750-750
9. Traction and Tractive Resistance 751-751

UNIT 20: CPM & PERT (752-772)

1. Project Management 752-754
2. Network Technique 755-756
3. Programme Evaluation Review Technique 757-760
4. Critical Path Method 761-763
5. CRASHING, Updating & Resource Allocation 764-766
6. Fundamental of Equipments 767-769
7. Excavation Equipment 770-772

UNIT 21: Applied Mechanics (773-791)

1. Basic Fundamental 773-776
2. Velocity & Projectile Motion 777-784
3. Friction 785-786
4. Force 787-789
5. Work, Power & Energy 790-791

UNIT 22: Structural Analysis (792-829)

1.	Determinacy, Indeterminacy & Stability of Structure	792-795
2.	Force Method Of Analysis	796-798
3.	Slope-Deflection Method	799-802
4.	Moment-Distribution Method	803-805
5.	Arches	806-811
6.	Trusses	812-816
	ADVANCE TOPICS	
7.	Influence-Line Diagram	817-823
8.	Matrix-Method Of Analysis	824-829

UNIT 23: Design of Steel Structure (830-876)

1.	Rivets	830-836
2.	Limit State Method of Design	837-838
3.	Bolts	839-844
4.	Welded Connections	845-849
5.	Tension Member	850-854
6.	Compression-Members	855-861
7.	Column Bases and Caps	862-863
8.	Beams (WSM)	864-866
9.	Plate-Girders	867-869
10.	Industrial Building	870-871
11.	Plastic-Analysis	872-876

UNIT 24: Auto Cad (877-893)

ESE - CIVIL ENGG. PAPER 1 CUT OFF

Year	UR	OBC	SC	ST	OH	HH
2011	125	121	107	107	-	-
2012	149	146	124	105	87	87
2013	165	153	110	102	113	101
2014	202	186	156	100	90	101
2015	262	228	180	187	91	114
2016	229	214	187	183	83	76
2017	202	177	148	151	102	68
2018	207	194	169	188	114	87
2019	188	185	143	159	88	52

ESE - CIVIL ENGG. PAPER MAINS CUT OFF

Year	UR	OBC	SC	ST	OH	HH
2011	283	239	224	221	125	159
2012	342	296	280	255	126	126
2013	352	301	267	252	159	-
2014	391	373	315	293	158	158
2015	516	470	376	411	197	225
2016	464	418	387	395	223	143
2017	520	459	415	439	315	145
2018	546	502	467	513	308	161
2019	541	500	453	482	252	145

ESE - CIVIL ENGG. PAPER FINAL CUT OFF

Year	UR	OBC	SC	ST	OH	HH
2011	451	427	369	387	216	251
2012	512	484	422	422	274	393
2013	500	475	412	419	299	-
2014	572	540	467	453	329	263
2015	674	630	539	552	380	323
2016	623	588	538	539	414	217
2017	69	650	564	578	437	311
2018	710	679	609	671	476	423
2019	702	668	596	640	466	241

SSC JE PAPER 1 CUT OFF (OUT OF 200)

Year	UR	OBC	SC	ST	OH	HH	EWS
2019							
2018	127.4	122.91	107.61	107.01	97.45	61.61	118.99
2017	117	110.75	101.75	105	91.5	61.75	
2016	100	92.5	84.5	58.5	72.5	40	
2015	103.75	91.25	88	87.75	78	30	
2014	93.75	82	75.75	70	69	40	
2013	78	70.5	66.25	63.5	60	40	
2012	62.25	52.5	47.75	43.5	30	30	

SSC JE PAPER 2 CUT OFF (OUT OF 300)

Year	UR	OBC	SC	ST	OH	HH
2017 (Out of 500)	244.75	244.75	220.75	228	231.25	152
2016 (Out of 500)	220.5	186	164	163.75	139.5	87.5
2015	131	62	50	50	50	40
2014	136	100	80	79	79	30
2013	83	69	62	56	59	32
2012	84	54	62	40	40	45
2018 (Out of 500)	250.49	209.38	193.68	201.54	162.01	132.68

SSC JE FINAL CUT OFF RANGE

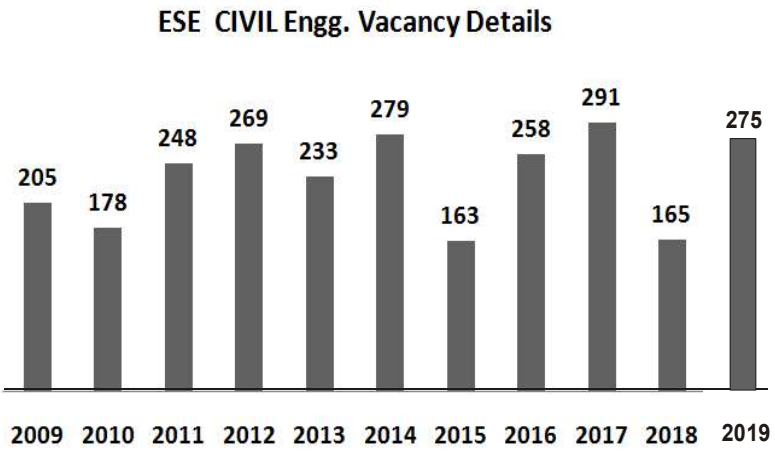
Year	UR	OBC	SC	ST	EWS
2018	295 - 275	280 - 250	270 - 235	270 - 245	295 - 265
2017	289.75-301.75	283.5-292.0	262.75-272.25	279.0-291.0	
2016	238.25-264.75	236-252.25	205.25-225	228.25-245	
2015	235.5-284.75	236.25-276.25	213.5-289.75	236.25-267.75	
2014	285-353	287.75-334.5	265.25-307.75	250-392.75	
2013	199.75-280.75	226-291.5	213.25-245.5	205-232.25	
2012	184-276.75	190-258.5	168-238.75	144.25-237.25	

GATE - CIVIL ENGG. CUT OFF

Year	UR	OBC	SC/ST
2020	32.9	29.6	21.9
2019	28.2	25.4	18.8
2018	26.9	24.2	17.9
2017	28.7	25.8	19.1
2016	25	22.5	16.6
2015	27.52	24.77	18.34
2014	26.57	23.91	17.71
2013	27.13	24.42	18.09
2012	33.03	29.73	22.02
2011	25	22.5	16.67

SSC JE APPEARED CANDIDATE DETAILS

SSC JE Exam Information	2018	2017	2016	2015	2014	2013	2012
Total Candidates appeared in Exam	377133	569930	339379	3,08,852	2,64,945	1,65,661	1,02, 145
Candidates qualified in paper-I (Civil)	8697	4433	5892	6788	8852	4809	5025
Candidates qualified in paper-I (Elect/Mech)	1938	1422	2440	1801	2135	1980	1986
Candidates qualified in paper-II (Civil)	3800	1280	2765	3291	3567	1980	2680
Candidates qualified in paper -II (Elect/Mech)	883	319	1177	836	850	842	1083
Final selected Candidates (Civil)	1506	256	918	1242	1718	844	1407
Final selected Candidates (Elect/Mech)	334	85	356	330	398	376	563


ESE CIVIL Engg. Vacancy Details
205
178
248
269
233
279
163
258
291
165
275
2009
2010
2011
2012
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2014
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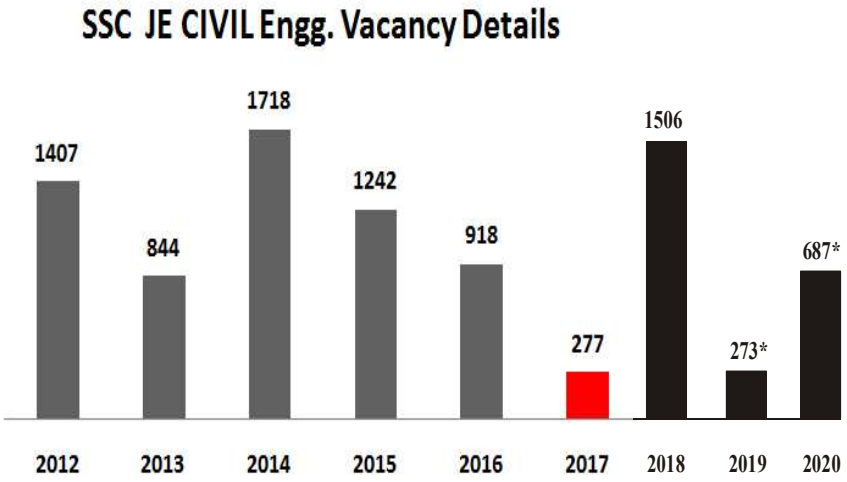
2016
2017
2018
2019


SSC JE CIVIL Engg. Vacancy Details
1407
844
1718
1242
918
277
1506
273*
687*
2012
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2014
2015
2016
2017
2018
2019
2020

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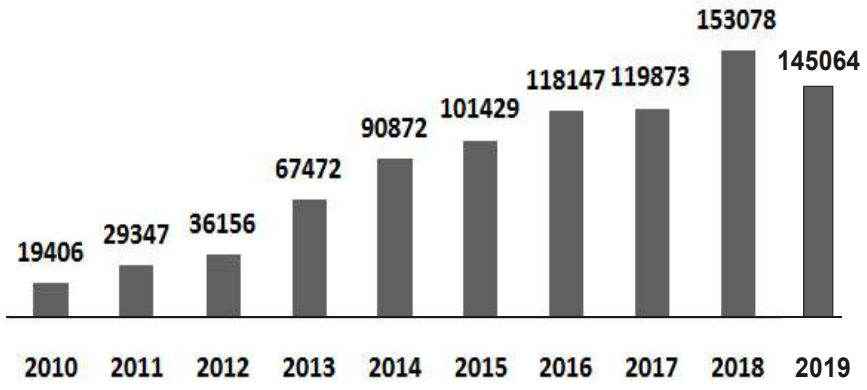
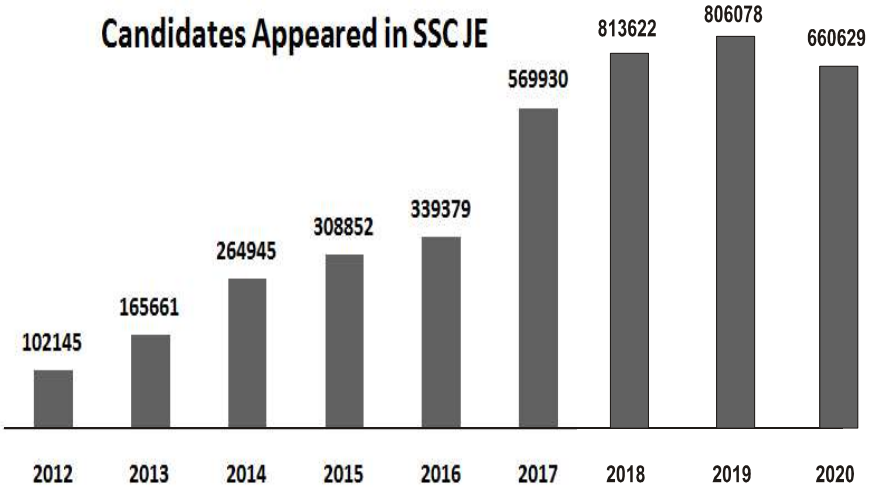

GATE CIVIL Engg.
Appeared Candidates
19406
29347
36156
67472
90872
101429
118147
119873
153078
145064
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


Candidates Appeared in SSC JE
102145
165661
264945
308852
339379
569930
813622
806078
660629
2012
2013
2014
2015
2016
2017
2018
2019
2020

GATE Subject-Wise Analysis

Year	SOM	SA	SOIL Mechanics	FM	Irrigation	Hydrology	RCC	Steel	Highway	Survey	E.E
2003	12	12	28	19	4	11	13	10	9	0	22
2004	13	9	26	26	3	4	12	12	15	0	21
2005	8	10	24	17	8	6	14	9	12	0	20
2006	21	6	21	17	3	6	11	6	14	10	15
2007	13	9	23	16	4	6	12	6	16	10	15
2008	17	6	25	15	6	1	12	5	20	9	14
2009	12	2	16	7	3	4	6	6	10	5	14
2010	9	3	17	7	4	1	5	4	7	3	9
2011	7	0	15	7	2	5	8	5	11	2	9
2012	9	0	15	4	2	7	8	3	10	3	10
2013	6	9	14	9	2	6	5	5	9	5	8
2014 set-1	2	8	12	13	0	2	7	4	10	5	10
2014 set-2	9	7	14	10	2	3	3	2	9	5	10
2015 set-1	5	4	12	12	1	2	5	4	10	6	6
2015 set-2	8	0	15	9	2	2	7	4	9	6	10
2016 set-1	6	3	17	7	0	2	6	4	6	5	10
2016 set-2	7	3	15	7	1	3	5	4	7	5	10
2017 set-1	6	5	13	8	2	3	5	2	9	4	10
2017 set-2	8	1	13	8	2	4	3	2	7	6	11
2018 set-1	7	2	14	9	0	5	9	3	9	4	10
2018 set-2	5	1	15	7	1	4	7	5	9	4	10
2019 set-1	5	4	17	8	3	3	4	5	6	7	10
2019 set-2	7	6	15	9	4	3	2	4	9	4	8
2020 set-1	6	6	15	9	1	1	5	2	8	4	14
2020 set-2	3	7	14	6	3	4	4	3	11	4	11

F

ESE Subject-Wise Analysis

Year	SOM	SA	SOIL Mechanics	FM	Irrigation	Hydrology	RCC	Steel	Highway	Survey	E.E	CPM	BMC
2003	26	10	22	30	9	10	22	21	19	10	19	19	22
2004	20	17	30	22	6	13	20	24	15	10	29	13	21
2005	25	15	37	13	6	5	25	23	20	8	27	14	18
2006	20	20	20	29	8	15	25	23	17	12	18	11	20
2007	23	13	21	30	7	13	22	23	20	9	20	13	26
2008	21	18	30	16	3	6	15	21	28	15	21	12	27
2009	26	15	27	20	12	10	24	21	18	16	18	18	15
2010	24	14	27	26	9	10	7	26	17	17	15	24	20
2011	15	11	18	34	11	3	30	27	10	19	20	13	20
2012	29	11	29	31	3	10	18	21	4	22	26	8	27
2013	22	16	16	46	6	10	13	13	8	9	22	33	19
2014	30	8	22	22	9	15	11	25	12	20	22	13	26
2015	39	10	24	21	9	9	19	17	16	13	26	11	22
2016	27	8	20	53	10	4	16	11	11	13	20	16	30
2017	22	11	24	17	5	10	9	6	7	4	14	4	13
2018	15	10	16	33	4	7	9	9	10	5	16	3	13
2019	20	8	12	12	8	6	12	12	12	12	11	12	13
2020	17	6	13	13	4	4	13	13	14	14	14	12	18

SSC JE Subject-Wise Analysis

Year	BMC	SOM	Estimate Costing	Survey	RCC	Steel	FM	Irrigation	Environment Engg.	Highway	Soil
2004	15	5	0	7	6	8	11	0	10	0	12
2005	12	10	0	5	9	8	6	0	9	0	11
2007	14	5	0	5	15	10	8	0	10	0	8
2008	17	9	0	7	11	7	7	0	7	0	10
2009	18	9	0	7	9	8	7	0	6	0	10
2010	22	12	0	8	16	12	11	0	8	0	11
2011	17	15	6	7	12	10	8	4	6	7	8
2011 CWC	12	7	0	3	8	5	3	3	3	3	4
2012	16	22	8	11	12	5	9	2	5	2	5
2013	20	25	5	12	13	3	9	2	4	2	5
2014 (M)	29	12	8	10	8	11	11	2	2	3	4
2014 (E)	28	9	7	11	11	12	9	3	2	2	4
2015	28	10	6	10	12	8	9	1	4	1	7
1/3/2017 (M)	29	7	7	10	17	10	10	2	2	2	4
1/3/2017 (E)	31	12	7	10	11	9	10	2	2	2	4
2/3/2017 (M)	22	23	9	10	11	4	10	2	2	2	5
2/3/2017 (E)	27	13	10	10	12	6	10	2	2	2	6
3/3/2017 (M)	28	28	7	7	3	2	9	3	2	4	4
3/3/2017 (E)	22	17	9	10	11	8	11	1	5	2	4
4/3/2017 (M)	27	14	7	10	10	7	10	3	2	4	4
4/3/2017 (E)	29	13	7	10	10	8	10	3	4	2	3
23/9/2019(M)	15	6	9	10	9	6	8	10	8	7	7
23/9/2019(E)	14	8	9	8	13	5	7	9	7	8	10
25/9/2019(M)	11	4	11	10	14	6	8	9	9	8	9
28/10/2020 (E)	14	2	12	9	10	7	10	8	8	8	8
29/10/2020(M)	13	4	12	9	10	7	6	11	8	10	8
30/10/2020 (M)	17	4	12	9	9	6	9	10	7	7	7
30/10/2020 (E)	12	5	13	9	9	4	8	8	7	9	11
11/12/2020 (E)	9	8	10	10	11	5	8	7	8	9	8

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S.Sorout

Year	BMC	RCC	Irrigation	Highway	FM	EE	EC	SOM	Survey	TOS	Soil
23.03.2021 (Morning)	10	11	10	9	11	8	10	4	10	1	9
23.03.2021 (Evening)	11	9	10	9	7	10	9	5	12	1	9

Important Indian Standard Codes

1

456 Plain and reinforced concrete
269 Specification of OPC 33 grade
8112 Specification of OPC 43 grade
12269 Specification of OPC 53 grade
8041 Rapid hardening Portland cement
8042 White Portland cement
8043 Hydrophobic Portland cement
IS:6452 High alumina cement
IS:1489 Part-I Portland Pozzolana cement (fly ash based)
IS:1489 Part-II Portland Pozzolana cement (Calcined clay based)
383 Coarse & fine aggregates from natural sources
516 Strength of concrete tests
650 Specification for standard sand (Ennore) for testing
2386 Test for Aggregate (1–8 Parts)
2430 Sampling of aggregate for concrete
5816 Splitting tensile strength of concrete
6461 Glossary of terms related to cement concrete (Part 1–12)
7320 Specification of concrete slump test apparatus
10262 Guidelines for concrete mixed design
13311 Part –1 Ultrasonic pulse velocity test
Part – 2 Rebound hammer
] Non-Destructive testing of concrete
875 Design loads (other than earthquakes) for building & structures
Part I : Dead load. Part II: Live load
Part III : Wind load, Part IV : Snow load
Part V : Special loads & load combinations
1893 Earthquake resistant design for structures

Note: The new code for all OPC 33, 43 & 53 grade is IS 269:2015

Cement

2

- Cement is a material which has cohesive & adhesive properties in the presence of water.
- Cement was invented by Joseph Aspdin of UK in 1824 & its colour resembles to stone found in Portland (England). So, it is called Portland cement.
- **John Smeaton** is considered as the **father of civil engineering**.

Basic - Cement has approximately 40 % voids.

$$\text{Standard density} = 1440\ \text{kg/m}^3$$

$$\text{Weight of 1 bag of cement} = 50\ \text{kg}$$

$$\therefore \quad \text{Volume} = \frac{50}{1440} = 0.0347\ \text{m}^3$$

The tolerance in measurement of cement, is $\pm 2\%$

Material	Unit weight (kN/m^3)
Brick Masonry	19 – 20
Plain cement concrete	22–24
Reinforced cement concrete	24–25
Cement mortar	20–21
Steel	78–80
Cement	14.4

Types of cement	
Hydraulic cement	**Non-hydraulic cement**
It sets & hardens quickly in presence of water & results in water-resistant product which is stable Ex:- Portland cement	It obtained from calcination of gypsum or limestone because their products of hydration are not water resistant Ex:- Plaster of Paris

Raw materials in cement manufacture

Argillaceous	Calcareous
Blast Furnace slag	Lime stone, Marl
Slate	Cement Rock,
Shale and Clay	Chalk

Chemical Composition of Raw materials

Oxide	Composition (%)	Avg.	Function
Lime, (CaO)	60–65	62	Control soundness & strength. Deficiency reduces strength & setting action
Silica, (SiO_2)	17–25	22	Excess of it causes slow setting
Alumina, (Al_2O_3)	3–8	6	Responsible for quick setting, excess of it lowers strength (No contribution in strength)
Iron oxide (Fe_2O_3)	0.5–6	3	Gives colour & helps in fusion of different ingredients of cement
Magnesia, (MgO)	0.1 –4	2	Give colour & hardness
Soda & Potash (Na_2O & K_2O)	0.5–1.3	1	If in excess causes efflorescence & cracking
Sulphur trioxide SO_3	1–3	1.5	Makes cement sound

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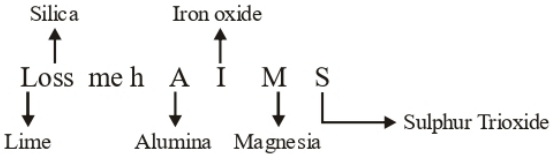

Cement Storage

- Floor area occupied by a cement bag in warehouse is 0.3 m^2 & Height is 0.18 m.
- The length of one bag of cement is 0.70m
- The width of one bag of cement is 0.42m
- Cement must be kept above from the ground level about 45 cm (but on site it is 15 cm).
- The distance of cement bags from the wall should be 60 cm
- **As per IS 4082 : 1996,** the stacking & storage of cement shall be done as follows:
- Cement shall be stored at the worksite in building or a shed which is dry, leakproof & moisture proof as possible.

- Cement bags shall be staked off the floor in godown on the wooden piles in such a way as to keep about 150 mm to 200 mm clear above the floor.
- Do not store cement in open. The storage in the open should be limited to the minimum possible time (about 48 hours).
- The height of stack shall not be more than 10 bags to prevent the possibility of lumping up under pressure.
- The width of stack shall not be more than 4 bags length or 3 meters.
- In stacks more than 8 bags high, the cement bags shall be arranged alternately lengthwise & crosswise in such a way to tie the stack together & minimize the danger of toppling over.
- There should be minimum no. of windows in the storage building.
- Cement bags should be stacked in manner to facilitate their removal & use in order in which they are received, a label showing date of receipt of cement shall be put on each stack to know the age of cement.

Period of Storage	% Strength at 28 days cement
Fresh	100
3 Month	80
6 Month	70
12 Month	60
24 Month	50

Bogue's Compound

When these raw materials are put in kiln. Then it fuses & following four major Compounds are formed:-

Principal Mineral	Compound	Formula	Avg.	Symbol Function
Tri calcium Silicate (Alite)	$3CaO.SiO_2$	C_3S	40%	7-day strength & Hardness, best cementing material (Resistance to freezing, thawing)
Dicalcium silicate (Belite)	$2CaO.SiO_2$	C_2S	32%	Ultimate strength (1 year strength) (Resistance to chemical attack)
Tricalcium Aluminate (Celite)	$3CaO.Al_2O_3$	C_3A	10%	Flash–set, initial setting time
Tetra calcium Alumina Ferrite (Felite)	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	8%	Poorest cementing value

Special Point:- Aluminium Sulphate can be used for quick setting of cement.

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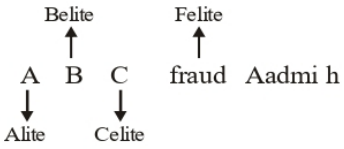


Special Point:- It is found that OPC achieves 70% of its final strength in 28 days & about 90% in one year but for design purpose we take 28 days strength as 100%.

- **Flash set** is the stiffening of cement paste without strength development with heat evolution (called premature hardening). It is cause by (C_3A), high Alkali etc.
- Tri calcium Aluminate (C_3A) reacts immediately with water & is responsible for flash set.
- Gypsum is added to cement to reduce flash setting.
- After flash set, mixing is not allowed because no gain in strength development after mixing.
- Gypsum retards setting of cement & delay the setting time.
- Gypsum is usually mixed with clinker at the time of final grinding
- Excess gypusm makes cement unsound. So Gypsum added to clinker should not be greater than 2.5-3%

False set

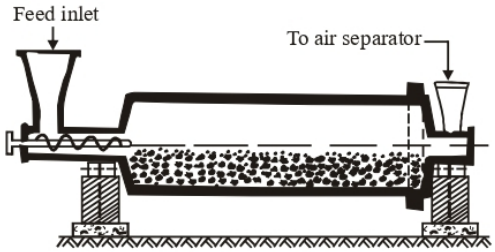
- Rapid stiffening/Hardening (with no appreciable evolution of heat) in freshly mixed P.C. paste, mortar or concrete.

Water Requirement for hydration

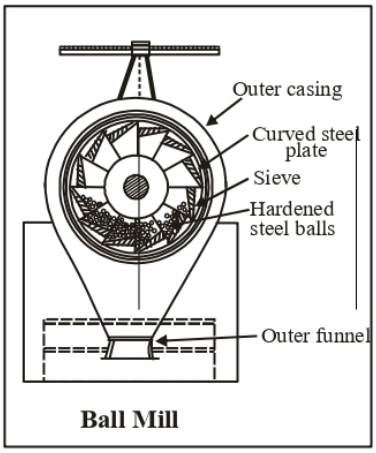
Hydration of cement is exothermic reaction.

Bound water = 23% by weight of cement.
Gel water = 15% by weight of cement
Total minimum = 38% by weight of cement.

- Rate of hydration $C_4AF > C_3A > C_3S > C_2S$
- Rate of Heat evolution $C_3A > C_3S > C_4AF > C_2S$
- Normal range for amount of water use to mix each 50 kg bag of cement is in the range 20-30 liters. (For OPC it is 27 litre/bag & for PPC it is 25 litre/bag at W/C 0.45).
- The rate of hydration is faster in finer cement due to high surface area.
- The capillary pores in Hydrated cement paste are not inter-connected but contains some quantity of gel water.



Tube mill



Ball Mill

Property	Dry Process	Wet Process
Temperature range	1400-1500ºC	1500-1600ºC
Gypsum amount	2-3%	3%
Economically (in fuel)	More	Less
Material	Dry state	Slurry state

Special point: Nowdays we use dry process.

Types of Cement

1. **Portland cement:** Classified on the basis of manufacturing as 33 grade, 43 grade & 53 grade.

OPC : - It has 63% Lime, 22% Silica and 15% Other Materials.

(i) OPC-33 (IS : 269-2015), (ii) OPC-43 (IS : 8112-1989)

(iii) OPC-53 (IS : 12269-1987)

(IST) – 30 minute & (FST) – 600 minute

- The expansion of Portland Cement is caused by excessive amounts

of free lime (CaO) or magnesia (MgO).

2. **Rapid hardening cement (IS:8041):** More C_3S & less C_2S as compared to OPC. It is 10% more costly as compared to OPC.
   - Not-used in mass concrete & it produce Large Shrinkage
   - RHC attains same strength in 1 day which an OPC attains in 3 days with same w/c. But its ultimate strength is same as normal setting cement.
   - It is suitable for repair of roads, bridges etc.
3. **Extra Rapid hardening cement:** Rapid hardening cement + 2% $CaCl_2$ (also called calcium chloride cement)
   - Especially used in cold weather but also give Excessive Shrinkages
4. **High alumina cement (IS:6452 - 1989):** Bauxite (40%), Lime stone (40%), Iron Oxide (15%)
   - IST – Min. 3hour 30 minute & FST – Max. 5 hour.
   - It is used for refractory concrete, industries & used widely in Pre-casting.
   - Particularly suitable to sea & under-water work
   - Very resistance to chemical attack, Expansion ≤ 5 mm
5. **Portland Slag cement:** Mixture of Portland cement, Granulated blast furnace slag & gypsum. It requires more time for curing & shuttering.
   - High Sulphate resistance & it is Used in mass concreting
6. **Super Sulphated Portland cement :** Mixture of 80–85% Granulated slag , 10– 15% calcium sulphate & 5% Portland cement clinker.
   - It is resistant to chemical attacks particularly to sulphate & highly resistant to sea water. Use for lining of canal and marine work.
   - It should not be used with any admixture
7. **Low heat Portland cement:** Low C_3S & C_3A and more contents of C_2S
   - It is use in mass concrete work & widely use in retaining wall.
   - Rate of development of strength is low but ultimate strength is same
8. **Portland Pozzolana cement (IS:1489 Part-I) :** OPC + 10– 30% of fly ash by mass of PPC. It is use in marine work.
   - Free lime is removed. Hence, resistant to chemical attack increases
   - Pozzolana increase impermeability & water retaining capacity of concrete
   - Pozzolana has no cementing property in itself but when it combines with lime, it produces a stable lime pozzolana compound which has cementitious property.

- The addition of pozzolanas to concrete results in.
  (a) Improvement in durability by reducing permeability
  (b) Increase in workability of concrete.
  (c) Reduction in shrinkage. (But in cement, it increases)
  (d) Reduction in segregation & bleeding of concrete.
- The optimum amount of Pozzolana, as replacement for cement, may normally range between (10-30)% & may be as low as (4-6) % for Natural Pozzolanas.

Fly Ash

- It is residue from the combustion of pulverized coal collected by Mechanical or electrostatic separaters from the flue gases or power plants. Fly ash particles are generally spherical in shape and having range 0.5 - 300 μm. It consists SiO_2 (30 - 60)%, Al_2O_3 (15 - 30)% & CaO.
- It is about 80% of total ash produced.
- It decrease segregation, bleeding & permeability of concrete.
- It also lowers the early strength of conerete mixture

Special Point:
- Blast furnace slag is a by product obtained while smelting Iron - ore in Blast furnace.

9. **Quick setting cement:** Fine grounded OPC with reduced Gypsum content & a small amount of aluminium sulphate.
   - IST = 5 minutes & FST = 30 minutes. It set quickly but not harden.
   - It is used in under water concreting.
10. **Air Entraining cement:** OPC + Vinsol resin or vegetable fats of oils or fatty acids.
   - Small amount (0.1%) by weight of an air entraining agent.
11. **White and Coloured Portland cement (IS: 8042) :** From Pure white chalk, china clay & Iron Oxide should not be more than 1%.
   - These are used for making Terrazzo flooring, ornamental works & casting stones, Monuments buildings.
   - It is also called Rainbow/ snowcem/ colocrete cement.
   - Hunter scale is use for checking the whiteness of cements
   - Whiteness should not be less than 70% when use ISI scale.
   - 5–10% Colouring pigment before grinding for colour cement.
12. **Water Repellent or Hydrophobic cement:** OPC + fractions of oleic acid, Stearic acid or pentachlorophenol.

- Suitable for basement & making water tight structures.

Minimum Specified Strength in N/mm²				
Type/days	1 day	3days	7 days	28 days
OPC (33 grade)	–	16.0	22.0	33.0
Portland Pozzolana	–	16.0	22.0	33.0
Low heat Portland	–	10.0	16.0	35.0

Testing of cement: It should be taken from 12 different bags or from 12 points from heap .Weight of sample collected should be atleast 5 kg. Following are field & laboratory tests -

(a) Field test - (i) It should be free from lumps & greyish in colour.

(ii) If hand is inserted in cement, it should feel cool, not warm.

(iii) The thin paste of cement feels sticked between fingers.

(iv) If small quantity of cement thrown in water float initially, then sinks.

(b) **Laboratory test** - (i) **Physical tests** - Fineness, Consistency, IST & FST, Soundness, Specific gravity, Heat of hydration & Strength determination.

(ii) **Chemical tests** - Total loss on ignition < 5%, wt. of insoluble residue < 4, %, Weight of magnesia < 6%, Weight of chloride < 0.1 %.

1. Fineness Tests: It the measure the mean size of grain in cement.

- With increase in fineness, the early development of strength is enchanced (it leads to higher shrinkage) but the ultimate strength is not affected.
- Setting time decrease with increase in the fineness.
- Fineness can be measured by following methods -

(a) **Sieve method** - It measures grain size using 100gm cement & 90 micron (9 no.) sieve.

(b) **Wanger turbidimeter** - It measures specific surface area.

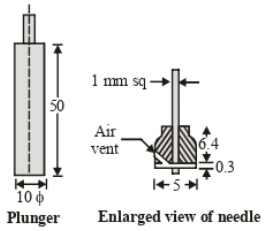
(c) **Air permeability method** - It also measures specific surface area. In it, Nurse & Blaine's apparatus is used. Flow meter for quantity of air passing and manometer for air pressure are used.

Type of Cement	% of residue	Min. Specific Surface (m²/kg)
Ordinary portland cement	10	225
Portland pozzolana cement	5	300
Rapid hardning cement	5	325

2. Consistency Test: It is the Amount of water used to make paste of normal consistency. It is about 30% generally. It is the percentage of water required for the cement paste, the viscosity of which will be such that Vicat's plunger penetrates upto 5 to 7 mm from bottom (33 to 35 mm from top) of the Vicat's mould.

Diameter length & shape of Vicat apparatus for different test:

S. No.	Types of test	Diameter or size	Shape
1.	Initial setting time	1mm of square needle or 1.13 mm circular	Square needle
2.	Final setting time	5mm	Annular ring
3.	Consistency	10mm	Solid circular
4.	Length of above apparatus lie in the range 40 to 50 mm.		



3. Initial and Final Setting time

Initial Setting Time	Final Setting Time
• It is possible to remix cement paste during this period • 300 gm cement + 0.85 P of water • 1 mm^2 square needle penetrates by 33–35 mm from top. • IST for OPC, RHC is 30 minute, for low Heat Cement - 1 hour, for High Alumina Cement – (3.5) hour	• Annular collar replaces square needle • It is the time elapsed between moments water is added and paste completely loose its plasticity. • Needle makes an impression but collar fails to do so. • FST for OPC, RHC, LHC – 10 Hour for High Alumina Cement – (5) Hour

4. Soundness Test: To detect change in volume after setting

Le – Chatelier method	Auto clave test
Measure unsoundness (free lime only)	Sensitive to both lime & magnesia
100 gm of cement + 0.78 P water	Internal mould dimension (25 × 25 × 282) mm
Result is given in "mm"	Result is given in %

The maximum expansion limit for OPC, rapid hardening, low heat, portland, masonry cement is 10 mm & for super sulphated, high alumina cement is 5 mm.

Test performed	Amount of water required
Initial & final setting time test	0.85P
Soundness test	0.78P
Compressive strength test	P/4 + 3
Tensile strength test	P/5 +2.5

5. Strength determination

Compressive strength	Tensile strength
• Cube test (size 7.06cm) • Cement (185 gm) + Ennore sand (555 gm), ratio of 1 : 3 • Water $=\left(\frac{P}{4}+3\right)\%$ • Temperature 27 ± 2°C • Atleast 3 cube for testing • Rate of loading:- 35 N/mm^2 /min	• Briquette test (6.45 cm^2), 6 no. • T.S = (10 – 15)% of compressive strength • Generally used for RHC • Cement : sand = 1 : 3 • Water $=\left(\frac{P}{5}+2.5\right)\%$ • Rate of loading:- (1.2 - 2.4)N/mm^2/min

Special Point:- The size of concrete cube is 150 × 150 × 150 mm

6. Heat of hydration: Measured by Calorimeter.

7. Specific Gravity Test: Measured by Le-chatelier's flask.

Specific gravity of OPC = **3.15**

Property	Lime	Cement
Slaking	Slaking takes place on adding water	Hardening takes place on adding water
Colour	White or greyish white	Dark grey or grayish brown
Setting	It sets slowly by taking CO_2 from air or reacting with water	It sets rapidly by reacting with water
Compressive strength	Less	High
Cost	Cheap	Costly
Hardening	Slow	Rapid
Use	Suitable for ordinary	Suitable for all construction

Special Points: Blast furnace slag has approximately 45% calcium oxide & about 35% silica.

- Fineness test give an estimate of rate of hydration
- It is experimentally that moderate rate of cooling of clinker in the rotary cooler, will result in higher strength.

1200° C $\xrightarrow{15 \text{ minutes}}$ 500°C $\xrightarrow{10 \text{ minutes}}$ Ambient temperature.

Concrete

3

- Concrete is a mixture of binding material like as lime or cement, well graded coarse & fine aggregate, water and some admixture. It is the most used construction material on the planet.
- **Elastic modulus of concrete:**

It varies from 14×10^3 N/mm^2 to 40×10^3 N/mm^2 & increases with density and to some extent with age.

$\boxed{E_c = 5700\sqrt{f_{ck}}\ N/mm^2.}$, Min. grade = M15 (IS 456:1978)

$\boxed{E_c = 5000\sqrt{f_{ck}}\ N/mm^2.}$, Min. grade = M20 (IS 456:2000)

- The weight of plain cement concrete is 2400 kg/m^3 & for RCC is 2500 kg/m^3. The poisson's ratio for normal concrete of strength design & serviceability criteria is 0.15 & 0.2 respectively.
- The behaviour of cement concrete under instantous load is elastic.
- The plain cement concrete is impermeable to moisture.

Concrete classification (Based upon)				
Cementing material	**Bulk density**	**Grade of cement**	**Perspective specification**	**Place of casting**
Lime concrete Gypsum concrete Cement concrete	Extra light <500 kg/m^3 Light 500-1800 kg/m^3 Dense weight 1800-2500 kg/m^3. Super heavy weight > 2500 kg/m^3	Low strength <20 N/mm^2 Medium strength 20-40 N/mm^2 High strength > 40 N/mm^2	1 : 4 : 8 → M7.5 1 : 3 : 6 → M10 1 : 2 : 4 → M15 1 : 1.5 : 3 → M20 1 : 1 : 2 → M25	In Situ concrete Precast concrete
			Use CIVIL Ki GOLI for Remembering	

- As per IS : 456 - 1978, The concrete mix are designed into 7 Grades. (As per IS : 456 - 2000 The concrete mix are designed into 19 Grades).

Stages of manufacturing of concrete

1. Batching
2. Mixing
3. Transporting
4. Placing
5. Compacting
6. Finishing.
7. Curing

1. Batching:

It refers to controlling the quantity of each material required for making a concrete mix in each batch.

Aggregate, admixture & water measured with accuracy of ± 3% of batch quantity & cement has ± 2% of batch quantity as per IS 456.

There are two types of batching :

(a) **Weight Batching-**

- It is recommended for all important work.
- The cement is always measured by weight ir-respective of method of batching.

(b) **Volume Batching-**

- It is recommended for small works.
- The standard box (also called gauge box) is used for measurement.
- The correction of bulking of sand is applied in it.
- Bulking of sand depends on the percentage of moisture present in the sand and it's fineness. It is about 20 to 40% at water content of 4 to 6 %.

2. Mixing: Approximate mixing time as per IS – 456 is 2 minutes.

- Concrete mixtures are specified by volume of mixed concrete discharged after mixing of each batch expressed in m^3.
- Generally mixers are specified by two quantities, the total volume of ingredients added & the volume of concrete produced for eg. 370/310.
- Generally 20 Revolution of concrete in mixture provides sufficient mixing.
- 10% Extra Cement is added in hand mixing.

Types of mixing- (a) Hand Mixing,

(b) Machine Mixing - (i) Batching plant - Manual, semi & fully automatic.

(ii) Mixers - Pan mixer,

- Drum mixers are classified into tilting, non-tilting & reversing mixers.

- Tilting mixers are used for large construction works.
- Non-tilting mixers are used for small works & can not be used when aggregate size is more than 75 mm.
- Pan type mixer is mostly use in precast concrete factories.

3. **Trasportation**: A belt conveyer is used when the concrete is to be transported continuously & to an inaccesible area.
   - Concrete pumps is commonly used on Tunnel,bridges works etc.
   - Best method for transportation of concrete is pumping
   - For pumping method, the compaction factor of concrete should be 0.90 to 0.92
   - Diameter of pipe for pumping method is 100 to 200 mm
   - By pumping method, concrete can be transported 400 m in horizontal & 80 m in vertical direction
4. **Placing:** Delayed placing of concrete results in a gain in ultimate compressive strength provided the concrete is adequately compacted.
   - As per IS : 456, Maximum permissible free fall of concrete may be taken as 1.5 m.
   - Placing of concrete under water is done by tremie pipe. (Slump-150–200 mm)
5. **Compaction:** It is the process of removal of entrapped air & of uniform placement of concrete to form a homogenous dense mass.
   - The presence of even 5% & 10% voids in Hardened Concrete left due to incomplete compaction may result in a decrease in compressive strength by about 30% & 60% respectively.
   - Surface vibrator/ Screedboard vibrators are used for Road surface, plain concrete floors, pavement etc. It is effective only if the depth is upto 15-20 cm.
   - External (Form) Vibrator: It is used only when the section is thin & heavily reinforced where penetration of needle vibrator is not possible.
   - Internal (Needle) vibrator: It is very effective for mass concreting.
   - By using a mechanical vibrator, a concrete of about 5 cm slump can be placed & compacted fully in a closely spaced RCC work, while for hand compaction, much higher consistency say 12 cm slump may be required.
6. **Finishing:** Levelling or smoothing of top surface of freshly placed concrete. It is done by Screeding, Floating & Trowelling.

   Screeding: The process of striking off the excess concrete to bring the top surface upto proper grade.

Floating: It consist of removing the irregularities on the surface of concrete & it is generally done by wooden float.

Trowelling: It is final operation of finishing & it gives a very smooth finish.

7. **Curing:** As per IS: 456, it is the process of preventing the loss of moisture from the concrete while maintaining a satisfactory temperature regime.
   - The test sample should be stored in a place free from vibration, in moist air of atleast 90% relative humidity & at a Temp. of 27° ± 2°C for 24 hour ± (1/2) hour from time of addition of water to dry ingredients.
   - Curing period for rapid hardening cement is 3 to 7 days, seven days for OPC, low heat cement have most longer curing period.
   - **Combined water:** It is chemically combined with hydration products and it is non evaporable.
   - **Capillary water:** It is easily evaporated. It partially occupies the capillary pores which constitute the space in the cement paste remaining offer accounting for the volumes of cement gel & unhydrated cement.
   - **Gel water:** It held physically or adsorbed on the surface area of the cement.

Method of curing	Suitability
Shading of concrete work/ Stagnating water Gunny bags	For large concrete surfaces such as road slab. For structural concrete
Sprinkling of water	For vertical surfaces
Membrane curing	At places of scarcity of water
Steam (accelerated) curing	For precast concrete work

Special Points: Steam curing is not suitable for high alumina cement

- Membrane curing is used for hilly areas. It is done by applying paraffin or resin-based liquids on the surface of the concrete.
- Steam curing increase ultimate strengths & reduced the shear strength of concrete.
- The Geopolymel concrete is produced by using fly ash and alkali activator solutions along with aggregates.
- Concrete heated by steam at 93°C either at low or high pressure.
- More rapid gain of strength can be obtained with the help of Infra-red radiation than steam curing.
- In lime concrete, the curing should start after 24 hours of its laying and should be continued for a minimum period of 7 days.

Maturity Concept in Concrete

- The strength of concrete not only depends upon the time, but also it depend upon the temperature during hydration.
- It is defined as the product of time & temperature.

  Maturity of Concrete = Time × Temperature = °C Hours
- A datum temperature of (–) 11°C is taken for maturity calculation because hydration starts at this temperature
- A sample of concrete cured at 18°C for 28 days is taken as fully matured concrete.

  Maturity at 28 days = 28 × 24 [18 – (–11)] = 19488°C-hr

Yield of Concrete

If proportion of concrete is a : b :c , then produced concrete will have volume of $\frac{2}{3}(a + b + c)$, where a is volume of cement, *b* is volume of sand & *c* is the volume of coarse aggregate.

Special Point :- If *w, a, b. c,* are absolute volumes of water, cement, sand & coarse aggregate respectively, then w + a + b + c = 1.

Mothods of Proportioning concrete mixes

1. **Fuller's maximum density method:**

   $$p = 100\sqrt{\frac{d}{D}}$$

   p = % by weight of matter finer than diameter d

   D = maximum size of aggregate
2. **Abram's water-cement law:** For any given conditions of the test, the strength of the workable concrete mix is dependent only on water-cement ratio.
   - The quantity of water used in concrete is 30% of the weight of cement + 5% of the weight of aggregate
   - By the use of compaction vibrator, the quantity of water can be reduced 20%
   - According to the law, the strength of the mix increase with decrease in water content.

- Strength of concrete increases with age in the following way.

Months	Age Factor
1	1.00
3	1.10
6	1.15
12	1.20

3. **Minimum Voids method:** Voids in coarse aggregate should be filled by sand & voids in sand should be filled by cement. Generally in actual practice, quantity of sand used in the mixture is kept 10% more than the voids in the coarse aggregate & quantity of cement is considered 15% more than the Voids in sand.

Water cement Ratio: It is the mass of 'free water' (excluding that adsorbed by the aggregate) to that of cement in the mix. The ratio generally lies between 0.35 to 0.65.

- It is mainly responsible for porosity of the hardened cement paste.
- For durable concrete W/C $\leq$ 0.8. If W/C > 0.6, Porosity increase & strength decrease.
- Due to the presence of 2% oil in water, the strength of concrete is reduced to 20% .
- Sea water in the world oceans has a salinity of approximately 3.5% or 35 parts per thousand.
- The constituents of sea water reacts chemically with constituents of cement concrete causing damage to concrete structure.
- Sea water corrodes the reinforcement of R.C.C. Thus, affecting durability of structure.
- Sea water due to presence of $CaCl_2$ acceelerates the setting time of cement.
- The sea water reduce the strength of concrete 10 to 20% .
- The seawater can not be used for pre-stressed concrete
- The strength of concrete cube made from normal water should not be less than 90% of strength of concrete cube made from distilled water

Exposure conditions and requirements for Building Construction works with normal aggregates of 20 mm nominal size.

Exposure	Description	Nominal cover (mm)	Min grade	Min cement Content (kg/m^3)	Max free w/c ratio
Mild	Normal	20	M20	300	0.55
Moderate	Expose to rain	30	M25	300	0.50
Severe	Immersed in sea water	45	M30	320	0.45
Very Severe	Exposed to sea spray	50	M35	340	0.45
Exterme	Tidal zone	75	M40	360	0.40

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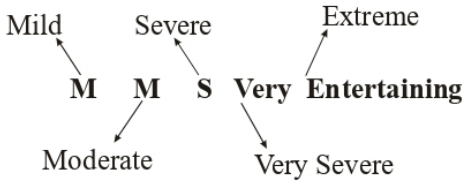
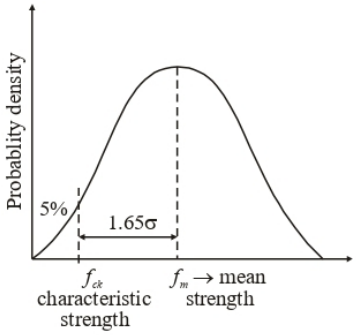


Strength of Concrete: It is designated in terms of numbers preceded by the letter 'M' where M refer to the '**Mix**' & number represents the characteristic strength.

Tensile strength = 10%, of compresive strength

Bending strength = 15%, of compressive strength

Shear Stregnth = 20%, of compressive strength



Days	Strength of Concrete
3	$\frac{1}{2} \times F_{Ck}$
7	$\frac{2}{3} \times F_{Ck}$
14	$0.9\ F_{Ck}$
28	F_{Ck}

Characteristic strength is the strength of material below which not more than 5% of the test result are expected to fall. $\boxed{f_m = f_{ck} + 1.65\ \sigma}$

- Generally samples are tested for 7 days or 28 days but IS code only suggest 28 days strength only.
- Average of 3 values is taken as compressive strength of concrete, provided the individual variation is not more than ±15% of the average.

Following are the laboratory test for strength of concrete

(a) Compressive strength test
(b) Flexural tensile strength test
(c) Split tensile strength test

- **Quality concrete methods are Inspection, Testing, Sampling.**
- For ensuring quality of concrete, we use graded aggregates because if the different size and shape of aggregate are mixed each other in concrete, the bonding is become strong.

1. Compressive strength test:

- Size of coarse aggregate upto 38 mm
- Size of concrete cube – 150 × 150 ×150 mm & Size of cylinder – 150 mm dia, 300 mm height
- Cube mould filled in 3 layers, tempered (35 times/layer for 15 cm cube & 25 times/ layer for the 10 cm cube) with tamping rod of 16 mm dia & 600 mm length.
- Rate of loading in compression testing machine = 14 N/mm ^{2}/ minute.
- Stored at temp of 27 ± 3°C at 90% humidity for 24 ± 1/2 hour.
- Then immersed in water for 7 days or 28 days.

Cube strength = 1.25 × Cylinder strength

(Important facts)

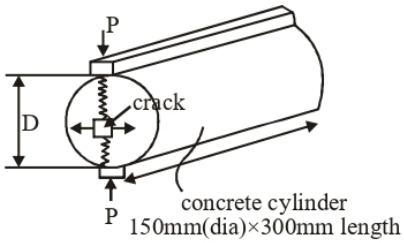
Volume of concrete	No. of sample
1 - 5	1
6 - 15	2
16 - 30	3
31 - 50	4
> 50	(4+1)No. for each 50 m^3

(a) Flexural tensile strength: Tensile strength of concrete in flexure is called flexural strength.

- IS : 516-1959, Specifies two point loading.
- Flexural strength is used to determine the onset of cracking or the loading at which cracking starts in a structure.

(b) Splitting tensile strength: It is measured by testing cylinders under diametrical compression.

Because due to difficulty in applying uniaxial tension to a concrete specimen & hence the tensile strength is determined by indirect method (by split tensile strength test).



$$\text{Splitting tensile strength } (f_{ct}) = \frac{2P}{\pi DL}$$

Special Point:- Since concrete does not take any tensile strength, it is taken as zero. But, IS code recommends the flexure tensile strength to be calculated using $f_{cr} = 0.7\sqrt{f_{ck}}$ N/mm²

(c) Direct tensile strength: It is measured by testing rectangular specimens under direct tension.

- In the absence of test results, the code recommends to use an estimate of the flexural tensile strength from the compressive strength by the following equation–

$$f_{cr} = 0.7\sqrt{f_{ck}}$$

where,

f_{ck} = Characteristic compressive strength of cubes in N/mm².

f_{cr} = Flexural tensile strength is N/mm²

Special Points: $f_{cr} = 0.7\sqrt{f_{ck}}$

$f_{ct} = 0.66\, f_{cr}$

& Direct tensile strength = $[0.5 - 0.625]f_{cr}$.

where, f_{cr} = Flexural tensile strength

f_{ct} = Splitting tensile strength.

$$f_{cr} = 0.7\sqrt{f_{ck}}, f_{ct} = 0.66 f_{cr} = \frac{2P}{\pi DL}$$

(flexure > splitting > Direct Tensile strength)

Factors affecting Strength of Concrete

1. **Size of specimen:** If size decreases then strength increases
2. **Age of cement:** If strength reduces as it absorbs moisture from atmosphere.

S.No.	Age of testing	Compressive strength
1	1 month	1 × Strength at 28 days
2	2 month	1.10 × Strength at 28 days
3	3 month	1.22 × Strength at 28 days
4	6 month	1.46 × Strength at 28 days
5	12 month	1.55× Strength at 28 days

3. **Moisture in specimen:** It reduces the strength.
   Strength of dry sample = (1.1 to 1.2) × strength of saturated sample.
4. **Rate of loading:** Strength increases with increase in rate of loading.
5. **Cement aggregate ratio:** If cement is increases, then ultimate strength will increase.
6. **Size of aggregate:** Larger aggregate size leads to lower strength.
7. **Type of aggregate:** Angular aggregates provide maximum void but they provide very good bond & are suitable for high strength concrete.
8. **Air Voids:** These are formed by evaporation of water used in making concrete or by entrapped air. They decrease the strength considerably.
9. **Degree of compaction:** 5% air Void decreases strength by 30% where as 10% air Void decreases strength by 60%.

Workability: Property of concrete which determines the amount of useful internal work necessary to produce full compaction.

- Slump test used for In-situ determination of workability.

Special Point: Consistency indicates fluidity or mobility. Concrete with high consistency may not be workable for a particular job & concrete having same consistency may vary in workability.

Factors affecting workability

Factor	Effect on Workability
Water content	As water content (Direct relationship) increases, fluidity of mix increases, hence workability increases
Aggregate size	• Higher the aggregate size, higher will be the workability • Big size aggregate, surface area to be wetted is less, paste required for lubricating the surface will be less.
Shape of aggregate	• Angular & flaky aggregate have large surface area, so they are less workable. • Rounded cubical shape aggregates have less surface area. Therefore, less amount of paste is required for lubrication. Hence they they are more workable.
Aggregate/cement	• Higher the ratio, leaner will be the concrete. • Lean concrete means concrete having less paste available for lubrication of per unit surface area of aggregate.
Surface texture	Smoother the surface, higher will be the workability
Grading of aggregates	• Well graded aggregates are more workable • Such type of mix will have least voids. So excess cement paste will be available as lubricants.

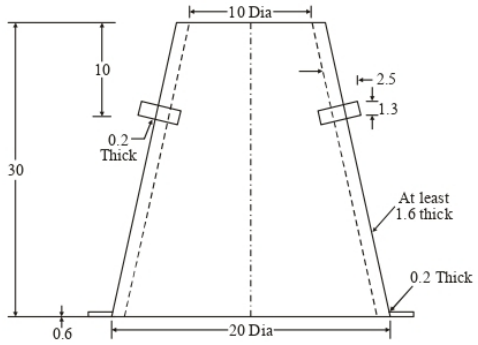
Types of Slump: True slump, Shear slump and Collapse slump

Adjustment in various igredients of concrete, if desired slump is not obtained - Water-cement ratio - 0.01 , Water -1%, Cementious material - 1%, Aggregate - 2%.

Measurement of workability

1. **Slump test:**
   - Dimensions of mould (frustum of a cone)
     Top diameter = 100mm
     Height = 300 mm
     Bottom diameter = 200 mm
   - As per IS 1199 (Part 2- 2018), three layers, 25 strokes/layer
   - Tamping rod: diameter 16 mm, length 600 mm

Special Point: Slump test is performed for maximum size of aggregate as 38 mm only, if aggregate size > 38 mm, then wet sieving is done through 38 mm sieve.



All dimensions are in cm in above diagram.

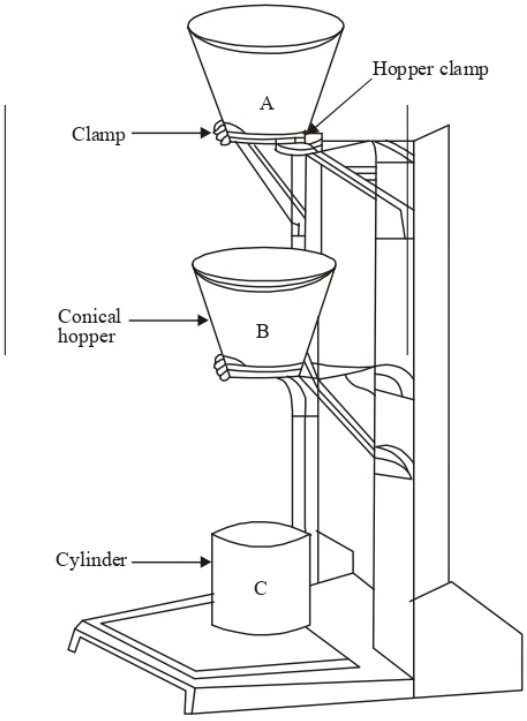
Recommended slumps of concrete

No.	Type of concrete	Slump (mm)
1.	Concrete for road construction	20 to 40
2.	Beams & slabs	50 to 100
3.	Mass concrete,Dam,Bridge,Retaining wall	25 to 50
4.	Normal RCC work,Column,Thin wall	80 to 150
5.	Concrete to be vibrated	10 to 25
6.	Impermeable work	75 to 120

2. **Compacting factor test:** Degree of workability is measured in terms of internal energy required to compact the concrete thoroughly.
   - Compacting factor test is useful for concrete mixes of medium & low workabilities.

$$\text{C.F.} = \frac{\text{Mass of Partially Compacted Concrete}}{\text{Mass of fully Compacted Concrete}}$$

CF = 0.85 low workability
CF = 0.92 Medium workability
CF = 0.95 High workability



As per CPWD specifications for concrete work:

- Concreting heavily reinforced sections with vibration - slump 25-75 mm for 20 mm aggregate.
- Concreting lightly reinforced sections with vibration-slump up to 25 mm.

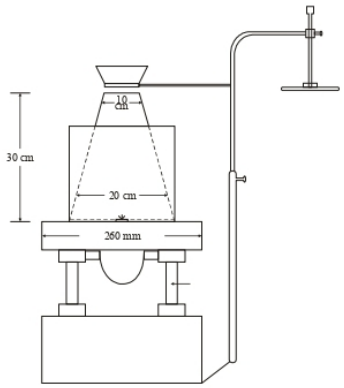
Values of workability for different placing conditions

Degree of workability	Consis-tency	Slump (mm)	Compac-ting factor	VeeBee degree (second)	Uses
Extremely	Moist Earth	0	0.65–-0.7	>20	Precast paving
Very Low	Very Dry	0–25	0.7–0.8	12–20	Roads (power vibrator)
Low	Dry	25–50	0.85–0.87	6–12	Mass concreting, light reinforced section,
Medium	Plastic	50–100	0.92–0.935	3–6	Flat slabs, heavily reinforced section, RCC Sections (Manual Vibrator)
High	Semi fluid	100–150	0.95–0.96	0-3	RCC with congested reinforecment (can not be vibrated)

Note - Above table as per the exam point only

3.Vee Bee consistometer: It determines the time required for transforming, by vibration, a concrete specimen in the shape of a conical frustum into a cylinder.

- It is suitable for concrete having slump less than 50 mm.
- Consistency of the concrete is expressed in VB degree which is equal to the recorded time in seconds.
- It is a good laboratory method, particularly for very dry mixes.



4. Flow table test: It is the laboratory test which gives an indication of the quality of concrete wrt consistency, cohesiveness & the proneness to segregation.

$$\text{Flow}\% = \frac{\text{Spread diameter (in cm)} - 25}{25} \times 100$$

Range = 0 to 150

Special Points: order of stability of test from low workability to high workability.

Vee bee consistometer < compacting factor test < slump test < flow table test

Kelly ball test is a field method & give more accurate and quicker result as compared to slump test.

Mix- Design:

When the proportions of cement, aggregate & water are adopted based on arbitrary standards, the concrete produced is termed as Nominal Mix Concrete. It may be adopted for concrete of M20 or lower grade.

When the proportions of the constituents of concrete is accompanied by use of certain established relationships, the produced concrete is termed as Design Mix Concrete.

Steps in mix-design (IS: 10262 - 1982 Concrete mix design)

(i) Find target mean strength ($\mathbf{f}_m$)

$$f_m = f_{ck} + 1.65\,\sigma$$

(ii) Get water cement ratio based on 28-day strength of cement

Grade of concrete	Assumed σ
M_{10} - M_{15}	3.5
M_{20} - M_{25}	4.0
M_{30} - M_{60}	5.0
M_{65} - M_{80}	6.0

(iii) Get water content based on workablity requirement.

(iv) Get cement required from (ii) & (iii)

(v) Calculate mass of fine M_{fa} & coarse aggregate M_{ca} based on absolute volume principle

$$\frac{M_c}{\rho_c} + \frac{M_{fa}}{\rho_{fa}} + \frac{M_{ca}}{\rho_{ca}} + V_w + V_v = 1$$

(vi) Determine weight of ingredients per batch, based on capacity of concrete mixer.

Special point: The maximum permissible size of aggregate for various works – RCC member (20 mm), cement concrete floor (10 mm), for massive work like as dams, retaining walls etc. (40 mm).

Permissible limit for solids as per IS 456 : 2000

Sr. No.		Tested as per	Permisible
1.	Organic	IS 3025 (Part 18)	200 ppm
2.	Suspended matter	IS 3025 (Part 17)	2000 ppm
3.	Sulphates (as SO_3)	IS 3025 (Part 24)	400 ppm
4.	Chlorides	IS 3025 (Part 32)	2000 ppm (for plain concrete) 500 ppm (for reinforced concrete)
5.	Inorganic	IS 3025 (Part 18)	3000 ppm

Special Point: The pH value of water must not be less than 6.

Defects in concrete

1. **Crazing:** It is the network of fine random cracks on the surface of concrete of mortar caused by shrinkage of surface layer.
2. **Cracks:** Acceptable limits for the surface width of cracks is 0.1 to 0.3 mm
3. **Efflorescence:** Fluffy white patches on the surface of concrete members.Different efflorescence deposits are sulphates of calcium.
   - Efflorescence is caused by salty water generally.

Following are the **types of efflorescence** -

(a) Nil - When there is not perceptible deposit of efflorescence.

(b) Slight - Not more than 10 % area of brick covered with a thin deposit of salt.

(c) Moderate - When covering upto 50 % area of brick.

(d) Heavy - When covering 50 % or more but unaccompanied by powdering or flacking of the brick surface.

(e) Serious - When there is a heavy deposit of salts accompanied by powdering or flaking of the exposed surfaces.

Segregation

- The separation of the constituent material of concrete (cement, sand & aggregate) because they have different specific gravity.
- It is of three types
  - Water separating out from rest of the material (Bleeding).
  - Coarser aggregate separating out & setting down.
  - Paste separating away from coarse aggregae.
- Segregation is seen in badly proportioned mixes or when concrete is

dropped from height more than 1.5m (IS : 456).

Bleeding : In this, water from concrete comes out to the surface of concrete because of low specific gravity.

- Rich mixes are less prone to bleeding than lean mixes.
- It leads to formation of pores insides & hence, cause decrease in strength.
- It can be reduce by use of uniformly graded aggregate, entraining agent, finer cement.
- It is seen in highly wet concrete or badly proportional mixes.
- When water comes up with cement particles to the surface it is called 'Laitance'.

Special Point: Alkali cause alkali aggregate reaction which increase volume of concrete and cause spalling.

Creep (plastic or yield): Continued deformation with time under a constant load. In general creep increases when aggregate content & relative humidity is low or when cement content, Air entrainment, water cement ratio & temperature are high.

Non-Destructive Testing

1. On Hardened concrete
   (a) Maturity Test (b) Pull-out Test (c) Penetration Test
   (d) Ultrasonic Pulse Velocity Test
   (e) Rebound Hammer Test (Schmidt Hammer Test)

- Rebound Hammer test provides useful information for surface layer upto 30 mm depth and is suitable for concrete having compressive strength 20-60 MPa.

Admixture

Chemical Admixture	**Mineral Admixture**
(a) Plasticizers	(a) Pozzolanas
(b) Retarders	(b) Silica fume
(c) Air entrainers	(c) Rice husk
(d) Accelerators	(d) Blast furnace slag
(e) Super plasticizer	

- **IS:9103** describes about admixture
- Mineral admixture are added after grinding of cement clinker. They replace the cement by 10-70% by mass.
- Chemical admixture are added at the time of mixing of concrete.

- Sugar an admixture (retarding agents) used for delaying the setting time of concrete without detrimental effect on the ultimate strength.

0.05% by weight of cement	No effect
0.15% by weight of cement	Reduces early strength & increases 28 day strength
0.2% by weight of cement	Final set may not take place even for 72 hours.

Oil contamination

- Mineral oils not mixed with animal or vegetable oils in mixing water have no adverse effects on the strength of concrete.
- Vegetable & animal oils have bad effect on strength of concrete at later stages.
- Skimmed milk powder (casein) has a retarding effect mainly due to sugar content.
- Mineral oils is up to 2% by weight of cement significant increase in strength.

Admixture	Use	Example	Remark
Plastisizer	Reduce water content (improve workability for a given w/c)	• Lingosulphonic acid • Hydroxylated carboxylic acid • Polyglycol esters	Dose 0.1 - 0.4% of wt. of cement
Air entrainers	Improved resistance to damage from freezing & thawing	• Wood resin • Vegetable oil • Tallous, soap • Stearic acid • Aluminium powder	Dose 0.005%-1% of wt. of cement. Reduce segregation, bleeding, density & strength increase impermeability of concrete
Accelerators	Rapid setting & high early strength	• Calcium chloride • Silicate	Dose 0.1-0.2% by weight of cement.
Super plastisizers	Workability greatly enhanced	• Sulphonated melamine formaldehyde • Modified lignosulphonate	Finer the cement, higher will be dose Reduced water requirement by 20-40%
Retarders	Longer setting time & slower initial strength gain	• Calcium sulphate • Sugar cellulose • Tartaric Acid	Dose 0.05-0.2% by weight of cement. Delay hydration process upto 72 hrs.

Special point : Retarders are also used for hot weathering concrete, to prevent cold joint, for grouting deep oil wells and In ready mix concrete

Durability of Concrete : It is defined as its ability to resist weathering action, chemical attack, abrasion or any other process of deterioration.

- Cinder is a pyroclastic material, they are extrusive igneous rocks. It has more shrinkage and affecting durability of concrete.

Formwork is a temporary structure

- There are two types of formwork shuttering & centering
- The type of formwork, which is in direct contact of structure is called shuttering. It support the structure until it becomes self supporting.
- The part of formwork, which is used to support the shuttering is called centering
- Stripping time may be reduced to 40% in the case of rapid hardening cement

Shoring: Shoring is the construction of temporary structure to support temporarily an unsafe structure these render lateral support to walls and are used under the following circumstances :

(a) When wall cracks due to unequal settlement of foundation
(b) When adjacent structure is to be dismantled
(c) When a wall shows signs of bulging out
(d) When opening are to be made or enlarged in the wall

Shores may be of following type:

(a) **Flying Shores:** It is also called horizontal shoring. These are used to give horizontal support to two adjacent parallel party wall which have become unsafe due to removal or collapse of the intermediate building.
(b) **Raking shores:** In this method inclined members rackers are used to give lateral support to the wall rackers should be inclined to the ground by 45° to make them more effective
(c) **Dead or vertical shores:** It consist of vertical member known as dead shores.
   - It is used for supporting temporarily wall for rebuilding etc.
   - The process of placing a New foundation under an existing one/ strengthening an existing foundation is called underpinning of foundations.
   - Cost of formwork/shuttering may be upto (20 – 25)% of the cost of structure in the building work.
   - Trestle scaffolding is used for painting & repair work inside the room up to a height of 15 meters

Type of formwork	Minimum period before removing formwork
(a) Vertical formwork to columns, beams, walls	16-24 h
(b) Soffit formwork to slabs (props to be refixed just after removal of formwork)	3 days
(c) Soffit formwork to beams (Props to be refixed just after removal of formwork)	7days
(d) Props to slabs	
(i) Spanning up to 4.5m	7 days
(ii) Spanning over 4.5m	14 days
(e) Props to beams & arches	
(i) Spanning up to 6 m	14 days
(ii) Spanning over 6 m	21 days

- Above specifications are valid for OPC & where ambient temperature do not fall below 15ºC & adequate curing is done.
- For other cements & lower temperature, the stripping time recommended above may be suitably modified.

Cellular concrete: It is also called aerated/foamed concrete. It is prepared by mixing aluminum in C.C. It is light in weight & spongy in structure

Trasparent concrete: It is also called as translucent concrete or light transmitting concrete. It is achieved by replacing aggregate with transparent alternate material use of optical fibre & fine concrete are also used as transparent concrete

Lean concrete: It is mix where the amount of cement is lower than the amount of liquid present in strata

S.No	Type of Construction	Min. Grade
1.	Lean Concrete bases	M5, M 7.5
2.	Plain Concrete Cement	M 15
3.	RCC (general construction)	M 20
4.	Water tanks, dome	M 30
5.	In sea water	M30(RCC) M20 (PCC)
6.	Post-tensioned PSC	M 30
7.	Pre - tensioned PSC	M40

Shortcrete (Grouted) Concrete:- Also known as spray concrete because the force of jet impacting on the surface compacts it so as to make itself supporting. In it, mortar/concrete is pneumatically projected at high velocity on the back-up surface. The size of aggregate used is less than 10 mm.

Ready mixed concrete: It is a concrete delivered at site in the plastic condition & do not required any further treatment before being place in a position in which it is to be set & harden. The first RMC plant was established in year 1992 in Pune.RMC technology employs retarders for the purpose of retaining the slump.

Ferrocement: It is use in thin walled structures. It has low cost.

Pumpable concrete: It is a type of concrete which can be pushed through a pipeline for constructions. Slumps of concrete should be in the range 50–80 mm & w/c in the range 0.5–0.65. Generally 12.5 cm diameter pipeline is used.

Light weight concrete: It is manufactured by using air entraining agents, light weight aggregate (Sawdust, pumice), omitting use of fines etc. Generally it's density 300–1850 kg/m^3. It is use for heat & sound insulation.

No-Fines Concrete is a lightweight concrete made up of only coarse aggregate, cement & water by omitting fines (sand or fine aggregates) from normal concrete.It is useful for higher permeability.

Heavy weight concrete: It is manufactured by using special weight aggregate (Barites or magnetite). Generally it's density 2600–3900 kg/m^3. It is suitable for gravity dams, retaining walls & atomic power plants etc.

High-density concrete provides excellent protection from harmful radiation & generated heat like as in nuclear plant. The concrete's structure is superior and has higher durability and in relation to composite lead or steel shields, it is cheaper also.

Vacuum concrete: Cement concrete from which entrained air and excess water are removed with a vacuum pump, after placing it in position.

Ordinary concrete: Concrete in which no preliminary test are performed for designing the mix.

Green concrete : It is made from wastes that are ecofriendly.

- Blast furnace slag, iron oxide & fly ash are common ingredients of Green Concrete.
- Wastes like slag, recycled concrete, power plant wastes, mining and quarrying wastes, red mud, burnt clay, waste glass, saw dust, etc. are used to make green concrete.

Timber

4

- Timber applies to the trees measuring not less than 600 mm in circumference of the trunk
- Timbers are of three types standing timber, dead timber & converted timber
- The tree which is be found in living condition is known as standing timber
- The trunk of tree left after cutting all the branches is known as log
- The art of dressing of edges of timber pieces, so as to make them straight & square with the face is called shooting
- The timber whose thickness is less than 5cm & the width exceeds 15cm, is called a board
- Screws for wood work are specified by length
- Best period for cutting of tree is, when sap is in rest condition.
- The best season for felling of trees for timber production in hilly area is mid summer & for plane area, its mid winter.
- Maximum deflection for timber beam: Span/360.
- Timber beam are Designed as laterally supported beam.

Types of trees		
Endogenous tree	**Exogeneous tree**	
These grow inward Bamboo, Cane, Palm	These grow outward Deodar, Sal, Teak	
	Conifers (soft wood) Needle shape leaves Evergreen tree Pine, Chir, Deodar	Deciduous (hard wood) Broad shape leaves Open tree Oak, Teak, Shishum

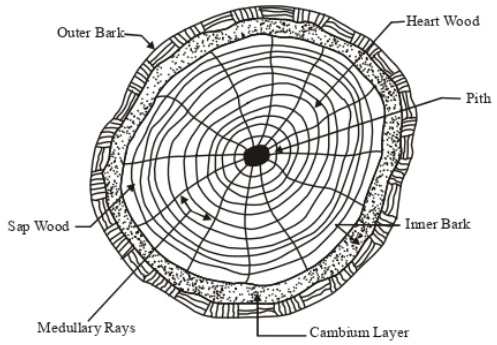
- For all engineering work we use exogeneous tree.

Special point: Softwood like Deodar are harder than hardwood like papita.

Comparison of softwood and Hardwood

Property	Softwood	Hard-wood
Colour	Lighter	Darker
Growth	Faster	Slower
Strength	Strong along grains	Strong along & across grains
Density	Low	High
Annual rings	Distinct	Indistinct
Heart-wood	Can not be distinguished	Can be distinguished
Weight	Lighter	Heavier
Conversion	Easy	Difficult
Resinous Material	Exist in pores	Does not exist
Examples	Chir, kali, Pine, fir, deodar	Teak, Poplar, Maple, Sal & Shishum

Structure of Timber



CIVIL Ki GOLI

Pith → Sapwood
PH SCale → Cambium layer
Heartwood

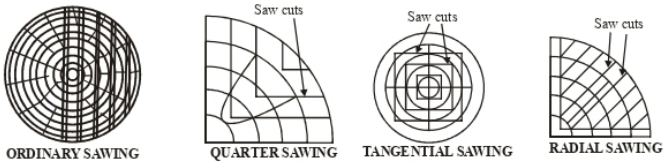
1. **Pith:** It is the innermost central portion consists of cellular tissues & nourishes plant at young age.
2. **Heart (True) wood:** It is the Dead portion of the tree, Dark in colour, Provides rigidity & durability
3. **Sap wood:** It is light in colour, shows recent growth, sap moves in upward direction through it & lie in b/w heart wood & cambium layer.
4. **Cambium layer:** It is sap that has yet not converted into sap wood.
5. **Inner bark:** Protection of cambium from injury.
6. **Outer bark (cortex):** It consists of cells of wood fiber.
7. **Medullary ray:** It hold the annual rings of heart wood & sap wood.

Special Points: Wood added during early part is different from the wood added during the late part. Because of this difference between the early wood & late wood, Growth rings (Annual rings) becomes apparent & use in age of tree.

Properties of Timber:

1. Specific gravity of wood = 1.54 & It is anisotropic elastic , shrinks least along length & maximum along circumference
2. Tensile strength along the grains is 2–4 times stronger than compressive strength. The stronger timber has closed grains.
3. The strength of any timber is highest in direction parallel to the grains.
4. Fibre saturation point is % moisture content at which cell walls are saturated & cell cavity contains no water.
5. Timber has high sound conductivity (nearly 2–17 times greater than air).
6. Weight of timber should be noted at 12% moisture content
7. Resistance of wood to cutting across the fibers (shear strength) is 3 to 4 times greater than along the fibers
8. Modulus of elasticity is generally $(0.5 - 1) \times 10^4$ N/mm^2 & its ratio of longitudinal to transverse direction is 1 –2 times.

Sawing of Timber



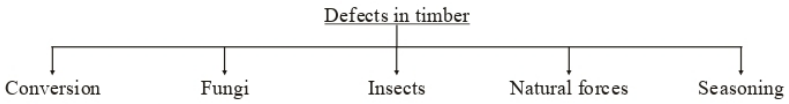
Ordinary– Flat/slab sawing: It is very quick & Economical method. It is widely adopted in our country.

Radial Sawing– Sawing is done Parallel to the rays & perpendicular to the rings. It give strongest timber

Tangential Sawing– Cutting is tangential to the Annual rings & at right angles to the meduallary rays. It is unsuitable for flooring.

Quarter/Rift Sawing– These wood wears better & shrink more evenly.

Special Point: Radial sawing will produce the strongest timber piece as in radial sawing, medulary rays are not out as the sawing is done parallel to the rays.



1. Conversion defects

(*i*) **Chip mark:** These are the marks or signs placed by chips on finished surface of timber.

(*ii*) **Wane:**It is the presence of original rounded surface on the manufactured timber.

(*iii*) **Diagonal grain:** Improper sawing, Indicated by diagonal mark or straight grained surface of timber.

(*iv*) **Torn grain:** It is the small depression on the finished surface due to falling of tool

2. Defects due to fungi:

(*i*) **Blue stain:** Sap of wood is stained to bluish colour

(*ii*) **Sap Stain:** Fungi feeds on cell contents of sap wood, then the sap wood looses its colour

(*iii*) **Dry rot:** It occurs due to lack of ventilation/absence of sunlight (in basements, rooms or in damp situations like kitchen.)

(*iv*) **White rot:** The fungi attacks on lignin of wood & wood assumes the appearance of white mass consisting of cellulose compounds

(*v*) **Brown rot:** Fungi of certain type remove cellulose compounds from wood & it attains brown colour.

(*vi*) **Heart rot:** In it, heart wood is exposed to atmosphere & attacked by atmospheric agents.

(*vii*) **Wet rot:** It is the chemical decompositons of wood due to alternate dry & wet conditions

3. Defects due to Natural forces:

(*i*) **Burls:** Also called as Excresccences, upset growth or irregular projection in a tree due to shock or injury received in its young age

(*ii*) **Callus:** It is the soft tissue or skin which covers the wound of a tree.

(*iii*) **Rind galls:** It is the abnormal growth or curved swellings on the body of tree.

(*iv*) **Knots:** These are the bases of branches which are broken or cut-off from the trees. The deviation of the fibres & discontinuous of wood is occured in it.

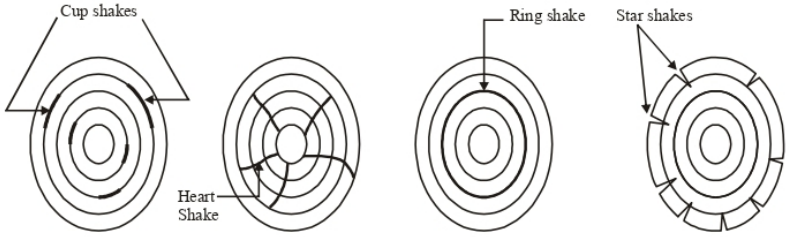
(*v*) **Foxiness:** Red or yellow thing or reddish brown stains around the pith due to lack of ventilation or over maturity of tree.

(*vi*) **Druxiness:** White decayed spots concealed by healthy woods

(*vii*) **Check :** It is a longitudinal crack which is usually normal to the annual rings. It adversly affect the durability of timber.

(*viii*) **Shakes:** These are longitudinal separations in the wood between the annual rings. Shakes are most harmful amongest all defects.

(a) Heart Shake:- Occurs in overmatured trees. These are wider at centre & diminish outward.



(b) Star shake:- It is opposite to heart shake.

- It is due frost & fierce heat of sun & in it, wood dries below fibre saturation point
- Radial splits, wide cracks at circumference

(c) Ring shakes

- When cup shake cover the entire ring

(d) Radial shakes

- When tree is exposed to sun for seasoning after being fell down



(e) Cup shake :-Excessive frost action on the sap of young trees.

(*ix*) **Upsets:**Also known as rupture due to improper felling of a tree.

(*x*) **Twisted fibres:** Twisting of young trees by fast blowing winds in one direction.

4. Defects due to seasoning:

(*a*) Bow
(*b*) Cup
(*c*) Twist
(*d*) wrap.
(*e*) Case hardening
(*f*) Split
(*g*) Honey Combing
(*h*) Shakes
(*i*) Collapse
(*j*) Spring

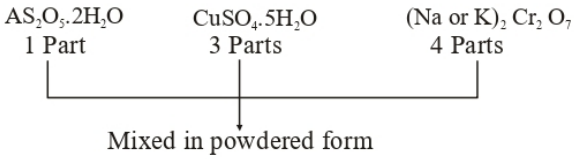
Preservation of Timber (IS : 401)

It is used to

1. Increase the life of timber & to make the timber durable.
2. Protect the timber structures from the attack of destroying agencies.

Types of Preservatives:

(*a*) **AsCu Treatment:** It is developed by forest Research Institute, Dehradun. This solution is odourless
Solution is made by 6 parts of powder in 100 parts of water by weight. It gives protection against white ants.



(*b*) **Chemical Salts:** These are water borne preservatives, mostly soluble in water like copper sulphate, Sodium flouride, mercury chloride & zinc-chloride.

(*c*) **Oil paints:** The timber is coated with 2 to 3 coats of oil paints. They preserve timber from moisture & make it durable.

(*d*) **Creosote oil:** The application of Creosote oil on timber is called creosoting. It is highly toxic in nature. It is obtained by distillations of tar. It is one of the best antiseptic. It is black or brown liquid weakly affected by water, neither volatile nor hygroscopic.

- It should not be used for interior surface of dwelling.

(*e*) **Coal tar:** Surface is coated with hot coal tar with the help of brush. This process is called tarring. It is fire resistant.

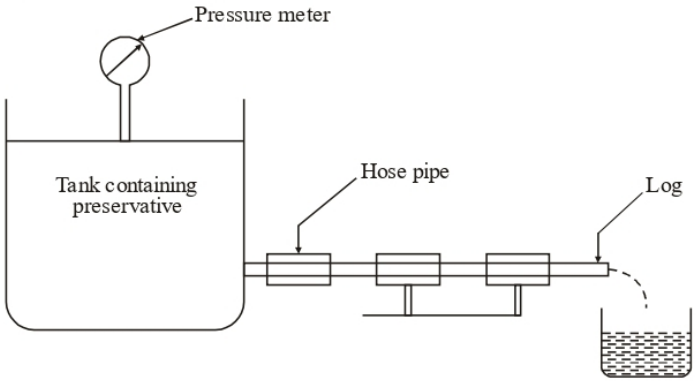
(*f*) **Solignum paints:** It is highly toxic in nature & preserve timber from white ants. It can be mixed with coloured pigments and applied in hot state with a brush

Methods of Treatment (IS: 401)

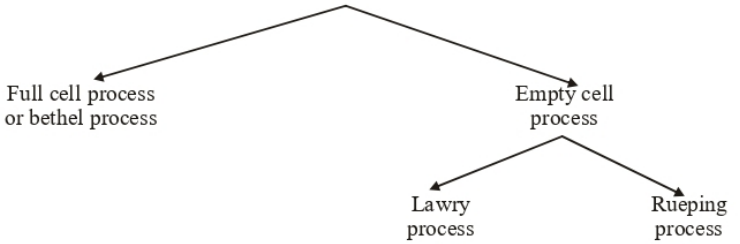
1. **Soaking:** Timber is debarked completely & submerged in the preservative solution for a sufficiently long period till the required absorption is obtained.
2. **Hot and cold process:** It is effective in giving protection to the sap wood. It ensure sterlization of timber against fungi & insects. Timber

is submerged in a tank containing solution of preservative which is heated for some hours at temp of 85°C–95°C. Then tank is allowed to cool down gradually but the timber is still submerged in the tank.

3. **Surface Application:** It is the simplest method & generally adopted for seasoned timber. It does not give surface absorption & but it is limited to treatment at site or for retreatment of cut surface.
4. **Charring:**
   - It can not be used for exterior surface due to black surface.
   - The surface to be charred is kept wet for about half an hour & then burnt to a depth of 15 mm over wood fire. Due to burning, a layer of coal is formed on the surface. This layer is neither effected by moisture nor by fungi. But there is loss of strength of timber.
5. **Diffusion process:** It is use for treatment of poles, planks & plant material. It can be done as
   (*i*) Momentary dipping of timber in concentrated solution
   (*ii*) Application of a preservative paste all over the surface of the timber.
   (*iii*) Prolonged immersion in dilute solution.
   In it, the inorganic toxic elements diffuse into timber from the place of application at high concentration to other zones through the medium of water contained in timber.
6. **Boucherie process:** This treatment is carried out by attaching the butt end of a pole to a hose pipe connected to a reservoir of the preservative at a higher level.



7. **Pressure or pneumatic process:**It is a commercial process for treating large quantity of timber. In it, large metallic drums are used into which the charge of timber stacked on trolleys is taken in drum, is then closed & the process treatment is started



Special Point: Effectiveness of Preservation methods: Pressure application > Hot & Cold treatment > Dipping > Spraying > Brushing.

Fire Resistance of timber: Timber can not be made fire proof, but it can be only made fire resistant by the following ways -

Sir Abel's process-

In it, surface of wood is painted by weak solution of sodium silicate.

Using special chemicals-

(a) Two coats of borax or sodium arsenate having 2% strength.

(b) The antipyrines containing salts of ammonium or phosphoric or boric acid are considered to be best.

Seasoning of Timber (IS: 1141) :

It is the process of reducing the moisture content of timber in order to prevent the timber. It is use for

(*a*) Reduce its weight & Increase strength & durability

(*b*) Make timber burn readily as a fuel

(*c*) Make it suitable for painting

(*d*) Reduce its tendency to split & decay & Reduce shrinkage and warping

Following are the methods of seasoning -

(a) Natural seasoning

(b) Artificial seasoning

Natural Seasoning: It is carried out by natural air, hence even called air seasoning & Moisture content can be brought down to 15–20%. The duration of a timber usually requires for natural seasoning is 6 months (minimum).

Artificial Seasoning: It is adopted for faster drying. It is possible to provide different drying conditions based on the species of timber. In it, we can reduced moisture content as per requirement.

Required time for artificial seasoning of wood is 5 to 10 day

(*a*) **Boiling:** Timber is immersed in water & it is boiled. It affects the elasticity & strength of wood. It is costly method

(*b*) **Kiln Seasoning:** Drying is carried out in air tight chamber or oven

(*c*) **Electrical Seasoning:** High frequency alternating current is used. It's most rapid but uneconmical method. It give uniform seasoning. High quality timber and plywood is obtained from it.

(*d*) **Chemical (Salt seasoning):** Timber is immersed in solution of suitable salt. It is taken out & seasoned in the ordinary way.

(*e*) **Water Seasoning:** The log of wood immersed in running water with their larger ends pointing upstream Therfore sap, sugar & gum are leached out and are replaced by water. (For 2-4 weeks).

Plywood: It has good & uniform tensile strength both along as well as across the grains. Useful for furniture, doors, ceiling.

- They are not suitable for applications which involve direct impact.
- It has odd no of layers & specified by thickness. The minimum number of plies in plywood is 3.
- Plywood is obtained by gluing wooden sheets at a pressure of (1.9 M Pa or 190 N/cm^2) but generally the pressure used is (1.38 Mpa or 138 N/cm^2). This variation is due to the different strength of raw material.
- It can be made from hardwood, softwood or both.

Timber	Uses
Babul	Agricultural Instruments
Bamboo	Scaffolding
Benteak	Boat Construction

Special Points: The timber having maximum resistance against white ant is obtained from teak

- The most valuable timber may be otained from teak
- Strength order of wood product: Battens > Lamin > Plywood > Veener.
- Cellulose in wood is 60%.
- 600 × 50 × 50mm is standard size of wood specimen for testing durability.
- The practical moisture content of wood is 15%.
- Wood decay at pH below 4.
- The sal is 30% heavier, 20 - 30% stronger and 50% harder than teak.
- **Deodar Wood**:- It's strength & weight is 20% less than teak. It is yellow in colour but darkens on exposure. It is easy to saw & works to a smooth finish. It is used for making cheap & rough furniture, railway sleepers.

Name	Property	Use
Chir	• It is moderately hard • It decays easily	Used in framing of windows, doors pattern making etc.
Teak	• Moderately hard • Easily seasoned & worked · Shrinks less • Durable & fire resistant • Not attacked by white ants & dry rot.	• For ship building, furniture railway carriages, mallets etc. • Limited to superior work only as it is comparatively very costly.
Sal	• Hard & coarse grained • Light in colour when freshly cut • Resinous& less durable.	• It has medicinal uses • It is used in Ayurveds for thousnad of year to treat variety of deseases including piles, skin disorders etc. • Not suitable for painting.
Mulberry	• Brown in colour	• For Sports goods
Shisham	• Strong & tough • Durable & maintains its shape well. • Easily seasoned.	• In sport goods. • In high class furniture • For decorative works & carvings.

Ques. What is free moisture and bound moisture for a timber ?

Ans. The moisture in timber can be present either in the cell cavities or in the cell walls. The later is called as the bound moisture & it is closely associated with the body of timber. The former is called as free moisture. The major part of moisture in timber is present as free moisture.

Sr. No.	Purpose	Nature of tree
1	Houses	Sissoo, jiyal, haritaki, teak, babul, walnut.
2	Bridge	Babul, red cedar, sal, sissoo
3	Column, beam, door frame	Arjun, bamboo, palm, coconut
4	Furniture	Teak, sissoo, deodar, walnut
5	Railway sleepers	Deodar, sundari, sal
6	Scaffolding	Bamboo

Aggregates

5

Aggregates are the inert materials basically used as fillers with binding material in the production of mortar & concrete. They give body to the concrete & occupy 70 to 80 % of volume of concrete.

Classification of aggregates -

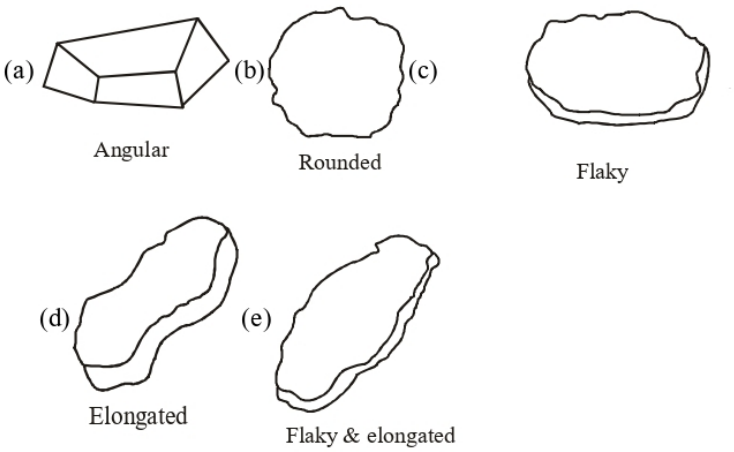
(a) On the basis of geological origin - Natural & artificial.

(b) On the basis of size - Coarse & fine aggregate.

(c) On the basis of shape - Rounded, Angular, Ir-regular and Flaky.

- Cyclopean aggregates have size more than 75 mm
- Broken bricks, blast furnace slag & synthetic aggregates are artificial aggregates.
- Natural aggregates are obtained by crushing from quarries of igneous sedimentary or metamorphic rocks. Mostly these are from igneous rocks.
- Aggregates ranging from 80 mm – 4.75 mm are called coarse aggregates while those passing from 4.75 mm sieve are fine aggregates.
- Best quality aggregates in concrete is obtained from igneous rock.
- Standard sand for testing is obtained from ennore (Tamilnadu)
- As per **IS 456 : 2000 CI 5.3.3**

  Maximum size of coarse aggregate $\not> 1/4^{th}$ of thickness of member.
- For most work 20 mm size is suitable but, when there is no restriction of flow of concrete into section, large size may be permitted.
- Irregular aggregates developed good bond & are suitable for making ordinary concrete (Voids is 35%).
- Angular aggregates provide maximum void (about 40%) but they provide very good bond & are suitable for high strength concrete.
- Rounded aggregates have minimum ratio of surface area to volume cement paste required is minimum & produce minimum voids (32%). It is best for workability.
- Saturated and surface dry aggregates imply that aggregates are 100% saturated with water with no extra water on their surface.



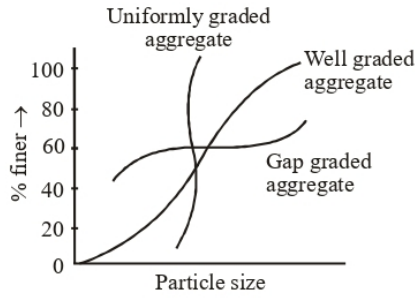
- Elongated aggregates are those whose length is more than 1.8 times its mean dimension.Flaky aggregates are those whose least lateral dimension (thickness) is less than 0.6 times the mean dimension. Both makes poor concrete.

S.No.	Classifiacation	Examples
1.	Rounded	River or seashore gravels, desert
2.	Angular	Crushed rocks
3.	Flaky	Laminated rocks
4.	Irregular or partly rounded	Pit sands & gravel, land or dug

Grading of aggregates

Grading of aggregates is one which is made up of stones of different sizes, ranging from small to large so as to have minimum of air voids.

Generally there are three types of aggregate grading:



Well graded aggregate:

It is characterized by S-shaped in gradation curve.

It has a gradation of particles size from the finest to the coarsest.

Poor graded

- It is characterized by small variation in size.
- It is also called uniformly graded aggregate or continuously graded aggregate.
- It contains aggregate particles that are almost of same size. This leaves large voids in concrete when packed.

Gap graded

- It is characterized by a gradation curve with a straight horizontal line in between two different size.
- It consists of aggregate particles in which some intermediate particle size is missing.

Characteristics of Aggregate

1. **Strength of aggregate:** Following are test for assessment of strength
   (*a*) Aggregate crushing value
   (*b*) Fineness value
   (*c*) Aggregate impact value
   (*d*) Aggregate abrasion value

   - **Strength order of Aggregates:** Cubical > Crushed > Rounded > flaky

2. **Bulk density:** It shown how densely the aggregate is packed when filled in a standard manner. Higher the bulk density, lower is the void content to be filled by the sand & cement.
3. **Stiffness:** Modulus of elasticity of concrete is approximately equal to the weighted average of the modulus of the cement paste & aggregate.

Special Point: The greater specific surface of angular particles should enable greater adhesive force to be developed, but the angular shape probably caused more severe concentrations of internal stress.

4. **Specific gravity:** Specific gravity of most of the natural aggregates lies between 2.6 to 2.7. Low specific gravity indicate high porosity & hence, poor durability and low strength.
5. **Shape and texture:**Rounded & irregular aggregates are highly

workable but yield low strength concrete. While flaky aggregates required more cement paste, produce maximum voids. So, not useful.

- **Workability order of Aggregates:** Rounded > Cubical > Crushed > flaky

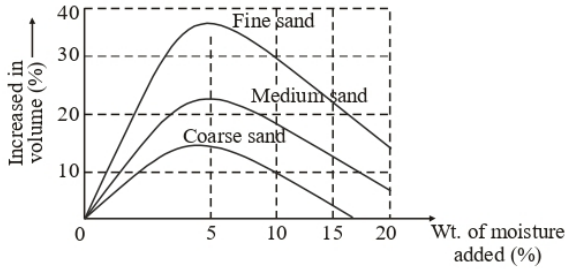
Special Points: Crushed & uncrushed aggregates generally give same strength for the same cement content.

Shape test on aggregates are done by using length gauge and thickness gauge.

6. **Moisture content:** Moisture as the percentage of the weight of the saturated surface dry aggregate.

$$\text{Total water content} = \text{Moisture content} + \text{Adsorbed water}$$

Bulking of sand: It is the increase in the volume of given mass of sand caused by the films of water pushing the sand particles apart is called bulking of sand. It depends on the percentage of moisture present in the sand & it's fineness. It is about 20 to 40% at water content of 4 to 6 %.



- If sand is measured by volume & no allowance is made for bulking, then concrete will be richer.

$$\% \text{ Bulking} = \frac{\text{Final volume} - \text{initial volume}}{\text{Initial volume}} \times 100$$

Special point: In volume batching we consider bulking of sand effect.

Fineness Modulus: It is an index number which is roughly proportional to the average size of the particles in the aggregate.

- Fineness modulus is defined as sum of cumulative percentage retained on the sieves of the standard sizes divided by 100.
- These standard sieves are 150 μm, 300 μm, 600 μm, 1.18 mm, 2.36 mm, 4.75 mm, 10 mm, 12.5 mm, 20 mm, 40 mm & 80 mm.

Aggregate type		F.M.
Fine aggregate (sand)	Fine sand	2.2-2.6
	Medium sand	2.6-2.9
	Coarse sand	2.9–3.2
Coarse aggregate		6.5-8.5
All in aggregate		4.7-7.0

- Fineness modulus 4 represent 4th sieve i.e. 1.18 mm is the average size of particle.
- Higher FM aggregated result in harsh concrete & a lower FM results in uneconmical mix.

According to fineness modulus of mix design method, the maximum quantity of water added in the first batch is determined by :

$$0.3P + 0.1Y + 0.01Z = \frac{W}{C} \times P$$

where P = Quantity of cement by weight

Z=Quantity of coarse aggregate by weight

Y = Quantity of fine aggregate by weight

$\frac{W}{C}$ = Water cement ratio

The proportion of fine aggregate to coarse aggregate is given by

$$P = \frac{x - z}{z - y} \times 100$$

where y =Fineness modulus of fine aggregate

x =Fineness modulus of coarse aggregate

z = Fineness modulus of combined aggregate

Soundness: It is the ability of aggregate to resist change in volume as a result in change of physical conditions. The physical conditions responsible for the unsoundness are:

(*a*) Alternate wetting & drying, Freezing and Thawing

(*b*) Thermal changes at temperature above freezing

Bricks

6

Basic Information-

- Standard size = 19 cm × 9 cm × 9 cm
- Nominal size (with mortar) = 20 cm × 10 cm ×10 cm
- Traditional bricks = 9" × 4.5" × 3" (23 cm × 11.4 cm× 7.6 cm)
- Frog (indent in the brick) = 10 cm × 4 cm × 1cm
- Frog is provided on top surface and it is useful in key joint between mortar and brick.
- Weight of 1 m^3 of brick = 1800 kg
- Avg. weight of the brick = 3 kg to 3.5 kg
- No. of bricks using 1m^3 brick work = 500
- The minimum thickness of brick wall is 100mm
- The density of bricks should be 1700 to 1900 kg/m^3

Comparison between Bricks and Stone

1. Brick resist more fire than stones & also resist other atomspheric effects in a better way. Dead load of brick masonary is less.
2. It is easy to construct openings in brick masonary.
3. Brick work is cheaper, requires less skilled labour & no complicated lifting device.
4. In brick work mortar joint are thin, hence more durable.
5. Brick work is less water tight & absorbs more moisture.
6. Stone work is stronger, gives solid appearance, attractive in texture.
   In stone masonary, mortar required is more to fill the voids.
   Life of stone masonary is more as compared to brick masonary.
7. Thickness of brick wall is 100 – 200 mm but stone wall has minimum thickness of 350 mm. Stone masonary do not require external plaster, so maintenance cost is low.
8. Stone work has higher compressive strength (adopted in piers, docks, dams) & doesn't requires any finishing.

Classification of bricks			
Unburnt bricks	**Burnt bricks**		
Bricks are dried in sun after moulding. These are used in temporary or cheap structures & can not be used at places exposed to heavy rains	First class	Second class	Third class

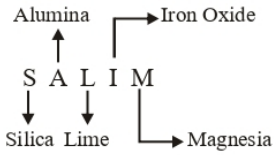
Property	1st class	2nd class	3rd class
Compressive strength (N/mm^2)	≥ 10.5	≥ 7.0	5.0
Water Absorption	20%	22%	25%
Appearance	Smooth surface, rectangular in shape with parallel, sharp & straight edges with square corners.	Small cracks & distortions permitted.	Soft & reddish yellow in colour.
Making process	Table moulded & burnt in kiln	Ground moulded & burnt in kiln	Ground moulded & burnt in clamps
Uses	Pointing & Important work	RB work & Hidden masonry work	Unimportant temporary structure

Speical Points:

1. Fourth class bricks: (Jhama)
   - Over burnt badly distorted.
   - Used as ballast in foundations & floors in lime concrete.
2. The most common colour of building bricks is red
3. **Heavy duty bricks** have compressive strength more than 40 N/mm^2, used in structures like as bridges, foundation of industrial buildings etc. Water absorption is limited to 10% as per IS:2180.
4. **Refractory bricks** have following qualities :
   - These bricks are capable of resisting very high temperature upto 1800°C without melting or softening.
   - The minimum average compressive strength of the brick should be 32.5 MPa.
   - The water absorption of refractory bricks varies from 4-10%.
   - These bricks are whitish yellow or light brown in colour.
   - These bricks are used in furnace lining, hollow tiles & crucibles etc.
5. The masonry work over the foundation lime concrete should be started only after 7 days.
6. In cement concrete, the masonry work over the foundation concrete may be started after 2 days of its laying.

Constitute	Function
(i) Silica (50-60%)	Provide strength, hardness, durability to brick.
(ii) Alumina (20 –30%)	Give plasticity to brick
(iii) Lime (<5%) Act as a flux	Causes silica to fuse during burning & binding particles together
(iv) Iron oxide (5-6%) Act as a flux	Provide red colour & improves impermeability & durability.
(v) Magnesia (<1%)	Give yellow tint

CIVIL Ki Goli



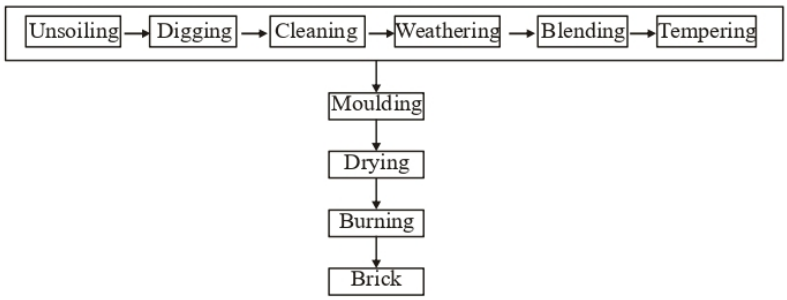
Properties of good brick

1. Bricks should have uniform size, parallel sides & sharp edges.
2. Brick earth should be free from stones, grits, organic matters etc.
3. It should not be too smooth to cause slipping mortar.
4. On scratching a brick by finger nail, no impression should be made.
5. Metallic sound is produced when bricks are struck together.
6. Water absorption ≤ 20% of its dry weight.
7. Crushing strength ≥ 10 N/mm^2
8. Uniform deep red or cherry colour as indicative of uniformity.

Harmful ingredients in brick earth

1. **Lime:** If in excess, colour of brick becomes yellow from red. Lumps of lime absorb moisture, swell & cause disintegration of the bricks.
2. **Alkalies:** Brick may melt & loose shape. Results in Efflorescence.
3. **Iron pyrites:** Discolourises the bricks. If present in brick earth, it gets oxidised & decompose during burning which may even split the brick.
4. **Pebbles, Gravels and Grits:** Result in non-uniform mixing of clay.

Manufacturing of bricks



Flowchart: Preparation of Brick Earth

2. **Moulding:** It is process of giving required shape to the brick earth.

- Classification of Moulding -

(a) **Hand moulding** - It is used for soft mud. It can be ground or table moulded.

(b) **Machine moulding** - It is used for stiff mud. It is of two types - (i) Plastic clay machines, (ii) Dry clay machines.

- The good clay for making Bricks is weathered clay.
- The tempering of bricks earth is also known as pugging or kneading
- The process of mixing clay, water & other ingredients to make bricks is known as kneading.The pug mill is used for kneading.
- Blending is the phenomenon in which clay is made loose & any ingredient to be added to it is spread out on top and turned up & down in a vertical direction.
- Generally wooden moulds are made from shishum
- Pressed bricks has two frogs & Handmade bricks has only one frog.
- Moulds are made (8–12)% larger in size.
- To prevent the moulded bricks from sticking to the side of the mould, sand is sprinkled on the inner sides of the mould.

3. **Drying:** If green bricks burnt, it can get cracked & distorted.

Types of Drying - (a) Natural drying

(b) Artificial drying - (i) Hot floor drier, (ii) Tunnel drier.

In clamp burning process, at 15^0 angle bricks are to be laid.

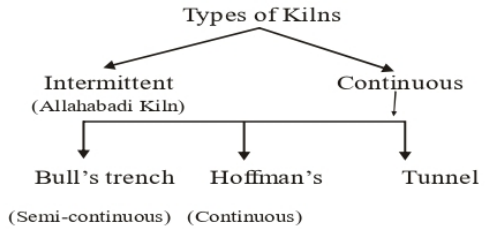
- The percentage of moisture in wet bricks is 7 to 30%
- The wet bricks should be dried in an open atmosphere 4 to 5 days
- The process of drying of bricks in an open atmosphere is called hacking.
- The Bricks after moulding should be dried in air for (3-8) days but not in sun.

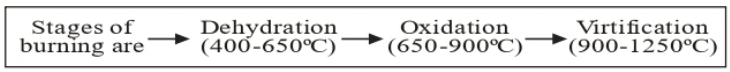
- It is a normal practice to dry moulded bricks to approx moisture content of (5–7)%. Drying period usually varies from (7–14) days.

Comparison between clamp Burning and Kiln Burning

S.N.	Item	Clamp burning	Kiln burning
1.	Capacity	About 20000 to 100000 bricks can be prepared at time	Average 25000 bricks can be prepared per day.
2.	Structure	Temporary structure.	Permanent structure
3.	Initial cost	Very low as no structures are to be built	More as permanent structures are to be constructed.
4.	Suitability	Suitable when bricks are to be manufactured on a small scale & when the demand of brick is not continuous	Suitable when bricks are to be manufactured on a large scale & when there is continuous demand of brick
5.	Regulation of fire	It is not possible to control or regulate fire during the process of burning	The fire is under control throughout the process of burning
6.	Skilled supervision	Not necessary through-out the process of burning	The continuous skilled supervion is necessary
7.	Cost of fuel	Low, as grass, cow dung litter, etc. may be used.	Generally high because coal dust is to be used.
8.	Quality of bricks	The percentage of good quality bricks is small about 60% or so.	The percentage of good quality bricks is more.
9.	Time of bruning & cooling	It requires about 2 to 6 months for burning & cooling of bricks	Actual time for burning is about 24 hours & only about 12 days are required for cooling of bricks.
10.	Wastage of heat	There is considerable wastage of heat from top & sides and hot fuel gas is not properly utilized.	The hot fuel gas is used to dry & pre heat raw bricks. Hence the wastage of heat is the least.

4. **Burning:** Over burnt bricks become brittle while under burnt bricks will be soft & hence can not carry loads. Moisture content is brought down to 2% for burning operation.





Comparison between Bull's trench Kiln and Hoffman's Kiln

S.N.	Item	Bull Trench Killn	Hoffman's Klin
1.	Burning capacity	About 3 lakhs in 12 days.	About 40 Lakhs in one season.
2.	Popularity	More popular because of less initial cost.	Less popular because of high initial cost.
3.	Drying space	It requires more space for drying of bricks	It requires less space for drying of bricks.
4.	Initial cost	Low	High
5.	Nature	It is semicontinuous in loose sense.	It is perfectly Continuous.
6.	Cost of fuel	High as consumption of fuel is more	Low as consumption of fuel is less.
7.	Quality of bricks	Percentage of good quality bricks is small	Percentage of good quality bricks is more.
8.	Suitability	Suitable when demand of bricks in monsoon is not continuous	Suitable when demand of bricks is throughout the year.

Testing of bricks

1. **Dimension Test (IS 1077):** 20 bricks are randomly selected of standard size (19 × 9 × 9) cm.

	Modular Brick	
	Dimension (cm)	**Tolerance (mm)**
Length	380	±80
Width	180	± 40
Height		
(*i*) 9 cm	180	± 40
(*ii*) 4 cm	80	± 20

2. **Compressive Strength test (IS : 3495 –Part I):** Bricks are immersed in water for 24 hours. Then taken out, Frogs filled with 1 : 3 mortar, covered with Gunny bags for 24 hours, Again immersed in water for 3 days. Now taken out & placed in compression testing machine at Rate of loading 14 N/mm^2.
3. **Water Absorption test:** (IS 3495 –Part II)
4. **Warpage Test (IS : 3495 –Part IV):**
5. **Efflorescence test (IS 3495 – Part III):** Brick is kept in a glass disc (diameter 150 mm) with water upto 25 mm till entire water is absorbed or evaporated. Again water is filled upto 25 mm, & allowed

to be absorbed or evaporated. Then area of white patch is measured.

Special points: IS : 3102: Classification of Burnt clay solid bricks.
IS : 2212 : Indian standard code of practice for brick work

Defects of bricks

1. **Over burning:** Bricks loose their shape.
2. **Efflorescence:** Already discuss
3. **Bloating:** Spongy swollen mass over bricks surface due to excess of carbonaceous & sulphur matter.
4. **Blisters:** Formed due to air imprisioned during their moulding.
5. **Chuffs:** Deformation of shape of the bricks caused by the rain water falling on hot bricks.
6. **Under burning:**Higher water absorption & less compressive strength. Unburnt or sun dried bricks can be used only in the construction of temporary & cheap structures. These should not be used at the places exposed to heavy rains.
7. **Laminations:** It is due to entrapped air in the Voids of clay.

Burnt Clay Perforated Bricks (lS :2222)

- Hollow bricks are also called perforated bricks.
- These are use for sound/heat/damp proof work and sometimes for thermal insulation as these are light in weight.
- Area of each perforation shall not exceed 500 mm^2.
- Area of perforations shall be between 30 to 45% of the area of face
- Direction of perforations can be vertical or horizontal.
- The modular and non modular size available is 19 × 9 × 9 cm and 23 × 11 × 7 cm respectively.
- Should have minimum compressive strength of 7MPa on gross area.
- For 24-hour cold water test water absorption 20% by weight.
- A maximum of 1.5 m high wall can be raised in brick masonry in a day. By this, the strength of the wall is unaffected. By making a high wall, the lower wall can not bear the weight of the top wall & it bend laterally.

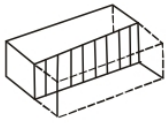
Bed joint:-These are horizontal mortar joints upon which masonary units are laid.Hence, the pressure always acts normal to the bed joint.
Cross joints or simple joints:- The joints (other than bed joint) which are perpendicular to face of wall are termed as cross-joints or simple joints.
Wall joints:- Joints which are parallel to the face of wall are termed as wall joint.

Brick Masonry

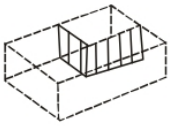
7



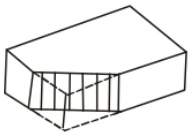
(a) Bevelled closer



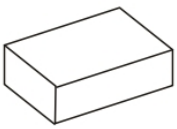
(b) Queen-closer (half)



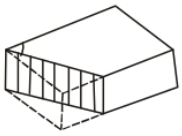
(c) Queen-closer (quarter)



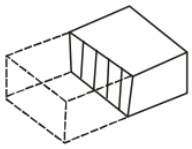
(d) King closer



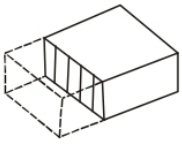
(e) Full brick



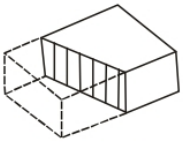
(f) Mitred closer



(g) Half bat



(h) Three quarter bat



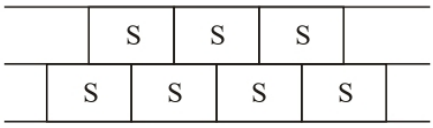
(i) Bevelled bat

Rules of Bonding

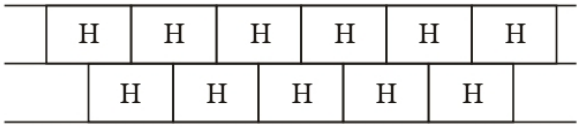
1. Lap should be minimum (1/4) bricks along the length of wall & (1/2) bricks across the thickness of the wall.
2. Vertical Joints in the alternate courses should be along the same perpend.
3. The strength of mortar in a masonry wall should be equal to the masonry units.
4. It is preferable to provide every 6th course as a header course.

Types of bonds

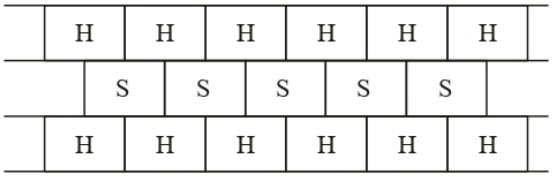
1. **Stretcher bond:** All the bricks are laid as Stretchers on the faces of the wall. Used for constructing 10 cm thick brick partition wall.



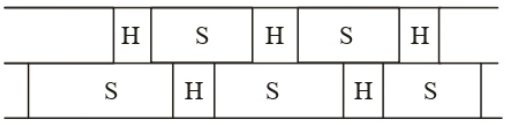
2. **Header bond:** All the bricks are laid as headers on the faces of the wall.Commonly used for constructing staining of wells, corbels, footing etc.
   - It is using three-quarter brick bats in each alternate courses as quoins.



3. **English bond:** Alternate courses of headers & stretchers.
   - English Bond is stronger & costly than flemish Bond.
   - Mostly English bond is used in government work
   - Adopted for work where strength is of prime importance.



4. **Flemish bond:** Each course has alternate header & stretcher.
   - Flemish Bond give better appearance than English Bond.
   - Construction with flemish Bond requirs greater skill in comparison to English Bond & bat bricks are use in it.
   - Minimum width of wall for single flemish bond is 1½ brick wall.



5. **Facing bond :** Bricks of different thickness are to be used in the facing or backing of the wall.

In **Raking bond**, bricks are kept at an inclination to the direction of the wall.

Slenderness ratio of brick masonry: It is the effective height of the wall divided by effective thickness or effective length divided by effective thickness, whichever is less.

Maximum slenderness ratio for load bearing walls

No. of storeys	Using Portland cement or pozzolana cement	Using lime mortar
Not exceeding 2	27	20
exceeding 2	27	13

Special Points:

- In order to check dampness, a narrow hollow space constructed parallel to the external walls, is known as air drain.
- A curtain wall is designed to carry wind load plus self-weight
- Arris $\rightarrow$ It is the edge of a brick.
- A cavity wall (Hollow wall) is constructed to resist heat flow & is designed to carry axial & bending stress. General size (4-10) cm.

Classification of Walls									
Load bearing wall				Non load bearing wall					
Solid wall with piers (Pilasters)	Veneered wall	Cavity wall	Solid wall	Faced wall	Partion wall	Panel wall	Free standing wall	Curtain wall	Faced wall

Frieze: A course of stone provided immediately below cornice is called frieze. Example of architectural frieze is on facade of a building, the octagonal tower of the winds. It is used to improve appearance of wall.

- Bull Nose/ cow nose brick is used for making corner/curve shape in brick masonary
- The projected course of brick used above opening of door/window in building construction, is called drip course. It is used to prevent from rain water to door & window.

Perpend:- It is that vertical joint on face of the wall, which lies directly above the vertical joints in the alternate courses.

- Prism test is a laboratory test to calculate the compressive strength of a masonry. A masonry Prism is an assembly of masonry unit & mortar that is constructed to serve as a test specimen for determining compressive strength.
- For first-class brickwork, the thickness of mortar joint shall not be less than 10mm.

Mortar & Lime

8

- Mortar is a mixture containing a binding agent (cement), water & aggregate (sand). It is used for filling joints as a binder in stone & brick masonry.
- Lime obtain from relatively pure lime stone (% purity 90% to 95%) is referred as quick lime or caustic lime or lump lime.
- **Slaking**:- Quick lime has very high affinity (reactivity) for water, hence instantly reacts with it & Undergoes slacking leading to the formation of hydrated lime. Quick lime slack vigrously, but set slowly

$$\underset{\substack{\text{Quick lime /}\\ \text{Caustic lime /}\\ \text{Lump lime}}}{CaO} + H_2O \xrightarrow{\text{slaking}} \underset{\substack{\text{Hydrated lime /}\\ \text{Slaked lime /}\\ \text{milk of lime}}}{Ca(OH)_2} + \text{Heat}$$

Calcination

It refers to the heating of lime stone to redness in the absence of Air.

Lime is obtained by Calcination of limestone. Moisture & CO_2 are removed from the limestone leaving behind lime.

$$CaCO_3 \xrightarrow{\text{calcination}} \underset{\text{(lime)}}{CaO} + CO_2$$

Hydraulicity: Hydraulicity is the property of lime by virtue of it, lime sets in a damp place with no free circulation of air.

Milk of Lime: A thin fluid pourable suspension of slaked lime is called milk of lime.

Note: Slaked lime if kept lying, has a tendency to absorb carbonic acid from the atmosphere (carbon dioxide & water) and hence must be used quickly without any delay.

Special Points:

(i) Plaster of Paris is obtained by calcining Gypsum.
- Gypsum is a crystalline mineral of hydrated calcium sulphate ($CaSO_4 2H_2O$)

- It is quick setting, gypsum plaster consisting of a fine white powder which hardens when moistened & allowed to dry.
- When gypsum is heated to 120°C–180°C, it gets dehydrated to form plaster of Paris ($CaSO_4.\frac{1}{2}H_2O$) which have 6.2 % water.
- It is used to precast & hold parts of ornamental plaster work placed on ceilings.

(ii) **Limestone** is a sedimentary rock, its major materials are minerals, calcite & aragonite (Crystal forms of $CaCO_3$).

(iii) **Kankar** is a term used in India for masses or layers of calcium carbonate, found in older arrival or stiff clay.

Classifications of Mortar on various factors -

(a) Type of material - Surkhi, Gauged, Cement, Gypsum, Lime mortar (Fat lime, Hydraulic lime and Poor lime)

(b) Bulk density based - Light density ($\gamma_t < 15$ kN/m³), Heavy density ($\gamma_t > 15$ kN/m³)

(c) Special types of mortar - Fire resistants, Sound absorbing, Light weight etc.

S. No.	Description	Fat lime	Hydraulic lime
1	Slacking action	Very rapid [Vigorously]	Low
2	Obtained or manufacture	It is obtained from pure lime	It is obtained from kankar
3	Setting action	In presence of air, low setting takes place.	It can be set in damp places also
4	Colour	Perfectly white	Not perfectly white
5	Hydraulicity	Nil	High
6	Strength	Not good in strength	Good in strength
7	Use	Used for plaster work, pointing work, white washing work	Used for making of masonary mortar

- Surkhi is a pozzolanic material. Surkhi mortar can not be used for plastering, flooring, pointing etc because surkhi is likely to disintegrate after some time. Main function of surkhi is to give strength & Hydraulic properties to mortar.

- Gauged mortar is a lime cement mortar. In lime mortar, cement is sometimes added to achieve early strength & it's called gauging.
- Light weight mortar is prepared by adding materials like as saw dust, wood powder etc. to lime or cement mortar. It is used in sound proof & heat proof construction.

Selection of mortar

S. No.	Nature of work	Type of mortar	Proportions
1.	Water logged areas	Hydraulic lime	1: 3
2.	Damp proof course & cement concrete roads	Cement mortar	1: 2
3.	General RCC works	Cement mortar	1: 3
4.	Brick masonry	Cement mortar	1 : 6
5.	Internal walls	Lime cinder mortar	1: 3
6.	Partition wall of Parapet wall	Cement mortar	1:3
7.	Plaster work	Cement mortar Lime mortar	1: 3 to 1: 4 1:2
8.	Pointing work	Cement mortar	1:1 to 1: 2.
9.	Stone masonry	Lime mortar	1 : 2

Gunting: It is the application of mortar or concrete under pneumatic pressure through cement gun. Its ratio of cement mortar is 1:3. It is done in layers of 40–50 mm. A thin layer of grout builds up & acts like a cushion reducing the percentage rebound in the successive layers. Average unit weight of gunite is 2300 kg/m^3.

Grout: Cement mortar of fluid consistency used to fill the voids & joints in masonry and to repair the cracks. Water-cement ratio should be kept as low as possible to increase strength & reduce shrinkage.

Porting: It is the method of injecting epoxy in the gap or crack for repair.

Special Points: Normal curing period for lime mortar is 7 days.

- Quick lime is measured in quintal.
- For 100 kg slaking, we required 40 kg water.
- Lime calcinated at 800-900°C
- Ball test is carried out to identify class B or class C lime.
- Hydraulic lime has earthy smell, grey colour.
- Weight of quick lime = 1050 kg/m^3 & slaked lime = 640 kg/m^3.
- Lime has initial setting time 2 hour & final setting time 48 hour.
- For lime concrete, Slump = 50 – 75 mm
- Flexural strength at 90 days = 0.2 N/mm^2
- Compressive strength at 28 days = 1.2 N/mm^2 & 90 days = 1.5 N/mm^2

STONE

9

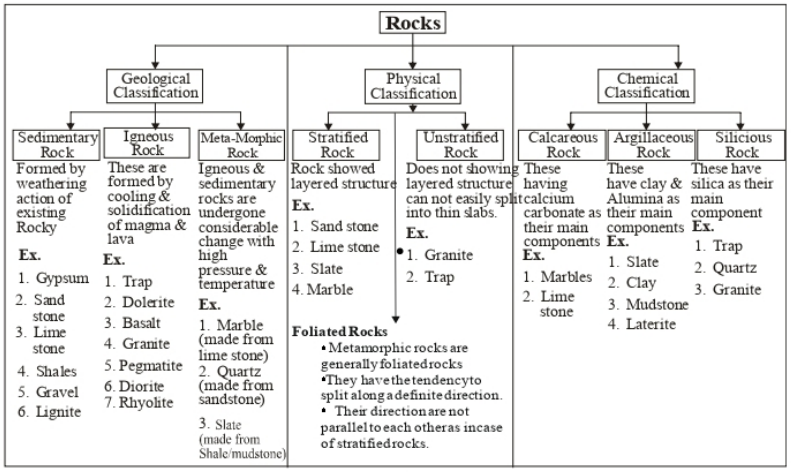
- Lithology is the study of the general physical characteristics of rocks.
- Mineralogy is the systematic study that extensively covers crystallography physical, chemical, minerals study etc.
- Petrology is the study of rocks and the conditions under which theyform.
- Rockology is introduction to geology at basic level.
- A Rock is an aggregate of one or more minerals. Like as Granite is composed of three minerals Feldspar, Quartz and Mica.
- A mineral is a naturally occurring, inorganic solid with a definite chemical composition & a crystalline structure formed by geological process.

  E.g. Mica, Quartz, Gypsum, Calcite, Diamond, Topaz etc.
- Building stones are obtained from rocks which have distinct planes of divisions along which stones can be easily split. This plane is known as natural bed.
- In stone masonry, the stones are placed in position such that the natural bedding plane is normal to the direction of pressure they carry

Types of work	Direction of natural bed
Masonry wall	Horizontal direction
Arches	Radial direction
Cornice/string course	Vertical direction

- For the construction of domes, lighter stones are preferred

S.No.	Rubble Masonry	Ashlar Masonry
1.	Use hard & irregular shape of stone	Use smooth shape of stone
2.	These type masonry having rough dressing & having wide joint.	These type masonry having smooth dressing & regular fine joints of 3 mm thick



Stone	Type of Rock	Uses
1. Granite	Igneous (Silicious)	Ornamental columns, sea walls, railway ballast, building blocks, bridge piers, in making of artificial stone. G_S=2.6 - 2.9 (general range)
2. Basalt or trap	Igneous (siliceous)	Paving sets, road material, aggregate in concrete
3. Marble	Metamorphic rock (from limestone or dolomite)	Carving & decoration work, steps, table slabs etc. G_S=2.72
4. Gneiss	Metamorphic rock	Street Paving
5. Sand stone	Sedimentary rock (silicious variety)	Coarse grained for rubble work for slabs, tiles & fine grained for ashlar work, moulding etc.
6. Slate	Metamorphic rock formed from shale	Making electrical Switch board, G_S=2.8, as DPC, use in cisterns for urinal partition
7. Laterite	Sedimentary (argillaceous)	As building stone, as road material

Rock Types	Chemically	Physically	Geologically
Granite	Siliceous	Unstratified	Igneous
Quartzite	Siliceous	Stratified*	Metamorphic
Marble	Calcarious	Stratified*	Metamorphic
Limestone	Calcarious	Stratified	Sedimentary
Sandstone	Siliceous	Stratified	Sedimentary
Slate	Argillacous	Stratified*	Metamorphic
Laterite	Argillacous	Stratified	Sedimentary.

Tools for Quarrying stones

Jumper:- It is used for making hole in rock.
Scraping Spoon:- It is used to scrap or remove dust of crushed stone from Blast holes.
Primary Needle:- It is used to maintain the hole when tamping is being done. It help in connecting fuse with blasting material.
Tamping Bar:- It is used to ram or tamp the material while refilling blast holes.

Dipper:- It is used to drill a hole to the required depth.

- Cross cut saw is used for cutting hard stone.
- Spalling hammer is used for rough dressing of stones.
- Metamorphic rocks are highly compact & solid. They carry no fissures or cracks & are difficult to quarry with hand tools. So, the quarry of these types rock is done by blasting in which drill holes are put down to the depth to which the rock is to split & the requisite amont of dynamite is put with sand & fired by a fuse.

Dressing of stones: Dressing of stones is performed to achieve following objectives

(a) To obtained desired appearance
(b) To increase the properties of stone such as durability & strength.
(c) To suit the requirements of stone masonary.
(d) To reduce the transportation & handling cost of stones

- Wedging Method is used for sedimentary Rock, Generally using Hammer. This method used for quarrying of soft, stratified rock. It is costly.
- Blasting method is generally used for Igneous & metamarphic rocks.
- Rough dressing of stone should be done at time of quarring because stone is in soft state at that time.
- Flush pointing is extensively used in brickwork & stone masonry face work.

Some Points about stone:

- Crushing strength of good building stone should be more than 100 MPa.
- Flush pointing is extensively used in brick masonary work & stone masonry face work
- Weight test is to be conducted on a stone used in docks & Harbours.
- The stones which can be polished easily marble & granite
- Sandstone is used in normal work of building construction and it also have highest fire resistance capacity.
- The best stone for Ashlar stone masonry is sandstone
- The samples are tested in saturated condition. hence they are placed in water for about 72 hours prior to test.
- Load bearing surface of sample is covered with plywood of about 5mm thickness.
- Load is applied axially at a rate of 14 MPa/min
- Crushing strength of the stone is load at which sample crushes divided by the area of bearing surface of the specimen.
- Coefficient of hardness $= 20 - \frac{\text{loss in wt}}{3}$
- If hardness coefficient >17, very hard (Generally used in road work), hardness coefficient- (14-17), Medium Hard
  hardness coefficient < 14, very poor hard
- If toughness coefficient <13, Poor Tough, toughness coefficient - (13-19) Moderate Tough,toughness coefficient >19, Very Tough.
- Stone samples are cut into cubes of size 40 × 40 × 40 mm.
- Average of atleast 3 sample is reported as crushing strength of stone.
- Shingle are widely used as roof covering on residential buildings & they are made up of asphalt, roof, slate and disintegrated laterite. They are attached in overlapping courses.
- Shingle is produced from washing ballast & is on of the graded gravels. They are perfect for paths, driveways, flower beds, & a veriety of other landscaping purposes.
- Generally seasoning period of stone is 6-12 months
- A good building stone water absorption capacity should not exceed 5% of the self weight.
- A stone should rejected/not use for masonry work if water absorption is 0.1 of the self weight.
- A good building stone has rate of wear < 3% & Devel attriation testing machine is used for attrition test.

Test	Purpose
Smith test	For presence of soluble matter
Brad's test	For frost resistance (durability)
Acid test	To check weather resistance
Mohs scale	For hardness

Rock	Classification	Rock after Metamorphism
Granite	Igneous	Gneiss
Basalt	Igneous	Schist
Limestone/Marl	Sedimentary	Marble
Mudstone/Shale	Sedimentary	Slate
Sandstone	Sedimentary	Quartzite

- **Blasting powder** contains 75% saltpetre, 10% sulphur & 15% charcoal. It is used in ordinary quarrying.It is cheap in cost and have weak destrusive power as compare to dynamite.
- **Cordite:** Powerful, smokeless explosive in which Nitroglycerine is used.
- **Dynamite** contains 75% nitroglycerine, absorbed in 25% of sandy earth, forming a thick paste, can be use in water. It is used in tunneling work.
- **Nitrocellulose or Gun cotton:** Made by saturating cotton with nitric acid.
- Explosive material is measured in kilograms.
- **Uses of stones:**
  (a) Abutment & Pier- Granite
  (b) Damp proof course/roofing material- Slate
  (c) Ornamental/carving work-Marble, sand stone
  (d) Flooring work: Limestone, Marble, sand stone
  (e) Facing work: Granite, Marble, sandstone
  (f) Retaining wall: Quartzite
  (g) Rubble masonry & foundation work: Basalt, Trap
  (h) Manufacturing of cement/Putty: Chalk

Special Point: Quartzite is a metamorphic rock consist of mostly quartz. Mica & Gypsum are the name of minerals found in the rock.

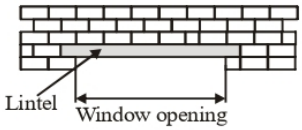
- Bearing capacity of rocks are as follows:
  Igneous rocks > Metamorphic rock > Sedimentary rock.
- The amount of calcium carbonate in lime stone is determined acid test

Door, Window, &Roof

10

$$\text{Window Width} = \frac{1}{8}[\text{Width of room} + \text{Height of Room}]$$

Lintel:



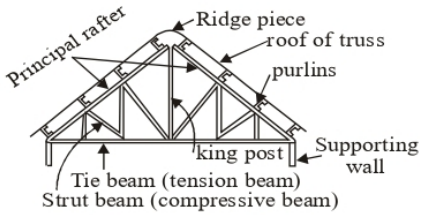
Lintels are the beams provided over the openings in walls for doors & windows.

Bearing of lintel should be minimum of following:

(a) 10 cm (b) Height of lintel (c) (1/10) to (1/12) of the span of lintel

Particulars	Arch	Lintels
Shape	Curved	Horizontal and straight
Bed Joint	Joints are radial except in monolithic construction	Joints are horizontal
Lateral thrust	Exert on vertical support	Do not exert
Rise	Provided	Not provided
Appearance	Good architectural appearance	Simple appearance
Strength	Quite strong vertical uniform loading but weak under point loading	Equally strong for uniform & point loading

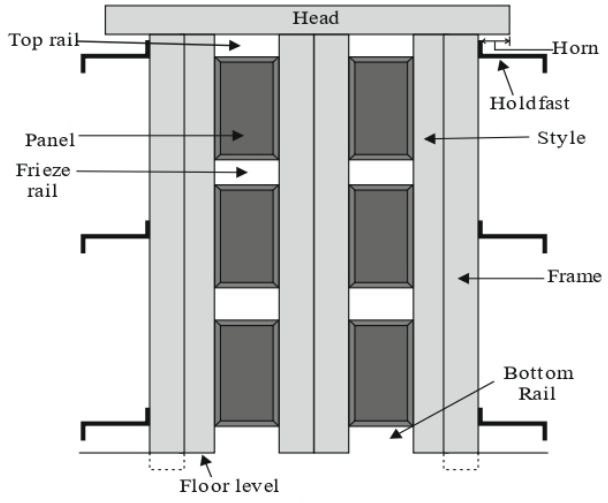
Rafter:



Cross section of a roof truss

It is one of a series of sloped structural members that extend from the ridge to the wall plate supporting down slope perimeter load in truss that are designed to support the roof.

- In residential building, The sill of a window (height 1-1.1m) should be located about (70 – 90) cm above floor level of the room. It should be properly weathered (slope 1:6) to drain off rain water & minimum projection is 50 mm.
- Generally Height of a Door should not be less than (1.8 – 2) m
- Commonly Width height relation used in India:
  (i) Width = (0.4 – 0.6) Height (ii) Height = (Width + 1.2) m



Door

1. **Shutters.** It is an assembly of styles, panels & rails. Shutters are the openable parts of a door or window.
2. **Frame.** It is an assembly of horizontal & vertical members, forming and enclosure, to which the shutters are fixed.
3. **Jamb**- This is the vertical wall face of an opening which supports the frame.
4. **Sill**- These are normally not provided in door frames. It is the lower-most or bottom horizontal part of a window frame.
5. **Reveal**- It is the external jamb of a door or window opening at right

angles door or to the wall face.

6. **Horn**- The length of horns is kept about 10 to 15 cm. These are the horizontal projections of the head & sill of a frame to facilitate the fixing of the frame on the wall opening.

7. **Transom**- It is a horizontal member of a frame, which is employed to sub-divide as window opening horizontally.

8. **Mullion**-It is a vertical member of a frame, which is employed to sub-divide a window opening vertically.

9. **Sash**- It is type of frame made of light section and designed to carrying glass.

10. **Hold fasts**- The horizontal length of hold fast is kept about 20 cm & is embedded in the masonry.These are mild steel flats (section 30 mm × 6 mm), generally bent-up into Z-shape, to fix or hold the frame to the opening.

11. **Rebate**- It is depression or recess made inside the door frame, to receive the door shutter.

- **Location** - The door should be preferable be located near the corner of a room at a distance of about 20 cm from the corner.
- Doors of residential Buildings:
  (a) External Door – (1 × 2) to (1.1 × 2) m
  (b) Internal Door – (0.9 × 2) to (1 × 2) m
  (c) Doors for bathrooms & Water closets:– (0.7 × 2) to (0.8 × 2) m
- Public Buildings (School, Hospital, library)
  (a) (1.2 × 2) m (b) (1.2 × 2.1) m (c) (1.2 × 2.25) m
- Revolving Doors are provided in only public Buildings (Store, Banks, Hotels etc) & AC buildings where continuous use of doors is necessary.
- Sliding doors have shutter slides on the sides.For this purpose runners & guide rails are provided.These are used in banks, offices,garrage & workshop etc.
- Glazed and panelled door - It is extensively used in residential & public buildings like hospital, colleges, offices etc.
- Rolling steel shutter Door are also used for Garrages, Godowns etc.
- Swinging door used for residential building in laudry,kitchen etc. and folding door for covering the large opening, preferable when the additional width is not available for installing a sliding door.
- Designation of Door = Length × Type of Door × Height
- 8 DS 20 – A door opening Having width (8 × 100 mm) × Height (20 × 100 mm) with S (Single Shutter) D (Door)

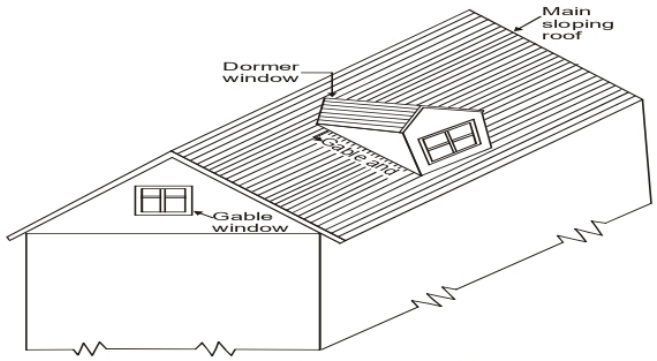
- 10 DT 21 – A door opening Having width (10 × 100 mm) & Height (21 × 100 mm). With T – (Double Shutter) D(Door)
- The window in a room should be located on Northen side from point of view of max-day light.
- Orientation of building means fixing the direction of building for maximum benefit from nature
- In a residential building, kitchen is most preferred on the corner of the building in S-E direction
- Bedroms are recommended in north-west and south-west direction while planning a residential building because of to get plentiful of breeze during summer
- Minimum window area in any habitable rooms will be $10\% or \frac{1}{8}$ of the total room area
- The total area of window openings should normally vary from (10 – 20)% of the floor area of room.
- In Public Buildings, the minimum area of window should be 20% of floor area.
- The area of window openings should be atleast 1 m^2 for every (30 – 40) m^3 of Inside content (Volume) of room.
- For sufficient Natural light, the area of glazed planes should atleast be (8 – 10%) of the floor area.
- 6 WS 10 – Single shutter window with Width (6 × 100) mm & height (10 × 100) mm
- Generally in W.C., kitchens & bathrooms the type of door used is ledged & braced type
- As compared to the floor area of a room, the glass area in a window should not be less than 15%

Types of Window

1. fixed 2. Pivoted 3. Sliding 4. Bay 5. Corner 6. Cable (7) Dormer (8) Skylights (9) Louvered (10) Lantern (11) Gable

1. The window, which projects outside the external wall of the room, is called bay window
2. A dormer window is a vertical window provided on sloping roof.
3. Bay window project outside the external wall of the room.
4. Louvered windows are provided for the aim of Ventilation & They do not permit Any outside vision.

5. Casement windows are common types of windows provided in Buildings, which open like shutter doors.

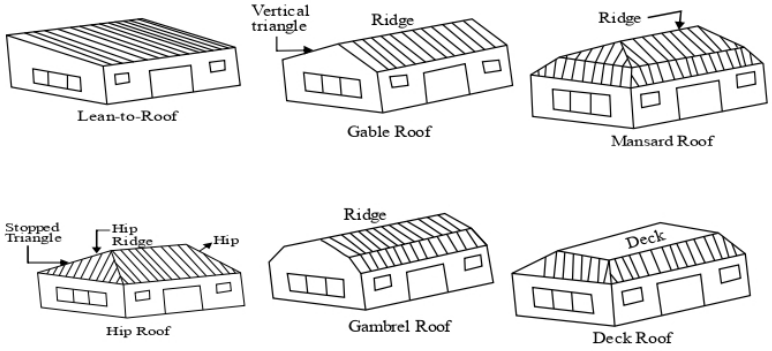


DORMER WINDOW AND GABLE WINDOW

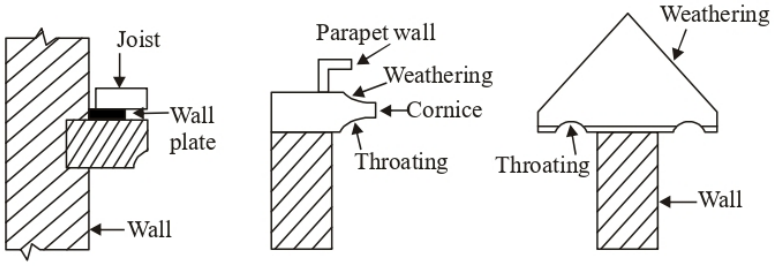
6. A dormer window is a vertical window provided on the sloping roof . Such a window provides ventilation & lighting to the enclosed space below the roof & at the same time, very much improve the appearance of the building.
7. Gable Window is a vertical window provided in the global end of a pitched roof.

Types of roofs:

- Gable roof is a common type of sloping roof which slopes in two directions. It looks like an inverted/upside down V. These are not ideal for the areas with high wind.
- Gambrel roof slopes in two direction but there is break in each slope. It is most commonly use on barns. It has the benefit of providing a good amount of space in the attic.
- Flat roofs are common in commercial building.
- Pitched roofs are use in areas of heavy rain falls and snow fall. The slope of roof shall be more than 10°. They may have slopes upto 45-60°. These are preferred in large span structure like as workshops, warehouses, factory buildings etc.
- Mansard roof is a french design & it is more difficult to construct than the hip or gable roof. It slopes in the four directions but each slope has a break.



- Butterfly roofs is provide plenty of light & ventilation but not the effective when it comes to water drainage.



Corbel **Cornice** **Coping**

Corbel: A corbel is a projecting stone which is usually provided to serve as support for roof truss, beam, weather sheds.

Cornice: A cornice is a course of stone provided at the top of wall. It is weathered and throated to dispose off rain water.

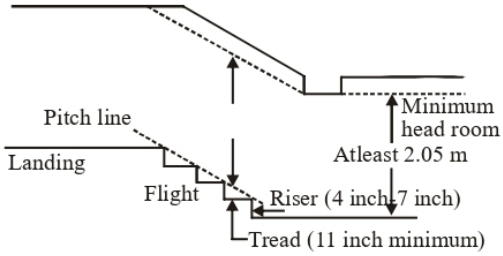
Coping: A coping is a coarse of stone which laid at the top wall so as to protect the wall from rain water.

Throating:-It is a groove provided on underside of teh projecting elements such as sills, coping, cornices etc. so that rain water can be discharged clear off the wall surface.

- Purposes of building ventilation are provide a continuous supply of fresh outside air,maintain temperature and humidity at comfortable levels.For the effective working of the ventilation system, the desired value of rate of air changes 5 m^3/ hour.
- Ventilaters are small windows, fixed at a greater height than the window (Generally (30 - 50) cm below roof level.
- Air changes per hour is a measure of the air volume added to or removed from a space divided by the volume of the space. Classrooms needs maximum number of air changes per hour.

Stair Case

11



Head room: It is the minimum clear vertical distance between the tread & overhead structure.

Scotia: It is a moulding provided under the nosing to improve the elevation of the step & to provide strength to nosing.

Soffit: It is the underside of a stair.

Newel Post: It is vertical member which is placed at end of flights to connects the ends of strings & hand rail.

Balustrade: It consist of a row of Balusters surmounted by a hand rail, to provide protection for the users of the stair.

- For making spiral staircase, ideal material is cast iron
- Width of stair in Domestic building 90 cm & in public Building, (1.5-1.8)m.
- No. of steps are not more than 12 & not less than 3 in a flight.
- Angle of Inclination (Pitch) – (25° – 40°) & Maximum pitch or slope in staircase for public building = 33^0
- Head room must not be less than 2.05 m.
- The width of landing should not be less than width of stair.
- Minimum width of stairs in residential building – 85 cm & in commercial building is 1 m.
- In a public building, the stairs should be located near the entrance of building

- In public buildings the maximum riser is limited to 15 cm
- The height of hand railing above the tread should be generally in between 75 cm to 80 cm
- **For residential building :** The size of step widely adopted 25 × 16cm.
- **For public building :** Generally length of steps are increased and width reduced slightly common step size for public buildings are 27 cm × 15 cm or 30 cm × 13 cm.

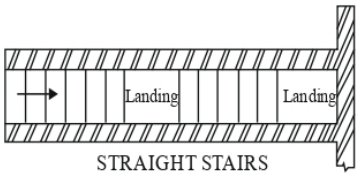
Some Thumb Rule:

(a) (2R + T) = 60, (b) (R + T) = (40 – 45), (c) R × T = (400 – 450).
where, R – Rise in cm, T – Tread in cm.

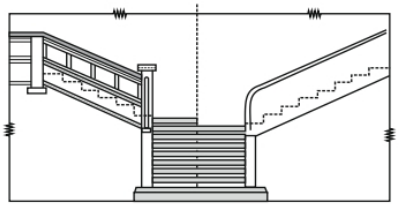
- In case of straight staircase,
  No. of Tread = (No. of Riser – 1)

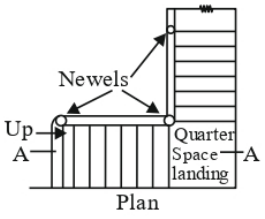
$$\text{No. of Riser} = \frac{\text{Total height between floor \& roof}}{\text{Height of one riser}}$$

- Types of Stairs: (1) Straight stairs



STRAIGHT STAIRS


Elevation
Bifurcated Stair



Plan
Quarter Turn Stairs

(2) Turning Stairs.
(a) Quarter Turn, (b) Half Turn Stair (Dog-legged & Open well stairs)
(c) Three-Quarter, (d) Bifurcated stairs.

- As per IS : 875 Part-2; the recommended **imposed load** on staircase-

Residential Building - 3kN/m^2, Educational Building - 4kN/m^2
Merchantile Building -5kN/m^2, Industrial Building - 5 kN/m^2

Floors

12

- Ground floor is that floor which is constructed just above the ground level & basement level
- The joints provided in wooden floor are tongue & groove
- The common size of a floor tile is 200 × 200 × 20mm
- **Polishing:** It is the mechanical process to grind the concrete floor surface to a high glass finish.
- In multistoried government buildings, the floor height is usually restricted to 3.4 metres

Mud/Muram flooring: It is cheap, Hard, fairly Impervious, easy to maintain & Construct. It has good thermal Insulation property due to which it remains cool in summer & fairly warm in winter. Commonly use in villages. This floor is washed with dilute oxalic acid.

Terazzo flooring: It is laid in thin layer over concrete topping. It is very decorative & has good wearing properties. It is mostly used in residential buildings, Hospitals, offices, schools & other public buildings

- In it, marble chips size is 3 to 6 mm.
- The flooring in which base concrete of lime, cement & concrete of mix 1:5:10 is laid over well compacted sub base is called terrazao flooring

Cork flooring: It is perfectly Noiseless & is used in libraries, Theatres, Art Galleries, Broadcasting stations etc. where noiseless floor covering is desired. It is available in the form of coloured tiles/sheets.

Glass flooring: It is used for entrance of light at basement from the upper floors

Mosaic flooring: In it, we use chips of marble in coloured cement. Its thickness is 4 cm generally.

- For cleaning mosaic floors, we use muriatic acid (spirit of salts) diluted with water.
- Precast concrete tiles with marble chips on the surface are known as mosaic tiles.

Steel & Glass

13

Some Special Varieties of Glass

Bullet proof glass: It is made up of several alternate layers of plate glass & vinyl resin plastic. The thickness of outer layers is small as compared to inner layers .

It is made of thick glass steel & a sandwiched layer of high strength plastic

Float glass: It is extensively used in residential & commercial buildings. It is superior to ordinary glasss in terms of energy consumption, cost effectiveness, appearance & strength.

Fibre glass : fibre glass consists of minute glass roads(fibres) made up of the parent material itself. It is soft & flexible.It is used for Thermal Insulation.

Safety glass : It is also called shatter proof glass. It is extensively used in automobile glass. the glass does not actually breaks but cracks therefore preventing damage from flying splinters, pieces of glass.

Ultra violet ray glass : This glass effectively transmits almost all of the ultra-violet rays incident on the glass irrespective of the angle of incidence.Other types of glasses made for specific purposes are Heat excluding glass, Shielding glass, Perforated glass, Structural glass.

Special Points:

- The common house hold glass is soda lime glass
- Foam glass is recommended while making a building air - conditioned
- The glass used for display windows of jewellery shop is laminated glass
- Glass used in railways coaches is wire glass
- Wired Glass: Used in outside window to resist fire & Breakage.
- Ground Glass: Used where light is to be admitted, but vision is to be obscured.

Steel

- Vanadium steel is normally used in the manufacture of Axles & springs.
- Manganese steel is used in manufacture of rails.

Physical properties of steel

Various physical properties of structural steel are given below.

Unit mass of steel, $\rho = 7850\ kg/m^3$

Modulus of elasticity, $E = 2 \times 10^5 N/mm^2$

modulus of rigidity, $G = 0.769 \times 10^5 N/mm^2$

Poisson ratio, $\mu = 0.3$

Coefficient of thermal expansion, $\alpha = 12 \times 10^{-6}/^oC$

Metals can be grouped in the following two categories.

1. **Ferrous metals:** Ferrous metals contain Iron (ferrous) as their main constituent.

   Main constituents of ferrous materials are Pig iron, wrought iron, cast iron, steel & alloys

2. **Non ferrous metals:** Commonly used non ferrous metals are aluminium, copper etc. These metals are obtained by processing the iron ores mined from the earth. Important varieties of iron ores are
   (1) Haematite - Fe_2O_3 (65-70 % of iron)
   (2) Pyrite - FeS_2 (45% of iron)
   (3) Magnetite - Fe_3O_4 (70-73% of iron)
   (4) Limonite - $2Fe_2O_3.3H_2O$ (60% of iron)
   (5) Siderite - $FeCO_3$ (40% of iron)

The crude iron extracted from iron ores is called Pig iron, which forms the basic material for manufacturing of cast iron, wrought iron & steel.

Manufacturing of steel

The process commonly used for manufacturing of steel are

(1) Bessemer Process
(2) Open hearth process
(3) Crucible steel process
(4) Duplex process
(5) Cementation process
(6) Electric process

Treatment of steel

(a) **Mechanical treatment** : Mechanical treatment are introduced to give desired shape to the steel so as to fit the purpose.

(i) **Drawing** : It refers to the reduction of cross section & to increase it

length proportionately. The metal is drawn through dies or specially shaped tools. This is essentially used for making wires & rods.

(ii) **Rolling** : This operation is carried out in specially prepared rolling mills. Angles, channels, joists, rails etc are obtained by rolling.

(iii) **Pressing** : The steel metal is pressed between a die & punch of an equipment known as press. The main advantage of this process is the absence of shock (unlike forging)

(iv) **Forging** : This process refers to the repeated blowing of the steel using a power hammer or a press. The metal is heated above the critical temperature before the blows. The process is implied to increase the density & improve the grain strength of steel.

Special points:

Annealing : This process refers to making the steel soft so as to increase its workability upon machines. Tensile strength is reduced but ductility is increased. Toughness of steel is also enhanced against sudden stresses. Annealing temperature range depends upon the carbon content. As the carbon content increases the required temperature for annealing decrease.

Purification

- Purification of iron is done by magnetic rollers.
- In which magnetic ore (Iron) is attached by magnetic roller.Therefore, non-magnetic part of ore (such as dust, clay, glass etc.) will left & removed easily.

Refining: In metallurgy, refining consists of purifying an impure metal & in this method, the final material obtained is generally similar to the original one (process doesn't involve any chemical reaction of material), only it is pure.

Dressing: In the field of extractive metallurgy, mineral processing, it is the process of separating commercially valuable minerals from their ores.

Calcination: Calcination is the process of heating any material in the limited supply of air or absence of air. It is used in metallurgy ores & other solid materials to bring about a thermal decomposition by calcination. This process is performed to remove CO_2,moisture, impurities of sulphur, arsenic etc.

- CRS TMT bars are produced with an addition of corrosion resistance elements such as copper, chromium, and phosphorus.

Commercial forms of steel

The following are the shape in which steel is available in the market.

(i) T sections
(ii) Round bars
(iii) Flat bars
(iv) Channel section
(v) Plates
(vi) Angle setions
(vii) I section
(viii) Expanded metal
(ix) Corrugated sheets (sheets)
(x) Square bars

Property	Hard steel	Mild steel
Melting Point (^{0}C)	1300	1400
Specific gravity	7.9	7.8
Tensile strength	11-12 t/cm^2	6-9 t/cm^2
Compressive strength	14-20 t/cm^2	8-12 t/cm^2
Uses	Slab, R/f, Mechanical Shop Equipment	R/f,Pipes, Building Construction Work

Material	Percentage carbon
Wrought iron (purest from of Iron)	< 0.1%
Steel	0.10–0. 25%
High carbon steel	0.55–0.95%
Cast Iron	2.00–4.00%

Pig iron: The crude impure iron (3-4% carbon) is known as Pig-iron.

It forms the basic material for the manufacture of cast-iron, wrought iron & steel. It is used for making base plattes, column, door brackets etc.Pig iron is obtained after smelting of calcined ore in a blast furnace.

Cast iron: Cast iron is manufactured by remelting pig iron with coke & limestone. It is used for making ornamental castings, like as lamp post, bathroom fittings, wall brackets etc.

Wrought iron: It is almost pure & it hardly contains carbon more than 0.10 percent. It is used for making roof covering, rivets, chimney gates etc.

Special Points: As the carbon content in steel increases, the Brittleness property of steel increases (steel becomes less ductile). Hence, cast iron (having higher carbon content) is less ductile than mild steel (having low carbon content).

- As compared to mild steel, cast Iron has High compressive strength & low tensile strength.

Impurities in steel are Phosphorous (0.12%), Sulphur (0.1%), Manganese (1.5%), Silicon (0.2 - 0.4)%.

Paint & Varnish

14

- Distemper are available in various colours, made with base as white chalk & thinner as water.
- Distemper is cheaper than paints.
- **Distempers** are the cheaper variety of paints in which chalk is used as base & water as carrier & glue as emulsifying agent. Available in powder or paste form.
- They are most suitable for plastered surfaces as well as white washed surface of interior walls.
- Distempers are workable & easy in application but less durable
- This is used as interior paint for homes.
- It is not used for surfaces exposed to weather.
- Distempers are washed away when used in exposed surfaces.

Varnish

- Varnish is a nearly homogenous solution of resin in oil, alcohol or turpentine.
- The surface looks after the varnish glossy. Varnish provides a protective coating without substantially changing the color of the surface.
- The type of solvent depends upon the type of resin used.
- The oil dries with time & other solvents evaporate leaving behind a solid transparent resin film over the surface.
- Drier in varnish is litharge.

Types of varnish

(a) Spirit Varnish: It uses resin of soft variety such as lac or shellac dissolved in spirit. It dries very quickly.
- These are not durable & easily affected by weathering action.
- Spirit varnish is made from spirit & Wax

(b) Water varnish: It is shellac resin dissolved in hot water to which enough quantity of either borax, ammonia, soda is added.
- These are used for varnishing maps & pictures.

(c) Oil varnish: It uses linseed oil & takes about 24 hours to dry.
- It is suitable for interior & exterior surfaces.
- Hard resin such as amber, copal etc are used which makes this type of varnish most durable.

(d) Spar varnish: It derives its name from its use on spars & other parts of ship.

(e) Flat varnish: Materials such as wax, metallic soap on finely divided silica when added to varnish produce a dull appearance on drying.

(f) Asphalt varnish: It is made by dissolving melted hard asphalt in linseed oil with a thinner such as petroleum or turpentine spirit.
- It is used over shop fabricated steel works.

- **A cement paint** is a water based paint is used to preventing water penetrating redemption of dirt collection prevent fungal & algal growth on interior and exterior walls.
- It usually contain hydrated lime, 5% to 10% colour pigments & are prepared with white cement. No oil is used in it.
- It is durable & water resistant.
- Its covering capacity is about $4m^{2}$/ kg per coat. It is standard.
- I.S. code recommendation for cement paint is IS:5410
- **Aluminium paint:** It has shining & visible in dark. It is corrosion & weather resistance, water proof etc. It is used for wood & metal work.
- **Bronze paint:** It has high reflective property. It is used as radiator.
- **Cellulose paint** is a normally used by enthusiast, first timer or trade professionals when an original finish is required. This paint can produce any flat colour & needs only thinners added to it prior to painting.
- Duco paints are cellulose paints. It is used for painting, motor car, aeroplane, etc.
- **Asbestos paints:** Asbestos was very inexpensive and was used as filler in many different products in different industries.
- Asbestos was widely used in 'fireproof' paints.
- **Fluorescent paint**: It gives illumination during nights.
- **Enamel paint** :-It contain vehicles (Binding Material) like as styrene, polyvinyl lacetate, alkyd resin etc. It dries quickly (1.5 to 2) hour.
- **Caesin Paints**:- It can be applied on walls, wall board, ceilings etc. to improve appearance. Caesin (a protein substance extracted from milk curd), is mixed with a base consisting of white pigments, to form pasty/powder form paint.

Defects in Painting

(a) **Blistering:** It is the defect caused due to the fomation of bubbles under film of water paint. The bubbles are formed by water vapours trapped behind the painted surface.

(b) **Running:** This defect occur when the surface to be painted is too smooth due to this the paint runs back & leaves small area of the surface uncovered.

(c) **Craling or sagging:** This defect occurs due to the application of too thick paint.

(d) **Bloom:** In this defect dull patches are formed on finished polished surface. This may be either due to defect in paints or due to bad ventilation.

(e) **Fading:** This is the gradual loss of color of paints due to effect of sunlight on pigments of paints.

(f) **Flashing:** It is the formation of glossy patches on the painted surface resulting from bad workmanship cheap paint or weather action.

(g) **Flaking:** Flaking is the dislocation or lossening of some portion of the painted surface resulting from a poor adhesion.

(h) **Grinning:** This defect is caused when the surface final coat does not have sufficient opacity so that background is clearly seen.

(i) **Saponification:** This is the formation of soap patches on the painted surface due to chemical action of alkalis.

Various constituents of an oil paint are:

(a) Base: It is metallic oxide which is the principal constituent of a paint. Most common base used for timber painting is white lead & for iron & steel surface is red lead

It makes the paint film opaque & possesses binding properties which reduces the shrinkage cracks in the film on drying.

(b) Vehicle: It is also known as binder or carrier or drying oil

- It is an oil to which base is mixed.
- It holds the constituents of paints in suspension & helps spread it over the surface to be painted.
- It gives durability, toughness & water proofness & resistance to weathering.
- Linseed oil, poppy oil, tung oil, animal oils are examples of vehicle.

(c) Solvents: These are oils used to thin the paints, increase the spread. Also called thinner. Ex. Naptha, Spirit, Petroleum, Turpentine oil.

(d) Pigments: It is used to hide the surface imperfections & to impart the desired colour.

Name of pigment	Colour
Zinc oxide	White
Copper sulphate	Green
Burnt siena	Brown
Indigo	Blue
Ivory black	Black
Red lead	Red

Special Points:

- The drier in an oil paint should not be more than 10% (by volume)
- Gypsum is an insulating material & used as sound proof material
- Gypsum is composed of calcium sulphate & di-hydrate
- Density of gypsum is 2960 kg/cum
- Galvanized iron pipe is used for making drinking water pipes
- Sewer pipes are made of stoneware
- The amount of water used for one kg of distemper is 0.6 litre.
- Putty is traditionally made by mixing a base of whiting (finally powdered chalk) with the linseed oil in the various parts. It has similar texture to clay. It is used for filling holes, microcracks etc. It is used in domestic construction & repair as a sealant & filler due to it's high plasticity characteristics.
- Resin is a natural or synthetic organic compound having a non-crystalline or viscous liquid substance.Natural resins are yellowish to brown in colour. These are typically fusible & flammable organic substances that are transparent or translucent.. They are formed in plant secretions & are soluble in various organic liquids like as spirit but not soluble in water. They are used as varnishes & left behind on evaporation of oil.
- Terpentine oil are also used to clean brushes & other tools.
- Peeling is the complete dislocation of some portion of plastered surface, resulting in the formation of a patch.
- Thermocol is a very light, cellular plastic.
- The compressive strength of thermocol varies from 117 - 144 kg/cm^2 .
- It resist dampness.It is light, strong and durable.
- It is used in acoustic treatment and lining of ceiling and walls.
- It is an excellent insulating material of heat, sound and electricity.

Building Maintenance Engineering

15

- The process of making the back ground rough, before plastering, is hacking
- Area of openings for buildings of large permeability is more than 20% of wall area
- In residential buildings the height of bathroom should not be less than 2.4m
- The most important tool in brick laying for lifting & spreading mortar & for forming joints is trowel
- The surface to which the first coat of plaster is applied is called background surface
- The function of cleats in a roof truss is to prevent the purlin from tilting.
- The function of king post in a king post roof truss is to prevent the tie beam from sagging at its centre.
- Complete dislocation of plastered surface, resulting in formation of a patch is known as peeling
- The skirting finish applied to the bottom most part of the interior wall.

Requirement of Part of Building

- **Plinth:** The height of plinth shall not be less than 30 cm from surroundings ground level.

Store room:

- Area of store room shall not be less than 3 m^2.
- Height of store room shall not be less than 2.2 m.

Stairway (Minimum Width)

- Residential building (dwelling) upto 3 story – 0.9 m
- Other residential building like flat, hotel etc. = 1.25 m
- Residential hotel building,Educational building like school & college, Assembly building like auditorium, theatre etc.= 1.5 m
- Institutional building like hospital = 2 m
- All other buildings = 1.5

Part of building	Minimum area	Minimum width
One habitable room	9.50 m^2	2.40 m
Two habitable room	One Room 9.5 m^2 other room 7.5 m^2	One Room 2.40 m^2 & other room 2.40 m^2
Kitchen with store	5.5 m^2	1.8 m
Kitchen only	4.50 m^2	1.8 m
Kitchen cum dinning room	9.5 m^2	2.4 m
W.C.	1.1 m^2	0.9 m
Bathroom	1.8 m^2 (1.5 m × 1.2 m)	1.20 m
Bath + W.C.	2.8 m^2	1.2 m

- Size of door for kitchen is 0.9 m × 2.1 m
- The height of habitable room shall not be less than 2.75 m.
- The minimum clear head room under a beam folded plate or eave shall be 2.4 m.

Depth of exploration

The term significant depth is used to indicate the depth upto which the increase in pressure due to structural loading is likely to cause perceptible settlement or shear failure of foundations.

Depth of exploration

- 1.50 times the length •1.50 times the width.
- 1.50 times the base width of 1.50 times the exposed height of face of wall whichever is greater.

Depth of construction.

- 1.50 m in general & 3.50 m in black cotton soil.
- **Methods of site exploration.**

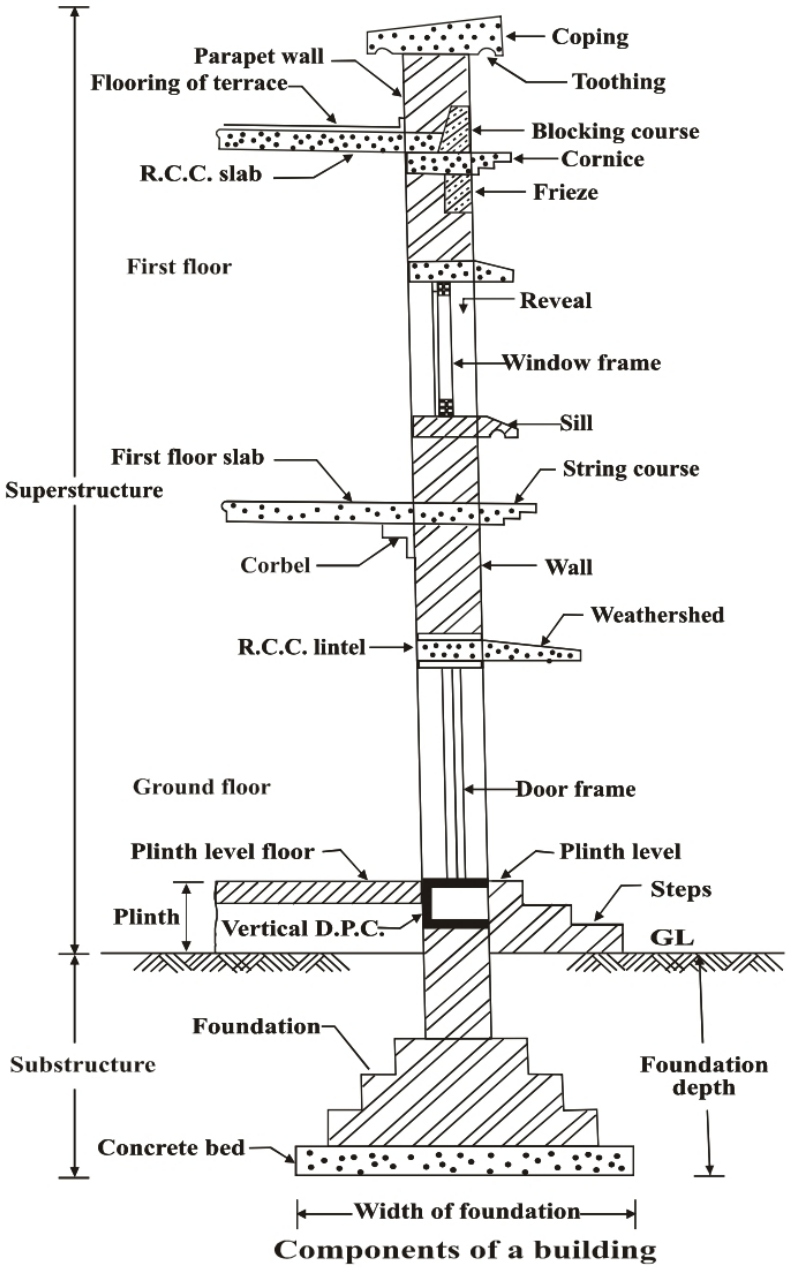
  1. Test pits, 2. Sub-surface sounding, 3. Boring, 4. Probing
  5. Geo-physical method

Is 1647-1960: Covers code of practice for fire safety of building (general) non electric equipment, oil, gas, and heater

Is 1646-1960: Code of practice for fire safety of buildings (general) electrical installation.

Is 1645-1960: Code of practice for fire safety of buildings (general) chimney, flues, and hearths

Is 1256-1967: Code of practice for building by laws.



Components of a building

Types of fire - Extinguisher

(a) Water type (b) Dry chemical powder

(c) Carbon - dioxide type (d) Foam Type (e) Wet chemical type

There are six types of fire:

Class A - (Combustible material fire)

Class B - (fire due to flammable liquid)

Class C - (fire due to flammable gases)

Class D - (fire due to metals)

Class E - (fire due to electrical equipments)

Class F - (fire due to cooking oils)

Various Locations of a room

(a) Kitchen - East or SE (b) Living - SE/ South

(c) Window - Northern side of a room (d) Bedroom - West

(e) Puja room - NE (North East)

- **Septic Tank**
  (a) Floor slope 1:20
  (b) Cleaning must be done within 3 years
  (c) Baffle wall divide the septic tank in two equal parts & its minimum width is 4 cm
  (d) Septic tank shall have minimum width of 750 mm, minimum depth of 1m below water level & a minimum liquid capacity of 1000 litres.
  (e) Minimum Height of free Board should not less than 30 cm

Special points :

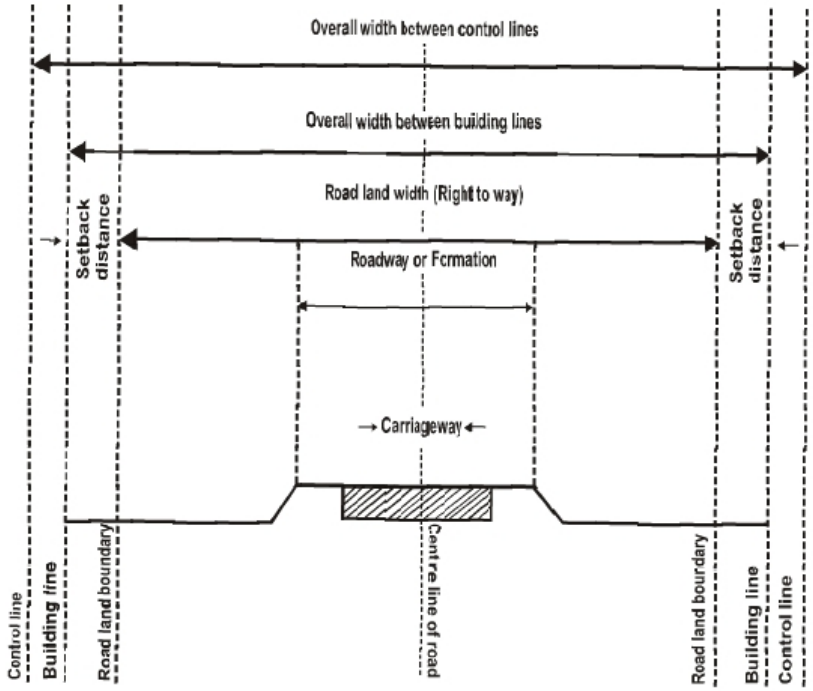
- Dado tiles are provided to prevent water seepage in wall.
- As per national building code of India it recommends a minimum front of 6 m on any road.
- The chemical formula of asbestos is $Mg_3Si_2O_5(OH)_4$. So it is inorganic.Asbestos refers to naturally occurring fibrous minerals that have the ability to resist heat fire and electricity.
- Unvented heaters shall not be installed in sleeping rooms, bathrooms & toilet rooms, storage closets and surgical rooms because they cause asphyxiation, carbon monoxidepoisoning and may lead to death.
- Asbestos is best known for causing mesothelioma, a rare and deadly cancer.

Building Laws

16

- In Rural areas, these bye-Laws are directed by Revenue authorities

1. Building Lines:



(a) Set back or front building line: The line upto which the plinth of a building adjoining a street or an extension of street or on a future street may lawfully extened.

- This line is laid parellel to the plot boundries by the authority beyond which nothing can be constructed.

(b) General building line: Sometime a line is fixed called general building line & no building or its portion should project beyond this building line.

(c) Control line: Certain buildings like as cinemas, business. centre factories etc which attract large number of vehicles should be further setback a further distance apart from building line. This line which accounts for extra-margin is called as control line.

Distances of Building line & Control line

Type of road	In open & Agricultural country		River development along approach		Actual limit in urban area.	
	Building Line	control Line	Building Line	Control Line	Building Line	Control Line
1. National & State Highways	30 m	56 m	18 m	30 m	30 m	45 m
2. Major District Roads	24 m	45 m	9 m	15 m	15 m	24 m
3. Other District Roads	15 m	24 m	6 m	9 m	9 m	25 m
4. Village Roads	12 m	18 m	6 m	9 m	9 m	25 m

Special point:

(i) Generally in urban areas, the distance of control line is considered as 1.5 times that of building line.

(ii) These distances are measured from centre of Roadway.

(iii) National building code specifies a minimum frontage of 6m on any street

(iv) National building code published in 1970, current version (2005)

(V) In 1966, the national safety council was setup in India.

2. Built- up (or covered Area) Limitation:

$$\text{Floor Area Ratio (F.A.R)} = \frac{\text{Total covered Area of all Floors}}{\text{Plot Aera}} \times 100$$

Floor Space Index (F.S.I)/Plan Efficiency/FAR

- FAR is used in classifying type of construction.
- The covered area is governed by F.A.R or F.S.I.
- FAR values are specified in Natinal Building code for different occupancies and types of construction.
- Following limitations for bult-up area have been Recommended

(i) In an industrial area the built - up area or covered area shall not exceed 60% of the site areas.

(ii) In a buisness area, the covered area shall not exceed 75% of the area of site. provided sufficient space for parking, etc is available on the same site.

(iii) In Residential areas, the covered areas are indicated as below.

Area of the plot	Maximum permissible built-up area
Less than 200 m^2	66% with two-storeyed structure
200 - 500 m^2	50% of the site
500 - 1,000 m^2	40% of the site
More than 1,000 m^2	33.33% of site.

3. Open space Requirement around building:

- These are required for lighting & ventilation requirements of the rooms.
- The national building code recommends the following open space requirements for varying heights of building.

(i) For buildings height less than 10m, the following values for front, rear & side yards are recommended as integral part of site:

(a) Front yard or open space width = 3m, when building fronting a street.

In no case less than 1.8 m, when building fronting two or more sides.

(b) Side yard or open space width = 3m, minimum for every semi detached or detached building.

(c) Rear yard or open space width = 3m, average & is no case less than 1.8 m, subject to condition of free ventilation.

(d) The minimum distance for construction of any Building from the centre line of any street shall not be less than 7.5 m as determined by authority.

(ii) For buildings with height more than 10m & less than 25 m, the values of minimum open spaces, requied for height of 10m, are increased at the Rate of 1m for every 3m or fraction the roof, for heights above 10 m.

(iii) For building with heights more than 25 m But less than 30m, there shall be a minimum open space of 10 m.

(iv) For building with heights above 30m , the minimum open space of 10 m required for heights of 30m, shall be increased at the rate of 1m for every additional height of 5m or fraction, subjected to a maximum of 16 m.

(v) The one side of one or more rooms intended for human habitation on interior open space having width not less than 3m.

4. Provision to size, height and ventilation of rooms & appartments:

(A) Size : From the view of heat and ventilation, certain absolute minimum

areas for individual rooms & appartments have been laid by national building code as follows: **(some are already discussed in previous chapter)**

(a) Mezzanine floor : It is an intermediate floor in a building which is partly open to the Double-height ceiling floor below or which does not extend over the which floor space of a building.

(i) The minimum area of mezzanine floor, which to be used as a living room = 9.5 m^2

(ii) The total area of such mezzanine floor, in a building should not exceed 1/3 rd of plinth area of a building.

(b) Height of building & rooms.

- Height of the building is decided by two factors.

(i) Either by the width of street on which it fronts

(ii) The minimum width of rear space.

Maximum height limits of building	
Width of street	**Height of the building**
Say W-m	Height =1.5 W + front open space (In general)
upto 8 m	≤1.5 times the width of street
8m to 12 m	Not more than 12 m
Above 12m	Not more than width of street in no case more than 24 m

Note: No plinth or building portion or out house shall be less than 30 cm above any portion of around within 3 m distance of such type of building.

- Minimum heights of individual rooms as specified by national building code of India are as followed:

(a) For habitable rooms = 2.75m, (b) For kitchen = 2.75m

(c) For habitable room under low housing schemes = 2.6m

(d) For bathroom & water closet=2.2m.

(e) In multi-storeyed government buildings, the height is usually restricted to 3.4 metres.

Note: The height of the building is measured upto the the room in case of pitched roof & up to the surface of the roof in case of flat roof. In case of pitch roof , the pitch is not expected in exceed 45^0 or the height of parapet by 3 ft in case of flat roof.

- The height at the building wrt rent space is fixed by the Imaginary lines i) Horizontal line ii) diagonal line.
- The Horizontal line is draw in the direction of the building at 63.5^0 from

where horizontal line meets the rear boundry.

- No part of the building is allowed to project beyond the diagonal line except that for minor port like as smoke chimney etc.

(c) Lighting & ventilation : Area of window opening exclusive of doors & inclusive of frames is as specified below:

(i) 1/6th of the floor area for wet hot climate &

(ii) 1/10th of the floor area for dry hot climate.

- The average area of door & window shall not be less than 1/7th of the floor area.
- For ventilating the spaces for w.c and bathrooms if not opening on the front side, rear and interior open spaces, shall open onto ventilating shaft.
- The minimum size of such shaft are as given below:

Height of Building (in m)	Minimum area of ventilating shaft(m^2)	Minimum side of shaft (in m)
upto 12m	3	1.5
18 m	4.5	1.8
20m	6	1.8

- No portion of the room should be assumed as lighted, if it is more than 7.5m away from the opening assumed for lighting that portion.

5. Water supply & sanitary conveniences:

(A) Residences:

(i) Dwelling with individual conveniences should have atleast.

(I) One bathroom with lap

(II) One water closet and one sink

- When only one w.c is provided in a dwelling the bathroom and the water closet should be separataly accommodated.

(ii) Dwellings without individual - for conveniences should have atleast following:

(I) One tap with draining arrangement in each terement.

(II) One w.c and one bathroom for crazy two terements

(III) Water taps in common bathrooms & commom water closet

(B) Building other than residence:

(i) For public building like as offices, schools, colleges etc. should be provided is determined on the basis of one person for each 5 m^2 of floor area of each room.

- For every 25 persons , there should be one water closet

- For every 100 persons there should be one urinal.
- The sanitory unit for either 6 should be separate.

(ii) For buildings such as cinemas, theaters and public assembly halls one water closet for every 200 males or females there should be provided urinals ,should be provided at the rate of one for 100 parsons.

(iii) For factory & workshop buildings there should be an absolute minimum one water closet for either 6 & total number of water closet and urinals are provided at following rate.

- One water closet for every 40 persons &
- One urinal for every 100 persons

Note: The number of persons in factory are decided on the basis of one person/m^2 of gross floor area

6. Structural design or sizes & sections

(A) Depth of foundation should be taken as Below:

(i) For single- storeyed building =0.75 - 1.0m below finished G.L

(ii) For Double- storeyed building = 1.0m - 1.30m below finished G.L

(B) Width of foundation -The thickness of the wall in spread foundation or stepped footings is extended by an offset on each side equal to half brick width (5 cm).

- The thickness of concrete in foundation should nearly be equal to 5/6 of the thickness of wall in superstructure .
- The thumb rule to deternine the width of foundation is to Double the thickness of wall in superstructure (just above plinth) and add 30cm

(C) Plinth : This portion of the building is in between the surface of the overounding ground level

- The plinth level of the building is generally kept higher (generally 30 cm or more) than the surounding ground level such that proper drainage of site is assured.
- In case that the plinth is 20cm or less, then there is no need to provide any step.

(D) Damp- proof course: D.P.C is provided to prevent moisture rising up the wall.

- The horizontal D.P.C is usually 4.0cm thick of cement concrete (1:2:4) is provided about 10 to 20 cm above final ground level.

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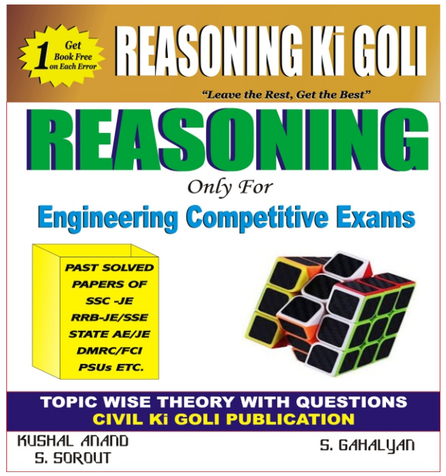

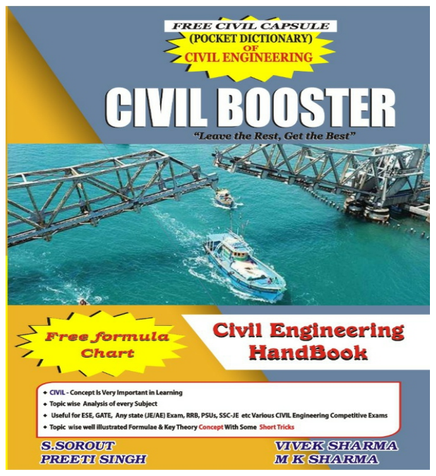

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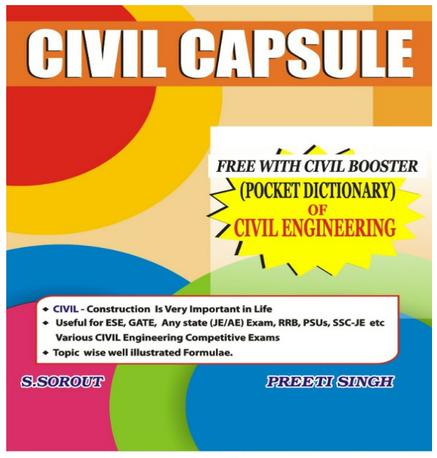

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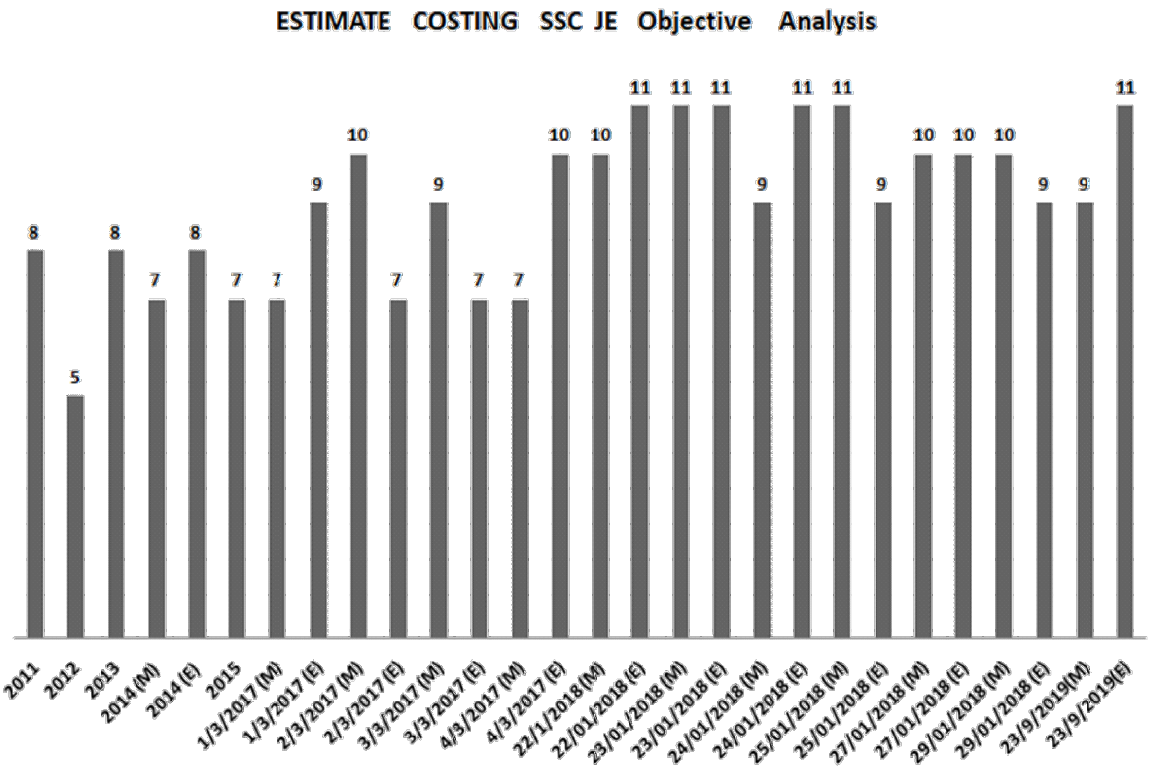
ESTIMATE COSTING SSC JE Objective Analysis
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Basic Measurement & Work

1

IS : 1200 – 1974 $\rightarrow$ measurement for civil work.

Basic Conversion

(Length)

1 meter = 3.281 ft;	1ft = 0.3048 m
1 km = 0.622 mile;	1mile = 1.6093 km
1cm = 0.394 in;	1 inch = 2.54 cm
1 mm = 1000 μ (micron)	1micron (μ) = 10^{-6}m

(Area)

$1m^2 = 10.764\ ft^2$;	$1ft^2 = 0.0929\ m^2$
$1\ km^2 = 10^6\ m^2 = 100$ha;	
1 ha = $10^4 m^2$ = 2.47 acres;	1 acre = 4840sq yards = 0.4047ha

(Volume and Discharge)

$1m^3 = 35.307\ ft^3$;	$1ft^3 = 0.028232m^3$
1cumec = 35.307cusecs;	1cusec = 0.02832 cumec
1ha.m = 8.13 acre ft;	
$1m^3$ = 1000litres (L)	1gallon = 4.546 litres

- The first stage of construction is the initiation of the proposal

Description	Unit
Earthwork, Stone/Brick Work, Wood Work/Sunshade	m^3
Surface/Shallow Excavation, shutter, panal, batten	m^2
Pointing, Soling, DPC, Plastering, door, window	m^2
Steel/Iron Work	kg/Quintal
Dressing of stone/Half Brick wall/partition wall	m^2
Painting Work/Distemper/Colour Washing/Jali Work	m^2

- Cornice (unit running meter), Cleaning & fixing Glass panel – No.
- Dados shall be measured in running metres & glazing is measured in m^2
- Skirting shall be measured in running metres, stating height.
- Cutting of tree - No., Lime concrete in Jefferies of roof terracing-(m^2).

Damp Proofing: Damp proofing in construction is a type of moisture control technique applied to building walls, floors & roads to prevent moisture from passing into the interior space by using damp proofing materials.It is provided at plinth level.

Damp Proofing Materials:

1. Flexible material like butyl rubber, hot bitumen, plastic sheets etc.
2. Rigid materials, like impervious bricks stones, slates, cement morter, or cement concrete painted with bitumen.
3. Semi-rigid materials like mastic asphalt.
4. Flexible material used for damp proofing is bitumen sheeting
5. The maximum size of the aggregate used in a DPC is about 20 mm
6. The most commonly used damp proofing material is bitumen

Binding wire (Steel work) - Binding wire required for (1000 kg) of reinfrocement = 9 to 13 kg (depending upon diameter of bar). Greater the diameter of bar, lesser will be the weight of binding wire required.

Special points:

(i) Order of Booking the Dimension in MB = L, B, H

(ii) If depth of excavation < 30 cm, surface excavation (unit m^2)

(iii) In Earthwork, Lead & Lift is 30 m & 1.5 m respectively.

(iv) Surface dressing up to 15 cm depth and surface excavation up to 30 cm depth measurements for payments is in the square meter

(v) The maximum depth of borrow pit and horizontal distance between two borrow pits is 30 to 60cm. and 5m

(vi) Number of Bricks using flat soling & edge soling (using conventional brick) 38 & 56 respectively.

(vii) For doors & window, we use 6 & 4 hold fast respectively.

(viii) **Truck:** No. of bricks = 4000, volume of sand = 3-5 m^3 (generally)

(ix) In steel roof truss about 5% of steel volume is provided for Rivets & Bolts.

- Formula for weight of steel bar per meter length = $(d^2/162)$ kg.

Degree of Accuracy

Wood Work: 2mm, Weight – 1 kg

length – 1 cm, Area – 0.01 m^2, Volume – 0.01 m^3

The thickness of slab and beams must be measured to the nearest of 0.01 m.

Valuation

2

- Valuation is the Technique for determining the fair price of a property/ structure.
- The term cost is used to indicate the actual amount incurred in producing a commodity which possesses some value.
- The term price is used to indicate the cost of commodity + profit of the manufacturer.
- A price is a fact, which has already occured in practice & a value indicates the estimation of a probable price of a commodity.
- Purpose of Valuation
  (a) Taxation– (10–14%)
  (b) Rent fixation – (6 –10% of total value)
  (c) Security/Loan/Mortage etc.
- **Property tax** is a levy on property that the owner is required to pay.
- **Sales taxes** is paid by a business man & it take a percentage of the prices of goods sold.
- **Wealth tax** is a tax on the market value of the assets that an individual holds (such as car, plot etc.)

Gross income = Net Income + Outgoing

Types of outgoing

(a) Taxation (b)Repairness – (10 – 15)% of total Income
(c) Management and collection Charge – (5 – 10)% of total Income.

- The charges/expenditures represented directly in the commodity produced is known as **prime cost** & other expenditures like as rent, salaries & services, management, depreciation etc. represented indirectly in the production of the commodity are called the **supplementary costs.**

Mortgage:

An owner can borrow money (by loan) against security of his property.

Mortgagor $\rightarrow$ person who takes the loan

Mortgagee $\rightarrow$ person who advances /gives the loan

Mortgage deed $\rightarrow$ Document for the mortgage transaction

Annuity

The annual payments (paid in months or year) paid for capital amount invested party.

(a) Annuity Due: The amount paid at the beginning of each period or year for definite number of intervals.

(b) Perceptual Annuity: The payments of the annuity continue for indefinite period (no end)

(c) Deffered Annuity: The payments of the annuity begined after some years

Note:- When payment of a debt is made by a series of equal periodic payments. It is known as Almortization.

Capital Cost

Total amount required to possess a property.

= Land Cost + Construction Cost ($\because$ when buying a land)

= Market Value ($\because$ when buying a whole property)

- Insurance premium = 1/2%of gross income
- Miscellaneous charges = 2 % of gross income

Capitalized Value

It is the amount of money whose annual interest (generally @high rate of interest) will be equal to net annual income from the property.

Capitalized value = Net annual income x Year's purchase

Year's Purchase (Y.P)

The capital sum required to be invested in order to receive annuity of Rs. 1 @ some rate of interest.

$$\text{Year's Purchase} = \frac{100}{\text{Rate of Interest}}$$

$$\text{Year's purchase} = \left(\frac{1}{I_P + I_C}\right)$$

$$\text{Where, } \begin{Bmatrix} I_P - \text{Rate of Interest for Year's purchase} \\ I_C - \text{Sinking fund Coefficient} \end{Bmatrix}$$

Types of Property

There are two types of properties namely:

(a) Free hold property:

- The free hold inherent the absolute owner of the property. He holds it without any payment in the nature of the rent. He may sell the property, divide it or grant it or donate it on lease at his own will.
- The freehold or owner who grants the lease known as 'lessor' and leaseholder is known as lessee'.
- In common practice, it give for 15, 21,25 or 50 years, when a lease is granted for a period of 99 years' it is known as long term lease & when it is for 999 years, it is said to be for endless duration.

(b) Leasehold Property:

The leaseholder is known as leasee and holds the physical possesion (under) of the property for the definite period under terms and condition specified in the lease document.

The different types of leases:

- Building lease •Life lease •Occupation lease
- Sub - lease •Perceptual lease

Easement: Easement are the rights & privileges which one owner of property enjoys through or over the property another.

Saleable property: As name subjected it is that area of property which is saleable generally super built-up area is saleable area.

- When the any Property structure comes under any development area. Then there is high increase in value of that property/ structure, such type of value is called **Accomodation value**.

Absolute property: An absolute title also called as a perfect title to a property is free to any encumbrances or deficiencies.

An absolute title gives unequivocal right of ownership to the owner & it can not be disputed or challenged by anyone else.

Contract Completion Date:

Completion date = Original change order additional days of completion + Time Extensions + Extension for date constructive changes

Scrap Value

(a) It is about 10% of total value.

(b) It is the value of Dismentled Material.

(c) It is the value of asset when its utility is considered to be as junk or scrap. Ex. Selling of vehicle after severe accidents, now vehicle can not be used as whole but some parts can be used.

Special Points:

(i) It may be positive, negative & zero.

(ii) For RCC structure, it is always –ve.

Salvage Value (Resale Value)

- The property after being discarded at the end of utility period, is sold as it is, without being broken into pieces & amount released after substracting its cost of removal & sale, is called as salvage value of the property.

Ex. The Railway sleeper may be reused as ports of a fencing or as buffer stops etc.

Sinking Fund

$$\text{Annual Installment (I)} = \frac{S.i.}{(1+i)^n - 1} = I_C.S$$

where, S – Total Sinking fund, i – Rate of Interest, n – Utility period, I_c $\rightarrow$ Sinking fund coefficient.

Book Value: It is the amount show in the account book after allowing permissible depreciation. At the end of utility period, it will be equal to Scrap value. It is not affected by market conditions. Hence, it represents the actual book cost.

$$\boxed{\text{Book value} = \text{Initial cost} - \text{Depreciation cost}}$$

Special Point: Not all the assets do not depreciate with time, example land & sometimes even gold, platinum etc.

- The net annual value of property, which is obtained after deducting the amount of yearly repairs from the gross income, is termed as **rateable value.** All property tax apply on rateable value
- Rateable value = Gross income – Annual repair/Maintenance cost

Distress Value: It is that value of property which is usually cheap price because its owner or its caretaker want to sell it forcefully due to some reasons like as fear of war, riots, financial problem etc. So, it is cheap value or lowest value than its money obtained to sale in open market.

Sentimental Value: The value of an object deriving from personal or emotional associations rather than material worth. So, it is priceless value. It can fetch more money from market than any other.

The extra price which is demanded by vendor when he attaches certain sentiments to his property is called as sentimental value.

Depreciation

It is the gradual deduction of usefulness of a property.

Types of Depreciation:

(a) Physical Depreciation: Wear & tear of an asset.

(b) Contingent depreciation: Accident due to liabilities, diseases etc.

(c) Functional Depreciation: Obsolescene due to change in structure, design, fashion etc.

(a) Straight line Method:

Assume depreciation by same amount

$$D = \frac{C - S}{n}$$

- It is used for all the assets which do not get obsolate during its utility period. ex-civil Engg. equipment.

(b) **Constant percentage Method:** Also called Declining Balance Method. It assume depreciation by same percentage.

$$D = 1 - \left(\frac{s}{c}\right)^{1/n}$$

- It is most suitable for assets which have probability/fear of obsolence before its utility period. ex-electronic equipments.

Note: This method cannot be used when salvage value is zero.

(c) Sinking fund method

(d) Quantity Survey Method.

• Buildings are considered to have a substantial life 40 to 80 years generally.

S.No.	Life of Structure	Annual Depreciation	Total Depreciation	Cumulative Depreciation
1.	0-5 year	Nill (Zero)	0	0
2.	5-10 years	1/2% per year	2.5%	2.5%
3.	10-20 years	3/4% per year	7.5%	10%
4.	20-40 year	1% per year	20%	30%
5.	40-80 year	1.5% per year	60%	90%

Difference Between Depreciation and Obsolescence:

Depreciation

(a) This is the physical loss in the value of property due to wear and tear and decay etc.

(b) It depends upon its original condition, quality of maintenance and mode of use. It varies with age.

(c) There are various methods for calculating the amount of depreciation.

Obsolescence

(a) This is the functional loss in the value of the property due to change in design, structure, fashion, utility, demand etc.

(b) It depends upon the technological advancement art etc. It does not depend on age.

(c) No method is available for calculation of obsolescence.

Depletion:

Depletion for a year =

$$\frac{\text{cost of property} \times \text{units sold during that year}}{\text{No. of units in the property}}$$

Special point -If contractor fails to perform the work successfully or discontinues the work before completion of the period of agreement, the agency handles that work at same cost is known as debitable agency.

Estimation and Area Types

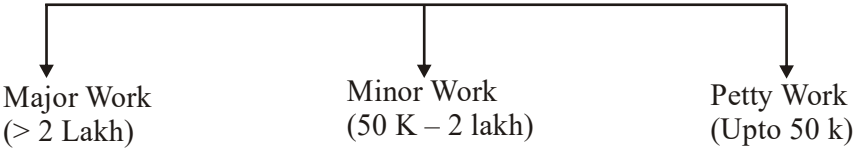
3

Schedule of Rate: It is the document which contain current price details per unit excluding quantity of Material.

Quantity Survey:- It is a schedule or list of quantities of all the possible items required for the construction of any structure

- It should be noted that quantity survey mentions all the items in the estimate. But it does not give the list of materials required.
- All these quantities are worked out by reading the plans of structure. Ex. - Cement plaster as m^2, but not no. of bag etc.
- If the distance between construction site and source of material is more than 8 km (5 mile), then Transportation charge should be consider.

Work Classification (On Cost Basis)



Over Head Cost

It is indirect/irregular cost of a project

General Overhead Cost	Job Overhead Cost
Telephone Bill	Salary Delay
Travelling charges	Establishment of a New Office
Printing, Post office	Compensation

- The quantity of dry distemper required for a single coat over area of 100 m^2 is 6.5 kg
- 1 cu. ft. water is equal to 28.31 liter

Turn Out: Task Work per day is also called labour constant.

It is the amount of work Done by a skill person in a day.

Description	Quantity
Work in foundation with Mud Mortar	1.5 m^3
Work in foundation with Lime/Cement Mortar	1.25 m^3
Work in Superstructure with Mortar	1 m^3
Work in Superstructure mud Mortar	1.25 m^3
Distemper (1 coat)	35 m^2
White Washing/Colour Washing (3 Coat)	70 m^2
White Washing/Colour Washing (1 Coat)	200 m^2
RCC Work	3m^3
Half Brick wall/Partition Wall	5 m^2
Lime concrete in Roof	6 m^3
Lime Concrete in foundation/Flooring	8.5 m^3
12 mm Plastering with cement/Lime Mortar	8 m^2

Types of Estimate

- **Preliminary or Approximate Estimate or Abstract Estimate:**

  It is required for preliminary studies of various aspect of a project or work, to decide the financial position & policy for administrative action by the competent authority.

  - In it various quantities are worked out with the help of many short cuts.
  - It is an estimate which is very near to final estimate.

- **Plinth Area Estimate:**Square Meter Method

  This is prepared on the basis of plinth area (B L) of building.

- **Cube Rate Estimate:**

  It is prepared on the basis of the cubical contents (LBH) of the building.

- **Detailed or Item Rate Estimate:**

  It is an most accurate & reliable method.It consists of working out the quantities of each item of works and working the cost.

- **Building cost Index** is an index number that measures the average rate of input construction cost changes of categorized building in comparison with that of the reference month.

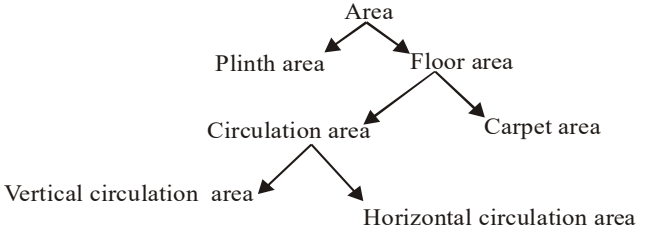
Special point: Degree of Accuracy (descreasing order)

Detailed > Cube rate > Plinth area > Rough estimate

Revise estimate: Estimate is revised If

(a) When the expenditure of work exceeds by more than 10% of the administrative approval.

(b) When a sanctioned estimate's variation is more than 5% due to any cause except important structural alterations.



Types of Area

1. **Plinth Area:** It is the built-up Covered area of a building at floor level of a story.
   - Courtyard, play ground, unclosed Balcony, cantilever porch, lift (area > $2m^2$) is not included in plinth area.
2. Floor area:

   F.A. = Plinth area – area occupied by walls/Intermediate supports

   $$\text{F.A. ratio} = \frac{\text{Area of all floor}}{\text{Area of total plot}} \times 100$$

   - Area of Balcony included upto 50% in the floor area.
   - The plinth area as compared to floor area is more than 30% to 40%

Circulation Area



Carpet Area: Useable area/Living area

C.A. = Total floor area – (circulation area + Non-useable area)

- C.A. in residential area (50 – 65)% and in commercial area (60 – 75)%.

Technical Section

(a) Chief Engineer is the Administrative Head of the Department and directly responsible to Govt of India.

(b) Each circle is Headed by Superintending Engineer (In CPWD, It is also called Surveyor Engineer).

Work	% of Estimate
Departmental charges (centage charge)	(10 – 15)
Contractor charge	10
Labour Charge	25
Electrification	8
Electric fan	4
Sanitary and Water Supply Charge	8
Contigences Charges	(3 – 5)
Work Charge Establishment	(1.5 – 2)
Tools and Plants	(1 - 1.5)

Special Points: Only for Water Charges 1.5%

Activity	Percentage Cost Break-Up(Labour)
RCC	37%
Brick work & Plaster	21%
POP	7%
Tiling	12%
Plumbing & Sanitation	3%
Doors	1%
Water Proofing	3%
Painting	8%
Electrical	8%
TOTAL	100%

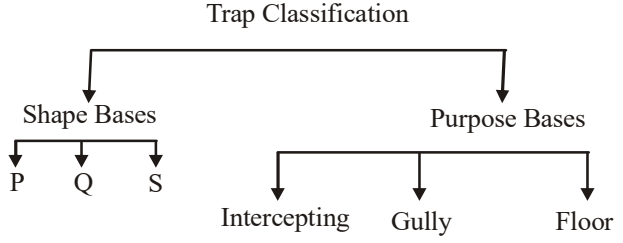
- The National Building Organisation (**NBO**) has suggested the following weighted % for double & triple storeyed. Load bearing residential buildings: - Bricks (17), Cement (18), Labour (27), Timber (15), Steel (10), Aggregates (08), Sand (05)%.

Material Calculation & other miscellaneous topics

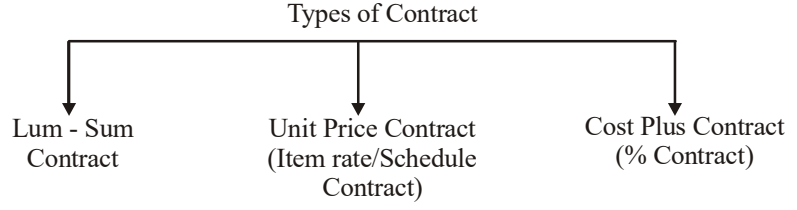
4

- Measurement of Building & Civil Engineering works- IS:1200 (Part I to XXV).
- Trap is used to prevent entry of foul gases into the house. It's efficiency depend upon depth of water seal. In it, General depth of water seal is (25 – 75) mm.

Compensation for delay in completion:- The contractor is liable to pay as penalty or compensation, an amount equal to 1% of the estimated cost of the work or smaller amounts as per the competent authority. The maximum limit of penalty is 10% of the total contract amount.



- Proposal $\xrightarrow{\text{Consent}}$ Promise $\xrightarrow{\text{Set of Promise}}$ Agreement
- As per the Indian contract act of 1872, a contract is an agreement enforceable by law.



- A tender is an offer in writing for executing certain specified work with specified certain terms & conditions likes rates, time limit etc.

Cost Plus Percentage Contract: In this contract, payment, expressed as a percentage, is paid by the client to contractor in form of cost of construction plus certain profit with it.

Contract Document

(a) **Title page:** Contract bond number, name of work etc.
(b) **Index Page:** Content of the agreement with page references.
(c) **Tender form:** Contractor's rates & time of completion, penalty clause, etc.
(d) **Bill of Quantitites:** Giving quantities & rates of each item of work & the total cost of the whole work.
(e) **Tender notice:** Giving brief description of work, etc. Generally 2-2.5% of the estimated cost is deposited along with tender.
(f) **Schedule of issue of materials:** Giving list of materials to be issued to the contractor with rates & place of issue.
(g) **Drawings:** Complete set of drawings like plans, elevations, etc. and site plan, of fully dimensioned.
(h) **Specifications:** General specifications:
Specifying the class & type of works.
Detailed specifications - Each item of work & of each material to be used in the work.

Special Points:

- For the confirmation of a ouction/Contract, the person has to submit some amount which is about (2 – 2.5)% of total contract, this amount is called earnest money.
- Security money is about 10% of total contract including Earnest Money.
- Security money and Earnest Money are refundable after some time Without Any Interest.

Material Calculation:

Plastering Work:

- IS Code: 1661, give specification about cement plaster.

- The first coat (rendering/under coat) is for straightening or levelling an uneven surface. Second coat is known as floating coat. Final coat (3rd coat) provide smooth surface. It is also called finishing/setting coat. 1st, 2nd & 3rd coat thickness are (10 - 15), (6 - 9) & (2 - 3) mm respectively.

Pargeting: It is a decorative or water proof plastering applied on the walls.

- If plastering is done in single coat, its thickness range is (6 - 12) mm.
- Bull mark is used to ensure that thickness of plastering is uniform.
- For calculation of platering work,
  (a) Volume is increased by 30% (if thickness 12 mm) & 20% (if thickness 20 mm) due to uneven surface.
  (b) Above calculated vol. is increased by 25% for dry vol. calculation.

Flooring Work:

(a) Volume is increased by 10% due to uneven surface.
(b) Above calculated vol. is increased by 50% for dry vol. calculation.

Cement Concrete Work: In C.C. mixture, we divide 1.52 by sum of ratio of material and multiply it with respective quantity ratio which will give you respective quantity.

Brick Work:

(a) Volume is increased by 15% due to frog filling, bonding/jointing, wastage etc.
(b) Above calculated vol. is increased by 25% for dry vol. calculation.

Note: It is an approximate method for calculation of quantity of material of mortar. In this method we divide 0.3 by sum of ratio of material to get respective quantity.

Special Points:

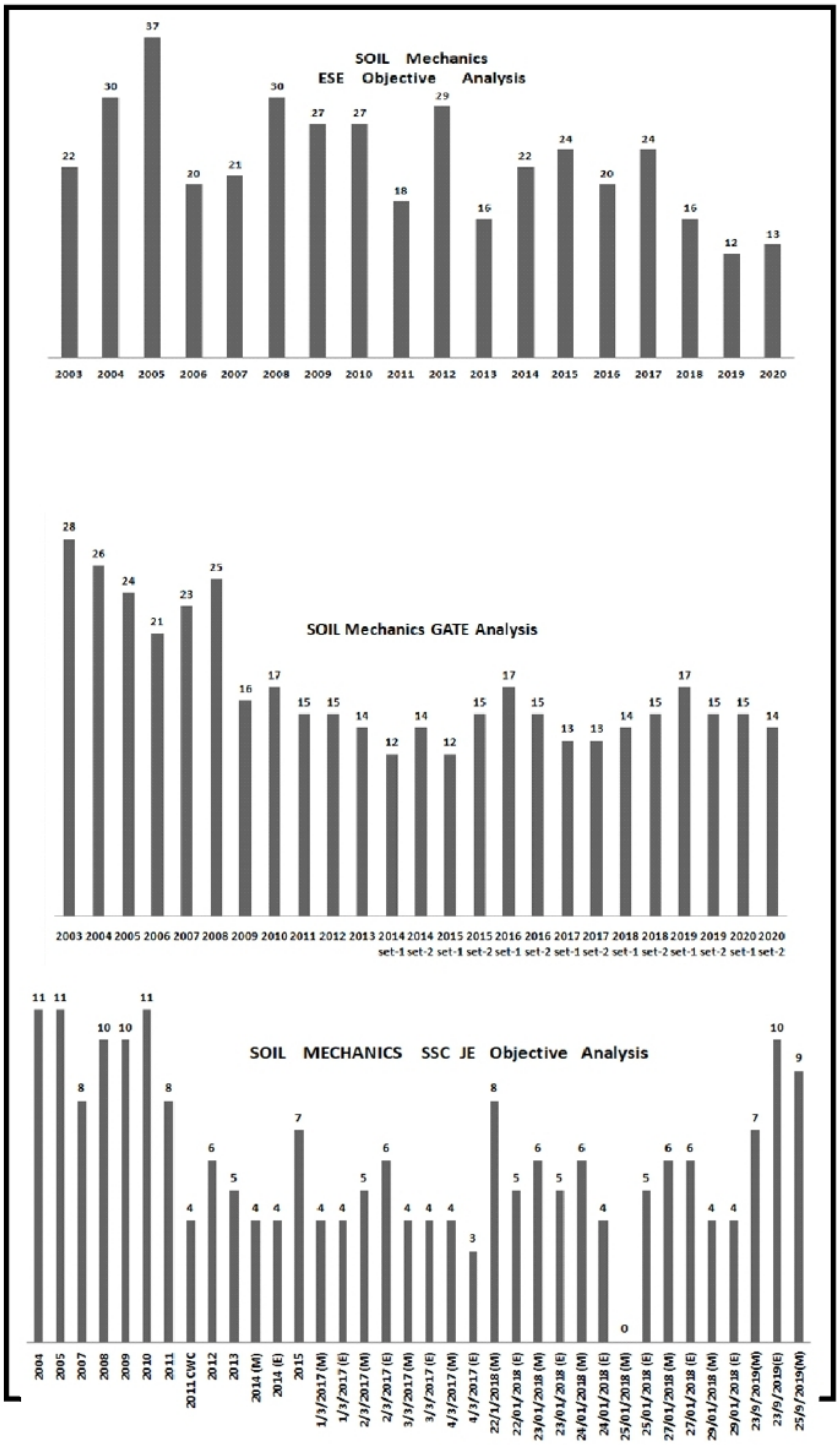
- A fixed stipulated sum of penalty payable by the contractor having no relationship with real damage, is called liquidated damage
- Borrow pits is also known as sand box
- Types of section used in road work, are longitudinal & Cross-section
- The types of construction have been specified, in the national building code 4
- For calculating the amount of cut & fill, the method is used longitudinal section method
- The percentage of void in dry aggregates is 40 to 50%
- Based on the occupancy, buildings are classified into 9 groups
- For making 1 m^3 wet concrete requires 1.54 m^3 dry concrete.
- For making 1 m^3 wet mortar require 1.25 m^3 dry mortar.
- The rates and costs committee 1957 recommended that an allowance of 10% of the prime cost as the contractor's profit.

Type of Buildings

As per National Building code of India, building is classified into nine groups based on occupancy as follows:

- **Group A: Residential Building:** Sleeping accommodation is provided for normal residential purpose.
- **Group B: Educational buildings:** Include any building used for shool college etc.
- **Group C: Institutional buildings:** Include any building used for purpose like medical or other treatment or care of infant, aged person etc. like sanatoria, nursing home, hospital, orphanage, jails, mental hospitals etc.
- **Group D: Assembly buildings:** Include any building like theatre, drama theatre, auditorium, museums, assembly hall, exhibition hall, restaurant, place of worship, dance hall, sport stadium, club house, skating rings, gymnasiums etc.
- **Group E: Business buildings:** Include any building for transaction of business, record for similar purpose etc.
- **Group F: Mercantile buildings:** Include any building which is used as stores, shop, market for display and sale for mercantile either whole sale or retail.
- **Group G: Industrial buildings:** Include any building in which product or material of all kind and property are fabricated or assembled such as gas plant, refineries, dairies, smoke house, textile mill and saw mill.
- **Group H: Storage buildings:** Include any buildings for storage or sheltering of goods, wares, like ware houses, garage, old storage, etc.
- **Group I: Hazardous buildings:** Include any building which is used for storage, handling, manufacturing of highly combustible explosive material or which are highly toxic in nature etc.

Long wall & Short wall	Centre line method
Also called individual/separate wall/general method,use in CPWD	Required special attention at the junction point
Simple method but time consuming	Quick method
More accurate	Less accurate
In it, length of long wall descreaseand short wall increase as we move from substructure to superstructure	Length remains constant, It is suitable for polygon shape structure without any cross wall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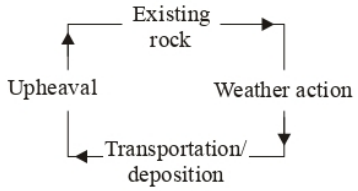
Soil Origin & Its Properties

1

- Father of Soil Mechanics **Dr. Karl Terzaghi** coined the term "Soil Mechanics" in 1925.
- A civil Engineer is concerned mainly with (10 -15) m from top crust of soil in dealing with small or medium size project.
- The soil particles coarser than 0.075 mm are visible to the naked eye

$$\text{Specific Surface} = \frac{\text{Surface Area}}{\text{Mass or Volume}}$$

- The specific surface is defined as the total area of surface of grains per unit of mass. A sphere has least specific surface area as compared to a plate.



Geological Phase

Erosion phase	
Physical weathering	**Chemical weathering**
• Retains same composition of Parent rock	• Change in mineral composition
• Bulky particles like as gravel, sand	• Plate like structure with high surface area, ex- clay, silt
• Shape-Angular, Rounded, Flat & Elongated	• Crystalline particle of colloidal size known as clay mineral
• Single grain particles without bonding between them	

Soil	Deposited by
Alluvial Soil	River/running water
Marine Soil	Sea water
Lacustrine Soil	Still water like as lakes
Aeolian Soil	Wind
Glacial Soil (Till/drift)	Ice

Special Points:

- Loess is a wind deposit soil (silt). It is generally of uniform gradation, with the particle size between 0.01 - 0.05 mm. These deposits have low density & high compressibility (when they are in wet form). For loess the permeability in vertical direction is generally larger than that of horizontal direction.
- Soil deposit due to gravity force is called talus (colluvial soil).

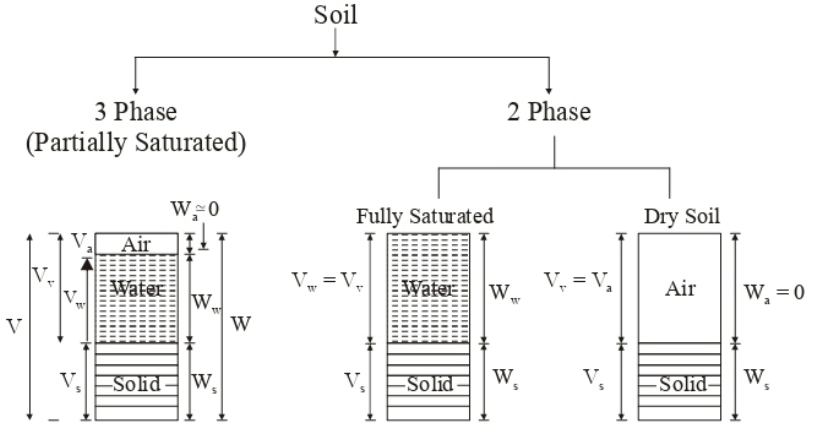
Various types of Soil

- **Alluvial soil:** Low density & liable to liquefaction in earthquake prone areas.
- **Black cotton soil:** Residual deposits form basalt or trap rocks, contain clay mineral. Very poor bearing capacity (50-100 kN/m^2).
- If depth of layer of B.C.S. is shallow, Then remove its layer for making structure.
- If depth of layer of BCS is Deep, then we use under-reamed piles In foundation for making structure.
- Generally we use raft foundation in BCS.
- Black cotton soil have high shrinkage & swelling characteristics, its shearing strength is extremely low. It is due to Montmorillonite mineral.
- **Laterite soil:** Iron oxide gives red or pink colour. It is residual soil formed from basalt. It is soft & can be cut with knife.
- **Desert soil:** It is uniform in gradation (ex. dune sand). It is Non-plastic & highly pervious.
- **Loam:** It is the mixture of sand, silt & clay.
- **Caliche:** It is the mixture of gravel, sand & silt.
- **Marine soil:** It has low shearing strength, highly compressible, soft & highly plastic.
- **Peat:** It is the organic soil with fibrous aggregates formed from vegetable matter in excess moisture (ex. in swamps), highly compressible. It is not suitable for foundation.
- **Bentonite:** It is formed from volcanic ash. It has high percentage of Montomorillonite.

Special Point: Lithification is a process by which unconsolidated materials are converted into coherent solid rock due to compaction or cementation action.

Phase diagram

It is the diagrammatic Representation of the different phases in a soil mass.



Special Point: If the voids absent in a system, it would not be termed soil. Ex:- Granite (Aquifuge rock).

- If the voids of a soil are completely filled with air, then it is known as dry soil.

Water content

$$w = \frac{W_w}{W_s} \times 100$$

There is no upper limit for it ($w \geq 0$).

Void ratio

$$e = \frac{V_v}{V_s}, \quad 0 < e < \text{Infinity}$$

Fine grained soil have higher Void ratio than coarse grained soil. But the size of void in coarse grained soil is greater than fine grained soil.

Porosity

$$n = \frac{V_v}{V} \times 100, \quad 0 < n < 100\%$$

Special Points: For uniformly graded coarse soil having perfectly spherical grain size when particles are arranged in

(*a*) Prismoidal array, $e_{min} = 35\%, n_{min} = 25.9\%$

(*b*) Cubical array, $e_{max} = 91\%, n_{max} = 47.6\%$

Void ratio is much better as compared to porosity because porosity is define with respect to total volume but void -ratio wrt volume of soild.

Value of porosity is less than void ratio for same soil sample generally.

Degree of Satuaration

$$S = \frac{V_w}{V_v}, \; 0 \le S \le 100\%$$

for fully saturated soil at shrinkage S = 100%

For partially saturated soil 0 < s < 100

for fully dry soil S= 0%

Soil Condition	S (%)
Dry Soil	0
Humid Soil	0-0.25
Damp Soil	0.25-0.5
Moist Soil	0.5-0.75
Wet Soil	0.75-1
Fully Saturated	1

Air Content

$$a_c = \frac{V_a}{V_v}, \; (0 \le a_c \le 1)$$

Percentage air Void

$$\eta_a = \frac{V_a}{V} \times 100, \; (0 \le \eta_a < 1)$$

Special Point: $\eta_a = n \times a_c$, $a_c + s = 1$, $(a_c > n_a)$

Bulk unit weight

$$\gamma_t = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_a}, \quad \text{units} \rightarrow \frac{KN}{m^3}, \frac{N}{m^3}, \frac{kgf}{cm^3}$$

Unit weight of water

$$\gamma_w = \frac{W_w}{V_w}$$

Value of γ_w changes with temperature but usually we take

$$\gamma_w = 9.81 \text{ KN/m}^3 \text{ at } 4^\circ\text{C}$$

Unit weight of solid

$$\gamma_s = \frac{W_s}{V_s}, \qquad \gamma_s = G\gamma_w$$

where G = specific gravity of soil solid

Dry unit weight

$$\gamma_d = \frac{W_s}{V}$$

High value of γ_d indicates more compacted soil/Dense sand.

Submerged or Buoyant unit weight

When the soil is below the water table, then a Buoyant force acts upward on the soil solid & its saturated weight is decreased by unit weight of water.

$$\gamma_{sub} = \gamma_{sat} - \gamma_w$$

Special Point: Saturated soil may or may not be submerged but a submerged soil will always be saturated.

Saturated unit weight

$$\gamma_{sat} = \frac{\text{Wt. of Saturated Soil}}{\text{Volume of Soil}}$$

It is the unit weight of soil when all the air voids are filled with water

Specific gravity of solids

$$G = \frac{\gamma_s}{\gamma_w} \text{ (Unitless)}$$

It is measured at 27°C by pycnometer method.

Also known as "Absolute specific gravity" or 'grain specific gravity'.

Specific gravity: G = 2.6 to 2.75 for Inorganic soil, G = 1.2 to 1.4 for organic soil

$$G \propto \text{mineral content}, \propto \frac{1}{amount\ of\ organic\ content}$$

$$G_{\text{fine grained}} > G_{\text{Coarse grained soil}}$$

Mass specific gravity of solid

$$G_m = \frac{\gamma_t}{\gamma_w} \quad (\text{unitless}, G_m < G)$$

Relative density: It is also called density index.

$$D_r = \frac{e_{max} - e_{natural}}{e_{max} - e_{min}}$$

$$= \frac{\gamma_{d\,max}}{\gamma_{d\,natural}}\left(\frac{\gamma_{d\,natural} - \gamma_{d\,min}}{\gamma_{d\,max} - \gamma_{d\,min}}\right)$$

It (D_r) is generally used for sandy & gravelly soils

Relative density	Classification
0–15	Very loose
15–35	Loose
35–65	Medium dense
65–85	Dense
85–100	Very dense

Some Important Relationships

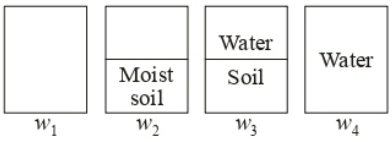
1. $W_s = \frac{W}{1+w}$
2. $V_s = \frac{V}{1+e}$
3. $\eta_a = n \times a_c$
4. $\gamma_d = \frac{\gamma_t}{1+w}$
5. $a_c + s = 1$
6. $e = \frac{n}{1-n}$
7. $n = \frac{e}{1+e}$
8. $se = wG$
9. $\gamma_t = \left(\frac{G+Se}{1+e}\right)\gamma_w$
10. $\gamma_d = \frac{G}{1+e}\gamma_w$
11. $\gamma_{sat} = \frac{G+e}{1+e}\gamma_w$
12. $\gamma_{submerged} = \frac{G-1}{1+e}\gamma_w$
13. $S = \frac{w}{\frac{\gamma_w}{\gamma_t}(1+w) - \frac{1}{G}}$
14. $\gamma_d = \frac{(1-\eta_a)G\gamma_w}{1+wG}$
15. $\gamma_{sub} = \gamma_{sat} - \gamma_w$

Special Points: 1. $\gamma_{sat} > \gamma > \gamma_{dry} > \gamma_{sub}$, 2. $\gamma_{sub} \simeq \frac{1}{2}\gamma_{sat}$

3.If in question,(a) $\gamma = g/cm^3$, then $\gamma_w = 1g/cm^3$, (b) $\gamma = kN/m^3$, $\gamma_w = 10KN/m^3$ or 9.81 kN/m³

Methods of determination of water content

1. **Oven drying method:** It is most accurate & standard laboratory test.
   - Soil sample is derived in controlled temperature (105 – 110°C) for 24 hrs. (for sand 4-6 hrs., organic soil 60-80°C for 24 hrs.) in laboratory. Above 110°C, water of crystallisation will be lost.
   - In it, free water, capillary water, adsorbed water is removed except structural water.
2. **Pycnometer method:** Pycnometer have volume 1000 ml having conical brass tip of 6mm diameter core.

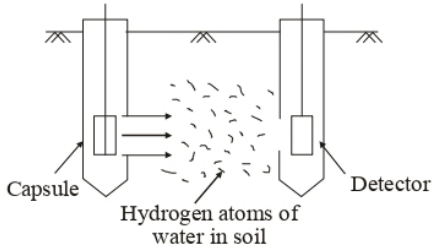


$$w = \left[\left(\frac{w_2 - w_1}{w_3 - w_4}\right)\left(\frac{G-1}{G}\right) - 1\right]$$

   - The Pycnometer method for the determination of water content can be used only if the specific gravity of solid particles is known.
   - It is more suitable for cohesionless soil as the removal of entrapped air from cohesive soil is difficult. Therefore, w_3 can not be measured accurately.
3. **Sand bath method:**
   - It ia a rapid field method. Hence, not accurate.
   - Sand bath is a large, open vessel containing sand filled to a depth of 3 cm or more.
4. **Torsion balance moisture meter method:** It is useful for rapid & accurate determination of water content. Because drying & weighing occur simultaneously, hence it is useful for soils which quickly reabsorb moisture after drying.
5. **Calcium Carbide method**
   - Quick method but not so acurate. (5-7 minute)
   - $CaC_2 + 2H_2O \rightarrow \underset{\text{Acetylene gas}}{C_2H_2\uparrow} + Ca(OH)_2$

- It is useful in embankment construction of highway.
- In it, scale is calibrated to give the water content based on total weight (w) of the soil. So, actual water content (based on soil solid) is to be recalculated.

6. **Alcohol method:**
   - It is a quick field method
   - It is not to be used with soils containing calcium compound or organic content.
7. **Radiation method:**
   - It gives water content in in-situ condition



- Loss of energy by radio-active material (cobalt 60) due to scattering of neutrons by hydrogen atoms of soil while travelling form capsule to detector is directly proportional to water content present in soil.

Determination of Unit Weight

1. **Core Cutter method**
   - It is a field method suitable for soft, fine grained & clayey soil.
   - It is not suitable for stoney, gravelly soil & dry soil.
2. **Sand replacement method:** It is a field method
   - It is used for gravelly, sandy & dry soil
3. **Water displacement method**
   - It is suitable for cohesive soils only & paraffin wax is used in it.
4. **Water ballon method**
   - In it, volume of the pit is measured by covering the pit with plastic sheet & then filling it with water.
   - Thus weight of water calculated is equal to volume of soil excavated.
5. **Radiation method:** It is quick & conveninent.
   - It is used for bulk density of in-situ soil.

Index Properties of Soil

2

Properties which help to access the engineering behaviour of soil (shear strength, compressibility etc.) & which help in determining its classification accurately are termed as index property:

For coarse grained soil, Index properties depend upon grain shape & size, relative density etc.

For fine grained soil, Index properties depend upon Atterberg's limit and consistency.

Sieve Analysis -

(a) **Coarse sieve analysis -** It is dry analysis.It is used for gravels.

In it, 4 sieves (80,20,10,4.75mm) are used.

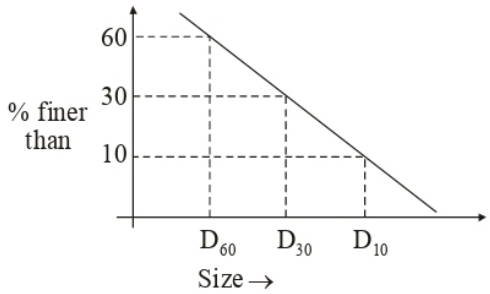
(b) **Fine sieve analysis -** It can be dry or wet analysis.

· It is used for sand (dry analysis). If size is less than 75 μ , then wet analysis is used.

· In it, seven sieves (2mm, 1mm,600 μ ,425 μ ,212 μ ,150 μ & 75 μ) are used.

According to IS : 1498-1970, The sieves are designated by the size of square opening, in mm or microns.

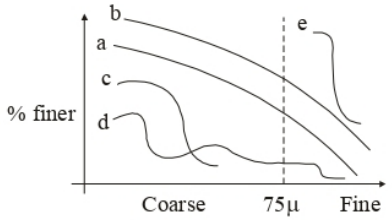
Grain Size Distribution Curves



D_{60} = Size of the particle such that 60% particle are finer than this size

D_{10} = effective size of particles (particles which if present alone will cause the same effect as caused by the soil).

$D_{60} > D_{30} > D_{10}$



$a \rightarrow$ Well graded

a & b $\rightarrow$ Similarly graded

$c \rightarrow$ Poorly/uniformly graded coarse grain soil.

$d \rightarrow$ Gap graded

$e \rightarrow$ Poorly graded fine soil

Special Points: If there is a abruptly change in the graph, then it shows the mixture of soil of two different geological formations.

- Boulder > Cobbles > Gravel > Sand > Silt > Clay > Colloidal particle (Size)
- In gap grading, one or more intermediate frictions of particles are absent.

Coefficient of uniformity $C_u = \frac{D_{60}}{D_{10}}$

(For Gravel, $C_u > 4$, For Sand, $C_u > 6$)

Coefficient of curvature $C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$

(For well graded soil, $1 \le C_c \le 3$)

- A uniform soil has less strength & stability than a Non-uniform soil.
- **Sedimentation Analysis:** Based upon Stoke's Law.

Stoke's Law: $V_t = \frac{(\gamma_s - \gamma_w)d^2}{18\mu}$

V_t = terminal velocity

d $\rightarrow$ diameter of the grain

- Stoke's law valid for range of diameter of particle = 0.2 mm to 0.0002 mm
- If particle size is smaller than 0.0002 mm, then Brownian motion will occur & if particle size is greater than 0.2 mm, then turbulent motion will occur.

$$\frac{h}{t} \propto d^2 \Rightarrow \frac{d_1}{d_2} = \sqrt{\frac{h_1}{t_1} \times \frac{t_2}{h_2}}$$

h = height through which particle falls in t-secs.

Special Points:

- Pipette method & Hydrometer method, both follow the same principal, but different in taking sample/observations.
- Hydrometer is a device which is used to measure the specific gravity of Liquid.
- 7 gm sodium carbonate + 33 gm Sodium Hexa Meta phosphate + 1 litre water → Dispersing Agent.
- (12 - 30) gm soil + 1 litre water → Soil solution.

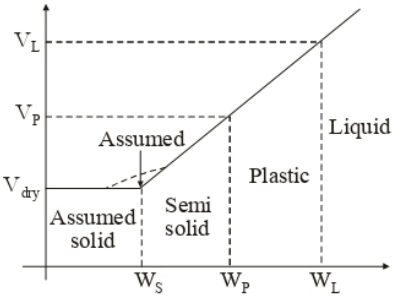
Corrections in hydrometer Analysis

- Defloculating (Dispersing) Agent correction → Always negative (C_d)
- Meniscus correction → Always positive (C_m)
- Temperature correction → If temp.is more than 27°C, its positive otherwise negative (C_t)
- Combined correction

$$C = C_m - C_d \pm C_t$$

Consistency limits

It is the relative ease with which a soil can be deformed. Atterberg classified the consistency in 4 - stages → solid, semi-solid, plastic, liquid stage.



V_{dry} = Volume at shrinkage limit.
V_P = Volume at Plastic limit.
V_L = Volume at liquid limit.
W_L = Water content at liquid limit.
W_P = Water content at plastic limit.
W_S = Water content at Shrinkage limit.

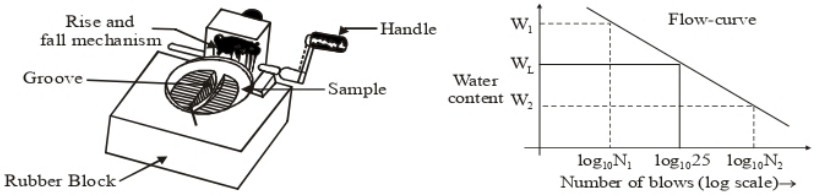
$$\frac{V_L - V_P}{W_L - W_P} = \frac{V_P - V_{dry}}{W_P - W_s}$$

Special Points: Naturally occurring water content in soil is generally between W_L & W_P

Liquid limit -Minimum water content at which soil has tendency to flow.

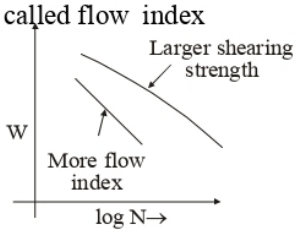
- All soil at liquit limit have similar shear strength (Negligible, 1.7 KN/m^2)
- Liquid Limit of soil used in both base & wearing course of highway should not be more than 35%.
- Found out by two tools → (*a*) Casagrande's tool (*b*) Cone penetration.

Casagrande's tool



- Soil about 120 gm of an air dried sample passing through 425μ IS sieve is taken in a dish and mixed with distilled water to form a uniform paste.
- Water content at which 25 blows close the groove (length-12 mm, width at bottom-2 mm, width at top- 12 mm) cut in soil sample placed in Casagrande's bowl is called liquid limit.
- If the Material of base of the casagrande's liquid limit device on which the cup containing soil paste drops is softer than standard hard rubber, then liquid limit of soil always increase.

Flow Index (I_f): Slope of flow curve is called flow index



$$I_f = \frac{W_1 - W_2}{(\log_{10} N_2 - \log_{10} N_1)}$$

$$I_f = \frac{W_1 - W_2}{\log \frac{N_2}{N_1}}$$

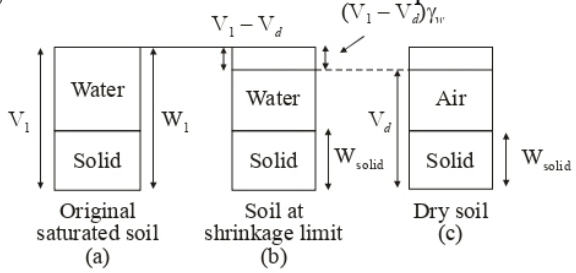
$$\text{Flow Index} \propto \frac{1}{\text{Shear Strength}}$$

Plastic limit

- It is minium water content at which soil is in plastic stage.
- Shear strength at the plastic limit is about 100 times at that liquid limit.
- At plastic limit, a soil when rolled into a thread of 3 mm, does not show any crack on surface. It starts to crumble.

Shrinkage limit

It is minimum water content at which soil is completely saturated or the maximum water content at which further reduction in water content does not cause any descrease in the volume of soil sample.



At shrinkage limit, (a) S = 1, (b) there are two phases (soil & water), (c) no volume change.

$$\text{Water content at shrinkage limit} = \frac{(W_1 - W_{Solid}) - (V_1 - V_d)\gamma_w}{W_{solid}}$$

Shrinkage ratio: It is the mass specific gravity of the soil in dry state.

$$\text{S.R.} = \frac{\left(\frac{V_1 - V_2}{V_d}\right) \times 100}{W_1 - W_2}, \qquad \text{S.R.} = \frac{\gamma_d}{\gamma_w}$$

$$\text{Volumetric Shrinkage} = \frac{V_1 - V_d}{V_d} \times 100$$

Plasticity Index:

$$I_P = W_L - W_P$$

- Soil with large I_P & $W_L \rightarrow$ Fat clay & Soil with low I_P & $W_L \rightarrow$ Lean clay.
- The soil used in the base course should have plasticity less than 6 %.

- If the plasticity index comes out negative, then it will be consider 0 (sand, gravel).

I_P	Consistency
0	Non Plastic
< 7	Low Plastic
7–17	Medium Plastic
> 17	Highly plastic

- If we add clay particles in gravel, sand etc. (coarser soil), then liquid & plastic limit of soil particle increases.
- Low plastic soil is used for Embankment because it is easy to compact.

Consistency Index: It is also called relative consistency.

$$I_c = \frac{W_L - W}{W_L - W_P}$$

Liquidity Index

$$I_L = \frac{W - W_P}{W_L - W_P} \quad , \quad (\text{Note: } I_c + I_L = 1)$$

Consistency	I_c	I_L
Very stiff	>1	<0
Stiff	1–0.75	0–0.25
Medium Stiff	0.75 – 0.5	0.25 – 0.5
Soft	0.5–0.25	0.5–0.75
Very soft	0.25–0	0.75–1
Iiquid State	< 0	> 1

Toughness Index: It indicate the loss of shear strength with increase in moisture content and strength of soil at plastic limit.

$$I_t = \frac{I_P}{I_f} = \log \frac{S_P}{S_l}$$

S_P = Shear strength at plastic limit

S_l = Shear strength at liquid limit

The **shrinkage index** in soil test is equal to plastic limit - shrinkage limit.

Thixotropy

It is regain of loss in strength of soil with passage of time.

During Pile driving in clayey soil, frictional resistance by soil increases due to property of thixotropy.

Sensitivity (S):

$$S_t = \frac{\text{Unconfined Compressive Strength of an undistrubed soil}}{\text{Unconfined compressive strength of remoulded soil}}$$

$$S_t = \frac{q_u(\text{undisturbed})}{q_u(\text{remoulded})}$$

Special Point: Stiff clay having fissures & crack have $S_t \leq 1$.

1	Insensitive (Gravel & Coarse sand)
2–4	Normal
4–8	Sensitive (Silt & Clay)
8–16	Extra
> 16	Quick

Activity Number (A_c):

More activity means more changes in volume. BCS has montmorrilonite.

$$A_c = \frac{I_P}{\%\text{ of clay size particles (size} < 2\mu)}$$

< 0.75	Inactive
0.75-1.25	Normal
> 1.25	Active

Dilatancy: It is the volume change observed in granular material when they are subjected to shear deformation.

- If soil is silty, water rises quickly to its surface & gives it a shiny or glistening appearance.

Classification of Soil

3

Soil classification is done on the basis of index properties such as grain size distribution & plasticity. These are important systems of classification -

1. **The Unified Soil Classification System (USCS):** It was developed by casagrande (1948) for the use in air field construction.Fine grained soils on the basis of plasticity characteristics but coarse grained soils were classified on the basis of grain size distribution.
   - The soils are classified into four major groups, namely, coarse grained, fine grained, organic soil & peat.
2. **American Association of State Highway and Transportation Official (AASHTO):** Soil are classfied into 8 groups from A_1 to A_7 with A_8 for muck or peat

   Group index : $GI = 0.2\,a + 0.005\,ac + 0.01\,bd$

   Where a = % passing through 75 μ sieve – 35 $\quad 1 \le a \le 40$

   b = % passing through 75 μ sieve –15 $\quad 1 \le b \le 40$

   c = liquid limit – 40 $\quad 1 \le c \le 20$

   d = plasticity index – 10 $\quad 1 \le d \le 20$

   - The value of GI lie in the range (0-20)

Type of subgrade soil	Group index range of subgrade
Good	0-1
Fair	2-4
Poor	5-9
Very poor	10-20

   - If the calculated value is negative, it is reported as zero.
   - Group index 0 indicates good subgrade material but group index of 20 indicates very poor subgrade material.

3. **Indian standard soil classification system:** Fine grained soil in indian standard soil classification are sub divided into low, medium, high on the basis of compressibility while in unified soil classification system it has only two categories of low & high compressibility.

Soil classification based upon grain size (mm)

Coarse Grained Soil							Fine Grained soil	
Boulder	Cobbler	Gravel		Sand				
		Coarse	Fine	Coarse	Medium	fine	silt	clay
>300mm	300-80	80-20	20-4.75	4.75-2.0	2-0.425	0.425-0.075	0.075-0.002	<0.002

Special Points:

Fine sand is a coarse grained soil

BIS classified soil into 18groups

Coarse grained soil classification

Case 1: When fines (particles less than 75 μ m) are less than 5%

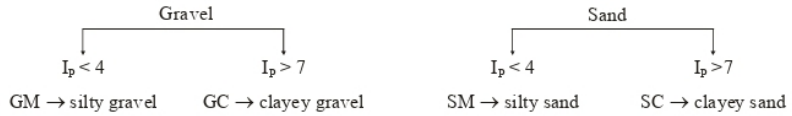
Case 2: When fines are between 5–12%

- Dual symbol is used & also called Border line case.
- Divided into 8 parts based on gradation & fines.
- For Ex:

SP-SC → Poorly graded sand with clay as fines.

GW-GM → Well graded gravel with silt as fines

Case 3: When fines are greater than 12%

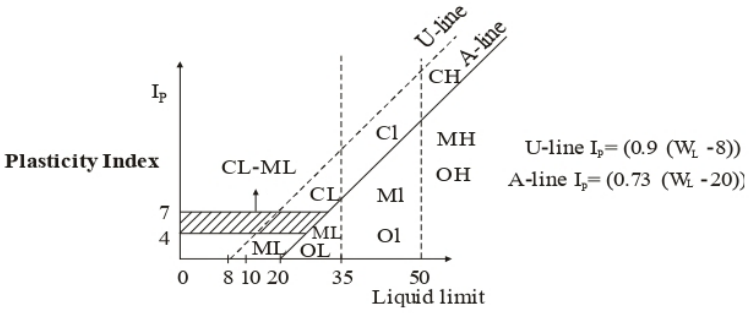


Special Point: If I_p betwen 4-7, dual symbols will be used.

From Dual symbol method -

Gravel -G, Sand - S, Well Graded Soil - W, Silt - M, Clay- C, High Compressibility- H, Low Compressibility- L, Intermediate Compressibility- I, Poor Graded Soil- P, Organic Soil- O, Peat- P_t.

Fine grained soil classification



- Classification of fine Grained soil is done on the basis of plasticity chart.

SAND

Sand particle consist of small grain of silica (SiO_2). It is formed from sandstone's decomposition due to various effects of weather.

According to natural source of sand, it is classified into following types-

1. **Pit Sand -** It is obtained by forming pit into soil.
- It consist of sharp angular grain.
- Excavated from a depth of about 1 - 2 m from the ground level.
- If it is free from salts, excellent material for mortar or concrete work.

2. **River Sand -** It is obtained from bank or bed of river.
- Its colour is almost white.
- It consist of fine rounded grains.

3. **Sea Sand** - It is obtained from sea shores.
- Its colour is light brown
- It is consist of fine rounded grains.
- It contain salts. So, its use is avoided for engineering work.

Special Point : Nala is not a good source of good quality sand due to the presence of impurities (specially organic impurity), which may cause detrimental effect on the engineering works.

According to size of grain-

Fine sand : It is the sand passing through a screen with clear opening of 1.5875 mm. It is mainly used for plastering

Coarse sand : It is the sand passing through a screen with clear opening of 3.175 mm. It is mainly used for masonry work.

Gravity sand : It is the sand passing through a screen with clear opening of 7.62 mm.Generally It is used for concrete work.

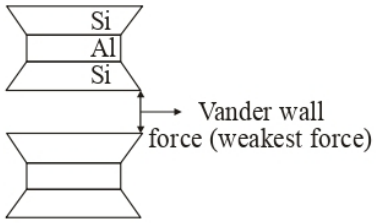
Clay Mineral & Soil Structure

4

- Clay particles always carry a Net Negative charge except at edges.

Various Clay Minerals

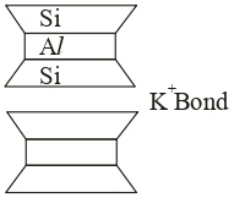
1. **Montmorillonite:**



- 2: 1 clay mineral, also called smectite.
- Bentonite is a montmorillonite clay, found in Black cotton soil.
- Highly plastic with little internal friction.
- Common in residual soil derived from volcanic ash.

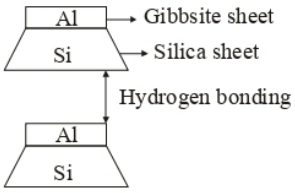
Isomorphic Substitution: Substitution of metallic Ion with another metallic Ion of lower valency but same physical size like as Si^{+4} replaced by Al^{+3} in a tetrahedral unit.

2. **Illite:**



- 2 : 1 clay mineral, Isomorphous substitution takes place, have Ionic bonding
- It is common in Stiff clays & in Lacustrine soft clay.

3. Kaolinite:



- 1 : 1 clay mineral, No isomorphous substitution, Found in old deposits/ Sedimentary & residual soil, ex. China clay.

Special Point: Halloysite when air dried gets converted to Kaolinite & both Halloysite & Kaolinite are used for making chinaware.

Properties of clay minerals

	Grain Size	Base exchange capacity	I_p	Dry strength	Active tip
Kaolinite	Maximum	Min	Min	Min	Min
Illite	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
Montmorillonite	Minimum	Max	Max	Max	Max

Soil Structure:

1. Single Grained structure:-
   (a) Found in Cohesionless soils such as Gravel & Sand.
   (b) Under shock & vibration, they show little settlement.
2. Honey combed structure:-
   (a) Found in sand & silt
   (b) Under shock & vibrations, structure collapses & show large deformation.
3. Flocculated Structure:-
   (a) These have mostly edge to face configuration but, it can be edge to edge also. Net force is attractive.
   (b) Soils in flocculated structure have low compressibility, high permeability & a high shear strength.
4. Dispersed structure:-
   (a) These have face to face configuration. Net force is repulsive.
   (b) Soils in dispersed structure have high compressibility, low permeability & a low shear strength.

Compaction of Soil

5

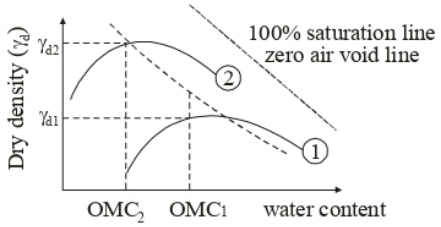
Compaction	Consolidation
Reduction in volume of air voids at a given water content	Volume reduction due to expulsion of pore water from voids
Always partially saturated soil	Always completely saturated soil
Instantaneous phenomenon	Time dependent phenomenon
Specific compaction Technique (use dynamic load)	By static load placed on soil

Special Point: Cohesionless soils are compacted by Vibrations but cohesive soils are compacted by application of static pressure.

Proctor Test

A definite relationship is established between the degree of dry density & soil moisture content.

- Compactive effort is a measure of mechanical energy applied to soil mass.The degree of compaction of a soil is characterised by its dry density.
- (OMC) is the water content at which a particular soil attains maximum dry density (MDD).
- Maximum dry unit weight obtained is a function of compactive effort & methods of compaction for a particular type of soil.
- On increasing the compactive effort, curve shifts backwards & upwards, OMC decreases & MDD increases.



Special Points: Zero air void line can not be practically achieved because all air voids can not be ever removed.

OMC $\rightarrow$ Clay > Silt > Sand > Gravel, $\rho_d \rightarrow$ Gravel > Sand > Silt > Clay

$$\text{Compactive effort } E = \frac{N n W h}{V}$$

N $\rightarrow$ No. of blows per layer, W $\rightarrow$ weight of hammer

$n \rightarrow$ no. of layers, $h \rightarrow$ height of fall, V $\rightarrow$ volume of mould

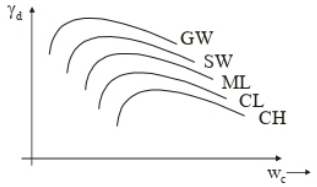
Compaction Tests:

	Standard Proctor Tests (Light Compaction Test)	Modified Proctor test (Heavy compaction test)
Volume of mould	944 cc	944 cc
No. of layers	3	5
No. of blows	25	25
Height of free fall	12 inches	18 inches
Wt. of hammer	2.495 kg	4.54 kg
Compactive effort (KJ/m^3)	594.29	2703.88

Note - Above table from exam point only.

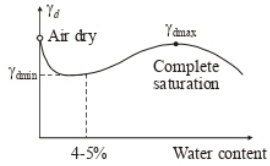
Special Point: Ratio of compactive effort (energy imparted), in modified proctor test to Standard proctor test is 4.5.

Compaction Curve for different Soils:



- Well graded soil can be compacted more than poorly graded soil
- Low plastic soil (L) can achieve higher compaction than highly plastic (H) soils.

Bulking of Sand



- In compaction of sand, intially γ_d decreases due to bulking of sand at nearly 4-5% water content & increase in volume is about 20-40%. Then γ_d increases & reaches to maximum at complete saturation.
- In volume batching in building construction, bulking of sand is considered & play important role.

Suitability of Compaction Equipment

Types of Equipment	Suitable of Soil Type	Nature of project
Rammers or tempers	All soils	In confined areas such as fills behind retaining walls, basement walls, Trench fills.
Frog hammer	Cohesionless soil	For small restricted & confined areas
Pneumatic tyred rollers	Gravel silts, sands, clayey soils, not suitable for uniformly graded soils	Base, sub-base & embankment compaction for highways, airfields, Earth dams etc.
Sheepfoot rollers	Clayey soil, Pure clay	Core of earth dams
Smooth wheeled rollers	Crushed rocks, gravels, sands	Road construction etc.
Vibratory rollers	Sands	Embankments for oil storage tanks etc.

- Vibrofloat can be use for compacting cohesionless soils upto 30 m depth (relatively larger depth)

Property	Dry of optimum	Wet of optimum
Structure after compaction	Flocculated (random)	Dispersed (oriented)
Permeability	More, isotropic	Less, anisotropic
Compressibility		
at low stress	Low	Higher
at high stress	High	Low
Water deficiency	More	Less
Swellability	High	Low
Shrinkage	Low	High
Stress-strain behaviour	Brittle: high peak higher elastic modulus	Ductile: no peak, lower elastic modulus
Pore water pressure	Low	High
Sensitivity	more	Low

Compressibility and Consolidation

6

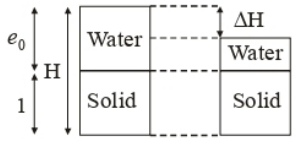
Settlement

- Gradual sinking of the structure due to compression of the soil below the loading.
- Consolidation settlement is a function of effective stress but not the function of total stress.

$$S_t = S_{immediate} + S_{1^\circ-consolidation} + S_{2^\circ-consolidation}$$

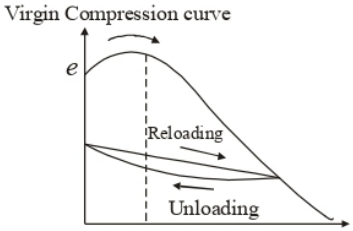
- In immediate consolidation, Expulsion of air or compression of pore air occurs.
- In primary consolidation, Expulsion of excess pore water pressure occurs due to increase in total stress.
- In secondary consolidation, Gradual re-adjustment of particles occurs due to adjustment of particles into more stable configuration under constant effective stress.
- In case of a coarse Grain sand, Having High permeability & low plasticity, 95% of consolidation occur, within 1 minutes after Application of load.
- The characteristics of soil during one-dimensional consolidation (zero lateral strain) can be measured by oedometer test/consolidation test.
- Soil sample in oedometer test will be in double drainage condition.
- The soil specimen is placed in the cell between top & bottom porous stones.
- Piston and spring analogy method was demonstrated by Terzaghi for consolidation.

General Settlement Formula



$$\frac{\Delta H}{H} = \frac{\Delta V}{V} = \frac{\Delta e}{1+e_0}$$

Compressibility characterstics



$\frac{\bar{\sigma}_0}{\bar{\sigma}}$ = Over consolidation ratio (OCR)

$\bar{\sigma}_0$ = Pre consolidation stress

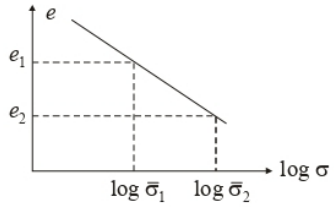
- Soil is normally consolidated, OCR = 1 .
- If $\bar{\sigma} < \bar{\sigma}_0$, then over consolidated soil, OCR > 1

Coefficients in Compressibility of clay

1. Compression index c_c

- c_c has a constant value for a given type of soil & is not a function of effective stress.

$$c_c = \frac{e_1 - e_2}{\log_{10}\bar{\sigma}_2 - \log_{10}\bar{\sigma}_1} = \frac{\Delta e}{\log_{10}\left(\frac{\bar{\sigma}_2}{\bar{\sigma}_1}\right)} \propto \Delta H$$



(*a*) $c_c = 1.15\ (e_o - 0.35)$ Remoulded soil of low sensitivity.

(*b*) $c_c = 0.009\ (w_L - 10)$ undisturbed soil (by Terzaghi & Peck)

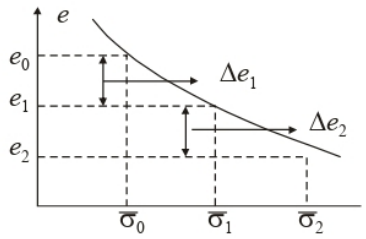
(*c*) $c_c = 0.4\ (e_o - 0.25)$ undisturbed soil of medium sensitivity

(*d*) $c_c = 0.007\ (w_L - 10)$ Remoulded soil (by Skempton)

(e) $c_c = 0.115$ w, where w = water content

2. Coefficient of Compresibility (a_v)

$$a_v = \frac{\Delta e}{\Delta \bar{\sigma}}$$



3. Coefficient of volume compressibility (m_v)

$$m_v = \frac{\text{Volume change per unit volume}}{\text{Increase in effective stress}}$$

$$m_v = \frac{a_v}{1+e_0} \quad \textit{where, } e_0 = \text{Initial void ratio}$$

Calculation of Primary Settlement

ΔH = Change in depth (settlement)

e_0 = Initial void ratio.

1. $\dfrac{\Delta H}{H} = \dfrac{\Delta e}{1+e_0}$

2. $\Delta H = m_v \, \Delta \bar{\sigma} \, H$, 3. $\Delta H = \dfrac{c_c H}{1+e_0} \log\left(\dfrac{\bar{\sigma}_0 + \Delta\bar{\sigma}}{\bar{\sigma}_0}\right)$

Calculation of Secondary Settlement:

- It is significant only for Highly plastic soil & it occurs due to readjustment of soil particles.

$$\Delta H = \frac{c_\alpha H_0}{1+e_0} \log_{10} \frac{t_2}{t_1}$$

H_0 = height at the end of 1° consolidation.

e_0 = Void ratio at the end of 1° consolidation

Terzaghi's one dimensional consolidation equation:

$$\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial z^2}$$

u = Excess pore pressure

$\frac{\partial u}{\partial t}$ = Rate of change of pore pressure with time

C_v = coefficient of consolidation

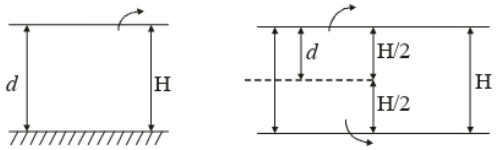
$\frac{\partial u}{\partial z}$ = Rate of change of pore pressure with depth

where $C_V = \frac{K}{m_v \gamma_w}$

- The progress of consolidation can be shown by plotting a series of curves of U_e (Excess pore water pressure) Against Z for different values of t. Such Curves are called Isochrones.These vary with time.

Time factor (T_V):

$$T_V = \frac{C_V\, t}{d^2}$$



One way drainage (semi open) Two way drainage (Open)

C_V = Coefficient of consolidation

d = Length of drainage path

(a) d = H (in one way drainage)

(b) $d = \frac{H}{2}$ (in two way drainage)

(*a*) u ≤ 60%, $T_V = \frac{\pi}{4}(u)^2$, where u = Avg. degree of consolidation

(*b*) u > 60%, $T_V = 1.781 - 0.933 \log (100 - u)$

Special Point: $T_{50} = 0.196$, $T_{90} = 0.848$

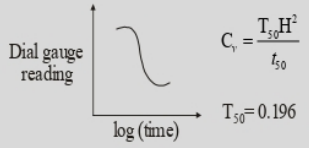
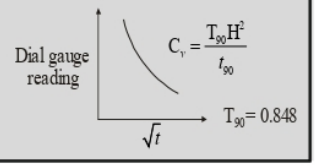
Degree of consolidation

(*a*) $U = \dfrac{e_0 - e}{e_0 - e_f}$, e_o = initial void ratio, e = void ratio at any stage, e_f = final void ratio

(*b*) $U = \dfrac{\Delta h}{h} \times 100$, Δh = settlement at any stage, h = settlement at end of consolidation.

(*c*) $U = \dfrac{U_i - U}{U_i}$, U_i = Initial pore water pressure, U = Pore water pressure at any stage

Determination of coefficient of consolidation (C_v)

Casagrande's method (Also called Logarithm of time fitting method)	**Taylor's method** (Also called Square root time fitting method)
	

- Taylor curve is much suitable as compared to Casagrande's method.
- C_V is inversely proportional to liquid limit (w_L) & C_c is directly proportional to liquid limit.
- Value of C_V decreases with increases in plasticity.

Special Point:

- During the installation of sand drains, disturbance of the soil adjacent to the drain is likely to decrease its permeability and hence, slow down the consolidation process. This effect is described as smear.
- It also depends on the method of installation. Dynamic driving creates more discordance of the soil than static pushing.
- The smear effect increases with increase in drain diameter.
- The size of drain has also influence on the extent of the disturbed zone.

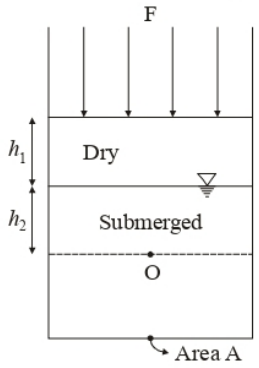
Effective Stress, Capillarity and Permeability

7

Effective stress concept is the developed by Terzaghi & applied to Fully Saturated soils only.

- Effective stress relates 3 types of stress:-
  (a) Total stress (σ)
  (b) Neutral stress (Pore Pressure) (U)
  (c) Effective stress ($\bar{\sigma}$)

  $(\sigma = \bar{\sigma} + U)$
- Total stress is a physical parameter which can be measured by suitable arrangement (Pressure cell)
- Pore water pressure is also called as Neutral stress because It acts on all sides of particles. It is measured by using a piezometer/a stand pipe.
- Effective stress (Intergranular stress) is not a physical parameter, but it is very Important parameter in soil mechanics.
- At bottom of a pond/swimming pool, total stress and neutral stress same but effective stress is zero.
- If we increase water table above ground level, then total stress & neutral stress increase by same amount, but effective stress remains constant.



$\bar{\sigma} = \sigma - u$
$\bar{\sigma}$ = Effective stress
σ = Total stress
u = Pore water pressure

$$\sigma = \frac{F}{A} + \gamma_d h_1 + \gamma_{sat} h_2 \text{ , } u = \gamma_w h_2 \text{ , } \qquad \bar{\sigma} = \frac{F}{A} + \gamma_d h_1 + \gamma_{sat} h_2 - \gamma_w h_2$$

Capilarity

- Water which is held above the water table by phenomenon of surface tension is called capillary water.
- Capillary rise is a function of Pore size.
- Due to capillary rise, Effective stress in capillary zone increase & hence shear strength also increases.

Empirical formula:

$$h_{cm} = \frac{C}{e D_{10}}, \quad D_{10} = \text{Effective size of particles}$$

$$c = \text{emperical constant} = 0.1 - 0.5 \text{ cm}^2$$

- Any fluctuation in the level of free water above the ground surface would not result in any change in the effective stress at any depth in the soil deposit.
- Bulking of sand also occurs due to capillary. It produces apparent cohesion which holds the particles in clusters, enclosing honeycombs.

Quick sand condition

- In case of upward seepage flow, if the upward seepage force becomes equal to the buoyant weight of soil, the effective stress in soil becomes zero.
- Quick sand condition is also called Boiling of sand because surface of sand looks as if It is boiling.
- Quick sand condition occurs in sand but not in clay becuase in clay cohesion exists.
- It can be prevented by lowering of water table at site before excavation or by increasing the upward flow length by providing a sheet pile wall.

Critical hydraulic gradient

$$i_{cr} = \frac{\gamma_{sub}}{\gamma_w} = \frac{G-1}{1+e} = (G-1)(1-n)$$

$$\text{Factor of safety} = \frac{i_{cr}}{i_e}, \qquad i_e = \text{exit hydraulic gradient.}$$

Permeability: It is the property by which water can flow through any medium. It is also called hydraulic conductivity.

Darcy's law: In one dimensional flow, discharge through fully saturated soil is given by

$$q = K\,i\,A \text{ or } V = Ki \;, \qquad i = \frac{\Delta h}{l}$$

A = Cross sectional area of the soil corresponding to flow 'q'
q = Discharge, i=Hydraulic gradient
Δh = Loss of head in length 'L'
K = Coefficient of permeability
V = Discharge velocity or superficial velocity

Special Point: Darcy's law is valid only for laminar flow ($R_e < 1$) & fine grained soil.

(*a*) Seepage velocity (V_s) is the true velocity of flow in which liquid leaks through a porous medium from high head to low head by taking area of voids into consideration.

- Discharge velocity (V) is not the true velocity .Because it consider the flow of water take place through the whole cross section of the soil but in reality water flow through the void present in between the soil particles. So, it is also called superficial velocity.
- Actual velocity/seepage velocity (V_s) is given by

$$\boxed{V_s = \frac{V}{n}}, \quad n = \text{porosity of soil}$$

- Because $n < 1$, V_s is always greater than V.

(*b*) $K_P = \dfrac{K}{n}$

where K_P = coefficient of percolation

Coefficient of Permeability

Pumping out test: It is useful for homogenous coarse grained soil & large project.

$$K = \frac{2.303\,q}{\pi(h_2^2 - h_1^2)} \log_{10}\left(\frac{r_2}{r_1}\right) \text{ (For unconfined aquifer)}$$

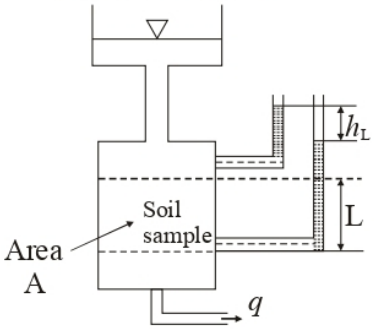
$$K = \frac{2.303\,q}{2\pi D(h_2 - h_1)} \log_{10}\left(\frac{r_2}{r_1}\right)$$ (For confined aquifer)

Pumping in test: It is more economical but less reliable than pumping out test as it gives coefficient of permeability of stratum which is close to the whole. It is use for small project.

Determination of coefficient of Permeability		
Laboratory methods	**Field methods**	**Indirect method**
Constant head	Pumping out	From consolidation
Variable/Falling head	Pumping in	From particle size & specific surface area

Constant head permeability test

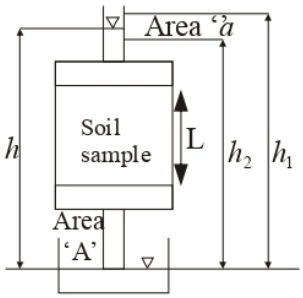
Use for coarse grained soil/ pervious soil/sand



$$K = \frac{qL}{h_L A} = \frac{QL}{t \times h_L \times A}$$

Falling head permeability method

Use for fine grained soil/ impervious soil/Clay



$$K = \frac{aL}{At_o} ln\left(\frac{h_1}{h_2}\right)$$

Special Point: Radius of influence,is the circle over which the effect of pumping is observed. It gradually merges asymptotically to the water table

$R = 3000\,d\,\sqrt{K}$ **Sichardt's formula**

K = Coefficient of permeability (*m/sec*)

R = Radius of influence in *m*

d = Drawdown of well in *m*

Factors affecting Permeability

(a) **Particle Size:** $K = CD_{10}^2$

(b) **Void ratio:** $K = \frac{e^3}{1+e}$

(c) **Viscosity and Unit Weight:** $K = \frac{\gamma_w}{\mu}$

(d) **Impurties:** More impurties, less permeability.

(e) **Effective Stress:** More effective stress, less permeability.

For particle size & specific surface

Kozeny-Carman equation	Allen Hazen's formula	Louden's formula
$K = \frac{1}{C}\frac{\gamma_w}{\mu}\frac{e^3}{1+e}\frac{1}{S_A^2}$	$K = CD_{10}^2$	$\log_{10}(KS^2) = a + bn$
	C = 100 (CGS)	n → porosity
C = Shape factor coefficient		a, b → constants
S_A = Surface area per unit volume	S = Specific surface Area	

Permeability of Stratified Soil

$$K_H = \frac{K_1H_1 + ... + K_nH_n}{H_1 + H_2 ..... H_n}, \quad K_V = \frac{H_1 + ... + H_n}{\frac{H_1}{K_1} + \frac{H_2}{K_2} .... + \frac{H_n}{K_n}}$$ (Flow normal to bedding plane)

Special Points: (Always $K_H > K_V$)

Consolidation equation:

$K = c_v m_v \gamma_w$

c_v = Coefficient of consolidation (cm^2/sec.)

m_v = Coefficient of volume compressibility (cm^2/N)

γ_w = Unit weight of water.

Various values of the coefficient of permeability

Soil Type	Coefficient of Permeability (cm/sec)	Drainage Properties
Gravel	100 - 1.0	Very pervious
Coarse Sand	1.0 - 0.01	Pervious
Fine sand	0.01 - 0.001	Poorly pervious
Silty clay	0.001 - 0.00001	Impervious
Clay	< 0.000001	Impervious

Seepage Through Soil

8

Laplace Equation in two dimensional Flow

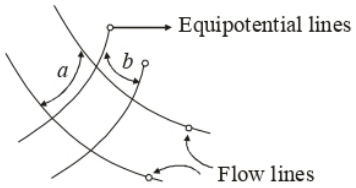
$$\boxed{\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0}$$

Special Point: Cofficient of permeability of transformed section K' = $\sqrt{K_x K_y}$ (in 2D).

Calculation of discharge through a flow net

- Flow lines is a line which indicates direction of flow of the water particles.
- Equipotential line is the line joining the points of equal total head.

(*Seepage Discharge*) $q = KH\frac{N_f}{N_D}\left(\frac{a}{b}\right)$



q = Flow per unit width perpendicular to the pressure plane of section

H = Total head loss

$\left(\frac{N_f}{N_D}\right)$ =Shape factor

N_D = No. of equipotential drops

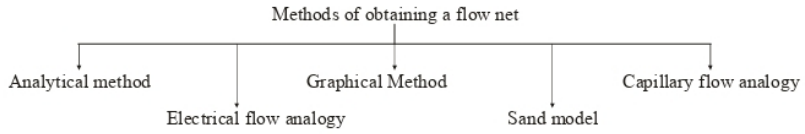
$N_D = N_\phi - 1$, N_ϕ = No. of equipotential lines

N_f = No. of flow channels

$N_f = N_\psi - 1$, N_ψ = No. of flow lines

a, b → Dimensions of an elementary square. Hence ratio of a/b is generally 1

Special Points: Shape factor (N_f/N_D) is the function of boundary conditions only, & will change only when extent of flow is changed. It will not change even if U/S & D/S water levels are interchanged & direction of flow is reversed,



Phreatic Line: It is the top flow line which follows the path of base parabola. It is a stream line. The pressure on this line is atmospheric & below this line is hydrostatic.

Piping: When the uplift forces due to seepage on the D/S side of a hydraulic structure is more than the submerged weight of the soil, the soil grains are dislodged & eroded. Gradually, it results into a pipe shaped discharge channel & finally it may lead to a failure of the structure. This is called piping failure.

It may be prevented by:

(a) Diverting the seepage water into filter wells

(b) Increasing the creep length of flow of water

(c) Increasing the stress due to weight of the structure

Seepage force:- $\gamma_w \times i \times V$

Seepage pressure:- $\gamma_w \times i \times Z$

- Seepage pressure is the energy transfer related to soil particles due to movement of pore water. It depend upon formation of Hydraulic gradient.It is always act in the direction of flow.
- It is taken as -ve when movement of water is in upward direction & value of effective stress descrease.
- It is taken as +ve when movement of water is in downward direction & effective stress on soil increase.

Shear Strength of Soil

9

It is defined as the maximum value of shear stress that can be mobilised within a soil mass.

It is the capacity of the soil to resist shearing stress.

Special Point: Shear strength parameters (C, ϕ, C′, ϕ') are not the inherent properties of soil. They are related to the type of test & the condition under which these are measured.

It depends upon two factors -

(a) **Cohesive strength** - It depend upon true cohesion (electrostatic attraction due to addition of Ca to clay)n and apparent cohesion (Capillary rise or suction due to negative pressure) .

(b) **Frictional strength** - It depend upon particle to particle friction & interlocking of particles.

Special Point: Whatever be the nature of loading on soil, failure on soil occurs by shearing, it never occurs by crushing of particles.

Mohr's hypothesis: Shear stress on failure plane at failure reaches a value which is a unique function of normal stress on that plane.

$\tau_{ff} = f(\sigma_{ff})$

σ_{ff} = Normal stress on failure plane at failure.

τ_{ff} = Shear stress on failure plane at failure (also called Shear strength)

In Mohr diagram for shear strength, any point above Mohr failure envelope indicate imaginary condition.

Coulomb's hypothesis:

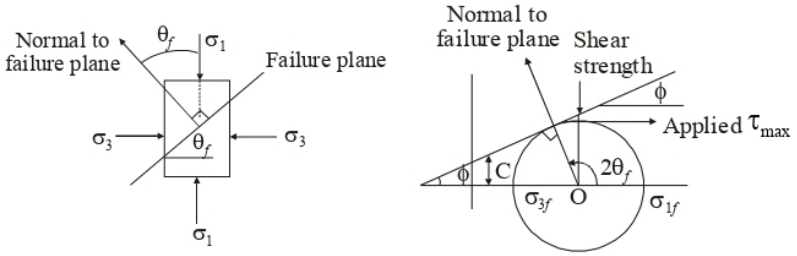
$\tau_{ff} = C + \sigma \tan \phi$

$\tau_f = C' + \bar{\sigma} \tan \phi'$

Where C', ϕ' are effective stress parameters & C, ϕ are total stress parameters

Relation between of $\theta_f, \phi, \sigma_{1f}$ & σ_{3f}.

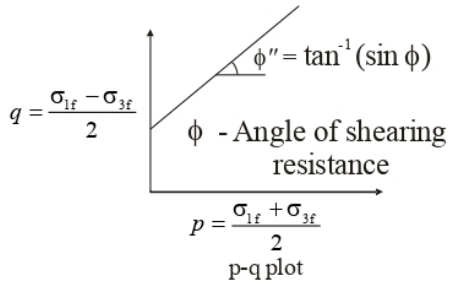
Based on Mohr's & Coulomb's failure envelope



$$\theta_f = 45° + \frac{\phi}{2}$$

(failure plane makes an angle of (45 + ϕ/2) degree with major principal plane)

$$\frac{\sigma_{1f} - \sigma_{3f}}{2} = \frac{\sigma_{1f} + \sigma_{3f}}{2} \sin\phi + C\cos\phi$$



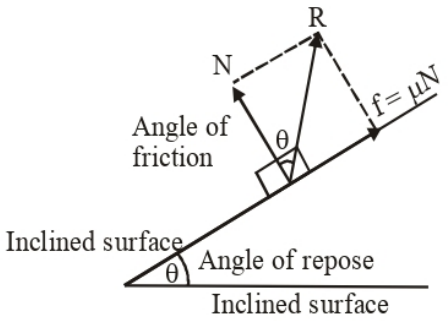
$$\sigma_{3f} = \sigma_{1f} \tan^2\left(45 - \frac{\phi}{2}\right) - 2C \tan\left(45 - \frac{\phi}{2}\right)$$

$$\sigma_{1f} = \sigma_{3f} \tan^2\left(45 + \frac{\phi}{2}\right) + 2C \tan\left(45 + \frac{\phi}{2}\right)$$

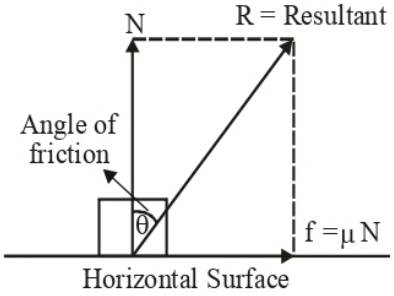
Where σ_1 major principle plane, σ_3 minor principle plane

- Angle of obliquity is defined as the angle b/w resultant stress on a plane & normal stress on the plane.

- The angle of inclination of the plane at which the body begins to move down the plane, is angle of repose.
- It is the minimum angle of an inclined plane which causes an object to slide down the plane.



- Angle of friction is the angle between the normal reaction force & the resulant force between friction & normal reaction forces when the object just begins to move along the surface.
- On a space when sliding just start angle of repose becomes equal to angle of friction.

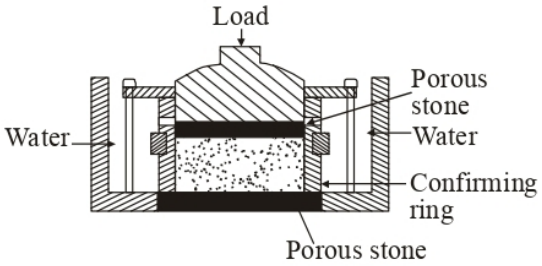


Drained Condition:	Effective stress analysis & long term stability is checked.
Un-drained Condition (with positive pore water pressure):	Total stress analysis & stability should be checked immediately after construction.
Un-drained Condition (with negative pore water pressure):	Effective stress analysis & long term stability Should be checked.

Direct shear test

- It is good for free draining soil like sand & gravel, not useful for clay.

- In it, effective stress & total stress are same because U = 0.



- In it , shear normally applied at constant rate of strain
- It is quick, inexpensive & simple.
- Shear & vertical deformations are measured during test using dial gauge

Disadvantage

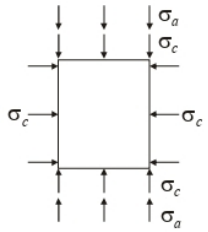
(a) Drainage condition can not be controlled & pore water pressure can not be measured.

(b) Failure plane is always horizontal & predetermined which may not be the weakest plane.

(c) Non-uniform stress distribution on the shear plane. Failure start at edge & progress towards centre.

Triaxial test

- It is suitable for all types of soil
- In it, pore water pressure & Volume change can be measured in undrained condition.
- Application of additional axial stress produce shear stresses within soil mass on all planes except horizontal & vertical planes.
- In triaxial test, Axial strain & deviator stress are determined.

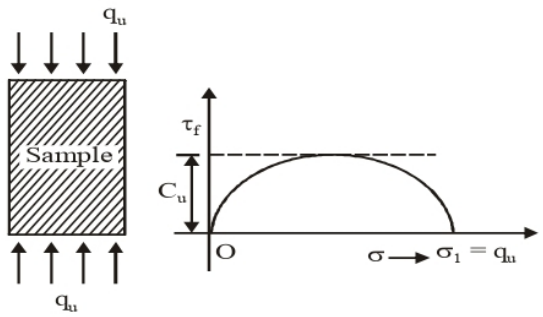


$\sigma_3 = \sigma_C$ = confining pressure/ Minor or Intermediate principal stress

$\sigma_1 = \sigma_C + \sigma_a$, σ_a = deviator stress.

Unconfined compression test

- The unconfined compression test is a special form of a triaxial test in which the confining pressure is zero.



- Load is rapidly applied.So, it is an undrained test. Angle of internal friction is not mobilized. ($\phi_u = 0$).
- The test can be conducted only on cohesive soils like clayey soil.
- Becaause there is no confining pressure $\sigma_3 = 0$. So, only one Mohr circle is obtained.

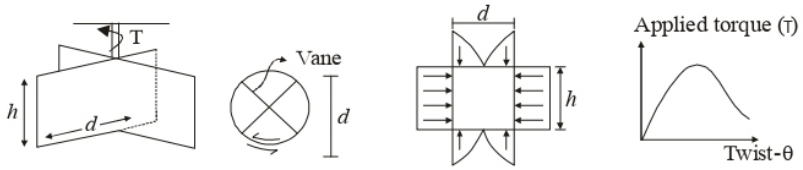
$$\tau_f = C_u = \frac{q_u}{2}$$

σ_1 = Axial stress at failure, τ_f = Undrained shear strength

q_u = Unconfined compressive strength.

Vane Shear test

- The maximum torque applied is the total shear
- It is use for plastic cohesive soil which is very sensitive



$$\tau_f = \frac{T}{\pi d^2\left(\frac{h}{2}+\frac{d}{6}\right)}$$ [when both top & bottom end shear the soil]

$$\tau_f = \frac{T}{\pi d^2\left(\frac{h}{2}+\frac{d}{12}\right)}$$ [when one end shear the soil]

h → height of vane used in shearing.

Here, τ_f = Shear strength = C_u (undrained cohesion)

From UC Test, $C_u = \frac{q_u}{2}$

$$\text{Sensitivity} = \frac{C_u \text{ undisturbed}}{C_u \text{ remoulded}}$$

	Lab size	Field size
Height of Vane (H)	20 mm	10–20 cm
Dia of Vane (D)	12 mm	10 cm
Thickness of Vane (t)	0.5–1 mm	2–3 cm

(i) Unconsolidated undrained test (UU test).

It is suitable for saturated clays subjected to fast loading rate.

- Drainage is not allowed in any stage.
- It takes 15 minutes (quick test).

(ii) Consolidated undrained condition (C-U test)

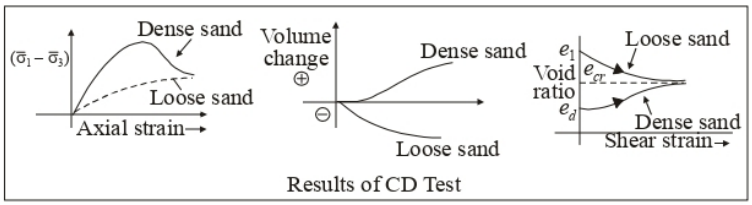
This test is suitable for investigation of stability analysis of earthen dam against failure caused by sudden drawdown of water.

- Drainage is allowed in first stage only.
- It takes 24 hour in first stage & about 2 hour in second stage.

(iii) Consolidated drained test (CD test)

- This is also known as 'show test' (S-test).
- Drainage is allowed in both stages.
- It takes long time.

- It is suitable for saturated sands and also for saturated clay under long terms.
- To Check long term stability of embankment which has been in existence from long time.
- It is used in Analysis of gradual loading condition



Results of CD Test

Soil Liquefaction: The phenomenon in which Saturated loose sand in undrained condition under rapid loading developes +ve pore water water pressure which ultimately reduces the effective stress to zero. It occurs due to high frequency of Vibration - e.x. vibration of machine, during pile driving, explosive blasting & earthquake shock. Liquefaction is generally associated with sandy soil (not possible in normal clays due to cohesion between the particles). But, highly sensitive clays may undergo liquefaction under vibrations.

Soil liquefaction may occur due to : The weight of the soil particles finer than 0.005 mm is less than 15% of the dry weight of the soil. The liquid limit of the soil is less than 35%.

Pore Pressure Coefficients: It is given by Skempton. It is used to express the response of pore water pressure to change in total stress under undrained conditions & enable the initial value excess of pore water pressure to be determined.

$$\Delta u = B[\Delta\sigma_3 + A\,(\Delta\sigma_1 - \Delta\sigma_3)]$$

$$\Delta U_1 = B\Delta\sigma_3, \qquad \Delta U_2 = AB(\Delta\sigma_1 - \Delta\sigma_3)$$

$$A = \frac{\Delta U}{\Delta\sigma_d}, \quad B = \frac{\Delta U_1}{\Delta\sigma_3}$$, For saturated soil B = 1, For dry soil B = 0

ΔU_1 = Change in pore pressure due to increase in cell pressure

ΔU_2 = Change in pore pressure due to increase in deviator stress.

- A is also not a constant, depends on type of soil, stress condition etc.

Earth pressure and Retaining walls

10

Earth presure is the lateral force exerted by the soil on any structure retaining that soil.

- Cohesive soil are poor for backfill because of large lateral pressure.

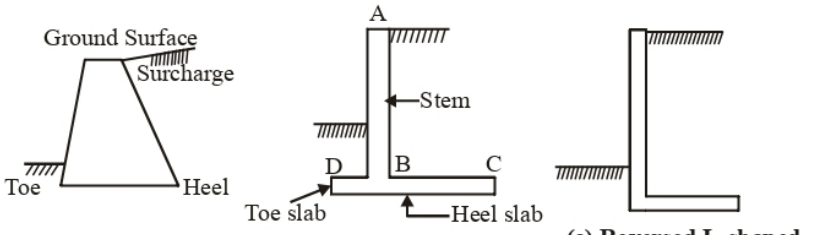
Retaining wall:

A retaining wall (structure) is used to retain the ground surface at different elevations on either side of it. Shear key is provided in a retaining wall to avoid sliding.

Types of retaining wall

Depending upon the mechanisms used to carry the earth pressure, these are classfied into following types:

1. Gravity retaining wall, 2. Cantilever retaining wall, 3. Buttress wall.



(a) Gravity wall **(b) T-Shaped cantilever retaining wall** **(c) Reversed L-shaped cantilever retaining wall**

Gravity retaining wall : Plain concrete gravity walls are not used for heights more than 3.0 m.

- In it , the resistance to the earth pressure is generated by weight of the structure only.

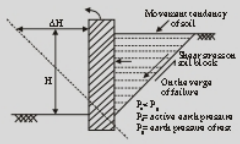
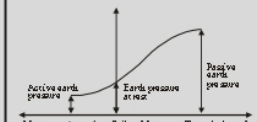
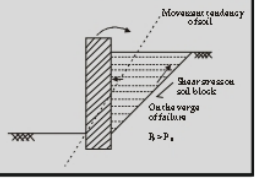
Cantilever retaining wall

- When height of retaining wall >6m, then, counterfort retaining wall is provided & cantilever is generally economical for heights of 6m - 7m.
- A cantilever retaining wall resists the earth pressure horizontal & any other, by the cantilever bending action.

Buttress wall

- These are structurally more efficient & more economical than counterforts.
- But, buttress reduces the clearance in front of the wall & therefore, it is not commonly used.

Classification of lateral earth pressure

Active earth pressure (wall moves away from backfill)	Earth pressure at rest (wall does not moves at all)	Passive earth pressure (wall moves towards the backfill)
		

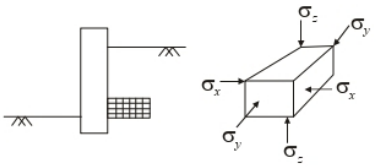
1. Earth pressure at rest

$$\Rightarrow \quad \sigma_x = \sigma_y \;\&\; \varepsilon_x = 0$$

$$\text{So} \quad \sigma_x = \frac{\mu}{1-\mu}\sigma_z$$

$$\sigma_x = K_0\,\sigma_z$$

$$\text{So,} \quad K_0 = \frac{\mu}{1-\mu}$$



• For cohesionless soil (C = 0), $K_0 = 1 - \sin\phi$

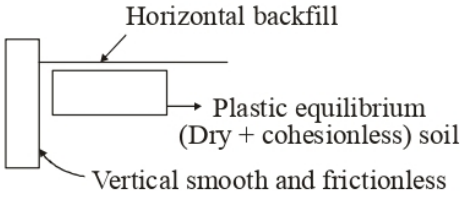
Active earth pressure	Passive earth pressure
Very little movement is required to mobilise the active pressure Failure plane is inclined at $(45 + \phi/2)$ with the horizontal $\Delta H = 0.2\%$ of H Dense sands $\Delta H = 0.5\%$ of H loose sands Length of failure block $= H \cot\left(45 + \frac{\phi}{2}\right)$ $K_a = \frac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45 - \frac{\phi}{2}\right)$	Much higher movement is required to mobilise the pressure Failure plane is inclined at $(45 - \phi/2)$ with the horizontal $\Delta H = 2\%$ of H Dense sands $\Delta H = (5\text{-}10)\%$ of H loose sands Length of failure block = $H \cot\left(45 - \frac{\phi}{2}\right)$ $k_P = \frac{1+\sin\phi}{1-\sin\phi} = \tan^2\left(45 + \frac{\phi}{2}\right)$

Earth pressure theories

1. Rankine theory (1857)
2. Coulomb's theory (1776)

1. **Rankine's theory.** Originally Rankine's theory was only for cohesionless soil but later it was extended to cohesive & submerged soil.

- For Cantilever & Counterfort wall, we use Rankine theory.
- Assumptions in Rankine's theory.

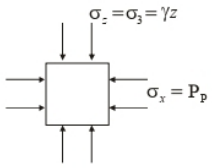


(a) Soil is semi-infinite, homogenous, isotropic, dry & cohesionless.
(b) Soil is in a state of plastic condition at the time of active & passive pressure generation.
(c) The Backfill soil is Horizontal.
(d) Back of wall is vertical & smooth.
(e) Rupture surface is a planar surface which may be horizontal/inclined

(*a*) Passive earth pressure

$$P_p = k_p \gamma z + 2c\sqrt{k_p}$$

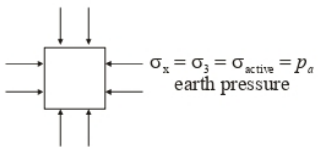
where $k_p = \dfrac{1+\sin\phi}{1-\sin\phi} = \tan^2\left(45+\dfrac{\phi}{2}\right)$



(*b*) Active earth pressure

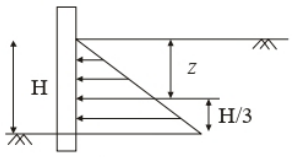
$$P_a = k_a \gamma z - 2c\sqrt{k_a}$$

Where $k_a = \dfrac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45-\dfrac{\phi}{2}\right)$



Various cases of earth pressures

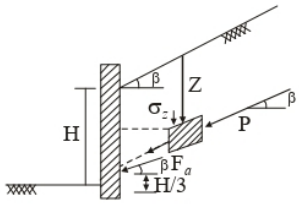
1. Cohesionless soil on a vertical smooth wall



$p_{az} = k_a \gamma z$, , $\quad p_{pz} = k_p \gamma z$

$$F_a = \frac{k_a \gamma H^2}{2}, \qquad F_p = \frac{k_p \gamma H^2}{2}$$

2. Soil with Inclined backfill



From above figure,

$\sigma_z = \gamma z \cos \beta$, $\quad P_a = k_a \gamma z \cos \beta$

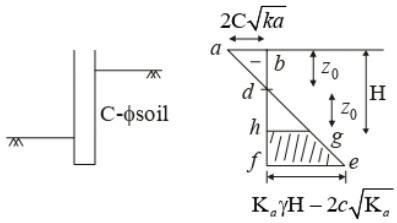
In It,

$$K_a = \left(\frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}} \right) \times \cos\beta$$

$$K_p = \left(\frac{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}} \right) \times \cos\beta$$

$$F_a = \frac{k_a \gamma H^2}{2} \cos\beta$$

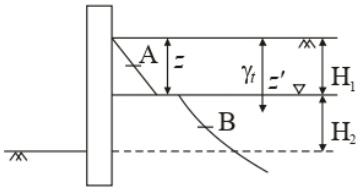
3. Active earth pressure on cohesive soil



$$H_C = 2z_0 = \frac{4C}{\gamma\sqrt{K_a}} = \text{Critical depth}$$

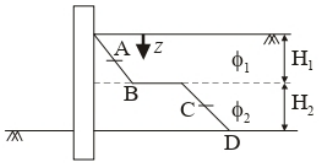
- No- contact loss= Active earth pressure corresponds to area efgh
- After contact loss = Active earth presure corresponds to area fde

4. **Partially submerged cohesionless soil on vertical smooth wall**
   For point A
   $P_a = k_a \gamma_t z$
   $P_a = K_a \underbrace{(\gamma_t H_1 + \gamma_{sub}(Z' - H_1))}_{\text{Effective stress}} + \gamma_w (Z' - H_1)$, at point B



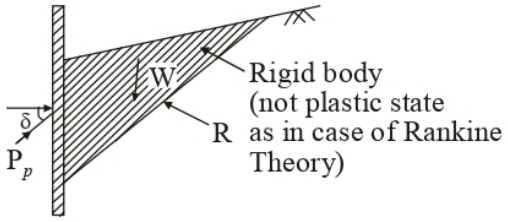
Special Point: Water pressure due to hydrostatic condition is same in all directions, therefore hydrostatic pressure is not multiplied by k_a

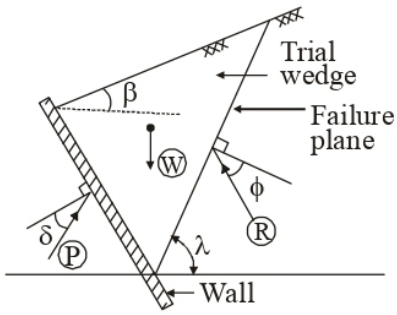
5. **Back fill with two different soils (ϕ_1 and ϕ_2)**
   A: $P_a = K_{a1} \gamma_1 Z$
   B: $P_a = K_{a1} \gamma_1 H_1$
   C: $P_a = K_{a2} (\gamma_1 H_1 + \gamma_2 (Z - H_1))$
   D: $P_a = K_{a2} (\gamma_1 H_1 + \gamma_2 H_2)$



Coulomb's theory of earth pressure:

- For gravity & for semi gravity wall, We use coulomb's theory.
- In it, sliding wedge is assumed at an angle λ from horizontal rigid body.
- The position & line of action of earth presure will also be known in advance.





- Forces acting on trial wedge will be W, R, P whose directions will be known.
- By assuming various trial wedges at different trial angle λ , the value of P will be calculated.
- Highest value of P is for active earth presure while lowers value of P is for passive earth pressure.

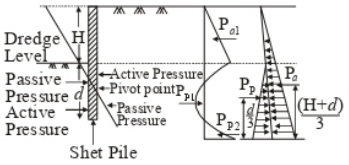
Special Points:
(i) Retaining wall are designed for P_a.
(ii) Due to compaction, P_a decrease & P_P Increase.

Cantilever sheet Pile and Anchored Bulkhead

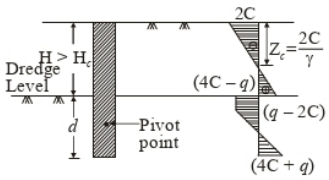
A sheet pile wall is an earth & water retaining structure which behaves as a fixed vertical cantilevers in resisting lateral earth pressure

Cantilever sheet pile

Granular Soil



Cohesive soil



$$P_P \frac{d}{3} = P_a \frac{(H+d)}{3} \text{ without FOS}$$

$$\frac{P_P}{FOS} \times \frac{d}{3} = P_a \times \frac{(H+d)}{3} \text{ with FOS}$$

$$P_p = \frac{1}{2} K_p \gamma d^2$$

$$P_a = \frac{1}{2} K_a \gamma (H+d)^2$$

$q = \gamma H$

at depth H,

$P_a = q - 2C$ ($\leftarrow$)

$P_P = q - 2C$ ($\rightarrow$)

Resultant at depth H,

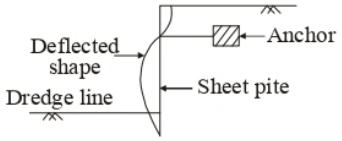
$P_P - P_a = 4C - q$ ($\rightarrow$)

Resultant earth Pressure at H + d

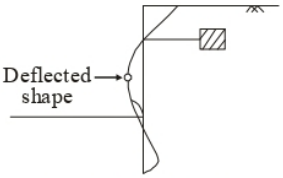
$P_P - P_a = 4C + q$ ($\leftarrow$)

Anchored Bulkhead

If the wall height is large, then support against the lateral pressure is provided by embankment in the ground & by tie rods near the top. This type of earth retaining structure is called as an anchored bulkhead.



Anchored bulkhead at shallow depth



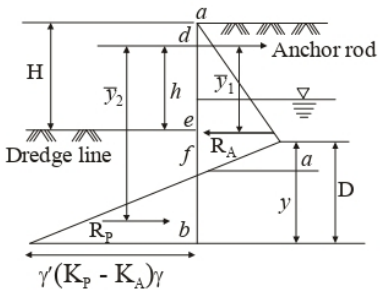
Anchored bulkhead down to deeper depth

(*a*) Anchored bulkhead in granular soil.

F_{ar} = Force in anchor rod

R_p = Resultant passive earth pressure acting at $\bar{y}_2$ below the anchor rod.

R_A = Resultant active earth pressure acting at $\bar{y}_1$ below the anchor rod level.



From above diagram

For equillibriun

$F_{ar} + R_P - R_a = 1$

At depth 'a' to the point of zero pressure

$$a = \frac{P_{ac}}{\gamma'(K_P - K_a)}$$

Special Points:

- A cantilever sheet pile derives its stability from lateral resistance of soil.
- Deflection of a sheet pile in a Braced cut increase from top to bottom.

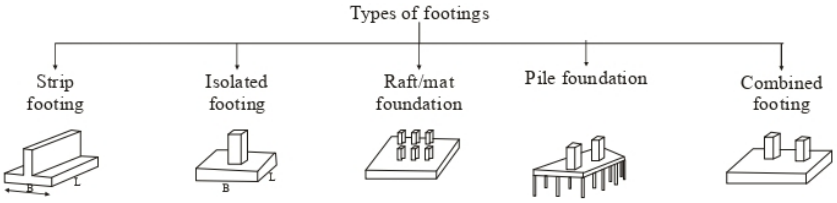
Coffer Dam: It is a temporary structure constructed in river,dam, lake etc to keep the working area dry for construction of other structure. After the construction of coffer dam, area is dewatered by pumping.

Construction type	Suitable Cofferdam Type
A. Cut-off trench of a dam to be constructed across flowing river	Embankment type cofferdam
A. Shallow foundation of a bridge pier	Single wall sheet pile cofferdam
A. Sequential repetition of underwater foundation work	Cellular sheet pile cofferdam
A. Control of groundwater to prevent entry into deep excavation	Floating steel cylinder cofferdam

Shallow Foundation

11

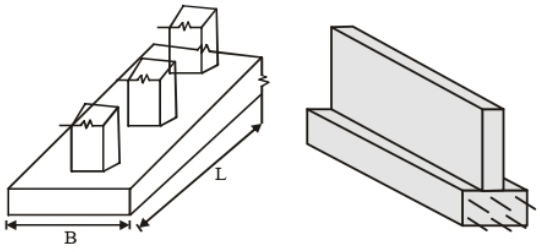
Footings are the lower most supporting part of any structure known as sub-structure & these are last structural elements through which load is transferred to foundation consisting soil/rock.



- A raft foundation is provided if its area exceeds the plan area of the building by 50%. It is a combined footing that covers the entire area beneath a structure and support all the walls and columns. **IS 2950:1981** for design of raft foundation.
- The weight of footings is assumed as 10% of the weight transferred to the column
- The minimum depth of building foundation on sandy soils is 0.8m to 1m, rocky soils is 0.05m to 0.5m & clay soils is 0.9m to 1.6m

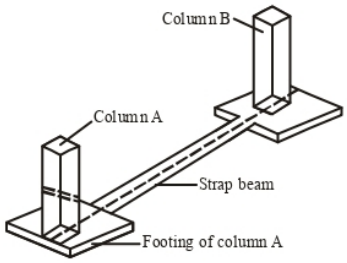
Strip Foundation

- For a number of columns constructed in a row, the type of foundation used is strip foundation.
- The foundation is called strip foundation because L > > B



Strap footing: Straps are provided to restrain the overturning force due to eccentric load on exterior footing.

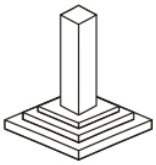
- These are used where the base for exterior column must not project beyond the property line.
- It consists of two or more footings of individual columns, connected by a beam, called a strap.



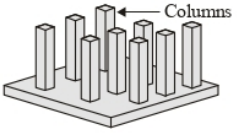
Strap footing

Special point: A raft foundation is used when soil has low bearing capacity, such that there is chances of differential settlement.

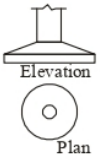
Stepped footing



Raft foundation



Circular footing



Types of foundation	Use of foundation
Combined footing	Closely spaced columns resting on compressible soil.
Micro piles	Loose sand

Following are the general requirement for foundation

(*a*) Settlement of the foundation should be within permissible limits.

(*b*) Foundation must be safe against shear failure.

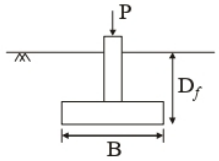
(*c*) Foundation should be located at such depth, such that its performance is not affected by seasonal volume changes.

Types of footings (As per Terzaghi)	
Shallow foundation	**Deep foundation**
$\frac{D_F}{B} \le 1$	$\frac{D_F}{B} > 1$
Ex:- Isolated footings combined footing, raft foundation	Ex:- Pile foundation

Basic Terms

1. **Gross Pressure or Gross Loading Intensity**(q)**:** It is the total pressure at the base of the footing due to weight of the super-structure, weight of the earth fill & self weight of the footing.

$$q_g = \frac{P}{B^2} + \gamma D_f$$



2. **Net Pressure Intensity:** It is the excess of gross pressure to over burden pressure.

   $q_{net} = q_g - \gamma D_f$

   For safe design, $\frac{P}{B^2} \le q_{net\text{-}allowable}$

3. **Ultimate bearing capacity** (q_u): It is the maximum gross intensity of loading that the soil can support before it fails in shear.
4. **Net ultimate bearing capacity:** It is the minimum net pressure causing shear failure of soil.

$$q_{nu} = q_u - \gamma D_f = \frac{P}{B^2}$$

5. **Gross safe bearing Capacity:**

$$q_s = \frac{q_{nu}}{FOS} + \gamma D_f$$

6. **Net Safe bearing Capacity:**

$$q_{ns} = \frac{q_{nu}}{FOS}$$, where FOS is generally 2-3 adopted.

7. **Allowable bearing pressure:** It is the maximum net intensity of loading that can be imposed on the soil with no possibility of shear failure or the possibility of excessive settlement.

Special Point: It is smaller of Net safe bearing capacity & safe bearing pressure.

8. **Safe bearing Pressure:** It is the maximum net intensity of loading that can be allowed on soil without the settlement exceeding the permissible value.

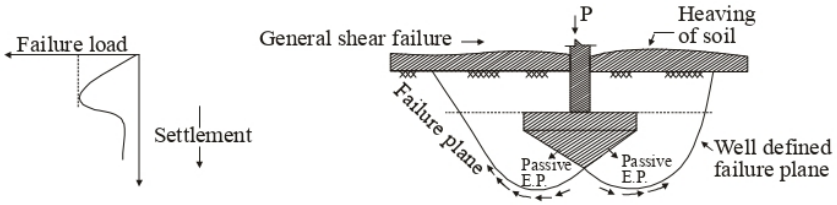
Special Point: No factor of Safety is used when dealing with settlement.

(Calculation of Bearing Capacity)		
Analytical methods	**Building codes**	**Field test methods**
General shear failure Punching shear failure Local shear failure	Rankine's method Bell's theory Prandtl method Terzaghi method Skempton's method Meyor's method Hensen's Recommendations	Standard penetration test Plate load test Static cone penetration test

Analytical Methods

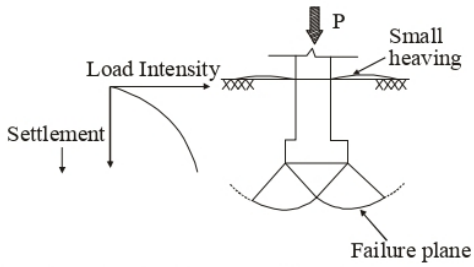
Based on shear failure criteria

1. **General Shear Failure:**



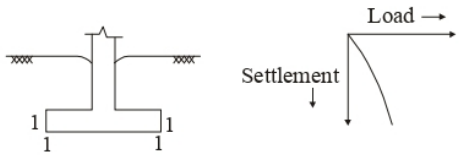
- Over consolidated clay with low compressibility
- Well defined failure pattern, large heaving will occur.
- Occurs after plastic equilibrium state is reached.
- Brittle type stress-strain curve
- Failure due to tilting of foundation
- Occurs in soil with relative density > 70%

2. **Local Shear Failure:**



- Slight heaving of soil adjacent to foundation
- Foundation does not tilts
- Partial development of state of plastic equillibrium
- Failure is not sudden
- Plastic stress-strain curve
- Occurs in loose sand with relative density (30—70)%

3. **Punching Shear Failure:**



- No heaving of adjacent soil
- Deep foundations generally fail by punching only
- No tilting of foundation
- Shearing in vertical direction around the edge
- Very loose sand with relative density less then 30%

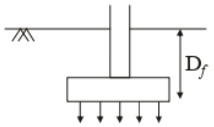
Parameter	General shear failure	Local Shear failure
1. Friction angle (ϕ)	> 36°	<29°
2. Strain at failure	≤ 5°	≥ 15°
3. Relative density	> 70%	< 30%
4. SPT number	> 30	< 5
5. Void ratio	< 0.55	> 0.75
6. Unconfined Compressive Strength	> 100 kN/m^2	< 80kN/m^2

Building Codes

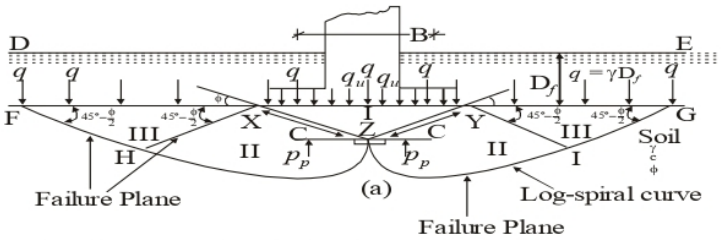
1. **Rankine's Method** (for ϕ-soil):

$$q_u = \gamma D_f \tan^4\left(45 + \frac{\phi}{2}\right)$$

$$q_u = \gamma D_f \left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$



2. **Prandtl Method** (for C – ϕ soil):
   $q_a = CN_C + \gamma D_f N_q + 0.5\ B\ \gamma\ N_r$ (For strip footing)
   For C- soil , $N_C = 5.14$, Nq = 1, Nγ = 0
3. **Bell Theory** (for C – ϕ soil):
   $q_s = CN_C + \gamma D_f N_q$
   for pure clays C = 4, $N_q = 1$
4. **Terzaghi Method** (for C–ϕ soil): It underestimate bearing capacity of soil.
   - Strip footing at shallow depth ($D_f/B \le 1$)
   - General shear failure governed by Mohr's criteria
   - Shear resistance of soil between ground surface & footing base is neglected



Zone I → Zone of elastic Equilibrium
Zone II → Radial Shear Zone
For C – ϕ soil → logarithmic shape, For C-soil → circular shape
Zone III → Rankine Passiave Zone, Passive plastic Equilibrium with $\left(45-\frac{\phi}{2}\right)$ angle with the Horizontal.
For strip footing,

$$q_u = CN_C + \gamma D_f N_q + 0.5\ B\gamma N_r$$
$$q_{mu} = CN_C + (N_q - 1)q + 0.5B\gamma N_\gamma$$

Due to cohesion, Due to Over burden, Due to soil in Shearing Zone

Special Point: N_c, N_q, N_γ are the functions of ϕ only. Hence the bearing capacity increases as the value of ϕ increases.
For clayey soil (ϕ = 0) $N_C = 5.7$, $N_q = 1$, $N_\gamma = 0$

Modification in Terzaghi's Equation

1. For Circular footing

$$q_{nu} = 1.3\ CN_C + q\ (N_q - 1) + 0.3\ B\gamma N_r$$

2. For Square footing

$$q_{nu} = 1.3\ CN_C + q\ (N_q - 1) + 0.4\ B\gamma N_r$$

3. For rectangular footing

$$q_{nu} = \left(1 + \frac{0.3\,B}{L}\right) CN_C + q(N_q - 1) + \left(1 - \frac{0.2B}{L}\right)(0.5\ B\gamma N_\gamma)$$

Special Point:

Load carrying capacity in order - Strip < Circular < Square Footing

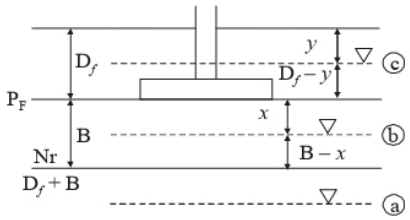
4. For local shear failure ($\phi < 29°$)

$$C_m \to \frac{2}{3}C, \qquad (\tan\phi_m) = \frac{2}{3}\tan\phi$$

From C_m & ϕ_m, find N_C', N_q', N_γ'

$$q_{nu} = \frac{2}{3}CN_C' + q(N_q' - 1) + 0.5B\gamma N'_\gamma$$

5. For water table, in strip footing



(a) For (a) → when water table below (D_f + B) (No effect)

$$q_{nu} = CN_C + \gamma_t D_f(N_q - 1) + 0.5\ B\gamma_t\ N_\gamma$$

(b) For (b) → when water table between D_f & (D_f + B)

$$q_{nu} = CN_C + \gamma_t D_f(N_q - 1) + 0.5\ (x\gamma_t + (B - x)\gamma_{sub})N_\gamma$$

(c) For (c) → when water table between 0 & D_f

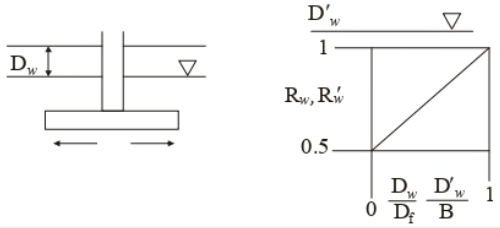
$$q_{nu} = CN_C + [\gamma_t y + (D_f - y)\gamma_{sub}]\ (N_q - 1) + 0.5\ B\ \gamma_{sub}N_\gamma$$

Another way of modification due to water table

$$q_{nu} = CN_C + D_f\gamma_t(N_q - 1)R_w + 0.5B\gamma_t N_\gamma R_w'$$

$$R_w = 0.5\left(1 + \frac{D_w}{D_f}\right), \qquad \text{when } 0 < \frac{D_w}{D_f} \le 1$$

$$R_w' = 0.5\left(1 + \frac{D_w'}{B}\right), \quad \text{when } 0 < \frac{D_w'}{B} < 1$$



Special Point:

- The rise of water Table in cohesionless soils upto ground surface reduces the Net ultimate Bearing capacity by 50%.

6. Skempton's Method

Applicable only for saturated clay & to deep foundations also.

$$q_{nu} = CN_C$$

'C' can be found out from

(*i*) U–U test

(*ii*) Vane shear test

(*iii*) Unconfined compression test

For value of N_C

(*a*) Strip footing

$$N_C = 5\left(1 + 0.2\frac{D_f}{B}\right), \frac{D_f}{B} < 2.5 \quad \left(\text{for } \frac{D_f}{B} \geq 2.5, N_C = 7.5\right)$$

(*b*) Square/circular footing

$$N_C = 6\left(1 + 0.2\frac{D_f}{B}\right), \frac{D_f}{B} < 2.5 \quad \left(\text{for } \frac{D_f}{B} \geq 2.5, N_C = 9\right)$$

(*c*) For rectangular footing

$$N_C = 5\left(1 + 0.2\frac{D_f}{B}\right)\left(1 + 0.2\frac{B}{L}\right), \frac{D_f}{B} < 2.5$$

$$\text{For } \frac{D_f}{B} \geq 2.5, N_C = 7.5\left(1 + \frac{0.2B}{L}\right)$$

7. Meyerhoff's Method (C-ϕ soil)

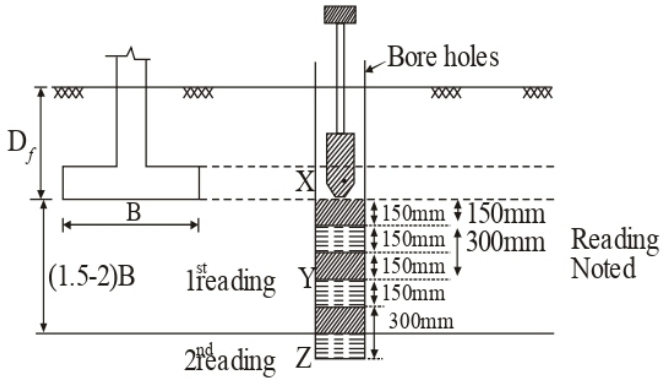
- Applicable for both shallow & deep foundation.
- Failure surface is assumed to go above the foundation level.

$$q_u = CN_cS_cd_ci_c + qN_qS_qd_qi_q + 0.5B\gamma N_\gamma S_\gamma d_\gamma i_\gamma$$

where S, *i, d* are emperical correlation factors for shape, inclination, depth. For ϕ-soil, $N_c = 5.14, N_q = 1, N_\gamma = 0$

Field Tests

1. Standard Penetration Test (IS 2131:1981)



- For Granular soils only
- The split spoon sampler is allowed to penetrate into the soil by applying Impact load of 63.5 kg having a free fall of 75 cm.
- N-value is determined at selected number of bore holes & average value of corrected N is calculated for the depth from D_f + (1.5–2) B.
- Any value greater than 50% of the average value is rejected & new average value is found out.
-

N	ϕ	Relative Density
<4	25–30	0
4–10	27 –32	15

Over burden Correction

- It is necessary because the N-value will have effect on it due to confinement of soil at various depth.

$$N_1 = N_0\left(\frac{350}{\bar{\sigma} + 70}\right), \quad N_0 = \text{observed SPT value}$$

Special Point : STP-N value recorded in clayey deposit dose not require corrections for overburden pressure & dilatancy

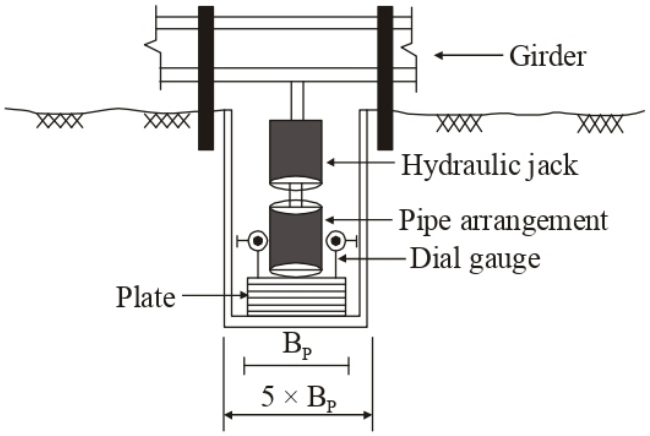
Dilatancy correction required only in saturated fine sand or silt.

- It is more significant in case of fine dense sand ($N_1 > 15$) because it

has tendency to dilate under rapid loading & -ve pore pressure will develop.

$$N_2 = 15 + \frac{1}{2}(N_1 - 15)$$

2. Plate Load test: (IS 1888–1982)



- Circular/square bearing plates of mild steels are used, having thickness 25 mm and size range (300-750) mm.
  - Significant only for cohesionless soil
- It is used to calculate

(*a*) Allowable bearing capacity

(*b*) Ultimate bearing capacity

(*c*) Safe settlement of foundation

For Granular Soil

$$\frac{q_{uf}}{q_{up}} = \frac{B_f}{B_P}$$

$$\frac{S_f}{S_P} = \left[\frac{B_f}{B_P}\left(\frac{B_P + 0.3}{B_f + 0.3}\right)\right]^2 \text{, where } B_f,\ B_P \text{ in metres}$$

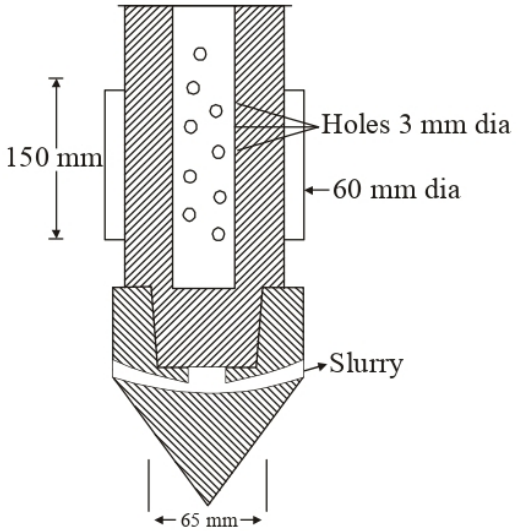
For Clayey soil $q_{uf} = q_{up}$

$$\frac{S_f}{S_P} = \frac{B_f}{B_P}$$

3. Static cone penetration test (CPT):

- Particularly for soft clays, silts & fine to medium sand deposits.

- Cone area 10 cm^2, Apex angle 60°
- Continuous record of soil resistance
- Rate of pushing cone 20 mm/sec upto depth of 100 mm.



Allowable Bearing Capacity ($Q_{A\ net}$)

Peck Henson's Formula

$$q_{a(net)} = 0.41\ NS\ C_w$$

$$C_w = 0.5\left(1+\frac{D_w}{D_f+B}\right)$$

N = corrected SPT N-value, C_w = Water table correction factor

S = Permissible settlement (mm), D_w = depth of WT below ground

Settlement of foundatin:

$$S = S_{immidiate} + S_{1°} + S_{2°}$$

Where $S_{immediate} = \frac{q_n B(1-\mu^2)}{E_S} \times I_f$

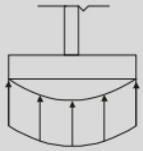
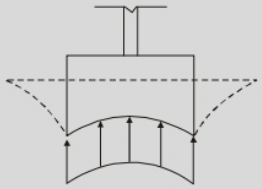
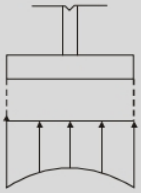
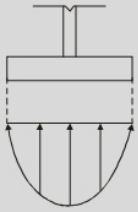
$S_{immediate} \Rightarrow$ Elastic settlement for both sandy & clayey soil,

E_s = modulus of elasticity, μ=Poisson's ratio

I_f = Influence factor = f(shape, rigidity of structure)

$$S_{\substack{rigid \\ immediate}} = S_{\substack{flexible \\ immediate}} \times 0.8$$

Deflected shape of Footings

	Clayey Soil	Granular soil
Flexible Footing Settlement varies, Pressure constant		
Rigid Footing Settlement constant Pressure varies		

Permissible Settlements in Shallow Foundation

	Total settlement (mm)
Isolated footing on clay	65
Isolated footing on sand	40
Raft on clay	65-100
Raft on sand	40-65

Permissible Angular Distortion: In case of large frame structure, angular distortion must not exceed $\frac{1}{500}$ in general and if all kind of minor damages are to be prvented, then angular distortion must not exceed $\frac{1}{1000}$.

- Incompressibility is an important property to avoid differential settlement of soil.

Deep Foundation

12

- **Pile:** Small diameter shaft which is driven or bored into ground.
- **Piers and wells:** These are large diameter shafts constructed by excavation & sunk to required depth.

Classification of Piles based on various factors -

(a) Function/Action - Fender, sheet, batter, tension (uplift), load bearing etc.

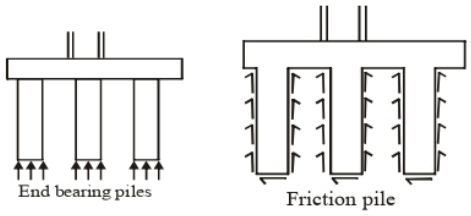
(b) Installation method - Driven, jack, screw & Bored (cast in-situ) piles.

(c) Material - Steel, timber, concrete & composite piles.

(d) Displace-ment of soil - Displacement and non-displacement piles.

(e) Mode of load transfer - End bearing, friction and combined piles.

- **Friction (floating) pile:** These are used in soft soil clay.
- **End bearing piles:** These are used in stiff clay, Dense sand.
- **Tension or uplift piles:** These are anchor structures subjected to hydrostatic pressure or overturning moment.
- The advantage of a concrete pile over a timber pile is no decay due to termites, no restriction of the length & not necessary to cut below the water mark
- **Fender & dolphin piles:** Thses protect water-front structure against impact from ships & other floating objects from the abrasion or impact.
- **Franki pile**:- It has an enlarged base of mush-room shape, which gives effect of a spread footing. It is best suited to granular soil. It is more useful w where a bearing stratum of limited thickness can be reached at reasonable depth.



- **Compaction pile:** These compact loose granular soil. It itself do not carry any load. It may be made up of sand.
- **Anchor pile:** Anchor against horizontal pull for water or sheet piling.
- **Batter piles:** These resist horizontal & inclined forces, especially in water front structure. These are drive at an inclination to resist large horizontal inclined forces
- **Displacement Piles:** It displaces the soil laterally or upward.
- In case of clays, large displacement piles remould the soil to a distance of 2 times the diameter of pile.
- In loose sand, a pile densifies the sand upto a distance of 3.5 times the diameter or pile measurd from the centre of pile.

Non-displacement piles: These are bored piles. Such piles are formed in the soil by boring or excavation & then these voids are filled with concrete sides are either supported by casing or by Bentonite slurry.

Special Point: Driven concrete piles are generally of diameter upto 500 mm. But bored piles may be even 2-3 m.

1. Static formula

$$Q_u = Q_{pu} + Q_f$$

$$Q_{pu} = q_{pu} \cdot A_b$$

$$Q_f = F_s \cdot A_s$$

Where q_{pu} = Unit point bearing resistance

Q_u = Ultimate load

Q_f = Ultimate skin friction.

Q_{pu} = Ultimate point bearing load

A_b = Area of base

A_s = Surface area of pile in contact with soil.

F_s = Unit skin friction resistance

So $Q_u = q_{pu} A_b + F_s A_s$

For C – ϕ soil $q_{pu} = CN_c + \gamma D_F N_q + 0.5 B\gamma N\gamma$

Neglecting 0.5 Bγ Nγ wrt. γD_f as B <<< D_f

So, $q_{pu} = CN_c + \gamma D_f N_q$

for C – soil $q_{pu} = CN_c$

(*a*) Static formula in driven granular soil

$$Q_u = (\gamma D_f N_q) A_b + F_s A_s$$

where $F_s = K \bar{\sigma}_{avg} \tan \delta$

For dense sand, $D_f = 20$ (diameter of pile)

From loose to medium sand, $D_f = 15$ (diameter of pile)

For values of K and S

Pile material	δ	Value of K	
		Loose	Dense
Steel	20°	0.5	1
Concrete	3/4 ϕ	1	2
Timber	2/3 ϕ	1.5	4.0

Special Point: As per IS code $\delta = \phi$ & $K = 1 - 3$ for driven piles in loose to medium sand

When there are various layers of soil, then

$Q_p = K \tan \delta (\sigma_{avg1} A_1 + \sigma_{avg2} A_2 + ... + \sigma_{avgn} A_n)$

(*b*) Static formula in bored granular soil.

- Point bearing of bored cast in situ piles = 0.5 (point bearing resistance of driven piles.)
- Due to boring, the value of K becomes very small (0.5).
- Rest remaining calculations as above.

(*c*) Static formula for piles in clay.

- Static formulae are suitable for friction piles driven through cohesive soils.

$$Q_u = (C_{ub} N_c) A_b + \alpha (C_u) A_s$$

Where C_u = Undrained cohesion in the embedded length of pile.

C_{ub} = Undrained cohesion at the base of the pile

$N_c = 9$ (By **skempton**).

α = Depends on adhesion between soil & pile called adhesion factor

$\alpha = 1 \rightarrow$ for very loose clays

$\alpha = 0.3 \rightarrow$ for very stiff clays

Special Points: Smaller the undrained strength, softer is the consistency.

2. Dynamic formula: It is based on resistance to penetration, hence used in driven piles only

- Dynamic formulae are suitable for friction piles through cohesionless soil.

Energy Imparted = Work done in pile driving

$$Q_u \times S = W \times H$$

(*a*) Engineering News Formula

$$Q_{allowable} = \frac{WH}{FOS\ (S + C)}$$

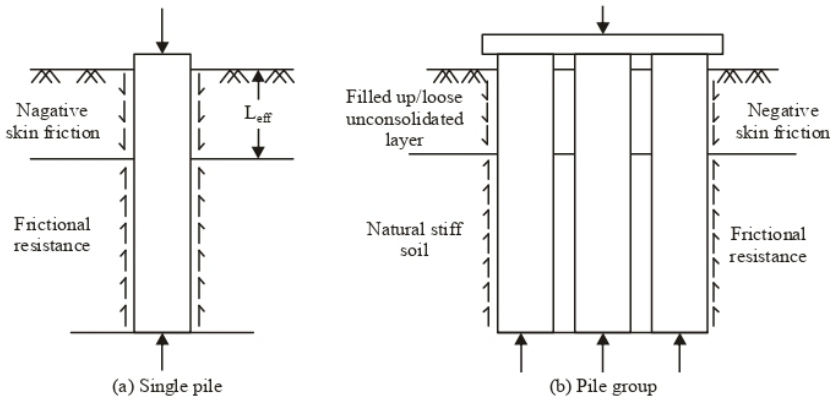
Where H = Height of fall in cm
W = load in Kg
S = Settlement/blow in cm
= last 5-blows of drop hammer also called, as real set per blow.
= last 20 blows of steam hammer.
C = Emperical factor
= 2.5 cm for drop hammer
= 0.25 cm for single acting steam hammer.
FOS = 6

(*b*) Modified Hilly Formula:

$$\text{Ultimate Driving Resistance (R)} = \frac{Wh\eta}{S + \frac{C}{2}}$$

Where W= Weight of hammer (Tonnes)
S = Final set per blow (last– one blow – cm)
h = Height of fall (cm)
C = Total elastic compression per blow (of soil + pile + Dolly)
η = Efficiency of blow.

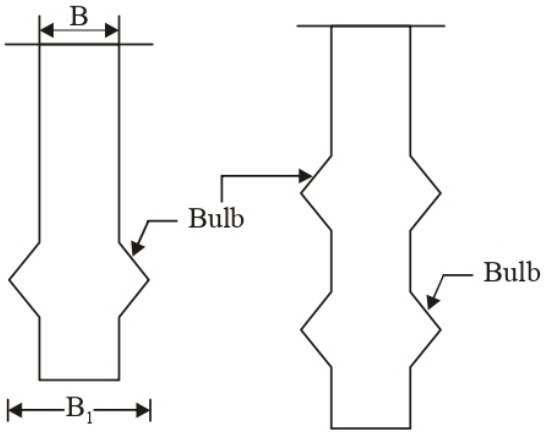
Negative Skin Friction (Down drag)



- It is a phenomenon, which occurs when a portion of soil layer surrounding a pile settles more than the pile.

- It reduces the load carrying capacity of pile/pile group.
- It is develop due to lowering of ground water table, sudden compression loading etc.
- It occurs in soft/filled up/loose unconsolidated layers of soil.
- It can be prevented by providing a casing around the pile/by providing a bitumen coting around the precast pile.

Under Reamed Piles



(a) Single under-reamed pile

(b) Double under-reamed pile

- Suitable for expansive soil like as black cotton soil.
- These are bored, cast-in-situ concrete piles with a one bulb/more bulb.
- Bulb help in increasing the load carrying capacity of pile.
- IS: 2911 Part 3 (1980) recommended a maximum of two bulb.
- Diameter of bulb is taken as 2-3 times shaft diameter.
- Minimum horizontal spacing of piles should be two times the bulb diameter under normal conditions.
- Vertical spacing between the two bulbs should not be less than 1.5 times bulb diameter for the bulb diameter upto 30 cm.

3. Pile load test: (IS 2911)

- It is considered to be most reliable as it is an in-situ test.
- It is the only direct method for determining the allowable loads on the piles.
- Initial pile load test is used to check the allowable load or settlement at working load.

- Routine pile load test is done for working piles for checking the settlement under working load.
- **Types of pile load test** -

(a) Pull load, (b) Lateral load, (c) Cyclic load, (d) Vetical/Compression

Cyclic load: It is carried out to determine skin friction & end bearing separately for a pile load on a single pile. It is generally an initial test.

Special Points:

- Working pile is a pile which is a part of foundation & is being used for the purpose of testing at present.
- Test pile is a pile which is especially bored for the purpose of conducting test & will not be the part of foundation in future.
- As per IS : 2911 Part IV for more than 200 piles, there should be a minimum of two initial test but routine test is done on 0.5% to 2% of total number of piles.
- Ultimate load will be determined from the load settlement curve

Allowable load on single pile: It will be the minimum of the following cases:

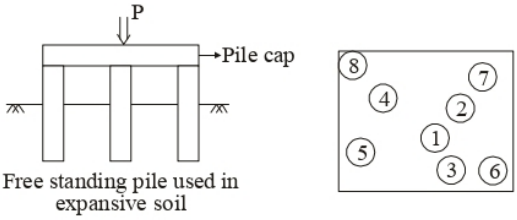
(*a*) 2/3rd of the load at which total settlement is 12 mm.

(*b*) 50% of the ultimate load at which total settlement is equal to the (1/10) of the pile diameter.

(c) 2/3rd of final load which cause a net settlement of 6 mm.

Group Action of Piles

Minimum number of piles driven are 3, but in case of bored piles single pile can also be used.



Free standing pile used in expansive soil

Special Point: To avoid tightening of ground, pile in sand should begin at centre & then moved out-ward.

$$\text{Group efficiency } \eta = \frac{Q_{ug}}{nQ_u}$$

Q_{ug} = ultimate load capacity of pile group
n = No. of piles.
Q_u = ultimate load capacity of single pile

Special Points: Minimum spacing between piles according to I.S code
- For friction piles = 3 × Diameter
- For point bearing piles = 2.5 × Diameter
- For loose sand or back filled soil = 2 × Diameter
- In case of non-circular piles, diameter of the circumscribed circle is taken as diameter

Ultimate bearing capacity of pile group

In sand - The group efficiency of driven piles in loose or medium sand in larger than one due to the compaction of soil from vibrations but in dense sand efficiency can be less than one. Therefore, for design purpose we consider $\eta = 1$. So, $Q_{ug} = nQ_u$

In Clay - (a) Individual pile failure occurs when S > 8D.

(b) Block failure occurs when spacing in the range (2 - 3)D

$$Q_{ug} = C_{ub}N_cA_b + \alpha C_uA_s$$

Safe load capacity

$$Q_s = \left[\frac{\text{minimum of } [Q_{ug}, nQ_u]}{FOS}\right]$$

Special point : The load carrying capacity of a pile group is not necessarily equal to the sum of the capacity of the individual piles.

Converse labarre pile group efficiency

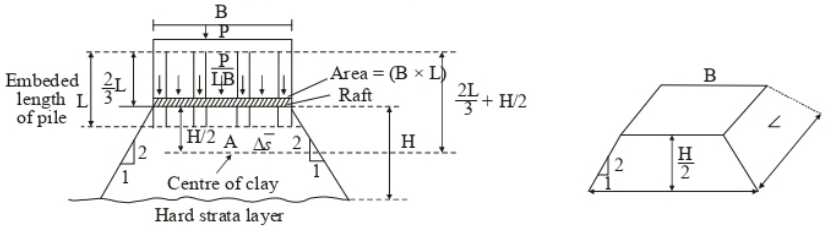
$$\eta_g = 1 - \frac{\theta}{90}\left[\frac{(n-1)m + (m-1)n}{mn}\right]$$

$$\tan\theta = \left(\frac{d}{s}\right)$$

s = Centre to centre spacing.
d = Diameter of pile
m = No. of rows
n = No. of piles in a row.

Settlement of pile groups

1. Settlement of pile group in clays



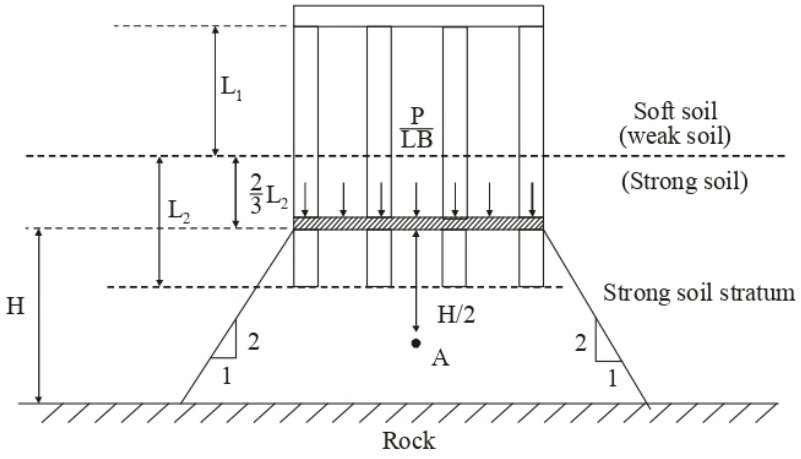
(*a*) When pile is driven in uniform clay deposit

$$\Delta H = \frac{C_c}{1+e_0} H \log\left(\frac{\bar{\sigma}_o + \Delta\bar{\sigma}}{\bar{\sigma}_o}\right)$$

$$\Delta\bar{\sigma} = \frac{P}{\left(B + \frac{H}{2}\right)\left(L + \frac{H}{2}\right)}$$

$$\bar{\sigma}_o = \left(\frac{2}{3}L + \frac{H}{2}\right)\gamma_t$$

(*b*) When piles are driven into strong stratum through an overlaying weak stratum

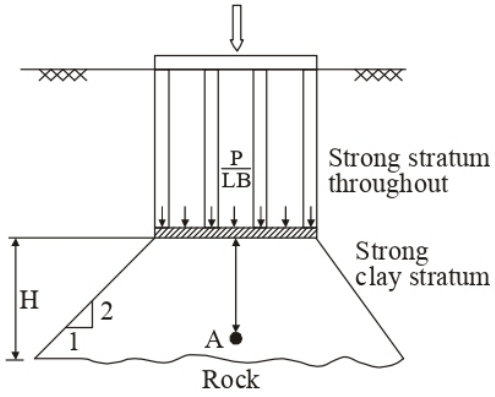


In it, depth H is measured from $\frac{2}{3}L_2$ to the bottom solid surface where L_2 is the depth of embedment in strong soil.

$$\Delta H = \frac{C_C}{1+e_o} H \log\left(\frac{\bar{\sigma}_o + \Delta\bar{\sigma}}{\bar{\sigma}_o}\right)$$

Where, $\bar{\sigma}_o$ is measured at point A (mid depth of H)

(*c*) In case of bored piles of end bearing piles resting on firm stratum
In it, H is measured from the bottom of piles to the bottom hard strata

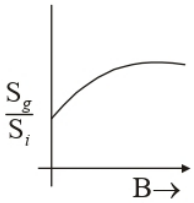


$$\Delta H = \frac{C_C}{1+e_o} H \log\left(\frac{\bar{\sigma}_o + \Delta\bar{\sigma}}{\bar{\sigma}_o}\right)$$

$\bar{\sigma}_o$ = effective stress at point A

2. Settlement of pile groups in sand

Group settlement ratio $\left(\frac{S_g}{S_i}\right) = \left(\frac{4B+2.7}{B+3.6}\right)^2$



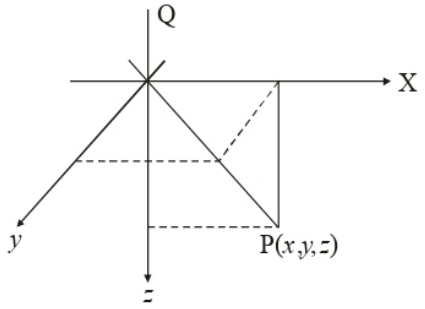
S_g = Group settlement at the same load of pile group.
S_i = Settlement of individual pile calculated from the pile
B = Size of pile group in meter.

Vertical Stress

13

Vertical stress due to concentrated load

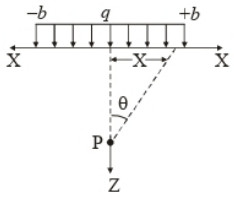
Vertical Stress due to concentrated load	
Boussinesq's Equation	**Westergaard's Equation**
Use for isotropic soil It provides conservative value and is commonly used in soil engineering problems Newmark Chart is based upon it.	Use for An-Isotropic soil Poisson's ratio assumed zero It's result are more close to field. Fenske Chart is based upon it.
$\sigma_{z_b} = \frac{3}{2\pi}\frac{Q}{z^2}\frac{1}{\left(1+\left(\frac{r}{z}\right)^2\right)^{5/2}}$	$\sigma_{z_w} = \frac{1}{\pi}\frac{Q}{z^2}\frac{1}{\left(1+2\left(\frac{r}{z}\right)^2\right)^{3/2}}$



Special Point: If $\frac{r}{z} < 1.5, then\ \sigma_{z_B} > \sigma_{z_W}$

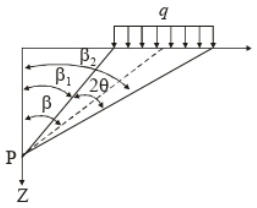
Vertical stress due to strip load

Point P below the centre of strip



$$\sigma_z = \frac{q}{\pi}(2\theta + \sin 2\theta)$$

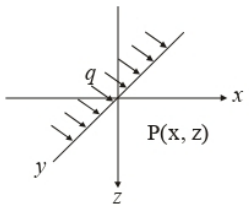
Point P not below the centre of strip



$$\sigma_z = \frac{q}{\pi}(2\theta + \sin 2\theta \cos 2\beta)$$

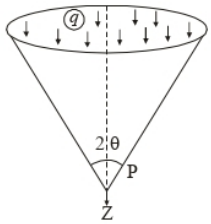
Vertical stress due to line load

$$\sigma_z = \frac{2q}{\pi z}\left(\frac{1}{1+\left(\frac{x}{z}\right)^2}\right)^2$$

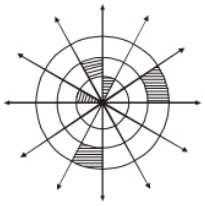


Vertical stress due to a circular area

$\sigma_z = q\,(1-\cos^3\theta)$



Newmark's Influence chart: It is based on Boussinesq's equation to calculate horizontal stress, vertical & shear stress due to uniformly loaded area of any shape (regular or irregular) below any point, inside or outside the loaded area



$$\sigma = \frac{1}{m \times n} \times q \times N$$

n = No. of radial lines (Generally 20)

m = No. of concentric circles (Generally 10)

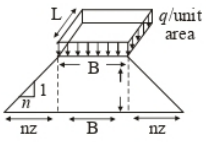
N = Equivalent no. of areas

q = Intensity of load

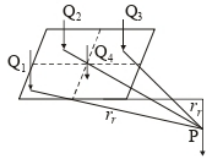
Special Point: All the area units will have equal influence at the centre despite the area is inside or outside the loaded area, it will have the same influence at the centre of the chart.

Approximate methods

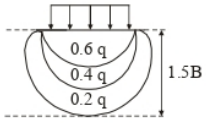
Trapezoidal method



Equivalent load method



Stress isobar method



$$\sigma_z = \frac{q(B \times L)}{(B+2nz)(L+2nz)}$$

$$\sigma_z = \sigma_{z_1} + \sigma_{z_2} + \sigma_{z_3} + ...$$

0.2 q = 20% Stress isobar

$$\sigma_{z_1} = K_{B_1} \frac{Q_1}{z^2}, \quad \sigma_{z_2} = K_{B_2} \frac{Q_2}{z^2}$$

Area bounded by 0.2 q

The vertical stress (stress distribution in soil) at any point to any loaded area is calculated by **equivalent point load method**.

Stability of slopes

14

Assumption in analysis of slope stability

(*a*) Shear parameters of the soil are constant along any possible slip surface.

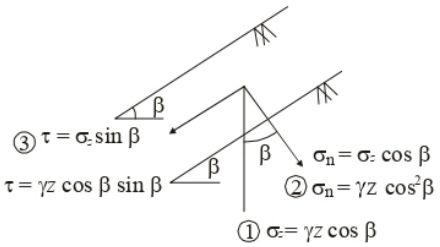
(*b*) Slope–stability problem is a two dimensional problem.

Stabillity of Infinite Slope

$$\text{F.O.S} = \frac{\tau_f}{\tau}$$

$$\text{F.O.S} = \frac{C + \sigma \tan\phi}{\gamma z \cos\beta \sin\beta}$$

$$\sigma = \gamma z \cos^2 \beta$$

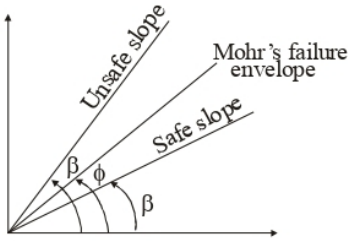


(*i*) $F = \dfrac{C + \gamma z \cos^2 \beta \tan\phi}{\gamma z \cos\beta \sin\beta}$ (for c-ϕ soil)

(*ii*) $F = \dfrac{\tan\phi}{\tan\beta}$ (for C = 0)

(*iii*) F = 1, & Z = H_c then

$$H_c = \frac{C}{\gamma \cos^2 \beta (\tan\beta - \tan\phi)}$$

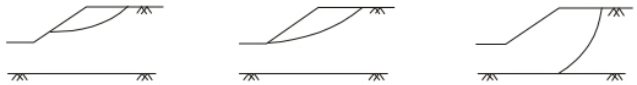


(*d*) $S_n = \dfrac{C}{\gamma H_C} = \cos^2\beta\,(\tan\beta - \tan\phi)$

So, S_n is a dimensionless Quantity

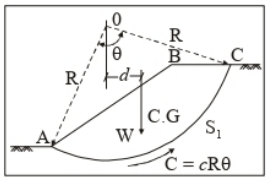
Stability of Finite Slope

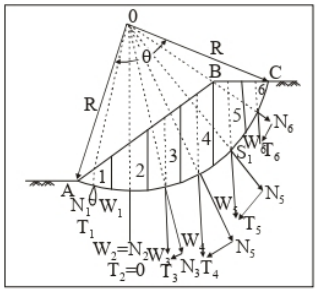
(*a*) **Swedish Circle Method:** Surface of sliding is assumed as "arc of circle"



Face/slope failure (soil close to the toe is quite strong) depth factor < 1	Toe failure (most common mode of failure) depth factor = 1	Base failure (soil below the toe is soft & slope is flat) depth factor > 1

Purely cohesive soil — Cohesive frictional soil





$$F = \frac{CR^2\theta}{Wd}$$

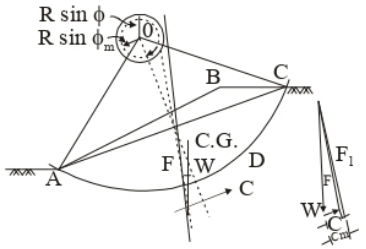
$$F = \frac{CR\theta + \Sigma N \tan\phi}{\Sigma T}$$

(*b*) **Taylor's stability number:** It is a dimensionless parameter. It is obtained for FOS wrt cohesion but the factor of safety wrt friction F_ϕ is considered to be unity.

$$S_n = \frac{C}{\gamma H_c} = \frac{C}{\gamma F_c H}$$

Maximum theoretical value = 0.5 & maximum practical value = 0.261

(*c*) **Friction Circle Method:** It is based on the assumption that the resultant force R on the rupture surface is tangential to a circle of radius r = R sin ϕ which is concentric with the trial slip circle.



- Total stress approach is used
- Friction is assumed to be fully moblised

$$F_c = \frac{C}{C_m}$$

$$F_\phi = \frac{\tan\phi}{\tan\beta} = \frac{\tan\phi}{\tan\phi_m}$$

(*d*) **Fellinious Methods:** For purely cohesive soil.

The method of slices for determination of stabilty of the slope was first suggested by 'Fellineous' in 1926.

According to this method.

$$FOS = \frac{Cr\theta + \mu\Sigma N}{\Sigma T}$$

where,

μ = Friction coefficient of soil

C = Cohesion of soil

N = Normal component of weight of soil

T = Tangential component of weight of soil

Soil Exploration 15

The field & laboratory studies carried out for obtaining the necessary information about characteristics including the position of GWT is called soil-exploration. Following are two stages in it,

In preliminary stage, Geological study at site and site reconnaissance is done.

In detailed stage Site investigation, sequence and thickness of various subsoil layers, nature & their lateral variations, physical properties, position of GWT etc. are done.

Boring and its methods

It is the making & advancing of bore holes is called boring

Various methods of boring -

(a) Auger boring - It is use in partially saturated sands, silts and medium to stiff clays. But it gives highly disturbed sample. It is suitable for small depth of exploration (hand operated auger upto 6m depth) like as highway & borrow pit etc.

(b) Wash boring - It gives disturbed sample. It is not use in hard soils, rock and soil containing boulder.

(c) Percussion boring - In it, heavy drilling bit is dropped and raised. It can be used only in boulder & gravel strata.

(d) Rotary boring - It gives least disturbed samples.

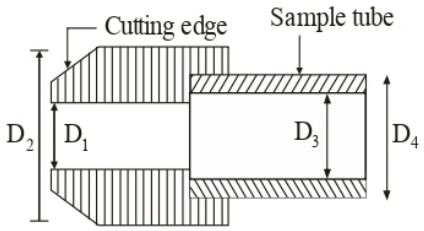
Soil samples

Undisturbed samples are those in which original soil structure is preserved & mineral properties have not undergone any change. These samples are use in size distribution, Atterberg's limits, consolidation parameters, coefficient of permeability, shear strength parameters etc.

- Thin wall sampler are use for undisturbed soil sample.

Disturbed sample are those in which natural soil structure gets modified or destroyed during the sampling operation.

(*a*) Inside clearance

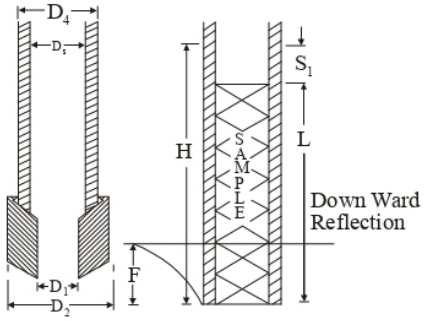


$$C_i = \frac{D_3 - D_1}{D_1} \times 100\,,\ (1\text{–}3)\%$$

(*b*) Outside clearance

$$C_o = \frac{D_2 - D_4}{D_4} \times 100\,,\ (0\text{–}2)\%$$

Note: ($C_0 > C_i$ always)



(*c*) Area ratio

$$A_r = \frac{D_2^2 - D_1^2}{D_1^2} \times 100$$

$< 20\%$ for stiff clays

$< 10\ \%$ for senstitive clays

Special Point: For good quality soil sample, area ratio should be about 10%.

$$\text{Recovery Ratio } \left(\frac{L}{H}\right) = \frac{\text{length of sample before withdraw}}{\text{Penetration of the sampler in the soil mass}}$$

$$\text{Gross Recovery Ratio} = \frac{L_1}{H}$$

True Recovery Ratio = $\frac{L_1}{H - F}$

F = Depth of downward Refraction curve

L_1 = Gross length of sample, equal to the distance from the top of the sample to the cutting edge.

If Recovery Ratio = 1, Good soil

< 1, compressed soil

> 1, swelled soil

Types of Samplers -

- Thin walled sampler is used for obtaining undisturbed samples.
- Thick walled sampler is used for obtaining disturbed but representative samples.
- Thin walled sampler & thick walled sampler are open drive sampler.
- Piston sampler (having sample cylinder and piston system) are useful in sampling the saturated sands, soft & wet soils which can not be sampled by open drive sampler.
- Rotary samplers are useful for sampling in firm to hard cohesive soils & rocks.

Following are field tests for depth of exploration -

(a) Vane shear test

(b) Plate load test

(c) Pressure meter test

(d) Penetration test - Static cone penetration test (SCPT), Standard Penetration Test and Dynamic cone penetration test (DCPT).

(e) Geological methods - Using electrical resistivity , Seismic refraction.

Special Point: SPT is carried out in a bore hole but CPT & DCPT are carried without bore holes.

Expansive Soil

16

Soil Which has tendency to increase in volume in presence of water & decrease in volume in absence of water are called as expansive or swelling soils.

Identification of Expansive Soil

1. **Free Swell Test:** In it, 10 cm^3 of dry soil sample passed through 425 micron sieve, into a 100 cm^3 graduated cylinder filled with water. Then volume is observed after 24 hours.

$$\text{Free Swell (\%)} = \frac{\text{Final Volume} - \text{Initial Volume}}{\text{Initial Volume}} \times 100$$

Mineral present in Clay	Free Swell%
Montmorilonite	1200–2000
Kaolinite	80
Illite	30–80

2. **Swelling test:** In it, two identical undisturbed samples are obtained at a moisture content which is expected at construction time. Both samples are dried to a moisture content below shrinkage limit, Volume of one of them is measured. but specimen is first loaded to a pressure equal to that of the expected structural load & then allowed free access to water. Then volume of other is measured.
3. **Differential Free Swell Test:** In it, two samples of 10 gm, passing through 425 micron sieve into a 50 cm^3 cylinder one containing kerosene (non polar liquid) but carrying distilled water. The volume is observed after 24 hours.

$$\text{DFS} = \frac{\text{Soil volume in water} - \text{Soil volume in kerosene}}{\text{Soil volume in kerosene}} \times 100$$

Degree of Expansiveness	DFS%
Low	Less then 20
Moderate	20–35
High	35–50
Very High	Greater than 50

4. **Plasticity Index, Shrinkage limit and colloidal content:**
   - Higher the plasticity index, higher will be swelling potential.
   - Higher the colloidal content, higher will be the expansion possibility.
   - Lower shrinkage limit means soil will start swelling at low water content.

Soil Stablization

17

The process of increasing the strength and durability of the soil is known as soil stabilization.

Mechanical stabilization

1. Mechanical stabilization consists of

(i) The grading of the soil particles (by changing the composition of the soil mixture by adding or removing the different soil particles).

(ii) Compacting the soil to improve the stability and strength.

2. No chemicals are added to the soil in the machanical stabilization.
3. It is used in preparing base course of roads.

Chemical stabilization

Chemical stabilization uses lime, cement, fly ash and a combination of all above for soil improvement.

The chemical stabilization is used to

(i) Reduce the permeability of soil

(ii) Increase bearing capacity & improve shear strength,

Lime Stabilization

(i) Normal requirement is 4% to 6% of the soil weight.

(ii) Highly unstable, plastic and swelling clayey soils such as 'black cotton soils' may be stabilized by hydrated lime.

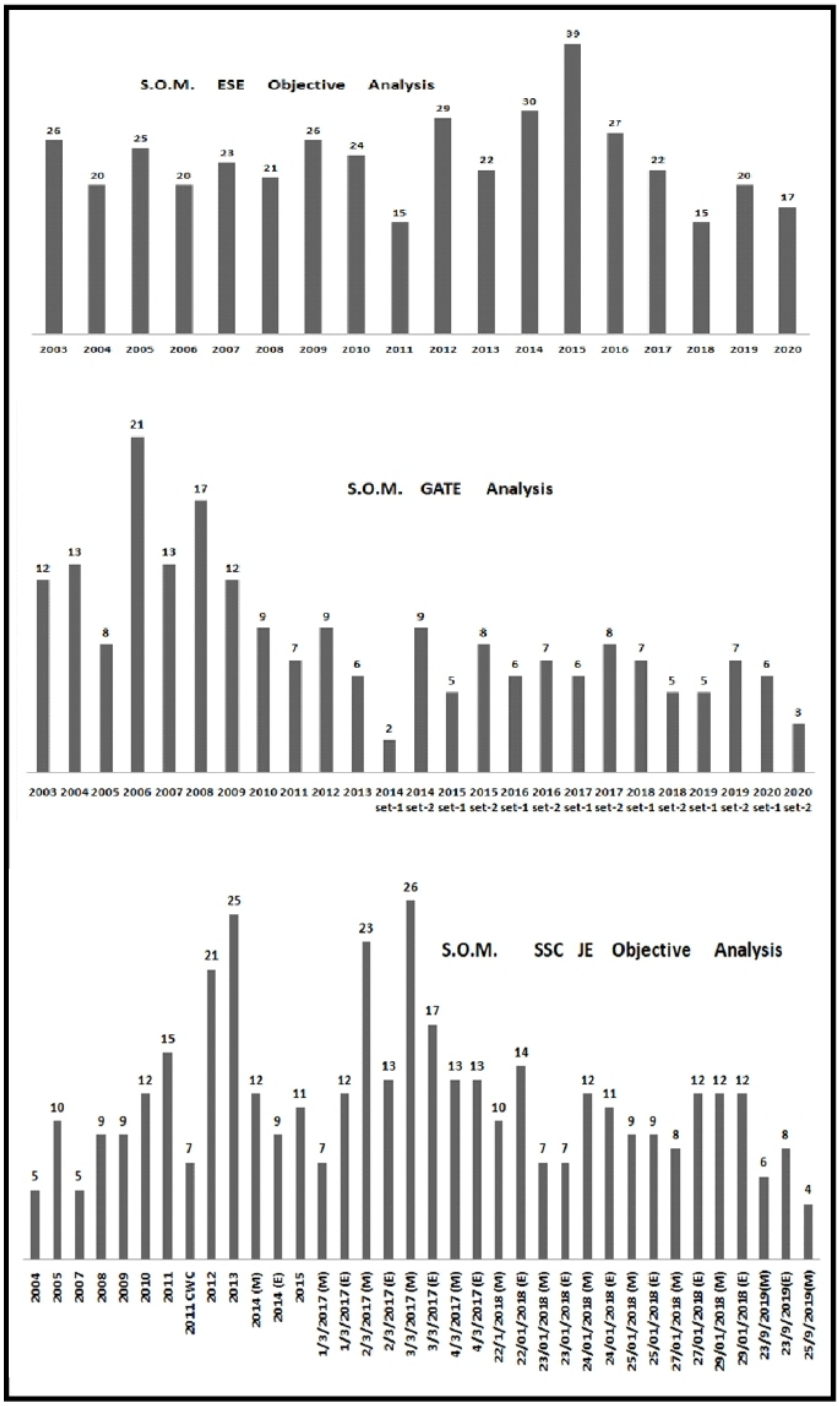
Bitumen Stabilization

(i) Bituminous substances like, bitumen, tar and emulsion are used to stabilize sub-grade or bases of roads built on granular deposits like sand and gravels.

(ii) Bitumen acts as a binder and as water proofing agent.

Special Points:-Grouting is a process by which stabilizers, either in the form of solution or suspension are injected into sub-surface soil.

- Cutback bitumen (bitumen with some dilutent such as Naphtha, petrol, kerosene etc) is used to stabilize moderatedly cohesive roads bases.
- Surface compaction is one of the most widely used technique and is also one of the oldest technique of soil densification.


S.O.M. ESE Objective Analysis
26 20 25 20 23 21 26 24 15 29 22 30 39 27 22 15 20 17
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
S.O.M. GATE Analysis
12 13 8 21 13 17 12 9 7 9 6 2 9 5 8 6 7 6 8 7 5 5 7 6 3
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 set-1 2014 set-2 2015 set-1 2015 set-2 2016 set-1 2016 set-2 2017 set-1 2017 set-2 2018 set-1 2018 set-2 2019 set-1 2019 set-2 2020 set-1 2020 set-2
S.O.M. SSC JE Objective Analysis
5 10 5 9 9 12 15 7 21 25 12 9 11 7 12 23 13 26 17 13 13 10 14 7 7 12 11 9 9 8 12 12 12 6 8 4
2004 2005 2007 2008 2009 2010 2011 CWC 2012 2013 2014 (M) 2014 (E) 2015 1/3/2017 (M) 1/3/2017 (E) 2/3/2017 (M) 2/3/2017 (E) 3/3/2017 (M) 3/3/2017 (E) 4/3/2017 (M) 4/3/2017 (E) 22/1/2018 (M) 22/01/2018 (E) 23/01/2018 (M) 23/01/2018 (E) 24/01/2018 (M) 24/01/2018 (E) 25/01/2018 (M) 25/01/2018 (E) 27/01/2018 (M) 27/01/2018 (E) 29/01/2018 (M) 29/01/2018 (E) 23/9/2019(M) 23/9/2019(E) 25/9/2019(M)

Properties of Material

1

Rigid and Deformable Material

A deformable material is the one in which change in size, shape or both will occur when it is subjected to force/moment.

Rigid material is one which does not undergo any change in its geometry, size or shape when it is subjected to force/moment.

Stresses and strain

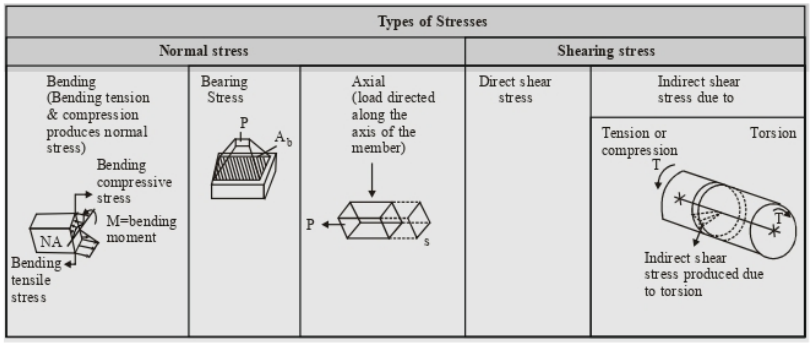
Stresses (Force/Area) are generated as a resistance to the applied external forces or as a result of restrained deformations.

	Unit	Dimension
Shear Force	Newton	MLT^{-2}
Strain	$\frac{\text{Change in length}}{\text{Actual length}}$	$M^0L^0T^0$ [Dimensionless]
Stress	$\frac{\text{Newton}}{\text{Area}}$	$ML^{-1}T^{-2}$
Modulus of elasticity	$\frac{\text{Newton}}{\text{Area}}$	$ML^{-1}T^{-2}$

$$\text{Nominal stress}\left(\text{Engineering stress}\right)=\frac{\text{Load}}{\text{OriginalArea}}$$

$$\text{Actual / True stress} = \frac{\text{Load}}{\text{ActualArea}}$$

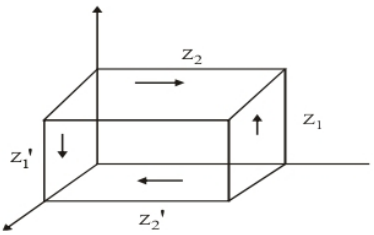
Actual area = Original area $\pm\Delta A$, (+ve for compression, -ve for tension)



Special points: Stress is the internal property while pressure is the external property.
If a body/bar is free to move, then no stress will be induced.

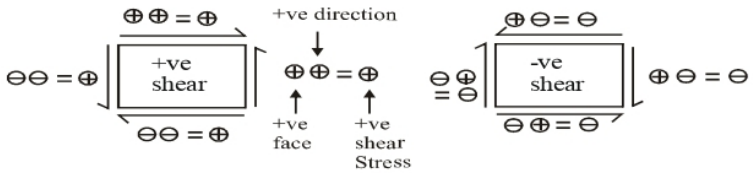
Equality of shear stress on perpendicular planes

- **Complimentary shear stresses**: Shear stress on adjacent & perpendicular faces of an element are equal in magnitude & they have directions such that both stresses point towards or both point away from the line of intersection of the faces.



(Shear stress on opposite face are equal and opposite) (By force equilibrium condition)

Sign convention for shear stress

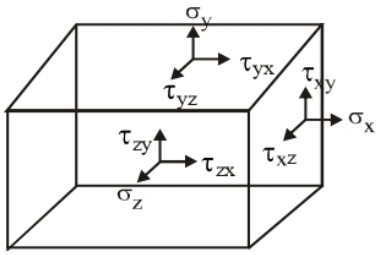


Stress under general loading conditions

(i) Stress is not a vector because its resultant can not be obtained by parallelogram law of vector addition.

(ii) It is a mathematical quantity called tensor, represented as

$$\sigma\ [\text{stress tensor}] = \begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{bmatrix}$$



(iii) Stress is a 2nd order Tensor.

(iv) Direction has three dimension. Hence it is $3^1 = 1^{st}$ order tensor

(v) Stress has 9-dimension ($3^2 = 2^{nd}$ order tensor)

(vi) At any point in 3D condition, 9 stress elements are there.

3 Normal stress components $(\sigma_{xx}, \sigma_{yy}, \sigma_{zz})$ &

6 shear stress components $(\tau_{xy}, \tau_{yx}, \tau_{xz}, \tau_{zx}, \tau_{yz}, \tau_{zy})$

Special Point: Only 6- stress components $(\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{xz}, \tau_{yz})$ are required to define conditions of stress at a point.

(vii) In 2-D condition, 4 stress elements exist $(\sigma_x, \sigma_y, \tau_{xy}, \tau_{yx})$ but ONLY 3-stress components $(\sigma_x, \sigma_y, \tau_{xy})$ are required to define conditions of stress at a point.

Design of members:

$$\text{Allowable stress} = \frac{\text{yield stress}}{\text{F.O.S}}$$

$$\text{Margin of safety} = \text{FOS} - 1$$

Special Points: For Brittle material: FOS is applied on Ultimate stress.
For Ductile material: FOS is applied on yield stress.
In air craft design, MOS is considered.

Normal Strain:

1. Deformation per unit length
2. It is measured by extensometer & is a dimensionless quantity
3. $\text{Strain} = \frac{\Delta L}{L}$ or $\frac{\delta L}{L}$

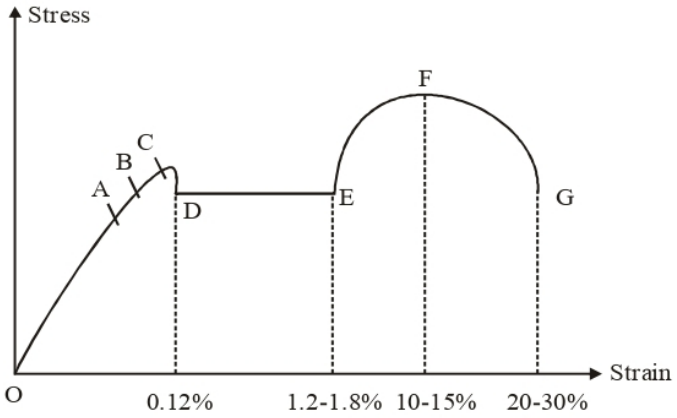
Mathematical definition of strain

$\varepsilon_x = \frac{\partial u}{\partial x}$ Normal strain in x-direction, similarly for y & z direction.

$\gamma_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}$ = Shearing strain in xy plane

$\varepsilon_x = \frac{\sigma_x}{E} - \mu\frac{\sigma_y}{E} - \mu\frac{\sigma_z}{E}$

Stress-strain Curve of mild steel (Low carbon steel - Ductile Steel) in Tension



where

OA	= Linear curve	A	= Proportional limit,
B	= Elastic limit,	C	= Upper yield point
D	= Lower yield point,	DE	= Plastic region,
EF	= Strain hardening region	FG	= Necking region,
F	= Ultimate stress point,	G	= Fracture point.

Explanation:

(a) Lower yield point should be used to calculate the yield strength of material

(b) Volume of specimen increases from O to D

(c) From D to E, large deformations but volume of specimen does not changes.

(d) From E to F, it is strain hardening, (material undergoes changes in its crystalline structure).
(e) From F to G, diameter of portion decreases due to instability known as Necking.
(f) Cup cone failure occurs at 45° with the tensile load in ductile material.

Stress-strain curves for other materials

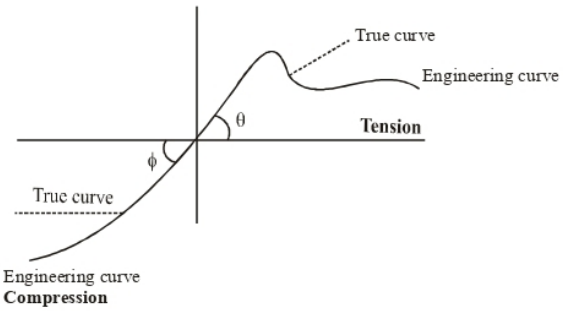
(a) All of them possess same modulus of Elasticity.
(b) For ductile materials like Aluminium & Copper, do not have defined yield point. Yield strength is defined by offset method.
(c) As yield strength increases, Ductility falls.
(d) $E_{AL} = \frac{1}{3} E_{st}$

Special points:

1. Dutile material at normal temp. may become brittle at very low temp.
2. A Brittle material at low temperature may become ductile at very high temperature.

True stress strain curve

True stress curve is below Engineering stress in compression as resisting area in compression increases



$$\text{Engineering stress} = \frac{P}{A_0}, \quad \text{Engineering strain} = \frac{\delta}{L_0}$$

$$\text{True stress} = \frac{P}{A}, \qquad \text{True strain} = \frac{\Delta L}{L}, \ (L = Lo \pm \Delta L)$$

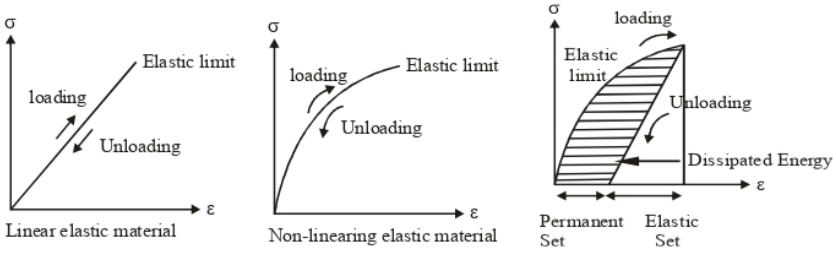
Relation between True stress and engineering stress

In Tension/compression $\boxed{\begin{matrix} A = \dfrac{A_0}{1 \pm \xi} \\ \sigma = \sigma_0 (1 \pm \xi) \end{matrix}}$, $\varepsilon = ln(1 \pm \varepsilon_0)$

Properties of Materials

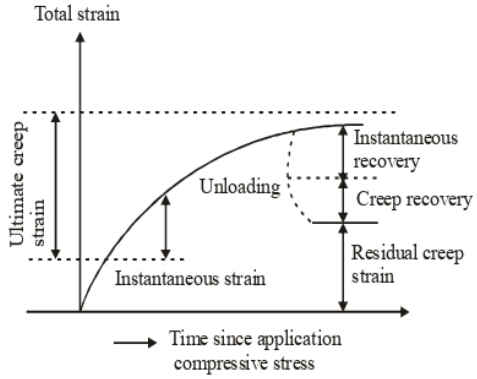
Elasticity: It is property by virtue of which material deformed under the load is enabled to return to its original dimension when the load is removed.

- Mild steel is more elastic than rubber.



Plasticity: The characteristics of material by which it undergoes inelastic strain beyond those at the elastic limit. The plasticity is particular useful in the operation of pressing & forging

Creep: It is the property by virtue of which a material undergoes additional defromation (over & above due to applied load) with passage of time under sustained loading within elastic limit



Relaxation: The decrease in stress in steel as a result of creep within steel under prolonged strain

Malleability

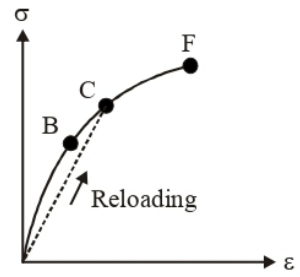
It is the property of material which allow material to be extended in all direction without rupture like sheets. A malleable material possess high degree of plasticity but not necessary great strength

Brittleness:- It is lack of ductility

- In brittle materials, strain at rupture is much smaller as compared to ductile material (rupture strain is elastic).
- In brittle materials, rupture occurs without any noticeable prior change in the rate of elongation. **Ex.** Cast iron, concrete, glass etc.
- There is no plastic zone for brittle material.
- Ordinary glass is nearly ideal brittle material.
- Brittleness is not an absolute property of material. A material which is brittle at room temperature is ductile at elevated temperature.
- Generally in brittle, post elastic strain <5%

Ductility: The percentage of elongation of piece under tension indicates its ductility. Ductile material must have low degree of elasticity & this is useful in wire drawing.Generally in ductile, post elastic strain >5%.

Reloading: Due to it, proportional limit increases from B to C but ductility decreases 'B to F' to 'C to F'

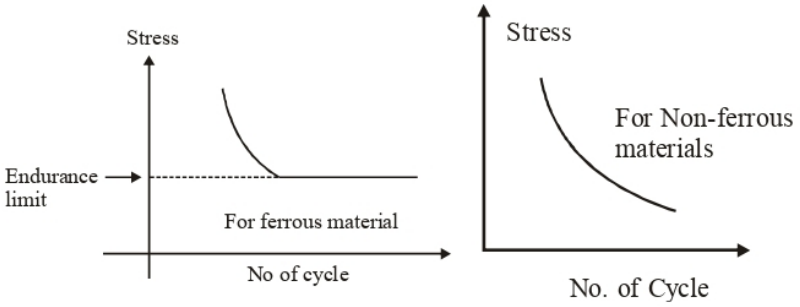


Fatigue: Deterioration of a material under repeated cycles of stress or strain resulting in progressive cracking that eventually producess fracture.

Fatigue failure occur if total strain energy > toughness

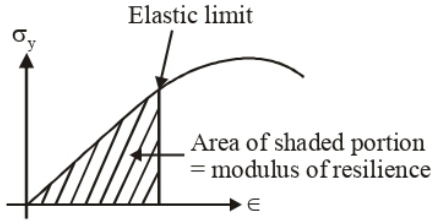
Endurance limit: It is the stress level below which even large number of stress cycle can not produce fatigue failure.

For structural steel, Endurance limit = $\frac{1}{2}$ × ultimate strength



Resilience

- It is the property/ability of a material to absorb energy when it is deformed elastically & then upon unloading to have this energy recovered.
- Hence greater the resilience, more desirable is the material for spring action.In shooting an arrow, the string stores the strain energy during stretching & when released the energy, it is utilised in shooting the arrow.
- Area under load-deformation curve within elastic limit is called resilience.
- The area under stress strain curve within elastic limit is called modulus of resilience.

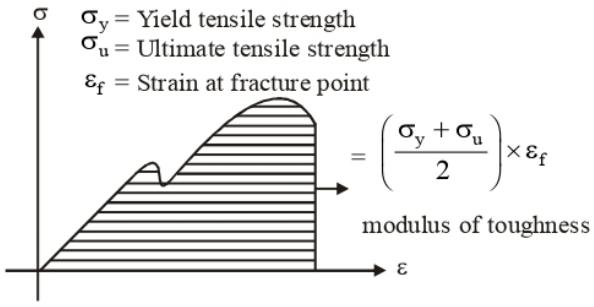


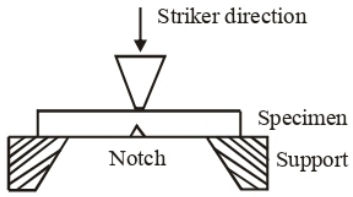
Strain energy stored per unit volume = $\frac{\sigma_y^2}{2E}$

Toughness:

- It represents the ability to resist fracture.
- Toughness is desirable against impact loading.
- Bend test is use to measure the toughness.
- The ability of the material to absorb energy till breaking/rupture/failure takes place is known as toughness.
- Area under stress-strain curve upto fracture is called modulus of toughness.

- As failure strain is more in ductile material. Hence, mild steel is more tough than cast iron.





- The Charpy impact test continues to be used as an economical quality control method for determining the notch, sensitivity & impact toughness of engineering materials. But izod testing machine used cantilever beam as support.
- Toughness- Resists fracture & Hardness- Resists scratch or abrasion

Hardness

- Ability to resist scratch or abrasion.
- The higher the yield stress, higher is the hardness.
- Surface hardness is measured by carrying out non-destructive indentation test.
- Brinell hardness test is used for checking the hardness of a material.
- It is noted that ductile material are tough and britle material are hard.
- Brinell hardness test uses hardened steel ball (10 mm diameter) as an indentor.

$$\text{Brinnell Hardness Number} = \frac{P}{\frac{\pi D}{2}\left[D-\sqrt{D^2-d^2}\right]}$$

Where P = Standard load(kg), D = Dia. of steel ball (mm), d = Dia. of indent (mm)

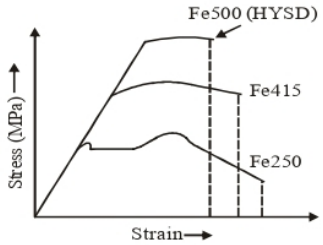
Tenacity: It is the property of material to resist fracture under the action of tensile load

Special Points: As the percentage carbon in steel increases.
(a) The ductility of steel member decrease.
(b) Strength of the steel member increases.
(c) Brittleness of the steel member increases.
(d) Hardness also increases.

Material	Percentage carbon
Wrought iron (purest form of Iron)	< 0.1%
Mild steel	0.10–0. 25%
High carbon steel	0.55–0.95%
Cast Iron	2.00–4.00%

From above table, if we go from top material to bottom material, then ductility decreases (ductility of cast iron is low as it brittle material) & strength, brittleness are increased.

Stress-strain curve for various steel grade.



- From stress-strain curve, we can say that initial slope of stress-strain curve (modulus of elasticity) is same for all grade of steel.
- Also, the % strain before failure decreases as the grade of steel increases which means that with increase in carbon content ductility of steel decreases.
- As the grade of steel increases means carbon content increases.

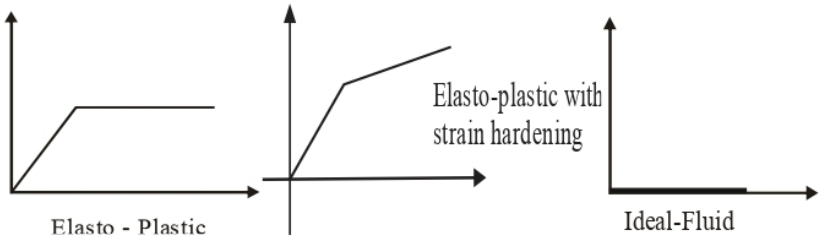
Special points: With increase in carbon content in steel, toughness of steel will decrease.

(a) Cast iron having high % carbon, has low toughness than the mild steel having low % carbon.

- Modulus of elasticity of steel = 2×10^5 MPa & is same for all Grade of steel.

Visco-Elastic material Materials having both Viscous & Elastic properties & exhibit time dependent strain.

Approximate stress-strain curves

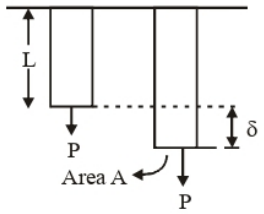


Hooke's law:- It's valid only for Homogenous, Isotropic & linearly elastic materials. It is valid upto proportional limit, which is depend upon type of material only.

$$\boxed{\sigma \propto \in}$$

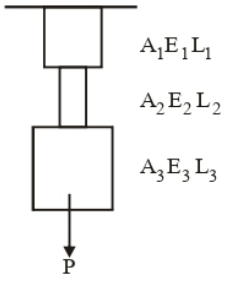
Deformation of member under axial load

1.



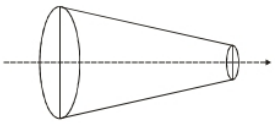
$$\delta = \frac{PL}{AE}$$

2.



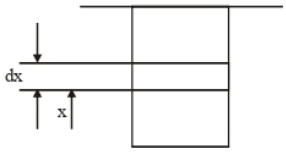
$$\delta = \delta_1 + \delta_2 + \delta_3$$

$$\boxed{\delta = \frac{PL_1}{A_1E_1} + \frac{PL_2}{A_2E_2} + \frac{PL_3}{A_3E_3}}$$

3. 

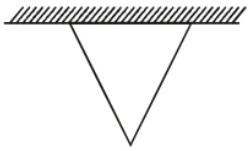
$$\boxed{\Delta = \frac{4PL}{\pi D_1 D_2 E}}$$

4. In prismatic bar due to self weight



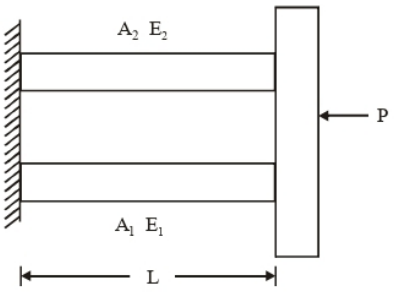
$$\boxed{\delta = \frac{\gamma L^2}{2E} \text{ or } \frac{(W/2)L}{AE}}$$

5. **Conical bar due to self weight**



$\boxed{\delta = \frac{\gamma L^2}{6E}} = \frac{1}{3}$ (deflection of prismatic bar of same length & same density)

Composite Bars Condition



$$P = P_1 + P_2$$

$$\delta_1 = \delta_2 = \frac{P_1 L}{A_1 E_1} = \frac{P_2 L}{A_2 E_2}$$

$$P_1 = \frac{A_1 E_1 P}{A_1 E_1 + A_2 E_2}, \; P_2 = \frac{A_2 E_2 P}{A_1 E_1 + A_2 E_2}$$

Poisson's Ratio:- For Homogenous & isotropic material, Elongation/ contraction produced by any Axial Force in the direction of force is accompanied by contraction/elongation in all transverse directions & all such contractions/elongations are same.

$$\mu = -\left(\frac{\text{Lateral Strain}}{\text{Axial Strain}}\right)$$

Material	μ
Cork	0
Glass	0.01-0.05
Concrete	0.1-0.2
Elastic Material	0.25-0.42
Mild Steel	0.286
Al. (Pure)	0.33
Wrought Iron	0.3
Copper	0.33-0.36
Nylon	0.4
Rubber	0.45-0.5
Brass/Bronze	0.34

Special points:

- Rubber has a Poisson's ratio close to 0.5 and is almost incompressible. While cork has a Poisson ratio close to zero. This makes cork function as a bottle stopper. Since on axial loading, cork will not swell laterally to resist bottle insertion.
- The poisson's ratio of a stable, isotropic, linear elastic material can not be less than –1.0 and nor greater than 0.5 due to the requirement that shear modulus, Young's modulus and bulk modulus have positive values.

Elastic Constants:

Young's modulus (E) = $\frac{\text{Normal stress}}{\text{Normal strain}}$, **Shear modulus (G) =** $\frac{\text{Shear stress}}{\text{Shear strain}}$, **Bulk modulus (K) =** $\frac{\text{Normal (Volumetric) stress}}{\text{Volumetric strain}}$

$$\boxed{\varepsilon_v = \frac{(\sigma_x + \sigma_y + \sigma_z)}{E}(1-2\mu)}$$

If $\sigma_x = \sigma_y = \sigma_z = p$, then $\varepsilon_v = \frac{3p}{E}(1-2\mu)$

$$\boxed{K = \frac{p}{\varepsilon_v} = \frac{E}{3(1-2\mu)}}$$

For Hydrostatic Pressure $= \frac{\sigma_x + \sigma_y + \sigma_z}{3}$, $\left[\sigma_x = \sigma_y = \sigma_z = \sigma\right]$

Special Points:

(i) Stretching of material in one direction will lead to increase in volume
(ii) Volume of rod remains unchanged as a result of combined effect of elongation & transverse contraction.
(iii) During plastic deformation, volume of specimen remains constant.
(iv) In Pure Shear case - centre of mohr circle will fall at origin.
(v) In hydrostatic loading - Mohr circle reduces to a point.

Shearing Strain:

1. Hooke's law for shearing stress & strain
   $\boxed{\tau_{xy} = G\gamma_{xy}}$
2. If only shearing stresses are acting, then volume of the specimen does not change.
3. Modulus of rigidity or shear modulus G, $\boxed{G = \frac{E}{2(1+\mu)}}$ as $\boxed{0 < \mu < 0.5}$, then $\boxed{\frac{E}{3} < G < \frac{E}{2}}$

Relationship between Elastic Constants

$\boxed{G = \frac{E}{2(1+\mu)}}$ $\boxed{K = \frac{E}{3(1-2\mu)}}$ $\boxed{E = \frac{9KG}{3K+G}}$ $\boxed{\mu = \frac{3K-2G}{6K+2G}}$

Young's modulus of elasticity of

Wood = 0.12×10^5 N/mm^2, Glass=0.8×10^5 N/mm^2

Copper = 1.17×10^5 N/mm^2, Aluminium=0.69×10^5 N/mm^2

No. of Independent Elastic Constants & total Elastic Constants

1. Homogenous & Isotorpic (steel) material - 2 (4)
2. Orthotropic (wood) material - 9 (12)
3. Anisotropic material - 21 (Infinity)

Residual stress: When some part of an indeterminate structure undergoes plastic deformation or different part undergoes different plastic deformation.Then stress in different parts of the structure will not return to zero after the load removal. These stresses are known as Residual stresses.

Thermal Stress and Strain

$$\sigma = E\alpha\Delta T\ ,\ \Delta L = L\alpha\Delta t$$

$$\text{Strain } (\Delta) = \frac{L\alpha\Delta t}{L} = \alpha\Delta t$$

$\alpha_{Aluminum} > \alpha_{Brass} > \alpha_{Copper} > \alpha_{Steel}$ **(CIVIL Ki GOLI - A > B > C > S)**

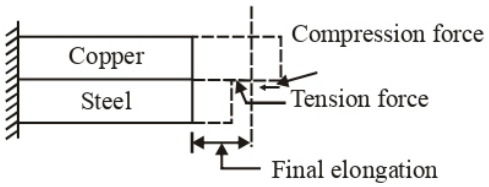
Special Points:

(a) Principle of superposition is applicable only when stress is within proportional limit

(b) If temperature is increased & member is restrained, then force produced is compressive. If temperature is decreased, the force produced is tensile.

(c) When bar is not restrained, then there will be no induced temperature stresses due to change in temperature.

Special Case :



Coefficient of thermal expansion of copper is more than steel, while copper will try to expand more but its expansion will be restrained by steel because both will move together by same amount (composite bar). Hence copper will be in compression & steel in tension.

Shear Force And Bending Moment

2

- A beam is a structural member subjected to transverse loading (bending moment & shear force).

Special Points:

- Shafts resist torque
- Ties & strut resist uniaxial tension & compression.
- Beam resist bending moment & shear force.
- The difference between two adjacent point of contraflexure is known as focal length.
- The portion of beam in which shear force is constant is known as shear span.

Classification of supports:

(i) Free support/Roller support/Rocker support.

It is a simplest support on which beam rest freely & gives only one reaction, because only one deflection is restrained.

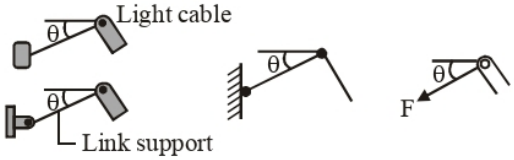
(ii) Built-in or fixed support.

It is a support which restrains complete movement of the beam both in position & direction. The support gives all the three relevant reactions (say R_x, R_y & M_z)

(iii) Hinged or pinned support.

(iv) Link Support

Gives reaction which acts in the direction of the cable or link.



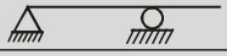
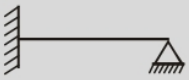
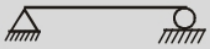
(v) Slider Support

- Two unknown reactions given by under support are a force & a moment



- There can not be reaction parallel to roller because the movement is free.

Types of Beam

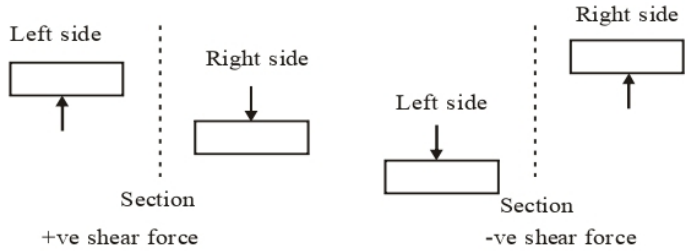
	Free cantilever beam
	Single overhanging beam
	Propped cantilever beam
	Double overhanging beam
	Simple supported beam
	Fixed end beam

Special Point: A continuous beam may or may not be an overhanging beam.

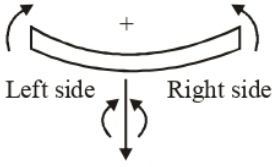
Span for a beam:

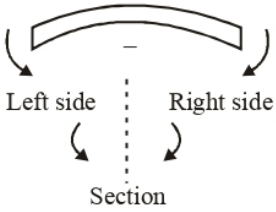
1. The horizontal distance between the centres of the end bearings is called the effective span of the beam
2. The clear horizontal distance between the supports is called clear span of the beam.

Shear force:- It is the resultant of all transverse forces to the right or left of the section.



Bending moment:- It is resultant moment at a section due to all the transverse forces either to the left or right of the section.





+Ve Bending moment = Sagging

-Ve Bending moment = Hogging

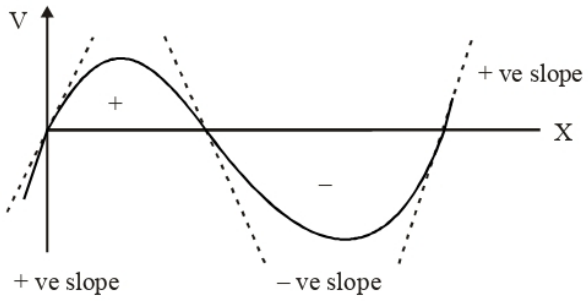
Special Points: Bending moment is the algebric sum of moments at that section but moment at a point is the summation of moment due to all loading on the beam produced at that point.

- **Point of contraflexture:** The point at which bending moment changes its sign.
- **Point of inflexion:** Point where deflected shape of beam changes it's curvature (concave to convex & vice-versa).
- At hinge, bending moment will be zero
- At Point of symmetry , shear force is zero

Relationship between Bending moment, Shear force and Loading

(a) Slope of the shear force diagram = Intensity of distributed load

$$\frac{dV}{dx} = W_x$$

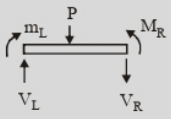
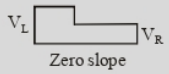
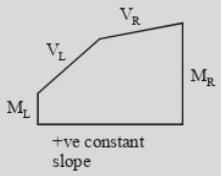
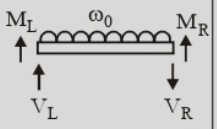
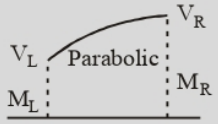
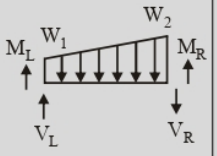
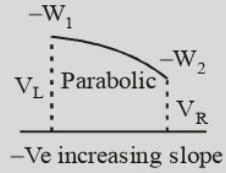
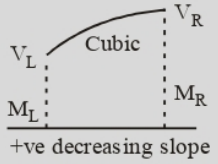
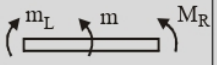
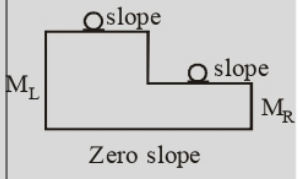
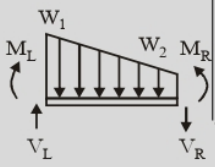
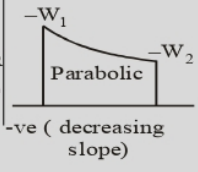
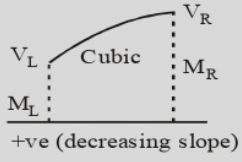


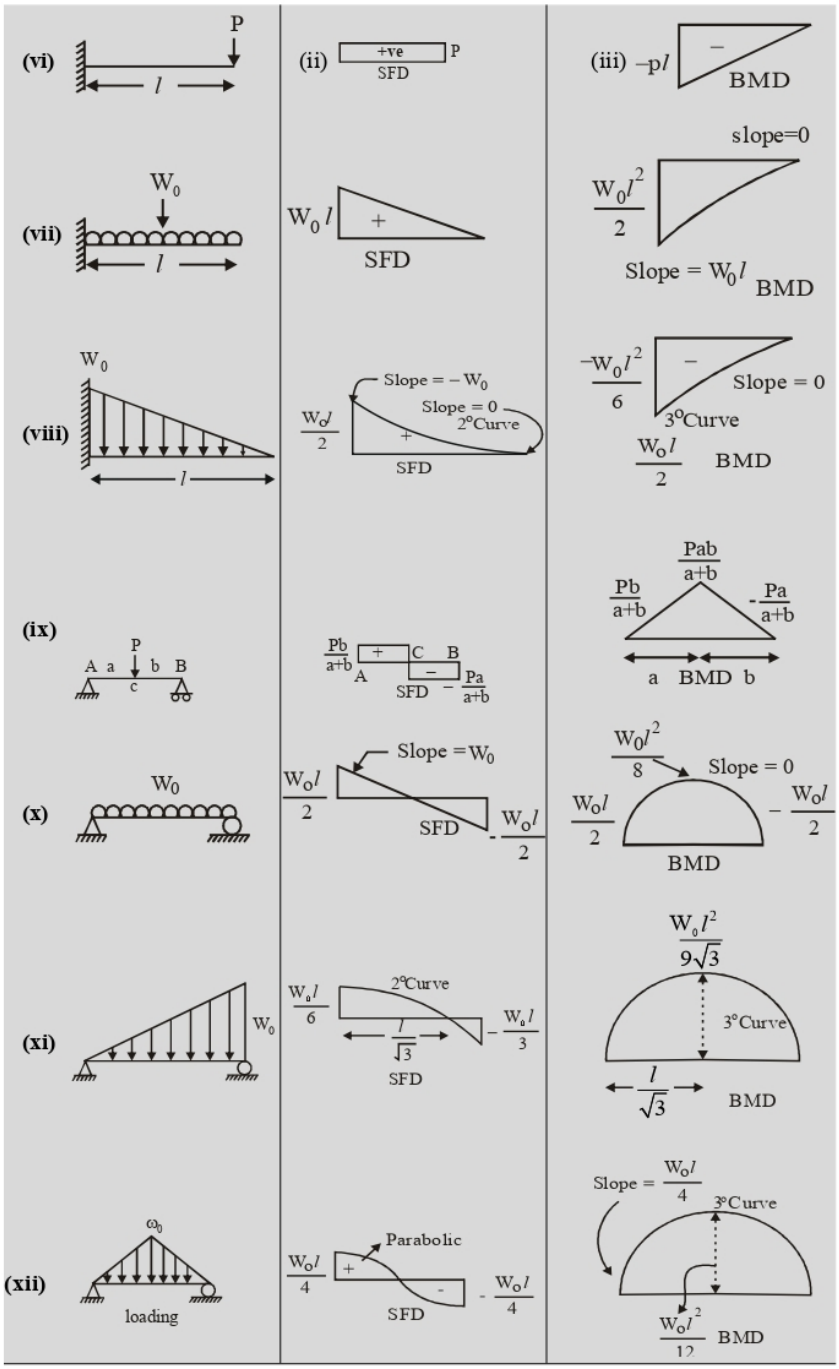
If the slope of SFD is +ve, this implies that load intensity at that point is + ve (upwards) and if the slope of SFD is -ve, this implies that load intensity at that point is –ve (downwards).

(b) Slope at any section of Bending moment diagram = Shear force at that section. $\boxed{\frac{dM}{dx} = V}$

Special Point : $\Delta V = \int W_x dx$, $\Delta M = \int V dx$

$M_{final} - M_{initial}$ = Area under the SFD between those two sections.

Loading	Shear Diagram, $\frac{dv}{dx} = W$	Moment Diagram, $\frac{dM}{dx} = V$
(i) 		
(ii) 		
(iii) 		
(iv) 		
(v) 		


(vi)
P
l
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slope=0
(vii)
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l
W0 l
+
SFD
W0l2/2
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(viii)
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l
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Slope = 0
2°Curve
Wol/2
+
SFD
–W0l2/6
–
Slope = 0
3°Curve
Wol/2
BMD
(ix)
P
A a b B
c
Pb/a+b
+
C B
A
–
SFD
– Pa/a+b
Pab/a+b
Pb/a+b
-Pa/a+b
a BMD b
(x)
W0
Slope = W0
Wol/2
SFD
- Wol/2
W0l2/8
Slope = 0
Wol/2
– Wol/2
BMD
(xi)
W0
Wol/6
2°Curve
l/√3
– Wol/3
SFD
W0l2/9√3
3°Curve
l/√3
BMD
(xii)
ω0
loading
Wol/4
Parabolic
+
-
SFD
- Wol/4
Slope = Wol/4
3°Curve
Wol2/12
BMD

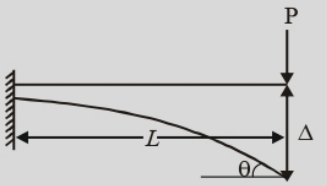
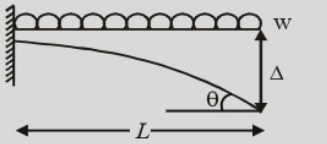
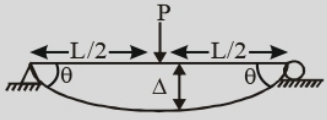
Deflection of Beams

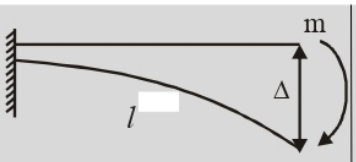
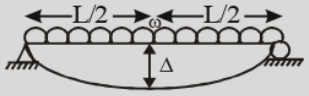
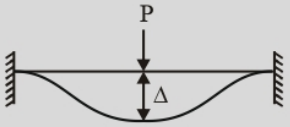
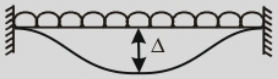
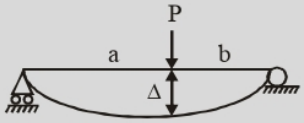
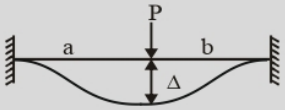
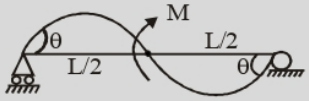
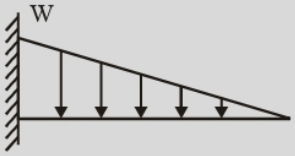
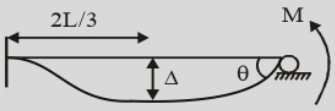
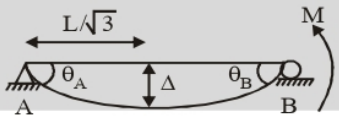
3

Deflection of structure is caused by its internal loading like as Normal force, Shear force, Bending Moment, Torsion.

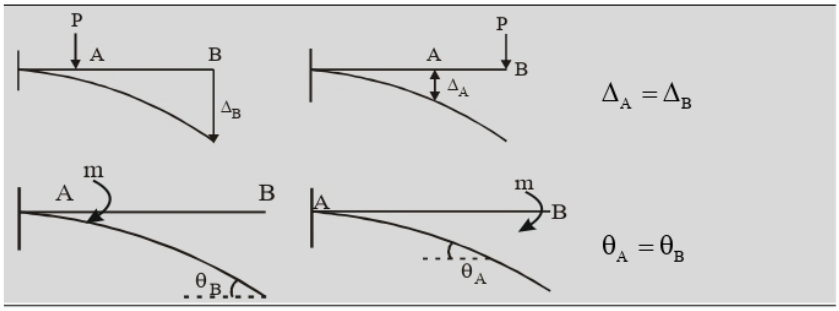
For Trusses, deflection is caused by internal Axial Forces. For Beams and Frames major deflection is due to Bending.

- Deflection of a beam is inversely proportional to the flexural rigidity EI, (where E is elastic modulus which is a property of a material, I is moment of inertia which depends upon dimension of section).
- Deflection decreases by
  (a) Providing stronger material (E↑)
  (b) Increasing moment of inertia (I), Increase in depth will increase more moment of inertia as compared to width.
  (c) Decrease length of the beam & load on the beam.

Loading	Deflection	Slopes
	$\Delta = \frac{PL^3}{3EI}$	$\theta = \frac{PL^2}{2EI}$
	$\Delta = \frac{wL^4}{8EI}$	$\theta = \frac{wL^3}{6EI}$
	$\Delta = \frac{PL^3}{48EI}$	$\theta = \frac{PL^2}{16EI}$

	$\Delta = \frac{ML^2}{2EI}$	$\theta = \frac{ML}{EI}$
	$\Delta = \frac{5}{384}\frac{wL^4}{EI}$	$\theta = \frac{wL^3}{24EI}$
	$\Delta = \frac{1}{4}\left(\frac{PL^3}{48EI}\right)$	$\theta = 0$
	$\Delta = \frac{1}{5}\left(\frac{5}{384}\frac{wL^4}{EI}\right)$	$\theta = 0$
	$\Delta = \frac{Pa^2b^2}{3EIL}$	
	$\Delta = \frac{Pa^3b^3}{3EIL^3}$	
	$\theta = \frac{ML}{24EI}$	
	$\Delta = \frac{wL^4}{30EI}$	$\theta = \frac{wL^3}{24EI}$
	$\Delta = \frac{ML^2}{27EI}$	$\theta = \frac{ML}{4EI}$
	$\Delta = \frac{ML^2}{9\sqrt{3}EI}$	$\theta_A = \frac{ML}{6EI}$ $\theta_B = \frac{ML}{3EI}$

Maxwell's Reciprocal Theorem: In any beam, frame or truss, the deflection at point B due to load P at any point A is equal to deflection at point A due to load P at point B.



Methods of determining slope and deflection at a point

(i) **Double Integration Method** – It gives deflection only due to bending

$$\boxed{\frac{d^2y}{dx^2} = \frac{M}{EI}} \Rightarrow \frac{d}{dx}\left(\frac{dy}{dx}\right) = \frac{M}{EI} \Rightarrow \boxed{\frac{d\theta}{dx} = \frac{M}{EI}}$$

$$\frac{d^3y}{dx^3} = \frac{(dM/dx)}{EI} \Rightarrow \boxed{\frac{d^3y}{dx^3} = \frac{V}{EI}} \Rightarrow \boxed{\frac{d^4y}{dx^4} = \frac{W}{EI}}$$

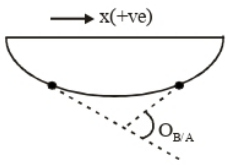
$$\frac{d^4y}{dx^4} = \frac{(dV/dx)}{EI}$$

Where, EI = Flexural rigidity

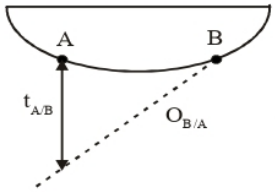
$$\text{Flexural Stiffness} = \frac{\text{Flexural rigidity}}{\text{Length}}$$

(ii) **Moment Area Method - Mohr's Method:**

- It is applicable to prismatic & non prismatic beams.
- In it, continuous slope is assumed. Hence, it can not be used in beams with internal hinge & link.
- It is a semi graphical method.
- It requires understanding of geometry of deflected shape & applicable only when deflected shape is continuous.



Theorem 1: The change in slope between two points on elastic curve equals the area of $\frac{M}{EI}$ diagram between these two points. $\theta_{B/A}$ = Slope of B wrt tangent drawn on elastic curve at A = Area of $\frac{M}{EI}$ diagram between A and B.



$$t_{A/B} = \bar{x}\int_{A}^{B}\frac{M}{EI}dx$$

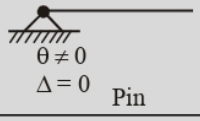
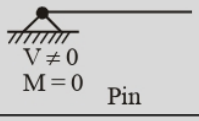
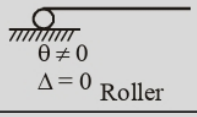
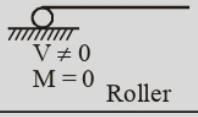
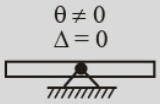
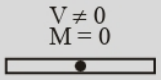
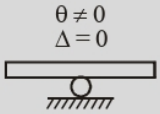
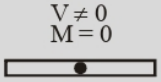
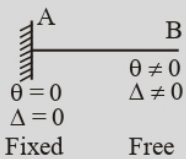
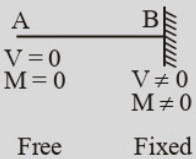
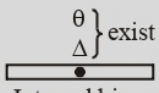
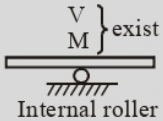
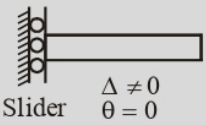
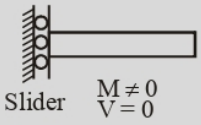
Theorem 2: Deflection of any point A on elastic curve wrt tangent drawn at another point B (t_{AB}) equals the moment of area under $\frac{M}{EI}$ diagram between A & B about point A.

(iii) **Moment diagram by parts:**- The resultant BM at any section is the algebric sum of BM at that section caused by each loading separately (either from left or right of that section). Hence, the effect of individual load considered instead of taking effects of all the loads together for drawing BMD.

(iv) **Macaulay's Method:**- The modification is done in loading pattern so that udl or uvl becomes continuous up to last segement.

(v) **Conjugate beam method:** In it, principle of statics is used. Hence, this method can also be used when deflected shape is not continuous (Internal Hinge case).

Real beam	Conjugate beam
Slope at any point in real beam = Shear force at that point in conjugate beam	Deflection at any point in real beam = BM at that point in conjugate beam
$V = \int w dx$ $\downarrow \quad \uparrow$ $\theta = \int \frac{M}{EI} dx$	$M = \int\left(\int w dx\right)dx$ $\downarrow \quad \uparrow$ $y = \int\left(\int \frac{M}{EI} dx\right)dx$

Special case:





A statically intermediate real beam can have unstable conjugate beam.

(vi) **Method of virtual work (Unit load method):** It can be applied to plastic range of stress-strain also, but $(d\theta)$ will not be equal to $\frac{M}{EI}dx$

External virtual work = Internal virtual work

$1 \times \Delta_c = \Sigma \, u \, dl$

where, 1-Virtual Force, Δ_c - Real displacement, Σu - Virtual Load, dl - Real displacement

(vii) **Castigliano's Theorems:**

Castigliano's 1st theorem	Castigliano's 2nd theorem
(a) The 1st partial derivative of total internal energy (strain energy) in a structure w.r.t. any particular deflection component at a point is equal to the force applied at that point & in the direction corresponding to the deflection component. $\frac{\partial U}{\partial \delta} = P$ or $\frac{\partial U}{\partial \theta} = M$	(a) The 1st partial derivative of total internal energy in a structure w.r.t. the force applied at any point is equal to the deflection at the point of application of that force in the direction of its line of action. $\frac{\partial U}{\partial P} = \delta$ or $\frac{\partial U}{\partial M} = \theta$
(b) Castigliano's 1st theorem is applicable to linearly or non-linearly elastic structures in which the temperature is constant & the supports are unyielding.	(b) Castigliano's 2nd theorem is applicable to linearly elastic structures.

It is also applied on self-straining systems. Self-straining is caused due to settlement of support of redundant structure (λ) or by any initial misfit of a member by an amount λ too short or too long.

$$\frac{\partial U}{\partial R} = \lambda$$

λ = Small displacement in the direction of Redundant force R.(Method of least work -its 2nd theorem)

Principal Stress & Principal Strain

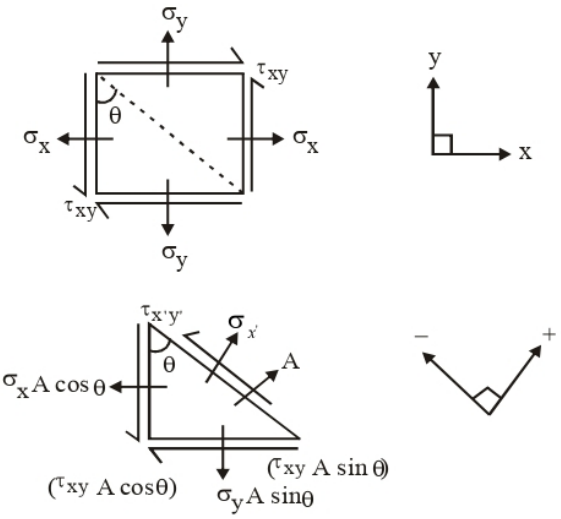
4

Plane stress: When two faces of cubic elements are free from any stress, the stress condition is termed as plane stress condition

$$\boxed{\sigma_z = \tau_{zx} = \tau_{zy} = 0}$$

So plane stress components are σ_x, σ_y & τ_{xy}

Transformation of Plane Stress



$$\sigma_x' = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} \cos 2\theta + \tau_{xy} \sin 2\theta$$

$$\tau_{x'y'} = -\frac{\sigma_x - \sigma_y}{2} \sin 2\theta + \tau_{xy} \cos 2\theta$$

$$\boxed{\sigma_x + \sigma_y = \sigma_x' + \sigma_y'}$$

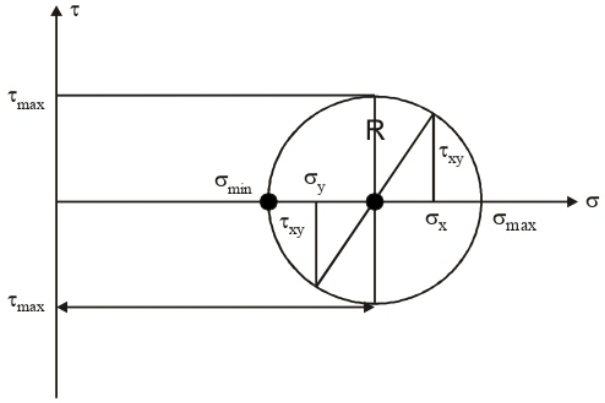
Special Point: The sum of normal stresses exerted on a cubic element of a material is independent of the orientation of element.

Principal Stress & maximum shear stress: It is the maximum or minimum normal stress which may be developed on a loaded body.

$$\sigma_{max/min} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\tau_{max} = \frac{\sigma_{max} - \sigma_{min}}{2} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} = R$$

The plane of principal stress does not carry any shear stress.



Mohr's Circle for plane stress $\rightarrow$ It is locus of points representing the magnitude of normal & shear stress at various plane in a given stress element.

(a) τ_{max} = maximum shear stress, whose magnitude is equal to radius of mohr's circle

(b) $\sigma_{max/min}$ = Principal stresses, end points of diameter on σ-axis

(c) $\tan 2\theta_s = \frac{-(\sigma_x - \sigma_y)}{2\tau_{xy}}$, $\tan 2\theta_P = \frac{2\tau_{xy}}{\sigma_x - \sigma_y}$

So, $\tan 2\theta_s \times \tan 2\theta_P = -1$

Hence, $2\theta_s$ & $2\theta_P$ are 90° apart.

Therefore, plane of Max. Shear stress are 45° to the principal planes.

(d) Normal stress on a plane of maximum shear stress is represented by co-ordinates of centre of Mohr's circle.

Strain Energy per unit Volume

1. Under Triaxial Stress Condition:

$$U = \frac{1}{2}\left(\sigma_x\varepsilon_x + \sigma_y\varepsilon_y + \sigma_z\varepsilon_z + \tau_{xy}\gamma_{xy} + \tau_{xz}\gamma_{xz} + \tau_{yz}\gamma_{yz}\right)$$

$$U = \frac{1}{2E}\left(\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - 2\mu\left(\sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x\right)\right)$$

2. Plane Stress Condition: $U = \frac{1}{2}\left(\sigma_x\varepsilon_x + \sigma_y\varepsilon_y + \tau_{xy}\gamma_{xy}\right)$

When σ_1 & σ_2 principal stress, then

$$U = \frac{1}{2E}(\sigma_1^2 + \sigma_2^2 - 2\mu\sigma_1\sigma_2)$$

Plane Strain: If the deformations are those in x-y plane only, then only 3-strain components exist $\varepsilon_x, \varepsilon_y, \gamma_{xy}$

Strain Rosette: A group of three gauges arranged in a particular pattern in such a way that it can measure normal strain in three different directions on the surface of a structural element.

Transformation of Plane Strain

$$\varepsilon_{x^1} = \frac{\varepsilon_x + \varepsilon_y}{2} + \frac{\varepsilon_x - \varepsilon_y}{2}\cos 2\theta + \frac{\gamma_{xy}}{2}\sin 2\theta$$

$$\varepsilon_{y^1} = \left(\frac{\varepsilon_x + \varepsilon_y}{2}\right) - \left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)\cos 2\theta - \left(\frac{\gamma_{xy}}{2}\sin 2\theta\right)$$

$$\varepsilon_{x^1} + \varepsilon_{y^1} = \varepsilon_x + \varepsilon_y$$

$$\frac{\gamma_{x^1y^1}}{2} = -\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)\sin 2\theta + \cos 2\theta\left(\frac{\gamma_{xy}}{2}\right)$$

Special Point: Strain energy only leads to distortion of element. It does not lead to change in volume. But normal stress leads to change in volume.

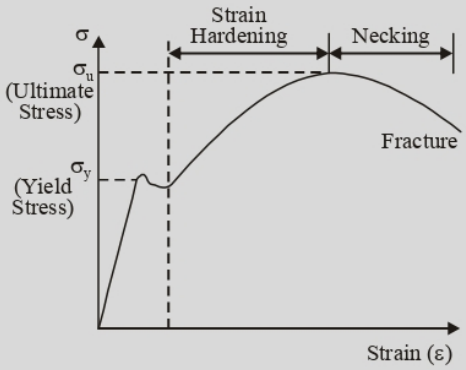
Comparison of Plane Stress and Plan Strain

Plain strain condition can be applied to thick elements.

Clear Your Confusion

- **Yield stress** (s_y) is the stress at which the material deform permanently.
- ***Working stress*** is known as the maximum allowable stress than a material can be subjected to under service load.
- It is always lower than the yield stress & the ultimate stress.
- **Ultimate stress** (s_u) is the stress at which the material fracture.

For mild steel:



$$\frac{\text{Yield Stress}}{\text{Working Stress}} = \text{Factor of safety}$$

- $$\left(\begin{matrix}\text{Ultimate}\\ \text{Stress}\end{matrix}\right) > \left(\begin{matrix}\text{Yield}\\ \text{Stress}\end{matrix}\right) > \left(\begin{matrix}\text{Working}\\ \text{Stress}\end{matrix}\right)$$

Theories of Failure

5

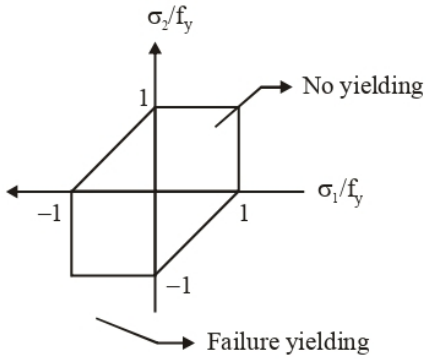
- These theories are applicable to static loading only.
- These are used to establish the behaviour of material subject to simple tension or compression, the point at which failure will occur under any type of combined loading.

1. Maximum Shear Stress Theory:

- It is also known as "Tresca, Guest, Coulomb Theory".
- It states that "Maximum shear stress should be less than or equal to maximum shear stress under uniaxial loading".
- Max shear stress under uniaxial loading like



$$\Rightarrow \boxed{\text{Max of}\left[\frac{|\sigma_{max}-\sigma_{min}|}{2}, \frac{|\sigma_{max}|}{2}, \frac{|\sigma_{min}|}{2}\right] \le \frac{f_y/2}{(FOS)}}$$



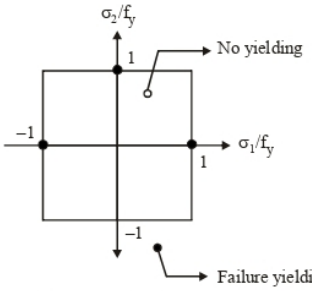
Graphical Representation Hexagon

- It gives the most conservative design out of various other theories of failure & It is applicable for ductile material.

- Not suitable for hydrostatic loading because under hydrostatic loading when $\sigma_{max} = \sigma_{min} = \sigma \Rightarrow \tau_{max} = 0$

2. Maximum principal stress theory ***(Rankine theory, Lame's theory or max stress theory").***

- It is applicable for brittle material as brittle material fail under tension leading to fracture.
- Not suitable for ductile material in which strength is limited by shear & Not suitable for pure shear case.

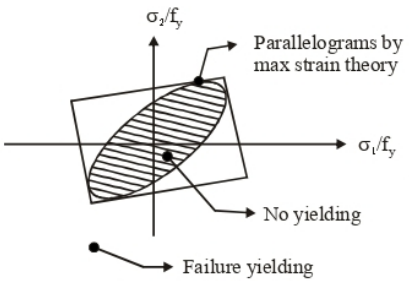


(Graphical representation square)

- For no failure, max principal stress should be less than or equal to the yield stress under uniaxial loading i.e. $\boxed{\sigma_{max} \le f_y}$
- For design purpose $\boxed{\sigma \le \frac{\sigma_y}{F.O.S.}}$

3. Max strain energy theory (Beltrami's-Haigh Theory)

- Total strain energy per unit volume absorbed at a point should be less than or equal to total strain energy per unit volume under uniaxial loading, when the material is subjected to stress upto elastic limit.
- It is applicable for ductile material.
- Not suitable for Brittle material & pure shear case.



(Graphical representation ellipse)

- Total strain energy per unit volume is given by:

$$U = \frac{1}{2E}\left[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\mu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)\right]$$

- Max strain energy per unit volume under uniaxial loading $= \frac{f_y^2}{2E}$

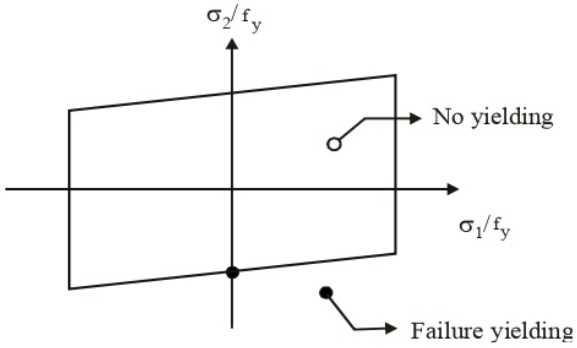
$$\frac{1}{2E}\left[\begin{matrix}\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \\ 2\mu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)\end{matrix}\right] \le \frac{f_y^2}{2E}$$

For design purpose:

$$\boxed{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\mu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1) \le \left(\frac{f_y}{FOS}\right)^2}$$

4. Max principal strain theory (St. venant theory)

$$\boxed{\sigma_1 - \mu(\sigma_2 + \sigma_3) \le \frac{f_y}{FOS}}$$



(Graphical Representation Rhombus)

Satisfactorily applicable to brittle material, but over estimates the strength of ductile material. Even not suitable for pure shear case.

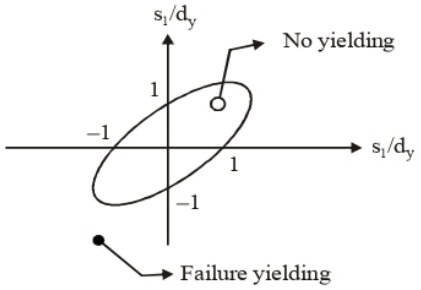
5. Maximum shear strain energy theory

[Distortion Energy theory][Huber Hencky Von - Mises Theory]

- Max shear strain energy in a body should be less than or equal to max

shear strain energy under uniaxial loading.

- It is applicable for ductile material.



$$\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]\le f_y^2$$

For design

$$\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]\le\left(\frac{f_y}{\text{F.O.S.}}\right)^2$$

- It is in perfect agreement with the case of pure shear.

6. Octahedral shear stress theory

$$\tau_{oct}=\frac{1}{3}\left(\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}\right)$$

Applicable to ductile material in pure shear case

Theory	Given by	Remark
Maximum Principle Stress or Maximum Normal stress	Rankine	Suitable for Brittle
Maximum Principle Strain	St. Venant	Can be applied for Brittle
Maximum shear Stress	Guest & Treseca	Suitable for Ductile
Maximum Strain Energy	Haigh & Beltrami	Ductile
Maximum shear Strain energy	Vonmises & Hencky	Ductile

Bending Stress

6

Unsymmetric Bending: When bending couple does not acts in the plane of symmetry of memeber

Symmetric Bending: When member possesses a Plane of symmetry & loading acts in the plane of symmetry, then bending is called symmetric bending.

Non-uniform Bending: Bending in presence of Shear force.

Pure Bending: Bending of beam under constant Bending moment.

In pure bending, a straight beam of prismatic section converts into a arc of circle.

Flexure Formula: $\frac{M}{I}=\frac{\sigma}{y}=\frac{E}{R}$

- Simple bending theory is applicable only if the cross-sectional area is symmetric.
- In deriving simple bending theory, it is assumed that Young's modulus is same in tension & compression

We know that , $\sigma_{max}=\frac{My}{I}$

Where, $\frac{I}{y}=Z$ = Section modulus about bending axis.

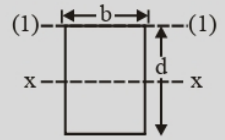
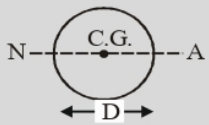
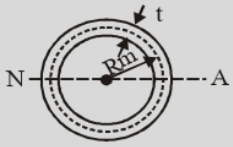
Section modulus represents the strength of section. If it is more, then section is stronger.

I = MOI about C.G axis about which bending occurs

Moment of resistant (MOR) = $\sigma_{max}\left(\frac{I}{y}\right)$

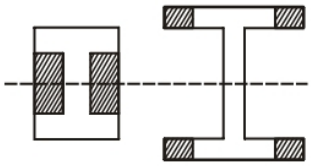
$$MOR=\sigma_{max}\times Z$$

Section modulus (Z)

S.No.	Section	Moment of Inertia	Section Modulus
(a)		$I_{xx} = \frac{bd^3}{12}$ $I_{yy} = \frac{db^3}{12}$	$Z = \frac{bd^2}{6}$
(b)		$I_{N.A.} = \frac{\pi D^4}{64}$ $y_{max} = \frac{D}{2}$	$z = \frac{\pi D^3}{32}$
(c)		$I_{N.A.} = \pi R^3 t$	$z = \frac{\pi R^3 t}{R}$ $z = \pi R^2 t$
(d)		$I_{N.A.} = \frac{bh^3}{36}$ $y_{max} = \frac{2h}{3}$ $I_{(1)-(1)} = \frac{bh^3}{12}$	$z = \frac{I}{y_{max}}$ $= \frac{bh^2}{24}$

Special Points:

- Rolled steel I-sections are most efficient & economical sections for beams.
- As compared to other sections, the lateral stability of I-sections is higher.
- For I-shape beam, section modulus is higher in comparison to other section. Its flanges carry bending but the webs carry the shear. We can have large spans with lesser weight of material due to its shape.
- In I-section, most of the material is positioned near the outer fibres, hence, its moment of inertia is larger than that of rectangular section.



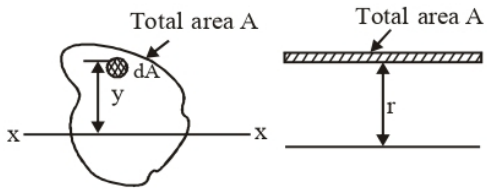
- From above figure, more area in I section is concentrated near outer fiber, resulting in increasing moment of inertia.
- In a beam if both bending & shear will be acting together, then strength comparison should be on their bending only.
- **I section is preferred over rectangular section because:**
  (1) In I section more than 80% of the bending moment is resisted by flange itself.
  (2) I section has higher MOR because the area of flange is away form the neutral axis.

Radius of gyration (r): It is the distance at which entire area must be kept as a strip in such a way that it will give same moment of inertia as that of original area.

- Radius of Gyration is a measure of resistance to rotation or buckling.
- If radius of gyration is more, then its resistance to buckling or rotation is more.

$$r = \sqrt{\frac{I}{A}}$$

where A = Area of the cross section
I = Moment of inertia



Polar Moment of Inertia: Moment of inertia of the given section about z axis is called polar moment of inertia.

$$I_{zz} = I_{xx} + I_{yy}$$

- The second moment of area can not be negative.
- The second moment of the area A about the x & y axis denoted as I_{xx} & I_{yy} respectively are defined as

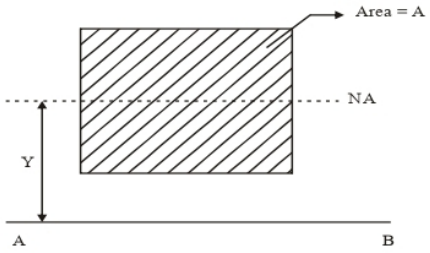
$$I_{xx} = \int_A y^2 dA, \text{ and }, \quad I_{yy} = \int_A x^2 dA$$

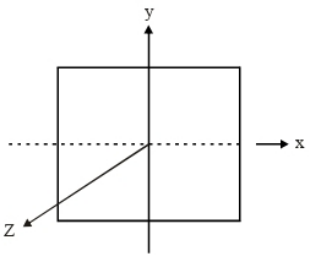
Parallel axis theorem

$I_{AB} = I_{NA} + AY^2$

Perpendicular axis theorem

$I_{ZZ} = I_{XX} + I_{YY}$

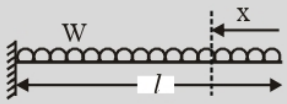
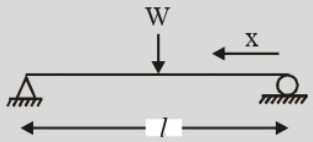




Special Points:

- Centre of gravity of a body is the point through which the resultant gravitational force act.
- Centre of gravity apply to the bodies with mass & weight.
- Centroid is a point in a plane area such that the moment of area about any Axis through that point is zero. The term centroid applied to the plain areas.

Beam of constant strength or fully stressed beam:- It is the beam in which maximum stress at every cross-section of the beam is equal to the maximum allowable bending stress in the beam.

Rectangular beam loading	Max. bending stress	when b = constant	when d = constant
	$\frac{3wx^2}{b_x d_x^2}$	$d_x \propto x$	$b_x \propto x^2$
	$\frac{3Wx}{b_x d_x^2}$	$d_x \propto \sqrt{x}$	$b_x \propto x$
	$\frac{6Px}{b_x d_x^2}$	$d_x \propto \sqrt{x}$	$b_x \propto x$

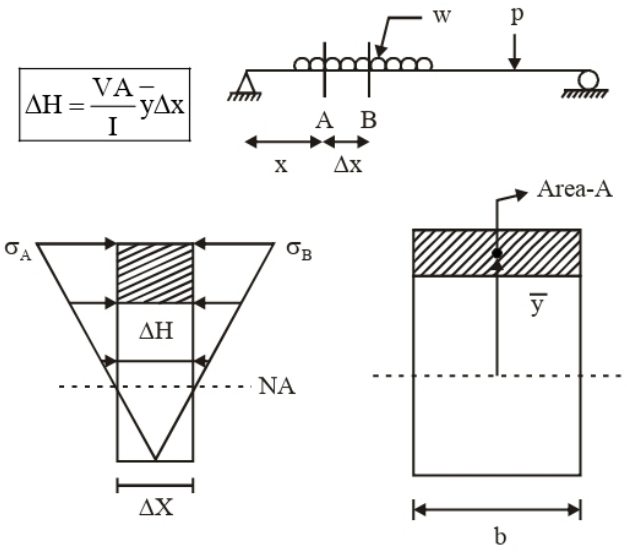
Shear Stress

7

- It acts parallel to the cross section of the material.
- Variation of transverse shear stress is parabolic in nature.
- It causes one object to slip over another.

Normal stress is produced by bending & shear stress is produced by shear force.

$$\Delta H = \frac{VA\bar{y}}{I}\Delta x$$



Where,

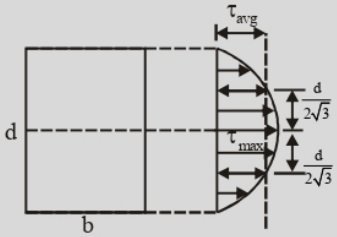
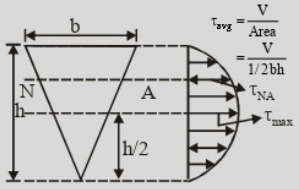
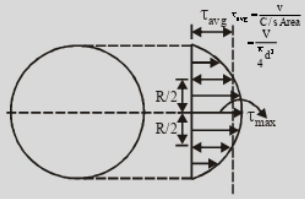
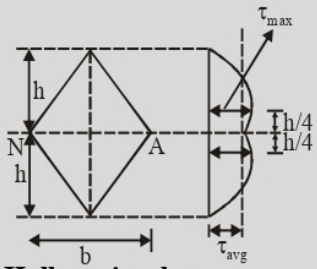
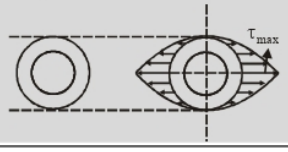
ΔH = Shear force in length Δx of beam

A = Moment of area of section above the level at which shear stress is to be found out.

V = S.F at the section where shear stress is to be found.

I = Moment of inertia of complete section about N.A

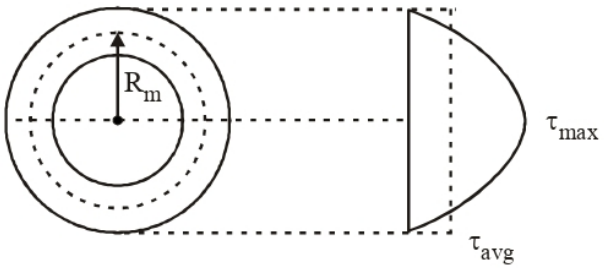
$$\text{Shear force per unit length} = \frac{\Delta H}{\Delta x} = \frac{VA\bar{y}}{I}$$

Cross-section distribution	Shear stress
(a) Rectangle 	$\tau_{max} = \frac{3}{2}.\tau_{avg}$ (at NA) $\tau = \tau_{avg}$ at distance from neutral axis $d/2\sqrt{3}$ $\tau_{avg} = \frac{V}{bd}$
(b) Triangular 	$\tau_{max} = \frac{3}{2}\tau_{avg}$ $= 1.5\tau_{avg}$.(at h/2) $\tau_{NA} = 4/3\ \tau_{avg}$ $= 1.33\tau_{avg}$ Distance betwen N.A. & τ_{max} location = h/6
(c) Circular 	$\tau_{max} = \frac{4}{3}\tau_{avg}$ (at NA) $= 1.33\ \tau_{avg}$ (at R/2 distance from neutral axis)
(d) Diamond 	$\tau_{max} = \frac{9}{8}\tau_{avg}$ All follow parabolic shape
(e) Hollow circular section 	$\tau_{max} = 2\tau_{avg}$

Shear Stress at the level y form NA = $q = \frac{VA\bar{y}}{Ib}$

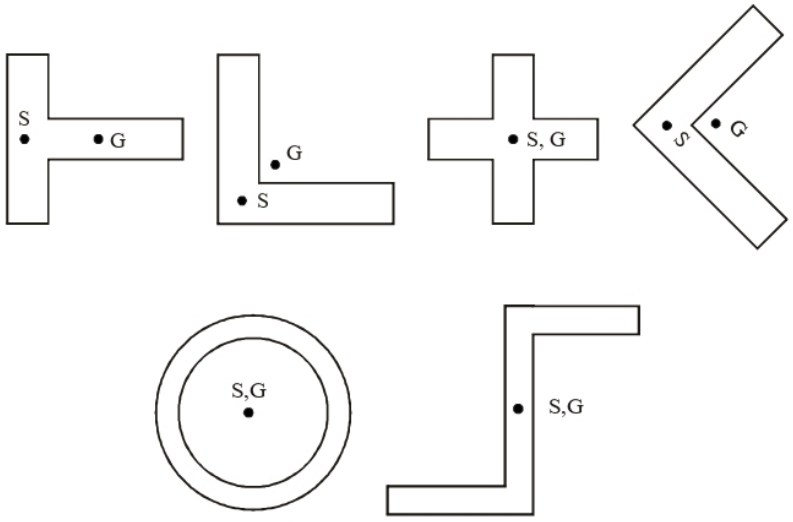
Where, b =width of section at the level where shear stress is to be found

Shear stress of thin walled section



Shear Centre: It is the point through which if transverse bending load passes, the beam will have no twisting.

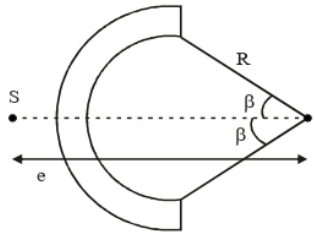
- Shear centre always lies on the axis of symmetry (if exists).
- It is the point through which resultant of shearing force on the section passes.
- It is also called centre of twist or centre of flexure.
- The variation of shear per unit length is known as shear flow.



Where S= Shear Centre, G = Centre of gravity

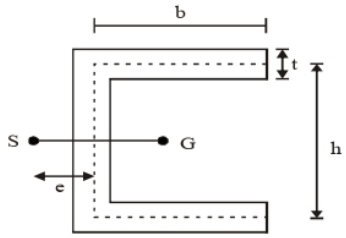
Distance of Shear Centre of Important sections:

(i) **Circular arc**



$$\left(\frac{2R}{\beta - \sin\beta\cos\beta}\right)(\sin\beta - \beta\cos\beta) = e$$

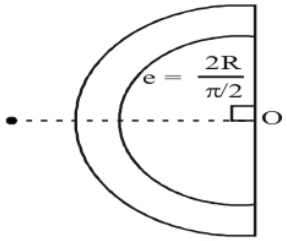
(ii) **Channel Section**



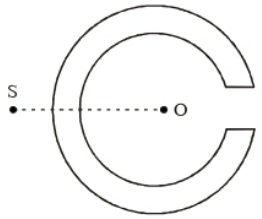
$$e = \frac{b^2 h^2 t}{4I}$$

Special cases

(a) Semi-circular:



(b) Open slit case

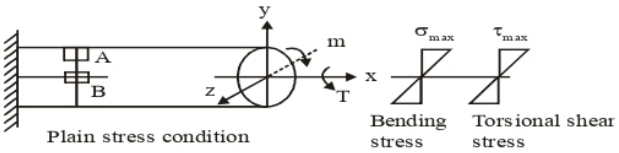


$e = 2R$

Combined Stress

8

Combined Bending and Torsion



For point A:

$$\text{(Principal stress)} \quad \sigma_{max/min} = \frac{16}{\pi D^3}\left[M \pm \sqrt{M^2 + T^2}\right]$$

$$\text{(Max. shear stress)}\ \tau_{max} = \frac{16}{\pi D^3}\left(\sqrt{M^2 + T^2}\right)$$

$$\text{(Pure torsion)}\ \tau_{max} = \frac{16T}{\pi D^3}, \quad \sigma_{max} = \frac{32M}{\pi D^3}$$

For point B: $\tau_{xy} = \frac{-16T}{\pi D^3}$

$$\boxed{\sigma_{max/min} = \pm \frac{16T}{\pi D^3}}$$

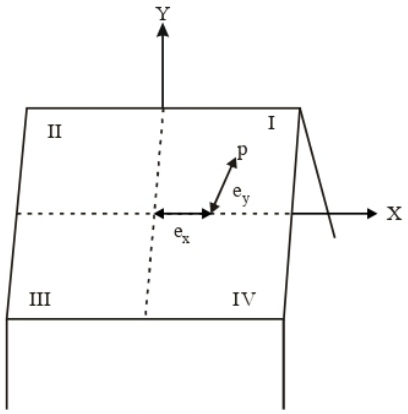
Equivalent Moment $\boxed{M_e = \frac{1}{2}\left(M + \sqrt{M^2 + T^2}\right)}$

Equivalent Torque $\boxed{T_e = \sqrt{M^2 + T^2}}$

Combined Bending and Axial Force

$$\sigma = \frac{-P}{A} - \frac{(Pe_x)x}{I_y} - \frac{(Pe_y)y}{I_x}$$

(-ve means compressive)

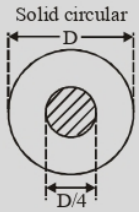
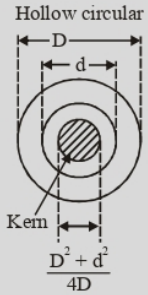


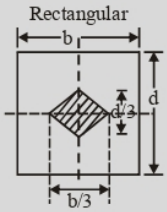
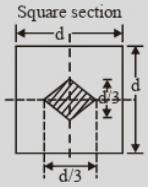
Equation of Neutral axis (put $\sigma = 0$)

$$\left(\frac{e_x}{r_y^2}\right)x + \left(\frac{e_y}{r_x^2}\right)y + 1 = 0$$

Kern is the core area of the section in which if the load applied, tension will not be induced in the section.

Core of Kern for different section:

S.No.	Section	Dimension of kern	Shape of kern
(i)		dia. of kern = D/4	Circular
(ii)		dia. of kern $= \frac{D^2+d^2}{4D}$	Circular

(iii).		b/3 × d/3	Rhombus
(iv)		d/3 × d/3	Square

Flitched Beam- It is a composite beam made of wood & steel in which wooden section is strenghened by the metal plate either provided at bottom & top or at sides symmetrically.

Generally top & bottom flithched beam is 3-5 times stronger than side flitched beam.

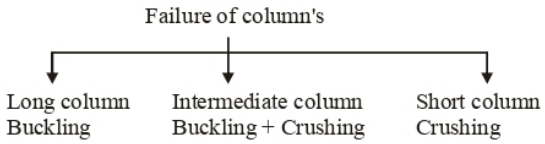
In composite beam, N.A. will not pass through the centroid of composite section but it passes through the centroid of equivalent section.

Columns

9

Classification of column based on slenderness ratio:

1. **Short Column:** Those columns have slenderness ratio less than 32 are called short struts.
2. **Medium Size Column:** Columns having slenderness ratio in the range 32 to 120 are known as medium column or intermediate column.
3. **Long Column:** Columns having slenderness ratio more than 120 are called long columns.



Assumptions of Euler's theory

1. Applicable to long columns only. (Buckling failure only)
2. Only for purely axial loading.
3. Material is isotropic, homogenous & linear elastic.
4. Perfectly straight axis of column after unloading.

Euler's Formula - It neglect the effect of direct stress.

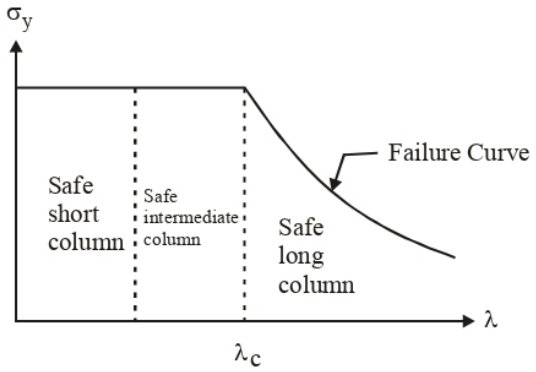
$$P_e = \frac{\pi^2 E I_{min}}{L_{eff}^2}$$

P_e = Buckling load
L_{eff} = Effective length of column.
I_{min} = Minimum MOI about centroidal axis.

Effective length of column based on end conditions

End condition	One end fixed one end free	Both end Hinged	Both end Fixed	One end fixed one end Hinged
L_{eff} (Theoretical)	2L 	L 	L/2 	$\frac{L}{\sqrt{2}}$ 
L_{eff} (As per IS code.)	2L	L	0.65L	0.8L

Validating of Euler's theory



$$P_e(\text{Load}) = \frac{\pi^2 E A r_{min}^2}{L_{eff}^2}$$

$$P_{critical} = \frac{P_e}{A} = \frac{\pi^2 E}{\left(L_{eff}/r_{min}\right)^2}$$

Hence, $\boxed{P_{cr} = \frac{\pi^2 E}{\lambda^2}}$

For mild steel $P_{cr} = 250$, $E = 2 \times 10^5$ N/mn²

So $\boxed{\lambda_c = 88.89}$ for Euler's Law to be applicable.

Rankine's Formula: For Both Short & Long column

$$\frac{1}{P_R} = \frac{1}{P_c} + \frac{1}{P_e}$$

P_C = Crushing load = $\sigma_C \times A$

P_e = Euler's load

P_R = Rankine load

$$P_R = \frac{\frac{P_C}{1+\frac{P_C}{P_e}}}{} = \frac{\sigma_C A}{1+\frac{\sigma_C A}{\frac{\pi^2 EA}{\lambda^2}}} = \boxed{\frac{\sigma_C A}{1+\alpha\lambda^2} = P_R}$$

Here, A = Area of column

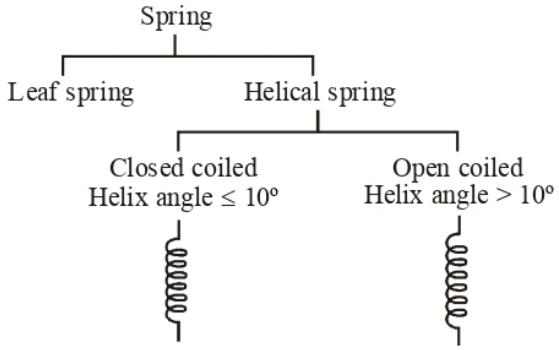
α = Rankines constant = $\frac{\sigma_C}{\pi^2 E}$

Special Point: For long column in which eccentric loading is applied, secant formula is used.

Springs

10

- The primary function of a spring is to deflect or distort under load & to recover its original shape when the load is released.
- Springs are used in many engineering applications such as automobiles & railway buffers in order to cushion, absorb or control energy due to shock & vibrations.
- During deflection or distortion, it absorbs energy & releases the same as & when required without having permanent deformation.



Springs are generally classified as leaf springs or helical springs.

(i) Leaf springs consist of a number of thin curved plates, each of same thickness & width but of different length. All bent to the same curvature.

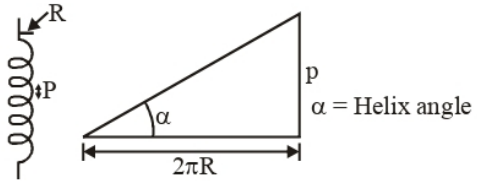
(ii) Helical spring are formed by coiling thick spring wire into a helix.

Helical spring are classified into two groups.

(a) When the helix angle is less than about 10°, it is named as close-coiled helical spring. Torsional stresses are predominant in such springs & Closed coil helical spring is called as torsion spring.

(b) If the helix angle is significant, then wire experiences both torsional & bending stresses. Such types of spring is termed as open-coiled

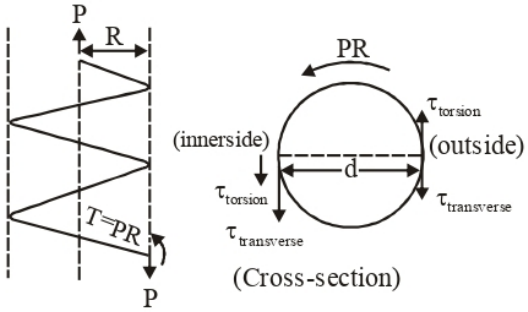
helical spring & open coiled helical spring is called as bending spring.
The angle made by the coil with horizontal is called as the angle of helix.



In close coiled helical springs, material is subjected to the torsional moment.

$$\tau_{max} = \tau_{transverse} \pm \tau_{torsion}$$

$\tau_{torsion}$ will be maximum at outermost fibers of wire.



Proof load: Greatest load that the spring can carry without getting permanently distorted.

Proof Resilience: Strain energy stored when proof load is applied.

Proof Stress: Max stress in the spring when proof load is applied.

Spring Constant: It is the stiffness of the spring measured in load per unit deflection.

Closed coil helical spring

Strain energy $U = \frac{1}{2}\frac{T^2L}{GJ}$

we know that , $T = PR$, $L = 2\pi Rn$, $J = \frac{\pi d^4}{32}$ (using these values)

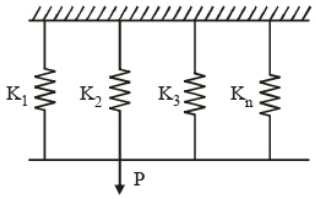
Axial deflection (δ): $\delta = \frac{\partial U}{\partial P} = \frac{64PR^3n}{Gd^4}$

Stiffness of Spring (K) $K = \frac{P}{\delta} = \frac{Gd^4}{64R^3n}$

Proof load $P_{max} = \frac{\pi d^3}{16R} \times \sigma_{max}$

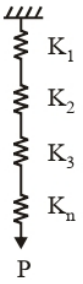
Equivalent Spring Constant

1. Parallel connection



$K_{eqa} = K_1 + K_2 + K_3 + ... K_n$

2. Series connection



$\frac{1}{K_{eq}} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + ... + \frac{1}{K_n}$

Special point: If a spring is cut down by K times, then its strain energy decreased by $\frac{1}{k}$ times, its stiftness is increased by K times, and its flexibity decreased by $\frac{1}{k}$ time.

· Flat spiral spring is made up of a band of steel wrapped aroung itself a number of times.

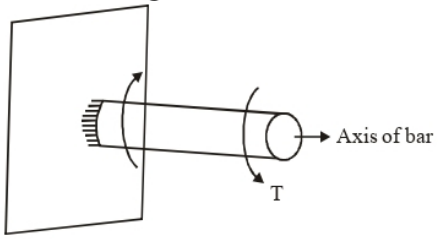
Applications: Alarm time piece. watch automotive seat recliners.

1. In road vehicles and railway wapons leaf spring are used to absorbed suspension load.
2. In cycle seats and bikes coiled spring or helical spring are used.

Torsion of Circular Shaft

11

Torsion means twisting of a member when it is loaded by torques that tend to produce rotation about the longitudinal axis of the bar



Pure torsion: For pure torsion, bar should be prismatic.

In it, cross sections are subjected to only torsional moments.

Assumptions in Torsion formula

(a) Stress should not be more than proportional limits.

(b) Plane section remains plane & do not warp, (warping occurs in Non-circular sections)

(c) Circular section remains circular

(d) Shaft is loaded by twisting couples in planes that are perpendicular to the axis of shaft.

Torsion formula

$$\boxed{\frac{T}{J}=\frac{\tau}{r}=\frac{G\theta}{L}}$$

T = Torque

τ = Shear stress

r = Distance from centre of shaft

J = Polar moment of Inertia

L = Length of shaft

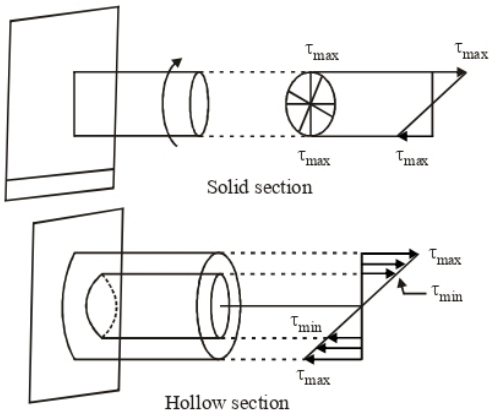
G = Shear modulus

θ = Angle of twist

Torsional rigidity (GJ) $\propto$ stength

Torsional stiffness (Torsional rigidity per unit length of shaft) $= \frac{T}{\theta}$

Torsional flexibility - It is the angle of twist produced by the unit Torque.



Special case: we know that $\frac{T}{J} = \frac{\tau}{r}$

For a given amount of torsional moment, the section which develops least value of maximum shear stress will be best.

$$J_{\substack{\text{solid}\\\text{circular}}} < J_{\substack{\text{hollow}\\\text{circular}}}$$

(Assuming same weight of solid & hollow sections)

$$\therefore \quad \tau_{\substack{\text{solid}\\\text{circular}}} > \tau_{\substack{\text{hollow}\\\text{circular}}}$$

Square, triangular, rectangular & other polygonal sections have sharp edges or fillets which reduce surface area, therefore increasing the stress in those places. They are not very effective in resisting stress against the torque.

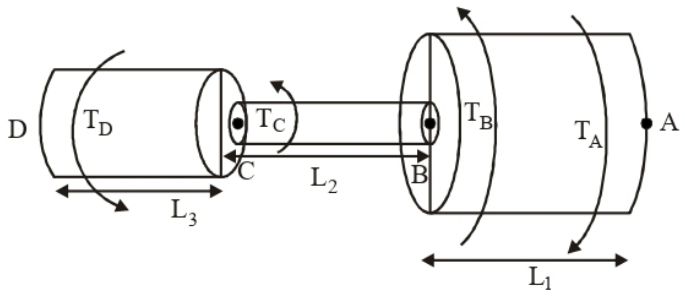
So Hollow circular section will be best in torsion.

Compound shaft

(a) Series connection

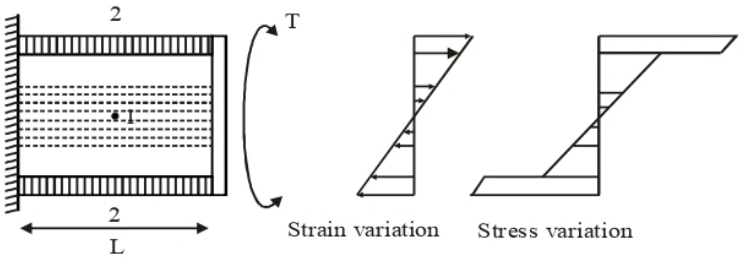
$$\theta_{AD} \Rightarrow \theta_A - \theta_D \Rightarrow (\theta_A - \theta_B) + (\theta_B - \theta_C) + (\theta_C - \theta_D)$$

$$\theta_{AD} \Rightarrow \theta_{AB} + \theta_{BC} + \theta_{CD}$$



(b) **Parallel Connection**

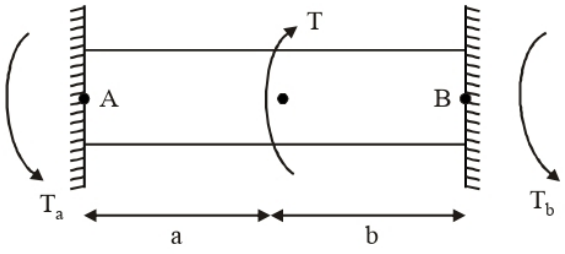
In it, $\boxed{\theta_1 = \theta_2} \Rightarrow \frac{T_1}{G_1}\frac{L}{J_1} = \frac{T_2}{G_2}\frac{L}{J_2}$



$$\boxed{\theta = \frac{TL}{G_1J_1 + G_2J_2}}$$

$$\boxed{T_1 = \frac{G_1J_1T}{G_1J_1 + G_2J_2}, T_2 = \frac{G_2J_2T}{G_1J_1 + G_2J_2}}$$

Torsion in fixed beam (statically Indeterminate)



$$\boxed{T_a = \frac{Tb}{a+b}} \qquad \boxed{T_b = \frac{Ta}{a+b}}$$

Torsional strain energy

$$U = \frac{1}{2}\ T.\theta = \frac{1}{2}\ T.\ \frac{TL}{GJ} = \frac{\tau^2_{max}}{4G} \times \text{Volume of shaft}$$

$$\text{So, Strain energy density} = \frac{\text{Strain energy}}{\text{Volume of shaft}} = \frac{1}{2} \times \tau \times \gamma$$

$$\boxed{P = T \times \omega}$$

Where, T = Applied Torque
P = Power transmitted by shaft
N = Rotation per minute
ω = Speed of rotation

$$\text{Where } \omega = 2\pi f \quad \text{or} \quad \omega = \frac{2\pi N}{60}$$

Special Points:

- Power (solid section) > power (hollow section) if diameter is same
- Power (solid section) < power (hollow section) if weight is same

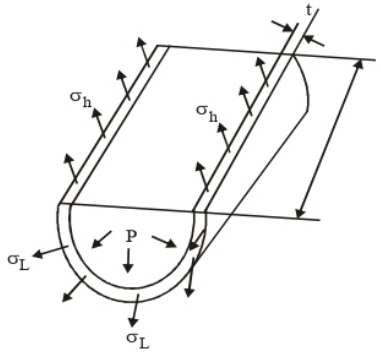
Thick & Thin Cylinder/Sphere

12

Thin shells are the shells in which thickness of the wall is less than $\frac{1}{10}$ th to $\frac{1}{15}$ th of its internal diameter. In this shells, normal stress is uniformly distributed throughout the thickness of the wall.

If thickness of wall is greater than $\frac{1}{10}$ th to $\frac{1}{15}$ th of internal diameter, it is called Thick Shell.

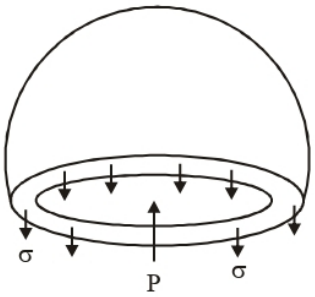
Thin Cylinder subject to internal pressure



1. Hoop Strees: $\sigma_h = \frac{pd}{2t}$
2. Radial pressure: Inside = p, outside = 0
3. Logitudinal Stress: $\sigma_L = \frac{pd}{4t}$
4. Longitudinal Strain: $\varepsilon_l = \frac{pd}{4tE}(1 - 2\mu)$

5. Hoop Strain: $\varepsilon_h = \frac{pd}{4tE}(2 - \mu)$
6. Volumetric Strain $\varepsilon_v = \varepsilon_1 + 2\varepsilon_h$, $\varepsilon_v = \frac{pd}{4tE}(5 - 4\mu)$
7. Absolute maximum shear: $\tau_{abs\ max} = \frac{pd}{4t} + \frac{p}{2}$
8. Maximum shear stress in plane of σ_h & σ_1, $\tau_{max\ (in\ plane)} = \frac{pd}{8t}$

Thin sphere subjected to internal pressure



1. Hoop strain = Longitudinal strain: $\varepsilon_h = \varepsilon_l = \frac{pd}{4tE}(1-\mu)$
2. Hoop stress = Longitudinal stress: $\sigma_h = \sigma_l = \frac{pd}{4t}$
3. Volumetric strain $\varepsilon_v = 3\varepsilon_h = 3\varepsilon_1$, $\varepsilon_v = \frac{3pd}{4tE}(1-\mu)$
4. Maximum shear stress in plane = 0
5. Absolute maximum shear stress: $\tau_{abs\,max} = \frac{pd}{8t}$

Lame's theorem of thick shells:

Assumptions:

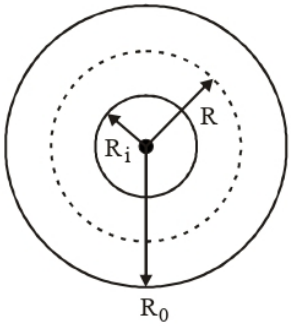
(a) Plane section of cylinder, perpendicular to longitudinal axis remains plane under pressure.

(b) Material is homogenous, isotropic & linear elastic.

Lame's equations for thick cylinder

1. Hoop strees $\rightarrow$ Tensile

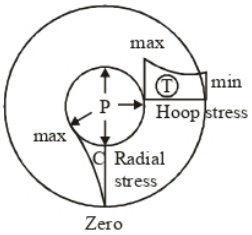
$$\sigma_h = \frac{B}{R^2} + A$$



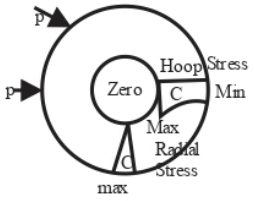
2. Radial strees - compressive, $\sigma_R = \frac{B}{R^2} - A$
3. Longitudinal strees $\sigma_l = \frac{pR_i^2}{R_0^2 - R_i^2}$

Variation of stress in thick cylinder

- Longitudinal stress remains constant (Tensile)
- Radial & Hoop compression vary hyperbolically.



Due to internal pressure



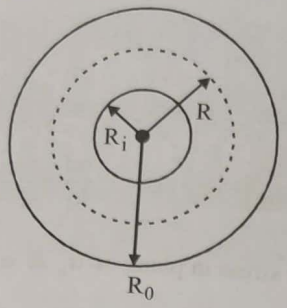
Due to external pressure

Where, T – Tensile
C – Compressive

Lame's equation for thick sphere

1. Radial stress: $\sigma_R = \frac{2B}{R^3} - A(\text{Compressive})$
2. Hoop stress = Longitudinal stress: $\sigma_h = \sigma_l = \frac{B}{R^3} + A(\text{Tensile})$

Special Point: Both lames's constant A & B are +ve for internal pressure & both are -ve for external pressure.



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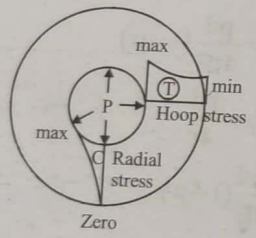
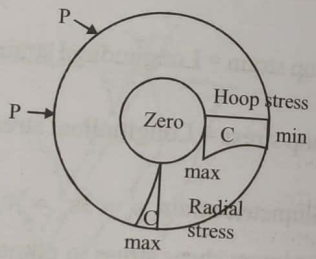


Due to internal pressure



Due to external pressure

Where, T – Tensile
C – Compressive

Lame's equation for thick sphere

1. Radial stress: $\sigma_R = \frac{2B}{R^3} - A\,(\text{Compressive})$

2. Hoop stress = Longitudinal stress: $\sigma_n = \sigma_l = \frac{B}{R^3} + A\,(\text{Tensile})$

Special Point: Both lames's constant A & B are positive for internal pressure & both are negative for external pressure.

5

NAVIGATION CHANNEL HARBOUR DOCK

1. Navigation Channel
2. Harbour
3. Breakwaters
4. Dock

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Navigation Channel

1

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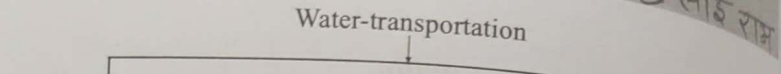
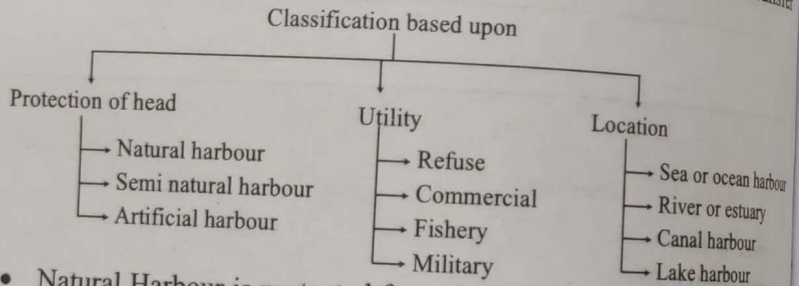


Water transportation has higher load carrying capacity but it's slow & risky (due to storms and hurricanes). It is cheapest.

Harbour: A partially enclosed protected water area to provide safe & suitable accommodation for vessels, supplies, refuelling, repair or transfer of cargo.



- Natural Harbour is protected from the storms & waves by the Natural configuration of land. Mumbai is Natural Harbour.
- Artificial Harbour is protected from the effect of waves either by break water/by dredging. Madras is Artificial Harbour.
- Semi natural Harbour is protected from storms and waves in one side by natural configuration and other side of artificial configurations. Vishakhapatnam is semi-Natural Harbour.

Special point: A lagoon is shallow body of water separated from a large body of water by barrier Island/the reefs which lies parallel to shore line, (called Lagoon Harbour). Ex. Mangalore, Paradip Harbour.

Harbour layout elements

(*a*) **Harbour Size:** Minimum harbour area is equal to the space required for the dock plus the turning basin in front of them.

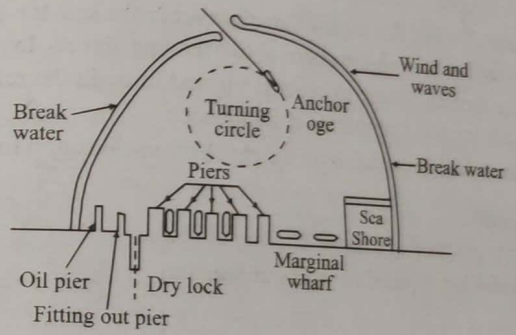
- Depth & width required at the entrance to a Harbour are more than those required in the channel

(*b*) **Anchorage Area:** Area of the circle whose radius is = (4 × depth of water) + (length of ship) + (safe clearance to adjacent ship)

(*c*) **Harbour depth**

$$D = D' + D'' + \frac{H}{3}$$

D'' = Draft of the largest ship
D' = Allowance for squat of the moving ship
H = Height of the storm wave, crest to trough.
D = Channel depth

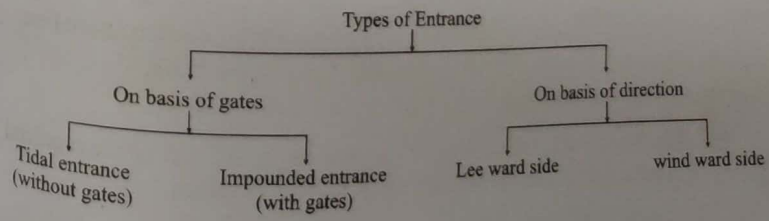


max. harbour depth = Loaded draft + 1.2 m (when bottom is soft)
max. harbour depth = Loaded draft + 1.8 m (when bottom is rock)

Loaded draft refers to submerge depth of ship when it is fully loaded.

(**d**) **Turning basin:** It's minimum radius which is twice the length of ship, where ship has tugboat assistance.

(*e*) **Harbour entrance channel:** It connects the harbour to the deep sea. The radius of the curve should be larger than five times the length of largest expected ship.



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Sounding

Measurement of depth below the water surface. Instruments used are

(i) Fathometer (Echo-Sounding):

- Depth of Sea bottom are obtained by use of fathometer/Echo Sounder.
- Main parts of an echo sounding apparatus are
  - (a) Recorder unit.
  - (b) Transmitting and receiving oscillators
  - (c) Transmitter/power unit.

(ii) Station Pointer: It is a three-armed protractor & consists of graduated circle with a fixed arm and two movable arms on either side. It is use for plotting of sounding in harbour area.

(iii) Sextant: To find the angle of an observer in the sea. It is also used to take simultaneous observations of two moving objects. In it, one object is seen directly where as other is viewed through the reflection and both are bought to apparent coincidence.

(iv) Hi-fix: A high precision light weight electronic position fixing system.

Special points:

- Moorings are provided for Anchoring of ships.
- Deep water bay is ideal for harbour location.

Harbour 2

Basis for Comparison	Port	Harbour
Meaning	Port refers to an arrangement, where boats and ships moor & transfer Passengers and cargo, to from land.	Harbour alludes to an area Next to the shore, where water Crafts are anchored for getting Safety from stormy weather
What is it?	It is a place for docking, Traffic and storage of boats.	It is a place for storing boats.
Used for	Tradition of goods & cargo, between countries.	Seeking shelter from bad weather.
Construction	Man-made	Natural or man-made
Vessels	It is a safe place for vessels.	It is a haven for vessels.
Onshore facilities	Available	May or may not be available

- Mean sea level is the based on analysis of tidal sea level fluctuations over 19 years.
- The influence of moon is greater than sun.
- **Tide:** A natural phenomenon by which level of ocean water undergoes periodic rise & fall.
- **Lunar day:** Time taken by moon to complete one revolution around earth. It is 50 minutes longer than solar day. (24 hour earth day)
- **Spring tides:** Highest tides when the generating forces due to moon & sun are additives.
  - The Lowest tide which occurs in Half linear month is called neap Tide (Moon tide).

Tidal range: Level difference between high level to low level of water for a particular tide. Tidal range of spring tides is generally 1.5 to 2 times the range of Neap tide.

- Tidal force due to sun = 0.45 × Tidal force due to moon

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Neap tides: When lines connecting the earth with sun & earth with moon form a right angle.

Wind: It's speed is expressed in **knots** (1.043 kmph). It is the length of one minute of area of a meridian which varies with different latitudes. It causes waves in open sea.

Wave: It is generated by transfer of energy from air which is moving over the water surface.

(*i*) Length of wave (m) $= \frac{t^2}{2\pi} g = 1.56t^2$ (By Bertin's formula)

t = time period (in sec.)

It is the distance between adjacent crest of a wave given wave length.

(*ii*) Height of wave (m) $= 0.34\sqrt{F}$ (By Stevenson's formula)

F = Fetch (surface giving rise to waves) in km

(*iii*) Significant wave height (H_S) = Average height of 1/3 highest waves.

(*v*) Highest wave $H_{max} = 1.87\ H_S$

(*iv*) Average height (H_A) $= 0.6\ H_S$

Shore protection works:

(*i*) **OFF shore breakwater:** Rubble mound type structure, effective for intercepting littoral movement.

(*ii*) **Sand dunes:** Formation along coast prevent movement of tides into the area.

(*iii*) **Seawalls, Bulkheads and revetments:** Structures parallel to shoreline which develop a demarcating line between land and sea. Bulkhead are mean to retain or prevent sliding of land.

- Seawalls & revetments are use mainly to protect the land & upland property against wave action.

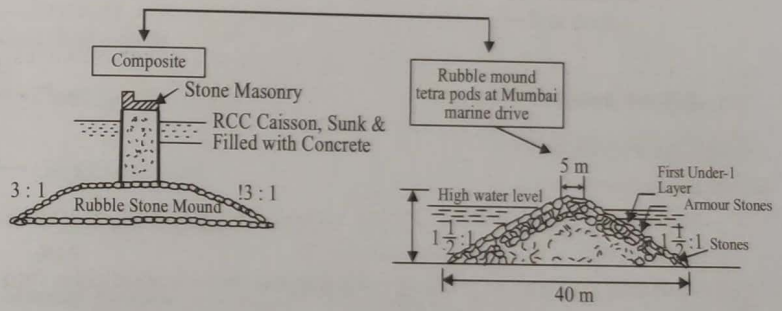
(*iv*) **Groynes:** Structures or projections from the bank for trapping of littoral drift.

Special Points: Littoral drift is the drifting of sand in a zigzag line. Beaufort scale is an empirical measure that relates wind speed to observe condition at sea/on land .

Clapotist: It is a phenomenon by which waves strikes a vertical break water in deep water.

Breakwaters 3

- It is a structure constructed with the purpose of protecting an area from the effect of sea waves so that ships can safely be moored in that area.
- Generally Break water height is kept equivalent to 1.2 to 1.25 times the height of the wave expected above the high water level.



Wharf: These are platforms at which vessels take on & discharge passenger and cargo. (They are the docks that are parallel to the shore).

- Wharfs which are built parallel with the shore are called guays.

Wharf Types

Open type

- Decks are supported by piles or cylinder
- Provide little resistance to water movement

Solid type

- Decks are supported by sheet piles cells, bulkhead, cribs, caisson and quay walls
- Provide adequate resistance to the impact of mooring vessels
- Stable & inexpensive

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Fenders: It is the form of cushion provided on jetty face to absorb the impact of the ship (impact absorber of quay walls) & protect them from damage. It also prevents the ship paint from being damaged because of relative motion between dock & ship.

Dolphins: Used for tying up ships & for transferring cargo between ships moored along both sides of dolphin

Breasting dolphins
- Designed to take impact of ship

Mooring dolphins
- Not designed for impact of ship

Special point: Fender system – Absorbs the energy of the moving vessel.

Jetties: Built roughly perpendicular to the shore for maintaining an entrance channel.

Dock

4

Dock is artificial enclosure for the reception of ships.

Dock Types

- Repair dock
  - Dry dock
    - Lift dry dock
    - Floating type of dock
    - Gravity dry dock
    - Marine railway, dry dock.
- Harbour dock
  - Wet dock
    - Enclosed wet docks
    - Wet docks in tidal basin

Special points:
- Keel & Bilge block serves as a support for ships during repair works in dry docks.
- Buoys are floating structures of small size employed for demarcation.
- Capstone & Bolards are used for Anchoring ships.

Harbour/Wet dock

For berthing of vessels to facilitate loading & unloading of passengers.

(*a*) In Enclosed wet docks water level is maintained by providing locks & lock gates so that cargo handing becomes convenient. but It is costly. Very useful in harbour/river where considerable silting takes place.

(*b*) Wet docks in tidal basin, are ports on the open sea coast protected by an outlaying breakwater.
- Lock gates for entrance are not provided, So lot of fluctuations in water level.

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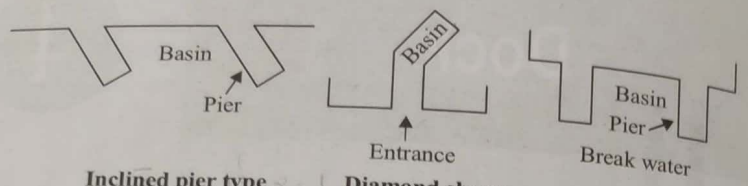
Shapes of dock and basin



Inclined pier type | **Diamond shape** | **Rectangular**

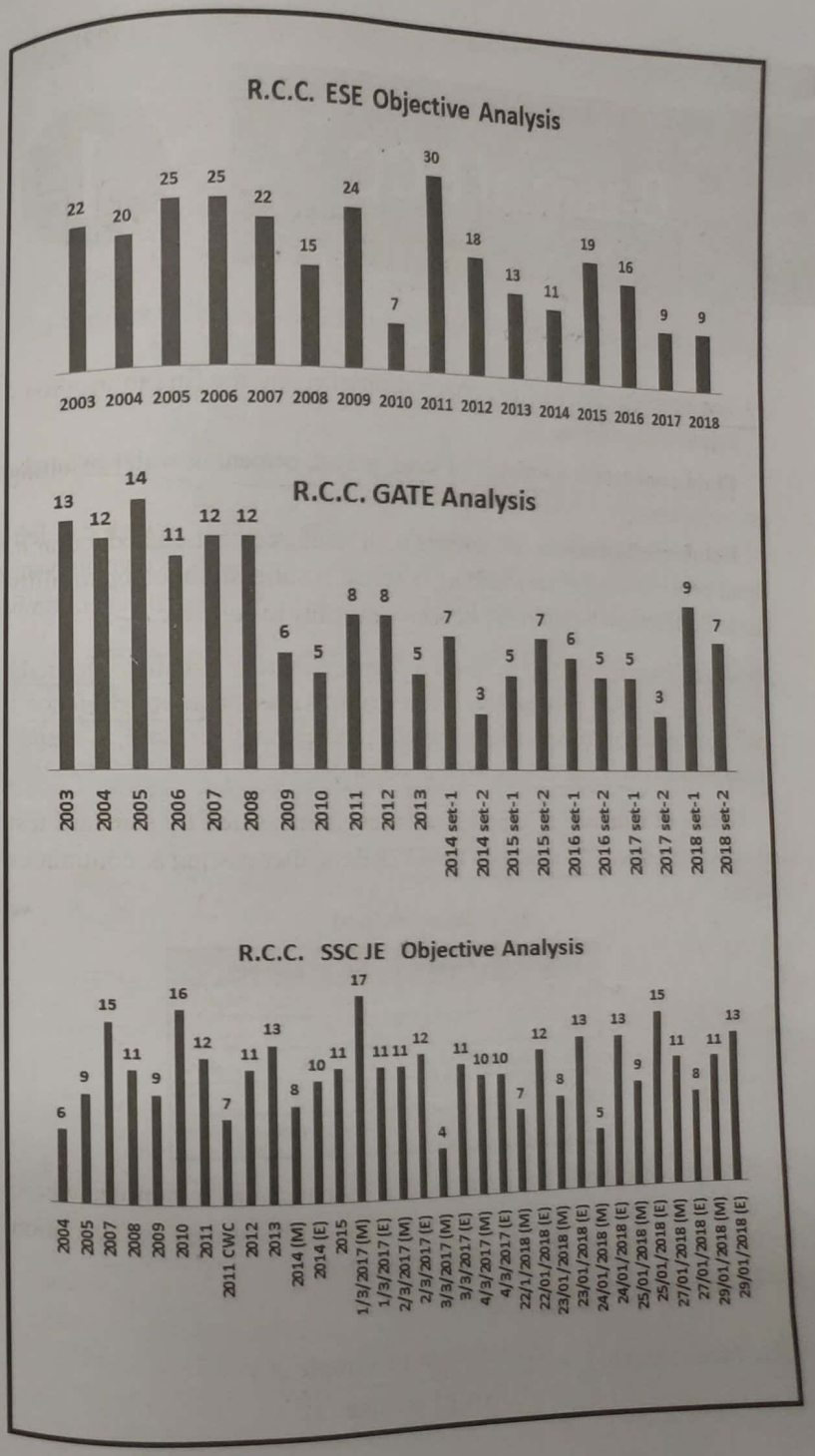
Repair/Dry dock

There are used for repair of vessels.

(*a*) **Graving dry dock:** Operates by admitting a vessel into the chamber, close the gate & then pumping out the water.

(*b*) **Floating type of dry dock:** It is a floating vessel which can left a ship out of water & retain it above water by means of its own buoyancy.

(*c*) **Marine railway dry dock (slip):** It consists of inclined path of timber or stone upon which a series of rails are fixed.



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Basic of RCC

1

- Francois Caignet was a French industrialist and the first to use iron - reinforced concrete.

Plain concrete is a mixture of sand, gravel, cement & water resulting into solid mass.

Reinforced concrete is Concrete with reinforcement embedded in it. Bond between steel & surrounding concrete ensures strain compatibililty (large deflection). Reinforcing steel give ductility to concrete.

Special Point: Steel is used along with concrete because thermal expansion coefficient of both steel & concrete is reasonable equal. Hence, with increase in temperature steel & concrete will expand in same magnitude & thermal cracks will not occur.

Grade of concrete: Compressive strength measured by standard test on concrete cube (150 mm size) tested 28 days after casting & continuous curing.

(Important facts)

Volume of concrete	No. of sample
1 - 5	1
6 - 15	2
16 - 30	3
31 - 50	4
> 50	(4+1)No. for each 50m³

- Strength of cube is the average of 3 specimens of a sample, where individual variation should not be more than ± 15% of average.If variation is more, test result of the sample is rejected.
- Cube is always tested on sides.

1. Mean stregth $f_m = \frac{\Sigma(\text{Strength of sample}, f)}{\text{No. of sample}, m}$

2. Standard deviation $\sigma = \sqrt{\frac{\Sigma(f - f_m)^2}{m-1}}$

Assumed Standard Deviation	
Grade of concrete	σ (N / mm²)
M10	3.5
M15	
M20	4
M25	
M30	5
M35	
M40	
M45	
M50	

Characteristic strength (f_{ck}): Strength below which not more than 5% of test result are expected to fall.

$$f_{ck} = f_m - 1.65\sigma$$

- As per **IS 456 : 200 CI 38.1 (C):** For the design of flexural members the characteristic strength of concrete is taken as 0.67 f_{ck}.
- Larger size leads to more variability in strength. Hence, the strength of concrete will be lesser than the cube strength.
- **Grade's of concrete**
  1. M_{10}, M_{15}, M_{20} → Ordinary
  2. M_{25} - M_{55} → Standard – 7 grade
  3. M_{60} - M_{80} → High strength

  Where 'M' stand for 'mix'
- (Minimum grade for RCC → M15 (IS 456: 1978)
- Minimum grade for RCC → M20 (IS 456:2000)

Concrete Mix Design: It is economical selection of relative proportions of various ingredients of concrete such that it remains workable in fresh state & impermeable and durable in hardened state.

Design Methods:(a) Nominal mix (upto M20 grade only) (b) Design mix (IS 10262:1982)

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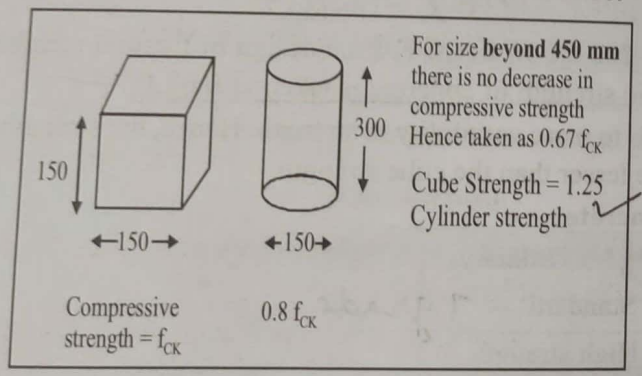
- In Nominal mix Design Method, Specified in terms of total mass of aggregate, and volume of water to be used per 50 kg of cement.

	cement : FA : CA		
M 5	1	: 5	: 10
M 7.5	1	: 4	: 8
M 10	1	: 3	: 6
M 15	1	: 2	: 4
M 20	1	: 1.5	: 3

Steps involved in Design Mix Process are

(a) Target mean strength
$f_t = f_{ck} + 1.65\,\sigma$
(b) Water cement ratio from charts.
(c) Water content based on work ability, ratio of fine& coarse aggregate, by mass based on type & grading of aggregate.
(d) Find cement content from (b) and (c) above
(e) Mass of FA & CA from absolute volume principle.
(f) Weight of ingredient per batch based on capacity mixer.

Compressive strength of concrete in structures:



Tensile strength of concrete

- Since concrete does not take have any tensile strength, it is taken as zero. But, IS code recommends the flextural tensile strength to be calculated using $f_{cr} = 0.7\sqrt{f_{ck}}$ N/mm²
- The tensile strength of concrete can be expressed as follows:
  (a) Flexural tensile strength.
  (b) Splitting tensile strength.
  (c) Direct tensile strength.

(a) Flexural tensile strength: Tensile strength of concrete in flexure is called flexural strength.

It is used to determine the onset of cracking or the loading at which cracking starts in a structure.

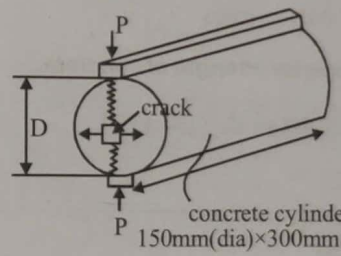
$$f_{cr} = 0.7\sqrt{f_{ck}}$$

where,

f_{ck} = Characteristic compressive strength of cubes in N/mm².
f_{cr} = Flexural tensile strength is N/mm²

(b) Splitting tensile strength: It is measured by testing cylinders under diametrical compression.

Because due to difficulty in applying uniaxial tension to a concrete specimen & hence the tensile strength is determined by indirect method (by split tensile strength test).



Splitting tensile strength $(f_{ct}) = \dfrac{2P}{\pi DL}$

(c) Direct tensile strength: It is measured by testing rectangular specimens under direct tension.

In the absence of test results, the code recommends to use an estimate of the flexural tensile strength from the compressive strength by the following equation–

Note: $f_{cr} = 0.7\sqrt{f_{ck}}$

$f_{ct} = 0.66\, f_{cr}$

& Direct tensile strength = $[0.5 - 0.625]f_{cr}$.

where, f_{cr} = Flexural tensile strength
f_{ct} = Splitting tensile strength.

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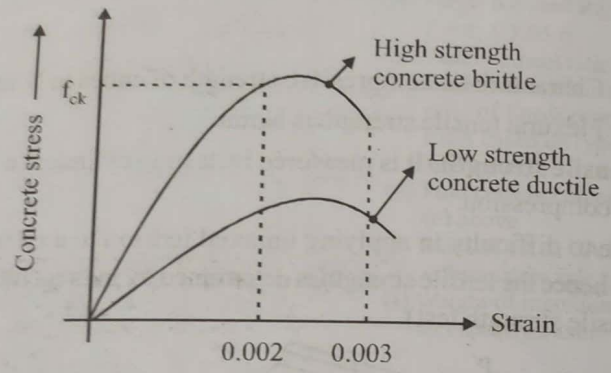
Stress-strain curve of concrete

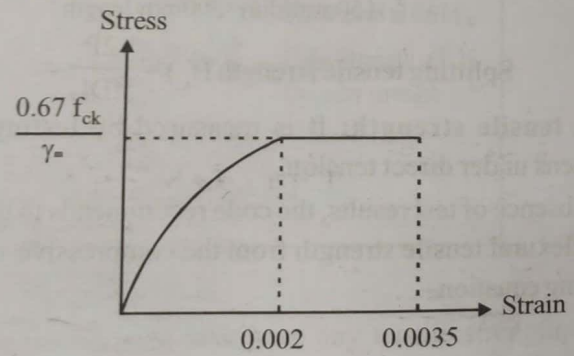
- Point where curve ends is called crushing strain.
- Curves are linear upto a stress of 0.6 times the peak stress
- Descending part of high strength concrete is steeper.
- Secant modulus of elasticitty of concrete at a stress of around 0.33 f_{ck}.



Design stress-Strain curve for strength of concrete

Partial safety factor for material strength (γ_m)

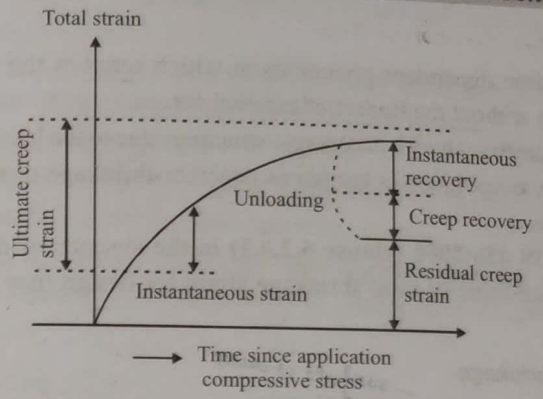
1. Collapse = 1.5
2. Serviceability = 1.0



Creep in Concrete

- It is time dependent component of total strain.
- It occurs due to internal movement of adsorbed water, loss of moisture,growth of micro-cracks, sliding between gel particles.

$$E_C = \frac{5000\sqrt{f_{ck}}}{1+\theta}$$



Advantages of creep	Disadvantages of creep
(1) Decrease in stress due to differential settlement in indeterminate structures. (2) Decrease in cracking stress developed due to restrained shrinkage.	(1) Gradual transfer of load from concrete to reinforcing steel in compression members. (2) Increased deflection of beams, slabs and columns (which can even buckle) & Loss of presstress.

Creep increases when following are

Low	High
Relative humidity	Temperature
Size thickness ratio	W/C
Aggregate content	Cement content
	Early stage loading

Special point: High strength concrete, delaying application of partition wall & finishes, steam curing under pressure decrease the effect of creep.

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Shrinkage:

- It is a time dependent phenomenon which reduces the volumes of concrete without the impact of external forces.
- The volumetric change in concrete structures due to the loss of *capillary water* by evaporation is known as concrete shrinkage or shrinkage of concrete.
- As per **IS 456:2000 (clause 6.2.4.1)** in the absence of data, the approximate value of total shrinkage strain for design may be taken as 0.0003.

Types of shrinkage

(a) Plastic shrinkage: Plastic shrinkage occurs very soon after curing the concrete. The hydration of cement results in reduction to the volumes of concrete. Due to this evaporation from the surface of concrete, which leads to cracking

(b) Carbonation shrinkage: Carbonation shrinkage occurs due to the reaction of (CO_2) with hydrated cement minerals, carbonating $Ca(OH)_2$ to $CaCO_3$. The carbonation slowly penetrates the outer surface of the concrete. This type of shrinkage mainly occurs at medium humidity & it will results in increased strength & permebility.

(c) Drying shrinkage: The shrinkage that appears after the setting & hardening of the concrete mixture due to loss of capillary water. Drying shrinkage generally occurs in the first few months & decreases with time.

(d) Autogeneous shrinkage: It is a minor problem of concrete & can the ignored.

Factors Affecting shrinkage

(a) Water-cement Ratio: It increase with the increase in water cement ratio

(b) Relative Humidity: It decreases with increase in the relative humidity. There will be no shrinkage if relative humidity is 100%

(c) Type of aggregates: Aggregates with moisture movement & low elastic modulus cause large shrinkage

- The rate of shrinkage generally decrease with the increase of the size of aggregates.

(d) Admixtures: The shrinkage increases with the addition of accelerating admixtures due to the presence of ($CaCl_2$) in it.

(e) Time: The rate of shrinkage rapidly decreases with time but shrinkage strain increases with time.

- It is found that 14-34% of the 20 years shrinkage occurs in two weeks, 40-80% shrinkage occurs in three months & the remaning 66-85% shrinkage occurs in one year

(f) Strength of concrete: High strength concrete have less shrinkage as compared to low strength concrete.

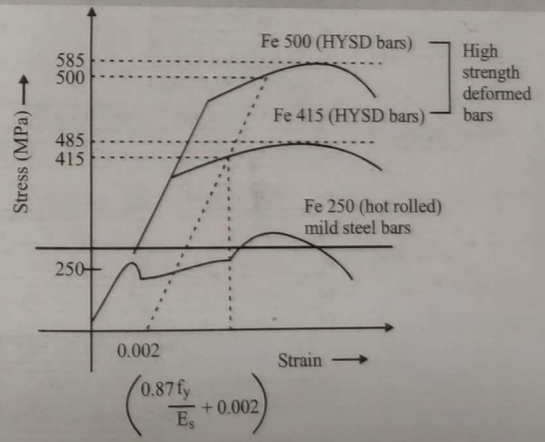
(g) Method of curing: Shrinkage does depends upon the method of curing adopted different method of curing have different rate of shrinkage.

Reinforcement

In Fe 250, Fe 415, Fe 500:- 250 MPa, 415 MPa, and 500 MPa is the minimum strength & can be treated as characteristic strength of steel respectively.

Special Points:

- HYSD bars fails at less elongation as compared to mild steel bars.
- By cold working (stretching and twisting) yield strength increases but ductility falls (HYSD bars have high yield strength than mild steel).



Following are design methods

1. Working stress method (Elastic/centroidal/Axis/Modular ratio/Traditional Method)
2. Limit state method

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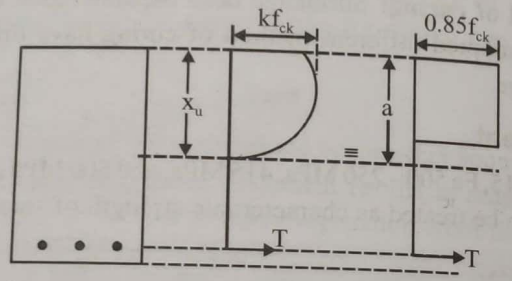
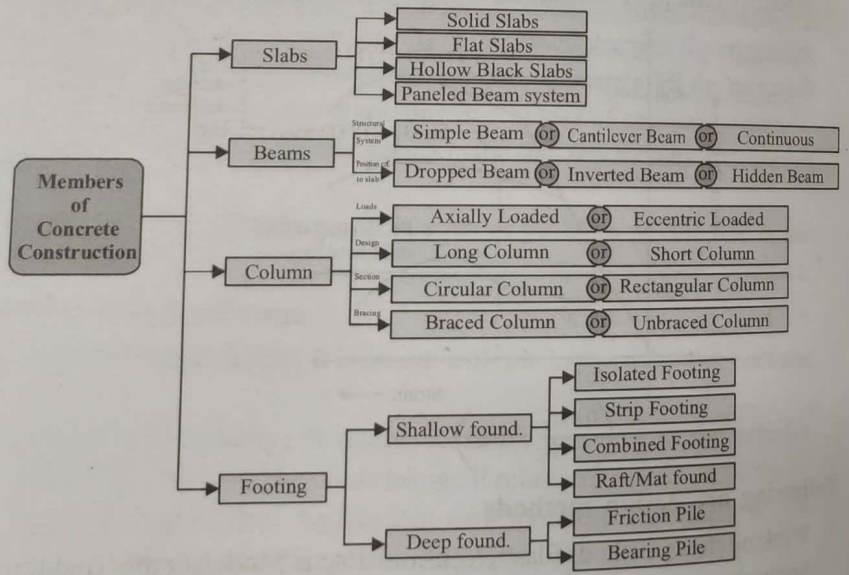
3. Ultimate load method.

Ultimate load Method: (Whitney's theory)

- It is based on assumption that at extreme edge of compressive side, strain is assumed to be 0.003 instead of 0.0035.
- Stress in compression is assumed as approximately parabolic distribution.
- Whitney found that average stress of the rectangular stress diagram is 0.85 f_{ck}.



- The depth of rectangular stress block is taken as = 0.573d



Limit State Method & Beam

2

The acceptable limit for the safety & serviceability requiment of a structure or structural element before occuring of failure is called limit state.

Limit state of serviceability
- Deflections, cracking, vibration, leakage, loss of durability etc.

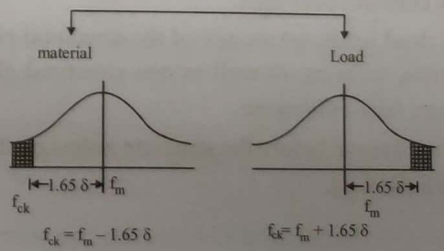
Limit state of collapse
- Flexure, compression, shear, torsion, over turning, sliding, buckling, fatigue.

Special points:

- In limit state approach, spacing of the main reinforcement primarily controls, cracking width within permissible limit under normal exposure condition.
- Structure will return to its original state. It has reached only till its limit state of serviceability. But, after reaching limit state of collapse it will not regain its shape.
- Durability of member is ensured by cover requirements, grade of materials etc.

Characteristic Strength

- To account for uncertainties reliability based analysis was performed & partial factor of safety were established for material & load.



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- $(f_m - 1.65\delta)$ and $(F_m + 1.65\delta)$ are limits with in which "Probability of lying test result" is maximum and called confidence limit.

(a) Partial factor of safety in material property

$$f_d = \frac{f_{ck}}{\gamma_{ms}}$$

Concrete

$$f_d = \frac{0.67 f_{ck}}{1.5} = 0.45 f_{ck}$$

Steel

$$f_{ck} = \frac{f_y}{1.15} = 0.87 f_y$$

(b) Partial factor of safety under various load combinations

$$f_d = F\gamma_f$$

S. No.	Discription	Collapse	Servicability
1.	D.L + L.L	1.5	1
2.	D.L + (W.L) or (E.L) combination		
	(i) for normal case D.L + W.L (or E.L) D.L + W.L (or E.L)	1.5	1
	(ii) for checking stability against over turning/stress reversal D.L + W.L (or E.L)	0.9	1
3.	D.L + (L.L) + W.L (or E.L) combination	1.2	1
	D.L	1.2	0.8
	W.L (or E.L)	1.2	0.8

Dead Load

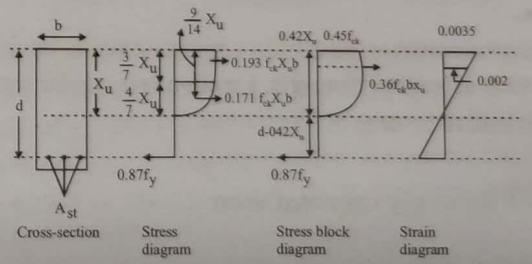
- Dead loads are examples of gravity loads (act vertically downwards) & are relatively constant over time.
- Examples of dead loads are weight of the structural elements such as beams, columns, slabs etc as well as non-structural elements such as floor coverings, false ceiling etc.
- Dead load is not known before the structure is designed & it is assumed as per IS : 875 (Part-1).

Live Load

- Live load or imposed loads are those which may change in position and magnitude.
- Examples of live loads are furniture, equipment and occupant of the structure
- Live load is expressed as UDL, given in IS : 875 (Part-2)
- These are temporary loads of short duration due to the use of structure.

Assumptions of limit state of collapses: Flexure

1. Plane section before bending remains plane after bending (Strain compatibility)
2. Relationship between compressive stress distribution in concrete & strain in concrete may be assumed to be rectangular, parabolic, trapezoidal or any other shape which results in prediction of strength in substantial agreement with the result of test.
3. Maximum strain in concrete at the outermost compression fibre is taken as 0.0035 in bending (Regardless of grade of concrete by Max. Principal strain theory).
4. Tensile strength of concrete is ignored.



5. Maximum strain in tension reinforcement in the section at failure shall not be less than

$$\epsilon_{st} = \frac{f_y}{1.15E_s} + 0.002 = \frac{0.87f_y}{E_s} + 0.002$$

This assumption restricts depth of neutral axis.

6. For design purpose partial factor of safety for steel $\gamma_{ms} = 1.15$ & the stress in steel is derived from stress-strain curve.

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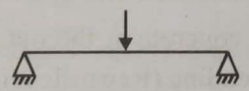
Limiting Depth of Neutral Axis

	X_u lim/ d	$R_u = \frac{M_{u\,lim}}{bd^2}$	p_t, lim
Fe250	0.53	$0.148f_{ck}$	$0.088f_{ck}$
Fe415	0.48	$0.138f_{ck}$	$0.0479f_{ck}$
Fe500	0.46	$0.133f_{ck}$	$0.038f_{ck}$

$$\left(\frac{X_u}{d}\right)_{lim} = \frac{0.0035}{0.0055 + \frac{0.87f_y}{E_s}}$$

Special Point: Failure always occurs due to crushing if concentrate on compression face in both the cases.

BEAM



- Beams resist bending moment & shear force.
- A beam is a structural member of sufficient length compared to lateral dimension.
- Beams may be concrete, steel even composite beam, having any type, sections such as angles, channels, I section rectangular square etc.
- A beam is said to be deep if

(a) $\frac{l}{D} < 2$ for simply supported beam.

(b) $\frac{l}{D} < 2.5$ for continuous beam.

Spandrel beam: In case of high rise buildings, the masonry walls are usually not able to withstand their self weight & the slab weight. In such cases, the beams are provided to exterior walls at each floor level to support the wall load. These beams are called as spandrel beam.

The beam outside a wall upto floor level above it, is known as spandrel beam.

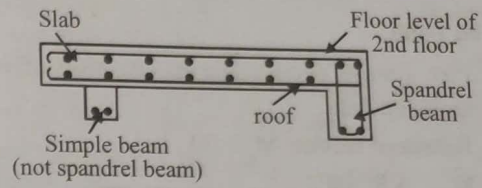


Fig.: Cross section of slab

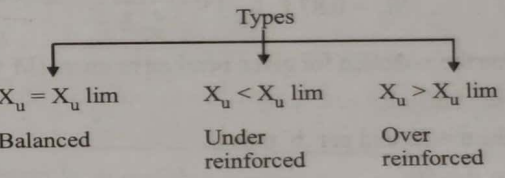
It is not necessary that under the beam always be wall, there can be column & window but spandrel beam will provide only at exterior wall.

Singly Reinforced Beam

1. To determine M.O.R (M_u) when beam cross-section is given

$$0.36f_{ck}bx_u = 0.87f_yA_{st}$$

$$x_u = \frac{0.87f_yA_{st}}{0.36f_{CK}b}$$



- If $x < x_{u\,lim}$, the steel in the tensile zone attains its maximum stress earlier which means that tension steel yields upto ultimate strength & the section will be *under reinforced* which results in tensile failure (ductile failure) & the under reinforced concrete flexural members are deeper & undergo larger deflection than balanced & over reinfoced member.
- If $x = x_{u\,lim}$, the concrete & steel attain their maximum stresses simultaneously. Such type of failure section is known as *balanced section.*
- Over-reinfoced & balanced concrete flexural member are stiffer than under reinforced member.
- If $x > x_{u\,lim}$, the concrete attains its maximum stress earlier which means that tension steel does not yield upto ultimate strength & the section will be *over reinforced* which results in compressive failure / brittle failure.

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Special point:

- Failure always occurs due to crushing of concrete on compression face.

(a) **Balanced section** $M_u = M_u$ lim

$M_{u\,lim} = R_u\, bd^2$

$M_{u\,lim} = 0.87\, f_y\, A_{st}\, (d - 0.42\, x_{u\,lim})$

(b) **Under reinforced section (tensile failure)**

$M_u = 0.36\, f_{ck}\, b\, x_u\, (d - 0.42\, x_u)$

$M_u = 0.87\, f_y\, A_{st}\, (d - 0.42\, x_u)$

(c) **Over reinforced section (Compression failure):** x_u is limited to $x_{u\,lim}$ & M_u is calculated as in balanced section.

2. To calculate area of steel, when concrete cross-section & applied moments are known.

$$M_u = 0.87\, f_y A_{st} \left(d - \frac{A_{st} f_y}{f_{CK} b}\right)$$

3. To calculate the x-section for given bending moment (M_u)

(a) $M_u = R_u\, bd^2$

- Take d = 2b and get 'b' then d
- D = d + 50

(b) $M_u = 0.87\, f_y A_{st} \left(d - 0.42 \times \frac{0.87 f_y A_{st}}{0.36 f_{CK} b}\right)$

Get A_{st}

(c) Apply reinforcement checks

- $\frac{A_{st\,min}}{bd} > \frac{0.85}{f_y}$, $A_{st\,max} = 0.04\, bD$, $x_u < x_{u\,lim}$

Double Reinforced Beam: If $M_u > M_{u\,lim}$, then either section dimensions need to be modified or higher grade of steel/concrete to be used.

Special point: If section dimensions are restrained, then compression reinforcement is provided such that neutral axis does not shifts downward by providing tension steel greater than $A_{st\,lim}$

Advantage

(a) Reduction in long term defletion due to Shrinkage & creep..

(b) Prevents Beam in Reversal of moments.

For Singly Reinforced Rectangular beam

Unbalanced Section	Balanced Section
$k = \frac{1}{1 + \frac{\sigma_{st}}{m f_c}} = \frac{m f_c}{\sigma_{st} + m f_c}$	$k_c = \frac{m\sigma_{cbc}}{\sigma_{st} + m\sigma_{cbc}}$ (if m is given)
$R = \frac{1}{2} f_c k \left(1 - \frac{k}{3}\right)$	$R_c = \frac{1}{2}\sigma_{cbc} k_c \left(1 - \frac{k_c}{3}\right)$
$M = Rbd^2 = A_{st} f_{st} \left(d - \frac{n}{3}\right) = A_{st} f_{st}\, d \left(1 - \frac{k}{3}\right)$	$M_c = R_c bd^2 = A_{st}\sigma_{st} \left(d - \frac{n_c}{3}\right) = A_{st}\sigma_{st}\, d \left(1 - \frac{k_c}{3}\right)$
$P = \frac{A_{st}}{bd} \times 100 = \frac{50 k f_c}{f_{st}}$	$P_c = \frac{A_{st}}{bd} \times 100 = \frac{50 k_c \sigma_{cbc}}{\sigma_{st}}$

Flanged beam: In monolithic construction, slab & beams are cast together. If slab in such cases is in compression zone, they become effective in adding significantly to the area of concrete in compression

Effective flange width for T and L beams

Monolithic L - Beam

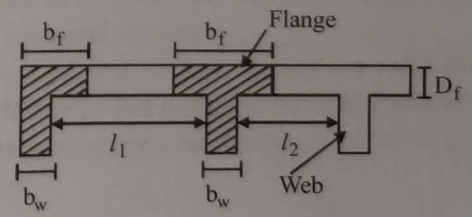
(a) $b_f = b_w + 3D_f + \frac{l_0}{12}$

$b_f \not> b_w + \frac{l_1}{2}$

Monolithic T - Beam

(b) $b_f = b_w + 6D_f + \frac{l_0}{6}$

$b_f \not> b_w + \frac{l_1 + l_2}{2}$



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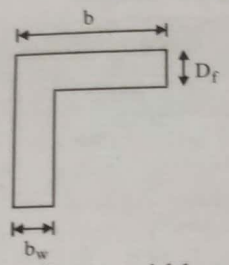
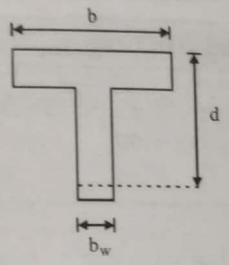
Isolated L - Beam

(c) $b_f = b_w + \dfrac{0.5l_0}{\frac{l_0}{b}+4} \le b$



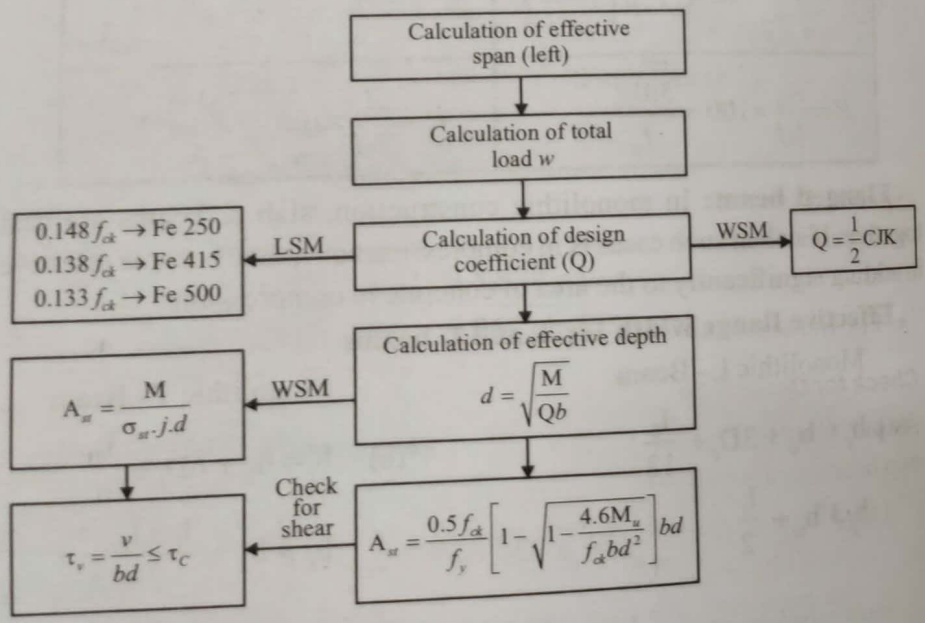
Isolated T - Beam

(d) $b_f = b_w + \dfrac{l_0}{\frac{l_0}{b}+4} \le b$



b_f = effective flange width

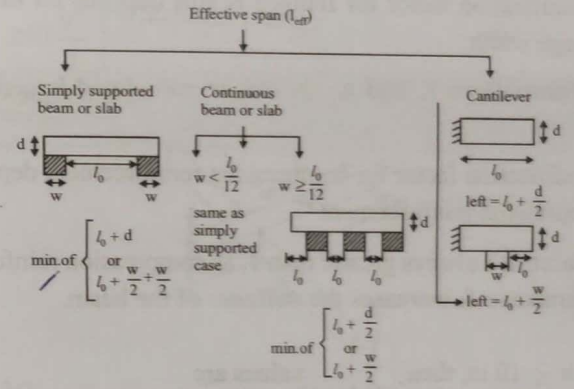
Special Point: Inverted beams are designed as rectangular beams, because slab in tension zone does not to resists any compression. These beams are recommended for architectural reqirement only.



Codal Provisions for Beam and Slab

3

Effective Span (L_{eff})



Special Points:

- In case of spans with roller or rocket bearings, the effective span shall always be the distance between the centres of bearings.
- For frames effective span is its centre distance between members.

Check for Deflection

As per Clause 23.2 of IS 456, stipulates the limiting deflections under two heads as given below:

(a) The *maximum final deflection* should not more than *span/250* due to all loads including the effects of temperature, creep & shrinkage & measured from the cast level of the supports of floors, roof & all other horizontal members.

(b) The *maximum deflection* should not more than the lesser of *span/350 or 20 mm* including the effects of temperature, creep & shrinkage occurring after erection of partitions & the application of finishes.

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Control of Deflection

$$\frac{\text{span}}{\text{depth}} < \left(\frac{l}{d}\right)_{basic} \times \frac{10}{\text{span}} \times K_t \times K_c \times K_f$$

where, K_t = modification factor for tension reinforcement depending upon area & stress of steel for tension reinforcement.

Special Point: This factor allows the designer to make shallow members by increasing area of tension reinforcement.

K_f = modification factor for flanged beams depends on ratio of web width to flange width.

Special Point: Here K_t and K_c should be calculated based on area $b_f d$.

K_c = modification factor for compression reinforcement depending on area of compression reinforcement

Special Point: It's always greater than 1, as compression reinforcement reduces shrinkage & increases the stiffness of the beam.

(1) If span $\leq$ 10 m, then $\left(\frac{l}{d}\right)_{basic}$ values are

Cantilever beam	7
Simply supported beam	20
Continuous beam	26

Type of slab	Type of reinforcement	
	Mild steel	Fe 415
Simply supported	35	$28 = 35 \times 0.8$
Continuous	40	$32 = 40 \times 0.8$

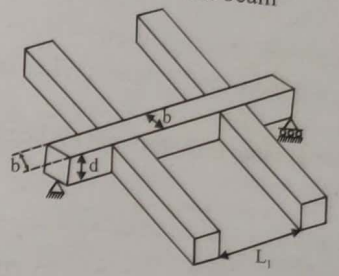
Where as $\left(\frac{10}{\text{span}}\right)$ factor is neglected.

(2) If span > 10 m, then $\left(\frac{10}{\text{span}}\right)$ factor is also multiplied (But if cantilever beam > 10 m, then actual deflection calculations should be made)

Slenderness Limits to Ensure Lateral Stability

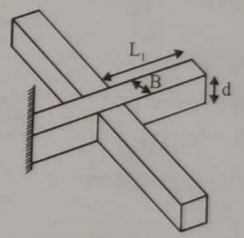
According to the IS code **456:2000 clause 23.3:**

1. For simple supported or continuous beam



$$\left.\begin{aligned} L_1 &\nless 60b \\ &\nless 250\frac{b^2}{d} \end{aligned}\right\} \text{Whichever is less}$$

2. For a cantilever



$$\left.\begin{aligned} L_1 &\nless 25b \\ &\nless \frac{100b^2}{d} \end{aligned}\right\} \text{Whichever is less}$$

Steel Reinforcement

Tension reinforcement

$$\frac{A_{st}\,min}{bd} = \frac{0.85}{f_y}$$

$A_{st}\,max = 0.04\,BD$ ← full section

Side face reinforcement:

As per IS 456 : 2000,

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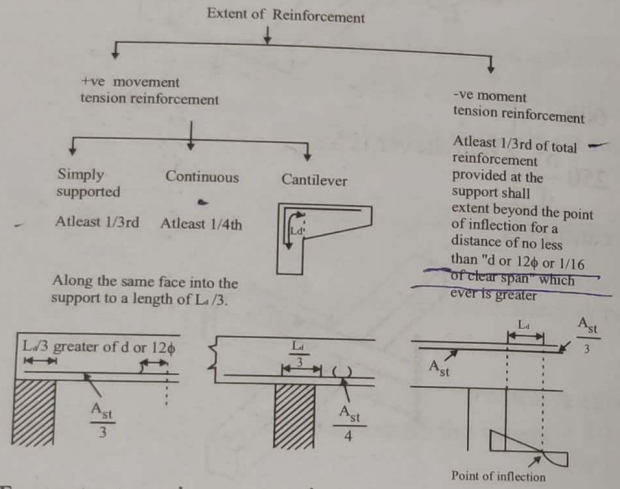
- Side reinforcement is provided 0.1% of web area equally distributed on both face.
- Maximum spacing of side face reinforcement = 300 mm or width of beam which ever less.
- Side face reinforement is provided when
  (a) Depth of beam is more than 750mm (When beam is not subjected to torsion)
  (b) Depth of beam is more than 450 mm (When beam is subjected to torsion)



Cover: To protect against corrosion

Environmental Condition	Minimum grade of conc.	Nominal cover
Mild	M20	20 mm
Moderate	M25	30 mm
Severe	M30	45 mm
Very severe	M35	50 mm
Extreme	M40	75 mm

Arrangement of loads in Continuous beams

(a) **For maximum span moment:** Dead load on all spans but live loads on alternate spans.

(b) **For maximum moment:** Dead load on all spans but live loads on two adjacent spans.

Types of load	At end support	At support next to the end support		At all other interior supports
		Outer side	Inner side	
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	0.4	0.6	0.55	0.5
Imposed load (not fixed)	0.45	0.6	0.6	0.6

Shear Coefficients

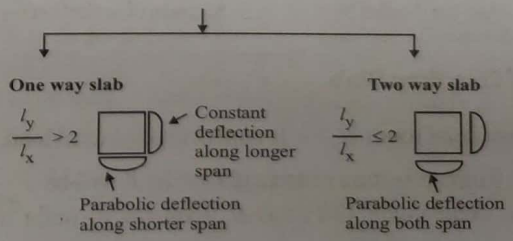
Types of load	Span moments		Support moments	
	Near middle of end span	At middle of interior span	At support next to the end support	At other interior supports
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	$+\frac{1}{12}$	$+\frac{1}{16}$	$-\frac{1}{10}$	$-\frac{1}{12}$
Imposed load (not fixed)	$+\frac{1}{10}$	$+\frac{1}{12}$	$-\frac{1}{9}$	$-\frac{1}{9}$

Moment Coefficients

Special Points: If the span of two sides of support are different or the loading are different then support moment will be calculated from both sides and average will be taken.

- Mild steel (Fe 250) is more ductile. Hence preferred for earthquake zones or where there are possiblities of vibration, impact, blast etc.
- Diameter of reinforcement bars generally available are 6, 8, 10, 12, 14, 16, 18, 20, 22, 25, 28, 30, 32, 36, 40 mm.

- **Slabs:** Plate elements having depth much smaller than its other two dimensions.
- They carry distributed load primarily by bending



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According to IS code 456:2000, clause 24.1 for slabs spanning in two directions, the shorter of the two spans should be used for calculating the span to effective depth ratios.

Special point: Even if $\frac{l_y}{l_x} \leq 2$ but the slab is supported only on two parallel edges, then it will be treated as one way slab.

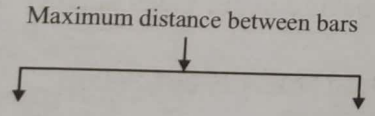
Minimum reinforcement in slabs (in either direction)

1. Fe 250 → 0.15 % of total cross-section area.
2. Fe 415/Fe 500 → 0.12% of total cross-sectional area.

Member	Max. reinforcement	Min. reinforcement
Column	6% of gross cross section area	0.8% of gross cross sectional area
Slab		0.15% for mild steel & 0.12% for HYSD bars
Beam	4% of gross section area for each compr-ession and tension	$\frac{A_{st_{min}}}{bd} = \frac{0.85}{f_y}$
Hanger bars in beams	0.2% of gross cross section area of beam	–
Side face reinforcement in beam	–	0.1% of the web area
Shear reincorcement	–	$0.87 f_y A_{Sv} \frac{d}{s_v} \geq 0.4bd$

Maximum diameter of reinforcing bar = $\frac{1}{8}$ × Depth of slab (D)

Maximum Distance between Bars



Main bar (bottom bar)
S = min (3d, 300 mm)

Secondary/distribution bar
S = min (5d, 450 mm)

Designs of One Way Slab

Given dimensions of room $(l_y \times l_x)$, superimposed/dead load, f_y, f_{ck}

1. Get 'd' from deflection criteria (Consider it will be $d_{provided}$).
2. Assume clear cover (20 mm) & diameter of main bar (10 mm), get D.

3. L_{eff_x} and L_{eff_y} from end conditions.
4. Check for one way or two way slab. If it is one way slab,
5. Then get factored Bending moment, $M_u = 1.5 \frac{Wl_{eff}^2}{8}$
   here w = (dead load + super imposed load) per metre of **width.**
6. Check for $d_{required}$
   $M_u \leq 0.36 f_{ck} x_{u\,lim} b (d - 0.42x_{u\,lim})$ where b = 1000 mm
   If d required < $d_{provided}$, Adjust values of $d_{provided}$ in such a way that slab remains under reinforced
7. Get A_{st} from, $M_u = 0.87 f_y A_{st} (d_{provided} - 0.42x_u)$
   where $x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} (1000)}$ b
8. Check for A_{st} min ($A_{st} > A_{st}$ min)
9. Spacing between bars = $\frac{1000}{\left(\frac{Ast}{\frac{\pi}{4}\phi^2}\right)}$
10. Get number of bars needed
11. Provide distribution bar similarly & check its spacing as per criteria.
12. Check for development length.
13. Design for shear.
14. Final diagram showing cross-section of slab & detail of bars and spacing in slab.

Design of Two way slab

Types of two way slab	Method of Analysis
1. Slab simply supported one the four edges, with corners not held down and carrying UDL	Grashoff-Rankine Method
2. Slab with edges fixed or continuous and carrying U.D.L.	I.S. Code method
3. Slab simply supported on the four edges with corners held down and	• Pigeaud's method • Marcus's method • I.S. Code method

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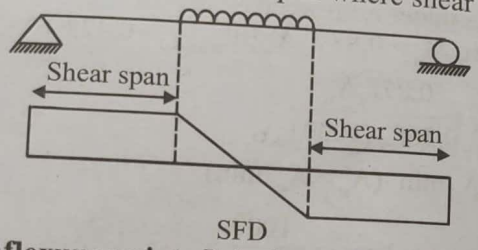
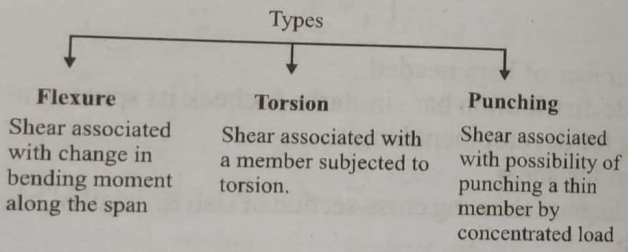
SHEAR

4

Shear span: Shear span is defined as span where shear force is constant.

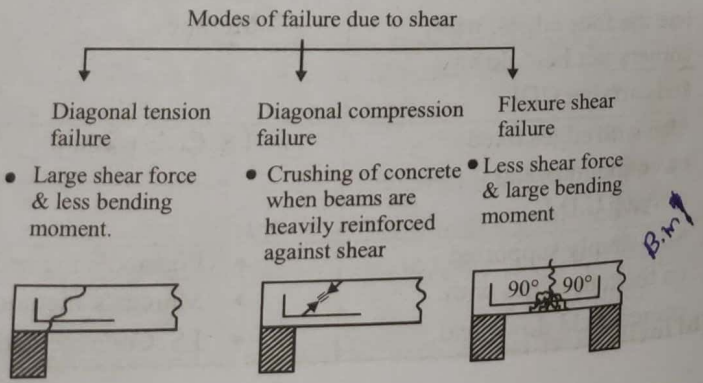


Note- Contraflexure point: It is the point on beam where bending moment changes its sign.

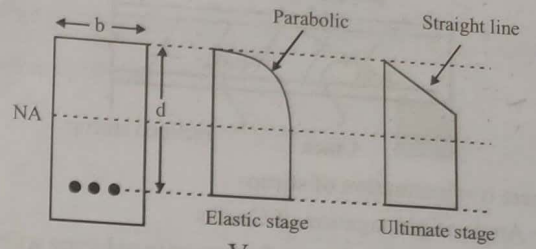


Special point: Flat slab is a **beam less** floor slab supported directly by columns.

Modes of Failure Due to Shear



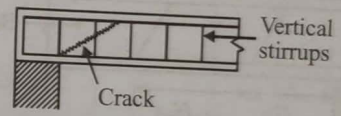
Shear stress distribution

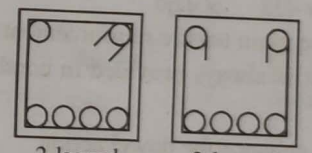


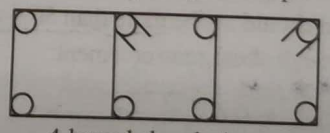
Nominal shear strength $(\tau_u) = \frac{V_u}{bd}$

- **Shear reinforcement can be provided in the form of:**
  (a) Vertical stirrups
  (b) Inclined stirrups
  (c) Bent up bars with vertical stirrups

(a) Vertical stirrups: These are best for load reversal case.







- It is the most effective in enhancing the shear resistance of beam
- Closed stirrups are better because it resist torsion & also helps in confining the compression reinforcement in doubly reinforced section and also reduces the chances of buckling of compression reinforcement.

(b) Inclined stirrups: It is ineffective in load reversal.

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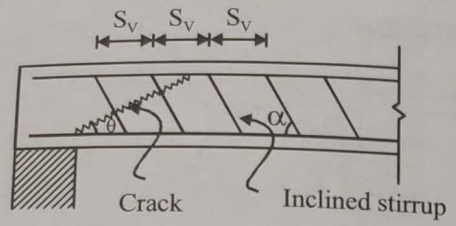


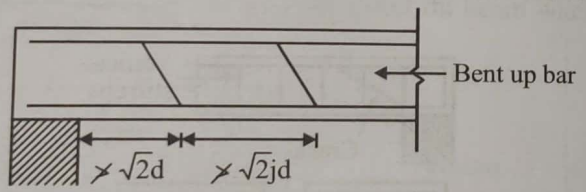
where α = Inclination of stirups

θ = Angle of propagation of Cracks

- It is the most effective reinforcement in reducing width of inclined cracks.
- It can be provided in member having axial tension resulting in full depth of inclined crack.

Note: $\alpha \neq 45°$, because for $\alpha < 45°$, there is a possibility of inclined stirrups slipping along the longitudual bars.

(c) Bent up bars



- These are the main tensile reinforcement bend at approapriate location & It is always provided in combination with vertical stirrups.
- They do not enhance the dowel action
- When bent up bars are provided, there shear resistance contribution should not be more than 50% of the total shear to be resisted through shear reinforcement.

Special points: $\tau_{cmax} \approx 0.63\sqrt{f_{ck}}$, $\tau_{cmax} > \tau$

τ_c depends on both f_{ck} and $A_{st.}$

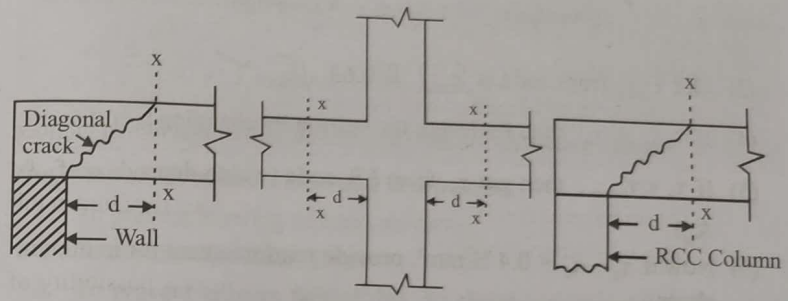
Maximum shear stress with shear reinforcement (τ_{cmax})

M	15	20	25	30	35	40 and above
LSM	2.5	2.8	3.1	3.5	3.7	4.0
WSM	1.6	1.8	1.9	2.2	2.3	2.5

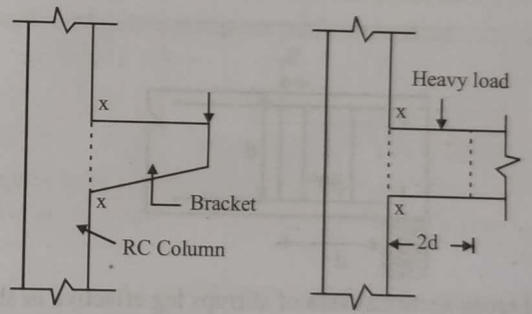
for LSM $\tau_{cmax} \approx 0.63\sqrt{f_{ck}}$, $\tau_{cmax} < \tau_u$

Special Point: τ_{cmax} depends only on concrete (f_{ck})

Critical Section for Shear



(a) Critical section X-X at d from the face of the support

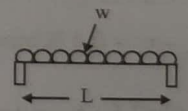


(b) Critical section X-X at the face of the support

Design for shear

(1) Get factored shear force V_u

$$V_u = 1.5\ V \text{ or } V_u = 1.5\left(\frac{wL}{2}\right)$$



(2) $\tau_u = \dfrac{V_u}{bd}$ or $\tau_u \dfrac{V_u \pm \dfrac{M_u \tan\beta}{d}}{bd}$ if

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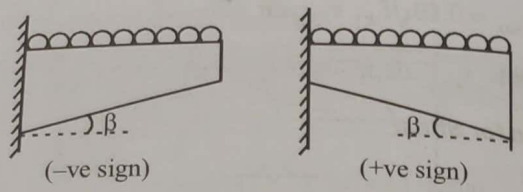


(–ve sign) (+ve sign)

(3) Get $\tau_{c\,max}$ from code or $\tau_{c\,max} \approx 0.63\sqrt{f_{ck}}$

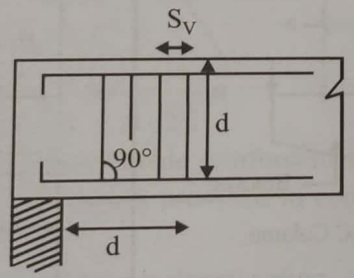
(4) If $\tau_{c\,max} < \tau_u$, then Redesign the section by changing b or d.

(5) If $\tau_u < \tau_{c\,max}$, then get τ_c from I.S. code (which depends on f_{ck} & A_{st})

(6) Now if $\tau_u - \tau_c < 0.4$ N/mm², provide reinforcement for minimum shear

$$\frac{d}{S_v}(0.87 f_y)\, A_{SV} = 0.4\, bd$$

Get S_V



A_{SV} = Total cross-sectional area of stirrups leg effective in shear.

$\frac{d}{S_V}$ = No. of stirrups till critical section for shear (till distance d from face of support (as S_V = spacing between strirrups))

f_y = yield strength of stirrup's subjected to maximum of 415 N/mm²

(7) If $\tau_u - \tau_c > 0.4$ N/mm² then get spacing S_V by

$$\frac{d}{S_V}(0.87 f_y)\, A_{SV} = (\tau_u - \tau_c)\, bd$$

(8) Check for maximum spacing of stirrups as per code

Max. S_V

$$\text{Minimum of} \begin{cases} 0.75\,d\,(\text{Vertical stirrups}),\ d\,(\text{Inclined stirrups}) \\ S_v \\ 300\ \text{mm} \end{cases}$$

Special point: For inclined stirrups or a series of bent up bars, we know

$$\left(\frac{d}{S_V}\right)(0.87 f_y)(\sin\alpha + \cos\alpha)\, A_{SV} = (\tau_u - \tau_c)\, bd$$

α = Angle of inclination of stirrups with the horizontal

Minimum shear reinforcement: It is provided

1. To prevent bursting of concrete cover.
2. To avoid brittle shear failure
3. To prevent tension failure due to shrinkage, thermal stresses and internal cracks.
4. To make the section effective with the tie effect.
5. To hold reinforcement in place while concreting.

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Bond and Anchorage

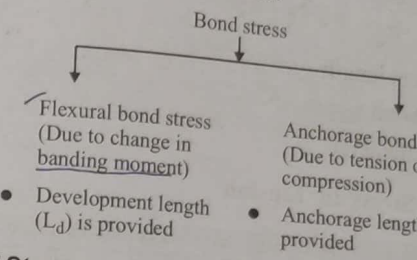
5

- The bond strength between steel & concrete can be defined as the resistance to longitudinal shear stress acting on the surface between steel & concrete.
- The bond strength is due to combined effect of frictional resistance, adhesive resistance & mechanical resistance (for deformed bars).
- The mechanical resistance is provided by deformed bars only.
- Adhesive resistance is provided by gripping of bars due to shrinkage.
- HYSD are deformed bar,the actual contact area of a bar increases as compared to contact area based on nominal diameter. So, bond strength increases if we use HYSD bars in place of mild steel bars.
- Allowable bond stress is increased by 60% for deformed bars.
- Increase in allowable bond stress reduces the development length requirement.

$$L_d = \frac{\phi\sigma_s}{4\tau_{bd}}$$

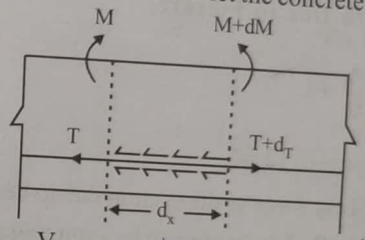
- The formula is applicable for mild steel bar in tension.
- For bars in compression, τ_{bd} is increased by 25 percentage.
- The most economical method to increase bond strength of beam is to use more number of thinner bars. By this way, we would be able to increase surface area of bars keeping the longitudinal or tension area of bars same. So, bond strength is increased without increased cost or material.
- **Following are the other methods for improving bond strength:**
  - (a) Increased grade of concrete.
  - (b) Using deformed bars in place of plain bars.
  - (c) Increases cover provided around each bar.
  - (d) Providing bends, hooks, mechanical anchorages.

(e) Any method which increases confinement around bar, would increases the bond strength of bar.



Flexural Bond Stress

It Develops along the length of a bar to let the concrete & steel act together.



$$\tau_{bd} = \frac{V}{jd(\Sigma O)} = \frac{V}{j \cdot d \cdot n\pi\phi} = \frac{dm}{dx \cdot j \cdot d \cdot n\pi \cdot \phi}$$

d = Effective depth of the section

V = Shear force at any section

ΣO = Summation of all perimeter of reinforcement

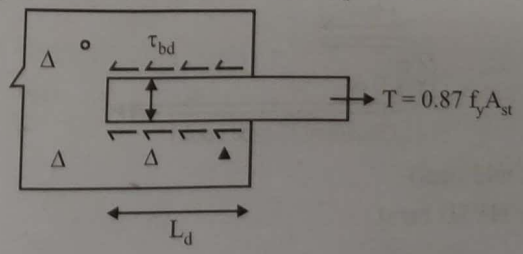
$\Sigma O = n(\pi\phi)$

ϕ = Diameter of reinforcement

n = Number of bars

Anchorage Bond Stress: (Due to tension)

It develops in the anchorage zone at the ends bar or at the cut off point of a bar within span of beam so that bars are not pulled out.



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$$L_d = \frac{0.87 f_y \phi}{4\tau_{bd}} = \frac{\phi \sigma_s}{4\tau_{bd}} \qquad A_{st} = \frac{\pi}{4}\phi^2$$

L_d = development length

τ_{bd} = Average bond stress

ϕ = Nominal diameter

Permissible Bond Stress in Tension

Grade of concrete	M20	M25	M30	M35	M40 and above
τ_{bd} (N/mm²)	1.2	1.4	1.5	1.7	1.9

Development Length Due to Flexure

$$L_d \le \frac{M_1}{V} + L_o$$

L_o = max (d, 12 ϕ)

V = Shear force at the section due to design load.

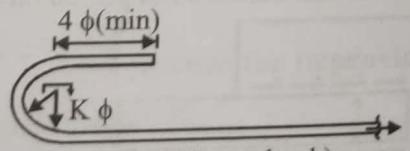
M_1 = MOR of the section to be assuming all reinforcement at the section to be stressed to 0.87 f_y

Special point: When the ends of the reinforcement are confined by compressive, then M_1 is increased by 30%

$$L_d \le \frac{1.3M_1}{V} + L_o$$

Bundled bars: The development length of each bundled bars shall be increased by 10% when two bars are bundled, by 20% when three bars are bundled & 33% when four bars are bundled. 33-4%

Bends and Hooks: The length of the straight portion of a bar beyond the end of the hook should be atleast 4 times the diameter.



(Standard U-type hook)

K = 2 (for mid steel)

K = 4 (for HYSD bars)

- As per IS 456- clause 26.2.5.1

Lap length including anchorage value of hooks for bars in flexural tension shall be L_d or 30ϕ (whichever is greater) and for direct tension shall be $2L_d$ or 30ϕ (which ever is greater). The straight length of the lap should not be less than 15ϕ or 200 mm

Lap Length in Compression: The lap length is equal to the development length calculated in compression but should not be less than 24ϕ.

Lap Length in Tension:

- For flexural tension -L_d or 30ϕ (whichever is greater)
- For direct tension- $2L_d$ or 30ϕ (whichever is greater)

As per IS 456 (clause 22.22.1(a))

The anchorage value of bend shall be taken as 4 times the diameter of the bar for each 45° bend subject to a maximum of 16 times the diameter of bars.

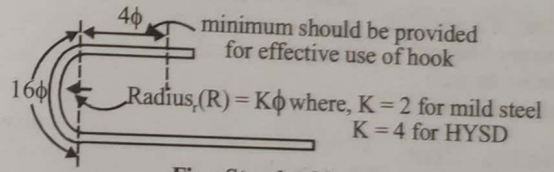


Fig.: Standard hook

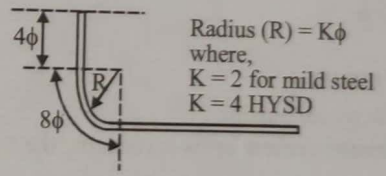


Fig.: Standard 90° hook

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Torsion 6

Equilibrium Torsion/ Primary Torsion	Compatibility Torsion / Secondary Torsion
• Torsion which can be determined only by using static equilibrium conditions	• It is induced in a structural member by rotation applied at one or more point along the length of member through inter connected members, instead of by diectly applied load.
• Also occurs in beams where the transverse loads are eccentric wrt the shear centre of the x-section	
• Torsion induced in beams curved in plan & subjected to gravity loads	

Effect of Torsional moment

(1) Beam fails in diagonal tension.
(2) Longitudinal reinforcement helps in reducing the crack width through **dowel action.**
(3) Longitudinal reinforcement is provided in the form of bars placed closed to the periphery but transvers reinforce-ment is in the form of closed rectangular stirrups placed perpendicular to the beam axis.
(4) Stirrups resist shear due to vertical loads and torsion.

Special point: As per IS code, clause 41, For design of torsion section located at a distance less than 'd' from the face of the support, may be designed for the same torsion as calculated at 'd' where 'd' is the effective depth.

The following shall apply for spacing of bars:
As per IS: 456,

(i) The horizontal distance between two parallel main reinforcing bars usually be should not less than the greatest of the following:
(a) The diameter of the bar if the diameter are equal.
(b) 5mm more than the nominal maximum size of coarse aggregate.
(c) The diameter of the larger bar if the diameter are unequal.
(ii) When there are two or more rows of bars, the bars shall be vertically in line & the minimum vertical distance between the bars shall be.
(a). 15 mm.
(b) The maximum size of bar whichever is greater.
(c) Two-thirds the nominal maximum size of aggregate.

Flat Slab

- A slab which is directly supported by column without beam or with/ without drops or with/without flared column is called flat slab and Monolathically casted with column.
- Main functions of Drop in flat slab is to resist shear
- Minimum thickness of flat slab should not less than 125 mm
- Maximum spacing between reinforcement in flat slab should not exceed 2x thickness of flat slab.
- Critical section for shear in the slab is $\frac{d}{2}$ distance away from the periph-ery of column. Where 'd' is the effective depth of flat slab.
- Permissible shear stress capacity in flat slab: $\tau'_c = K_s x \tau_c$

Where,

$$\tau'_c = 0.25\sqrt{F_{ck}} \text{ (in LSM)}, \quad \tau'_c = 0.16\sqrt{F_{ck}} \text{ (in WSM)}$$

$$k_s = 0.5 + \beta_c (\text{Where } K_s > 1.0), \quad \beta_c = \frac{\text{shorter side of column}}{\text{longer side of column}}$$

- Shear design in flat slab is required if nominal shear stear stress is ex-ceed the permissible shear but less than exceeding value is 1.5 τ_c ($\tau_c > \tau$)
- If stress are exceed 1.5 τ_c slab should be Redesign.

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Torsion

6

Equilibrium Torsion/ Primary Torsion	Compatibility Torsion / Secondary Torsion
• Torsion which can be determined only by using static equilibrium conditions	• It is induced in a structural member by rotation applied at one or more point along the length of member through inter connected members, instead of by diectly applied load.
• Also occurs in beams where the transverse loads are eccentric wrt the shear centre of the x-section	
• Torsion induced in beams curved in plan & subjected to gravity loads	

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- Permissible shear stress capacity in flat slab: $\tau'_c = K_s x \tau_c$

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- If stress are exceed 1.5 τ_c slab should be Redesign.

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Column 7

It is a compression member where slenderness ratio is greater than 3. If slenderness ratio is less than 3 it is termed as pedestal.

$$\text{Slenderness } (\lambda) \text{ ratio} = \frac{\text{Effective length}}{\text{Least lateral dimension}}$$

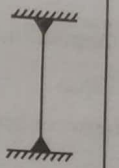
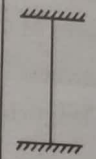
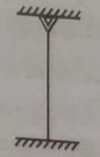
$\lambda < 12$ Short column, fails under ultimate loads by crushing

$\lambda \geq 12$ Long column, fails due to large lateral deflection under relatively low compressive loads.

Special Points:

- Construction joint is the interface between the different concrete placements.
- Location of construction joint should be planned in such a way that there should be considerable low Bending moment & shear force.
- In case of beams & slabs, they should be provided middle one third portion because of low BM and shear force.
- In case of column, they should be provided a few cm below the junction of beam & at the bottom hunching
- A beam is a structural member subjected to transverse loading (bending moment and shear force).
- Ties, struts, shafts and beams are all one-dimensional or line elements, where the length is much greater than the depth or width, & they have different names depending upon the main action they are designed to resist.
- *Shafts* resist *torque*.
- *Ties* and *strut* resist uniaxial *tension* and *compression respectively*.
- *Beam* resist *bending moment* and *shear force*.

Effective length of column: Length between the points of contraflexures of a buckled column.

End condition	One end fixed one end free	Both end Hinged	Both end Fixed	One end fixed one end Hinged
L_{eff} (Theoretical)	2L	L 	L/2 	$\frac{L}{\sqrt{2}}$ 
L_{eff} (As per IS code.)	2L	L	0.65L	0.8L

Minimum Eccentricity:

Rectangular section (generally square)

$$e_{x,min} = \max\left\{\frac{l_{ex}}{500} + \frac{D_x}{30},\ 20\text{ mm}\right\}$$

$$e_{y,min} = \max\left\{\frac{l_{ey}}{500} + \frac{D_y}{30},\ 20\text{ mm}\right\}$$

Non rectangular and non circular section

$$e_{min} = \max\left\{\frac{l_e}{300},\ 20\text{ mm}\right\}$$

Minimum longitudinal reinforcement:

1. **Pedestral with plain concrete columns:** 0.15% of gross section area
2. **Column:** 0.8% of gross cross section area
3. Concrete walls.
   (a) In general, 0.15% of gross cross sectional area
   (b) If wall thickness > 200 mm, two layers of vertical reinforcement needed.
   (c) If welded wire fabric or deformed bars (Fe 415/Fe 500), then 0.12% of gross cross-sectional area ($\phi < 16$mm)
   (d) Spacing of bars = min (3t, 450 mm)

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Maximum Longitudinal Reinforcement

- It is 6% of gross cross-sectional area of the column.
- Can even be reduced to 4% at lapped splice locations for better placement & compaction.

Other specifications

1. Minimum diameter of longitudinal bar = 12 mm
2. Column's Slenderness Limit
   (a) Unsupported length between end restrains $\not>$ 60 times least lateral dimension
   (b) If in any given plane one end of column is unrestrained, then its unsupported length $\not> \frac{100B^2}{D}$
3. Minimum Number of bars
   (a) For rectangular columns = 4
   (b) For circular columns = 6
4. Max centre to centre spacing of reinforcement = 300 mm
5. Cover to reinforcement
   (a) Minimum = 40 mm
   (b) Can be reduced to 25 mm for small sized column
   (c) Even in aggresive environment maximum cover is limited to 75 mm.

Lateral ties: Diameter is governed by criteria of stiffness not by strength. Hence, it is independent of grade of steel.

$$\text{Tie diameter } \phi_t \geq \begin{cases} \frac{\phi \text{longitudinal max}}{4} \\ 6 \text{ mm} \end{cases}$$

$$\text{Tie spacing } S_t \leq \begin{cases} D \\ 16\,\phi \text{ longitudinal min} \\ 300 \text{ mm} \end{cases}$$

Design of short column

1. Check for short column $\lambda < 12$
2. If $e_{min} \leq 0.05\,D$, then it is short axially loaded column

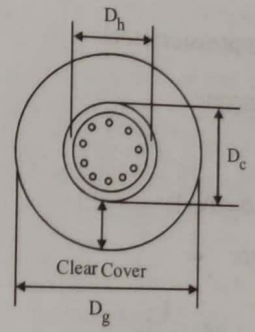
3. For A_{SC}
   a. For truly axially loaded column (e = 0)
   $P_u = 0.45\, f_{CK}\,(A_g - A_{SC}) + 0.75\, f_y\, A_{SC}$
   b. For short axially loaded column
   $P_u = 0.4\, f_{CK}\,(A_g - A_{SC}) + 0.67\, f_y\, A_{SC}$

Special point: It can also be used when member is subjected to combined axial load & biaxial bending and also used when $e < 0.05\,D$

4. Provide A_{SC} check for maximum & minimum reinforcement criteria, check for minimum diameter of longitudinal bar.
5. Provide lateral ties check for diameter & spacing.

Short axially loaded column with helical reinforcement

1. $P_u = 1.05\left(0.4\, f_{CK}\left(A_g - A_{SC}\right) + 0.67 f_y A_{SC}\right)$



2. Diameter of helical reinforcement should be selected such that

$$0.36\,\frac{f_{CK}}{f_y}\left(\frac{A_g}{A_C} - 1\right) \leq \frac{V_h}{V_c}$$

A_g = gross cross-sectional area = $\frac{\pi}{4}\left(D_g\right)^2$

Where, $D_c = D_g - 2d_c$

$$V_h = \frac{1000}{P} \times \pi D_h \times \frac{\pi}{4}\phi_h^2$$

D_h = diameter of helix

d_c = clear cover to tie distance

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p = pitch of helix

ϕ_h = diameter of helical reinforcement

V_c = Volume of core in unit length of column

$V_c = 1000 \times A_c$

3. Pitch $< \begin{cases} \dfrac{\text{core diameter}}{6} \\ 75 \text{ mm} \end{cases}$ pitch $> \begin{cases} 3(\text{diameter of tie}) \\ 25 \text{ mm} \end{cases}$

Design of column (WSM)

1. **For short column** $(\lambda < 12)$

$P_u = \sigma_{SC} A_{SC} + \sigma_{CC} A_C$

$A_c = A_g - A_{SC}$

σ_{SC} = Stress in compression steel

σ_{CC} = Stress in concrete

2. **For long column**

$P_u = C_r (\sigma_{SC} A_{SC} + \sigma_{CC} A_C)$

C_r = reduction factor

$\lambda \geq 12$, then $C_r = 1.25 - \dfrac{l_{eff}}{48b}$

l_{eff} = effective length

b = least lateral dimension

$\lambda > 50$, then $C_r = 1.25 - \dfrac{l_{eff}}{160 i_{min}}$

$i_{min} = \sqrt{\dfrac{I}{A}}$

i_{min} = least radius of gyration.

I = moment of inertia

A = cross-sectional area

Wall & FOOTING

8

Requirements of the Design of Foundation

(1) Avoid differential settlement.

(2) Foundation should sustain without exceeding safe bearing capacity of the soil.

Depth of Foundation: Minimum 50 cm (IS 1080 - 1962)

As per Rankine's Formula: $d = \dfrac{q_c}{\gamma}\left(\dfrac{1-\sin\phi}{1+\sin\phi}\right)^2$

d = minimum depth of foundation

γ = density of soil, ϕ = Angle of repose of soil

q_c = gross bearning capacity of soil

Design Considerations

1. Minimum Nominal Cover = 50 mm
2. Minimum Thickness at the edge of Footing
   (a) If footing rests on top of piles = 300 mm
   (b) If footing rests on soil = 150 mm
   (c) For plain Concrete pedestal footing without any longitudinal tension steel.

$\tan\alpha \leq 0.9\sqrt{\dfrac{100 q_o}{f_{ck}} + 1}$

q_o = Calculated maximum bearing

f_{CK} = Characteristic strength of concrete at 28 days in N/mm²

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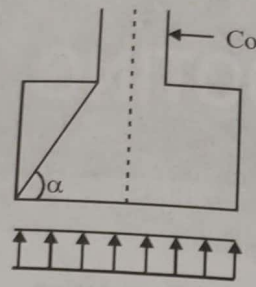


3. Critical section (maximum bending moment).
   a. Halfway between the centre-line & edge of the wall for footing under masonary wall.
   b. At the face of the column, pedestal or wall for footing supporting a concrete column, pedestal or reinforced concrete wall..
4. Critical section (one way shear).

Footing slab rests on	Distance from face of column, Pedestralor wall
Soil	d
Piles	d / 2

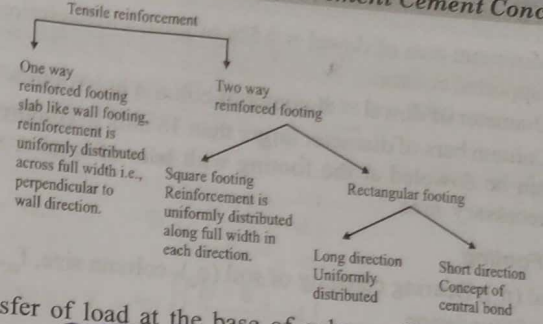
5. Critical section (two way shear) → It is at a distance d/2 around the column on a perimeter.
   Permissible shear stress when reinforcement is not provided should be less than $K_s \tau_C$

here K_s = Minimum $[1, (0.5 + \beta_C)]$, $K_s \leq 1$, $\beta_C = \dfrac{\text{Short side of column}}{\text{Long side of column}}$

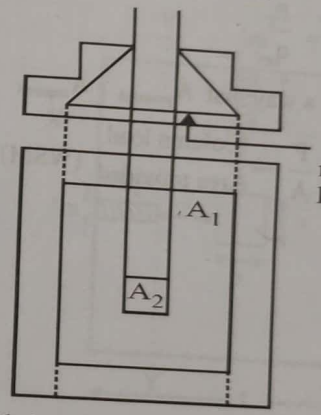
$$\tau_C = 0.25 \sqrt{F_{CK}}$$

Special Point: Generally, thickness of slab is governed by shear.

6. Critical section (checking development length) → in a footing slab be the same planes as those of bending moments.



8. Transfer of load at the base of column: Compression forces are transferred through direct bearing but tension forces are transferred through developed reinforcement.



Permissible bearing stress on full area of concrete

(a) WSM $\sigma_{br} = 0.25\, f_{CK}$

(b) LSM $\sigma_{br} = 0.45\, f_{CK}$

$$\sigma_{br} = 0.45\, f_{CK} \sqrt{\frac{A_1}{A_2}}, \text{ where } \sqrt{\frac{A_1}{A_2}} \leq 2$$

A_2 = loaded area at the base of the column.

A_1 = maximum supporting area of footing for bearing which is geometrically similar to and concentric with loaded area A_2

9. Dowel bars
   (a) Minimum number needed = 4

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(b) Minimum area of dowel = 0.5% of gross cross-sectional area of supported column.

(c) Diameter of dowel < diameter of column bar + 3 mm

(d) Column bars of diameter larger than 36 mm, in compression only can be doweled at the footing with bars of smaller size of the necessary area.

Design of Footing

Given: load (P_u), Bearing capacity of soil (q_u), column size, f_{ck}, f_y

1. Size of foundation

Column load = P, Foundation load (P_f) = 0.1P

Total load $P_T = P + 0.1P = 1.1P$ (also for LSM)

$$\text{Area reqired } (A_{required}) = \frac{P_T}{q_u}$$

Choose L & B in such a way that $A_{provided} > A_{required}$

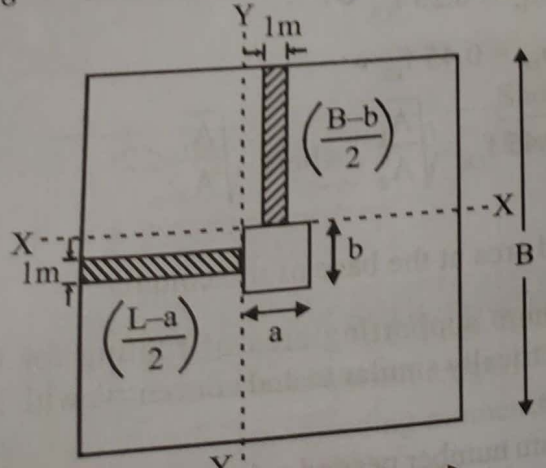
$$\text{Net soil pressure, } w = \frac{P}{A} = \frac{\text{Column load}}{\text{Area provided}} \text{ (WSM)}$$

$$w = \frac{1.5P}{A} \text{(LSM)}$$

2. Bending moment

$$M_x = \frac{w(B-b)^2}{8}$$

$$M_y = \frac{w(L-a)^2}{8}$$



Special point: For LSM it is 1.5 w

3. Get required depth 'd' (generally take b = 1000 mm)

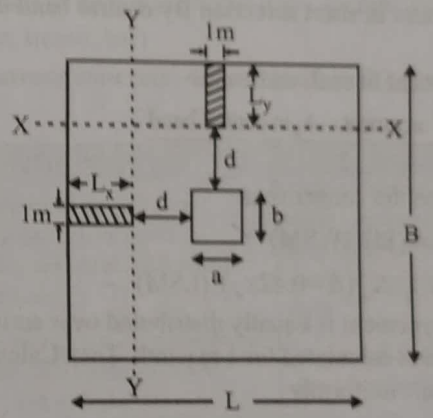
$M_{max} = Qbd^2$ (LSM)

4. One way shear check

$$V_y = W.1 \times L_x = W\left[\left(\frac{L-a}{2}\right)-d\right]$$

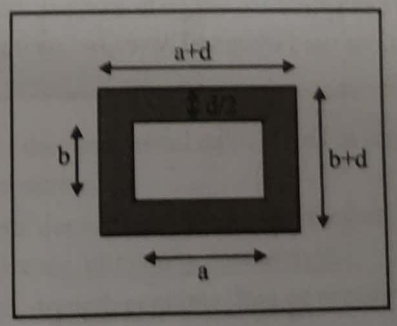
$$V_x = W.1 \times L_y = W\left[\left(\frac{B-b}{2}\right)-d\right]$$

$$V_{max} = \max\left(V_x, V_y\right)$$



Nominal shear stress $\tau_V = \frac{V_{max}}{Bd}$ (τ_c is taken from IS 456:2000)

5. Two way shear check



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$$\text{Punching stress developed} = \frac{\text{Net punching force}}{\text{Cross} - \text{sec tion resisting area}}$$

Net punching force, $P_{net} = P - W\,(a + d)\,(b + d)$

Cross-section resisting area $= 2\,((a + d) + (b + d)) \times d$

Punching stress developed < Permissible punching stress

6. Area of steel for shorter span

$M_x = \sigma_{st}\, A_{st}\, jd$, (WSM)

$M_{ux} = 0.87\, f_y\, A_{st}\,(d - 0.42x_u)$, (LSM)

This A_{st} is provided in the central band width B you can find total reinforcement in short direction By central band concept formulae also.

Reinforcement in each end bands=

$$\frac{\text{Total reinf orcement} - A_{st}\text{ in central band}}{2}$$

7. Area of steel for longer span

$M_y = A_{st}\,(\sigma_{st} jd)$ (WSM)

$M_{uy} = 0.87\, f_y\, A_{st}\,(d - 0.42x_u)$ (LSM)

This reinforcement is equally distributed over entire width B. Here area of steel is calculated for 1 m width. Then Calculate for width B, then distribute uniformly

Special Points:

- When the column ends Machined & smoothened, then splice are design to take 50% of total load transfer between two member.
- When the ends of column are not machined & smootheded for complete bearing, Then splice are design to transfer 100% of load.
- Grillage foondations used when soil have low bearing capacity & heavy loads on column.

Pre-Stressed Concrete Basic

9

- A concrete in which internal stress of suitable magnitude & distribution are introduced so that stress resulting from external load are counteracted to a desired degree.

Tendon: It is used to impart prestressed to concrete. (streched element in the form of wire, strand, bar)

Types of pre stress concrete: (a) pre tension (b) post tension

	Pre – tensioning	Post – tensioning
Stages	Anchoring of tendons, place ing jacks, applying tension, casting concrete & finally cutting of tendons.	Casting of concrete, placing tendons, placement of anch – orage block & jack, applying tension to tendons & finally seating w – edges
Devices	Prestressing bed, Jack Anchoring device, End Abutments, Shuttering / mould, Harping device	Casting bed, Ducts, mould / Shuttering, Anchoring devices, Jacks.
Advantages	• Suitable for Bulk production • Do not required Large Anchorage device	• Heavy cast in place members can be easily post – tensioned • Transfer of prestress is independent of length • Less waiting period in casting bed
Disadvan – tages	• Good bond is neccessary between transmission length. • Prestressing bed required	• Re quirement of anchorage de – vice & grouting equipment.

Anchorage: It is the mechanical device used to impart & maintain the prestressed in the concrete.

- High strength concrete results in reduction of cross-sectional dimensions. Hence, ultimately dead weight.
- By using high strength concrete, loss of prestress can be reduced.

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Special Points: In pipes or liquid storage tanks the hoop tensile stresses can be effectively counteracted by circular prestressing.

- Normally, due to creep and shrinkage loss in strain approximately 0.0008. So, stress loss is $0.0008 \times 2 \times 10^5 = 160$ N/mm². Hence, recommended high strength steel
- **Advantages:** Full section is utilised as section remains uncraked at service load, high span over depth ratio is possible, shear resistance capacity is increased, increases speed of construction.

Limitations: Skilled technology, high cost, better quality control

Types of pre-stressing

Source of force	Time of force application	Place of force application	Profile of cable tension
• Hydraulic • Mechanical • Electrical • Chemical	• Pre tensioning • Post tensioning	• External (bridges) • Internal (Sleepers)	• Linear (Beams, Poles) • Circular (Tanks, silos)

As per IS:1343-1980

Type 1 (Full-prestressing)	Type 2 (Limited Prestressing)	Type 3 (Partial Prestressing)
• No tensile stress in concrete under service loads	• Tensile stress under service loads is within permissible limits	• Tensile stress due to service loads, the crack width remains within allowable limit.

Partial prestression: When the level of prestressing is such that, the tensile stress due to service loads, crack with is within allowable limit called type II prestressing or partial prestressing.

In it, Tension as well as cracks are allowed within limits

Post-tensioning system

System (Country)	Type of tendon	Range of force	Arrangement of tendons in duct	Type of Anchorage
Freyssinet (France)	Wires & stands	Medium Large	Annular, spaced by helical wire core.	Concrete wedge
Lee-mc-call (Great Britain)	Bar threaded at ends	Small medium large	Single bars	High strength nut
Gifford-method (Great Britain)	Wires	Small medium	Evenly spaced by perforated spacers	Split Conical wedge
Magnel-Blaton (belgium)	wires	Small medium large	Horizontal rows of four wires spaced by metal griller	Flat steel wedge in sandwich plates

Long time method (Hoyer method) is most commonly used for prestressing for factory made products. It is generally used for small repetitive types of members.

Ex. P.S.C. railway slipper, electric poles etc.

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IS Code Recommendations for Pre-Stressed Concrete

10

1. Grade of concrete
   M 40 for pre tensioned members
   M30 for post tensioned members
2. Flexure tensile strength $F_{cr} = 0.7\sqrt{f_{ck}}$
3. **Design mix:** Only 'design mix concrete' can be used with cement content preferably less than 530 kg/m³
4. Short term modulus of elesticity $E_c = 5000\sqrt{f_{ck}}$ (As per IS 456:2000)
   $E_c = 5700\sqrt{f_{ck}}$ (As per IS 456:1978)
5. Modulus of elasticity of steel

Type of steel	$E_S\left(kN/mm^2\right)$
Plain cold drawn wires	210
High tension steel bars rolled or heat	200
Strands	195

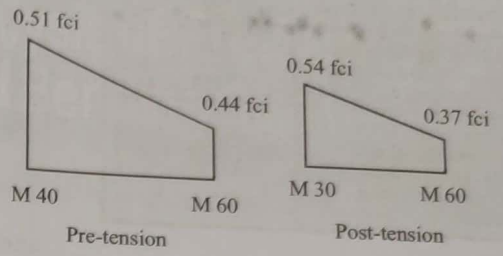
Special Point: Minimum cement content = 300 to 360 kg/m³ (Durability purpose)

6. **Minimum cover:**

Pre-tensioned work	20 mm
Post-tensioned work	max (30 mm, size of cable)

Special Point: For pre tensioned work in aggresive environment cover shall be increased by 10 mm.

7. Allowable stresses in concrete
   (a) Allowable compressive stresses under flexure



where f_{ci} = cube strength at transfer

(b) Allowable tensile stresses under flexure

Type 1	No tensile Stress
Type 2	$3N/mm^2$ can be increased to $4.5\ N/mm^2$ for temporary loads
Type 3	Table 8 of IS 1373 : 1980 prov – ides hypothetical values

(c) **Allowable compressive stresses under direct compression:** 80% of the compressive stress under flexure

(d) **Maximum Initial Prestress:** Should be such that, maximum tensile stress immediately behind the anchorage should not exceed 76% of the ultimate tensile strength of wire

8. Spacing of tendons
   (a) For single wires = max
   $\left(3d, \frac{4}{3}(\text{max aggregate size})\right)$
   (b) For grouped cables
      (i) Minimum horizontal spacing = max (40 mm, 5 mm + max aggregate size)
      (ii) Minimum vertical spacing = 50 mm.
   (c) For cable or large bars = max (40 mm, max. size of cable, 5 mm + max aggregate

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9. Maximum deflection allowable

(a)	Final deflection due to loads including effect of temp, shrinkage, creep	$\frac{\text{span}}{250}$
(b)	Deflection including effect of temp. shrinkage, creep accuring after partition erection and application of finishes	$\min\left(20\text{ mm}, \frac{\text{span}}{350}\right)$

Analysis of Pre-Stress And Bending Stresses

11

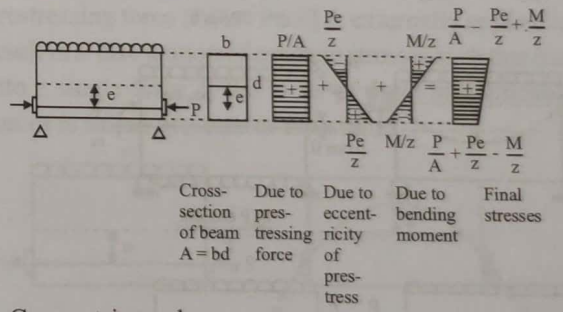
Assumptions:

1. Concrete is homogenous, elastic material.
2. Stress variation in steel due to external load is negligible.
3. Within working stresses, Hooke's law is valid.
4. Plane section before bending remains plane after bending.
5. Stress in reinforcement does not change along the length of member.

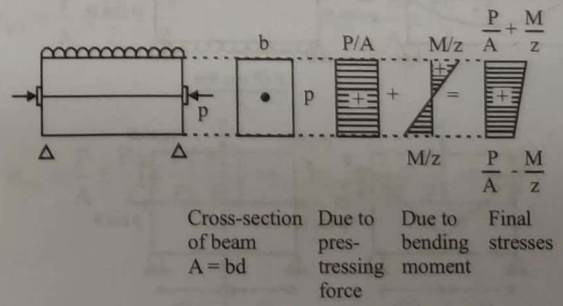
Analysis of Members Under Flexure

1. Stress concept

(a) Eccentric tendon



(b) Concentric tendon



$$\text{Load factor against cracking} = \frac{\text{Live load required for cracking}}{\text{Live load actually acting}}$$

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$$= \frac{\text{Live load moment required for cracking}}{\text{Actual live load moment}}$$

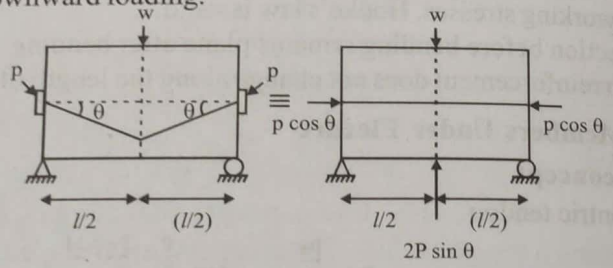
Load factor against cracking wrt total load

$$= \frac{\text{Total load causing cracking}}{\text{Total load actually acting}}$$

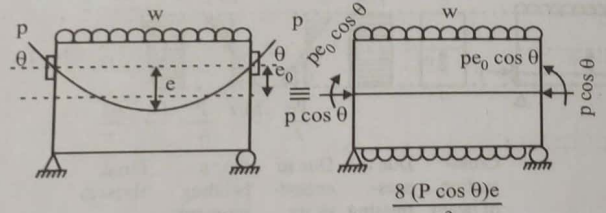
$$= \frac{\text{Total Bending moment required to cause cracking}}{\text{Total Bending moment actually acting}}$$

2. **Load Balancing Concept:** Bent tendon exerts an upward pressure on the concrete beam & so counteract a part or whole of the external downward loading.

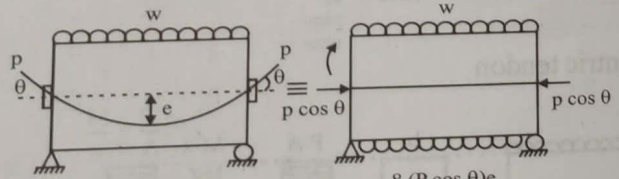
(a)



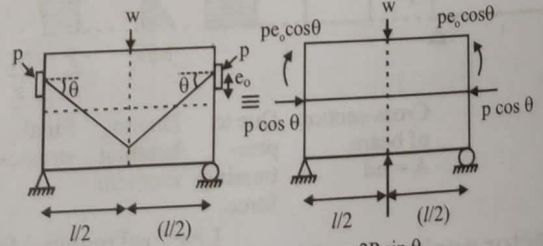
(b)



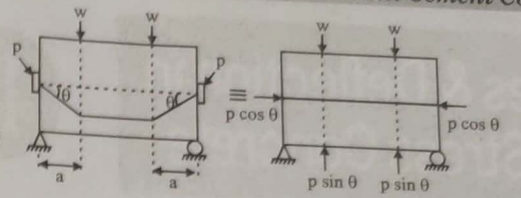
(c)



(d)



(e)



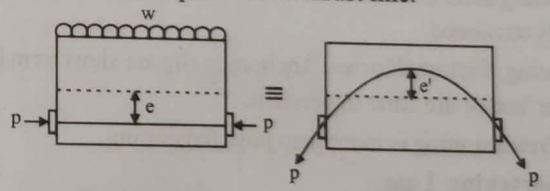
$$p \sin\theta \approx P \tan\theta = \frac{Pe}{a}$$

Special Point:

Equation of Parabolic profile is $y = \frac{4ex(l-x)}{l^2}$

Type of load	Bending moment diagram	Cable profile
Point load	Triangular	Triangular
Two point load	Trapezoidal	Trapezoidal
Udl	Parabolic	Parabolic

3. **Thrust line or pressure line concept:** The combined effect of prestressing force (P/A + Pe/Z) & externally applied load (M/Z) will result in a distribution of concrete stresses such that it can be revolved into a single force & the locus of point of application of resultant forces is called pressure or thrust line.



$$\sigma_{b/t} = \frac{P}{A} \pm \frac{Pe}{Z} \mp \frac{M}{Z} \qquad \sigma_{b/t} = \frac{P}{A} \pm \frac{Pe'}{Z}$$

$$\downarrow \qquad \uparrow$$

$$\sigma_{b/t} = \frac{P}{A} \pm \frac{Pe}{z} \mp \frac{P}{Z}\left(\frac{M}{P}\right) \rightarrow \sigma_{b/t} = \frac{P}{A} \mp \frac{P}{Z}\left(-e + \frac{M}{P}\right)$$

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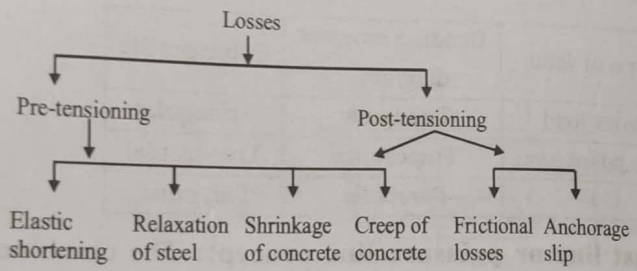
Losses & Deflection in Pre-Stress Concrete

12

Various reductions of prestressing force are termed as losses in prestress.



- There may be losses due to sudden change in temperature, especially in steam curing of pretensioned units.
- In Post-tensioning there is no loss of elastic shortening when all bars are simultaneously tensioned.
- Elastic shortening, frictional losses, Anchorage slip are short term losses where as other losses are time dependent.
- Total loss in Pretensioning is more than post tensioning.

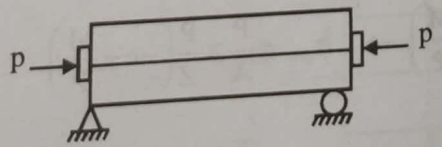
1. Elastic Shortening Loss

(a) Pre-tensioned members, Pre-stressing loss = m × f_c average

here m = modular ratio

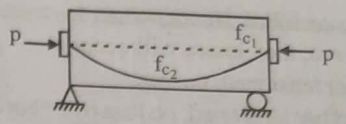
f_c average = stress in concrete at the level of tendon

(i)



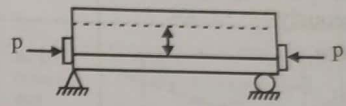
$$\Delta f_s = m\left(\frac{P}{A}\right) \text{ as } e = 0$$

(ii)



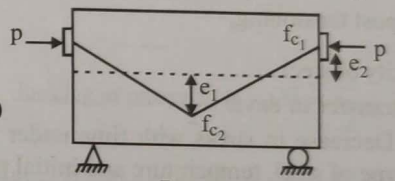
$$\Delta f_s = m\left[f_{c_1} + \frac{2}{3}\left(f_{c_2} - f_{c1}\right)\right]$$

(iii)



$$\Delta f_s = m\left[\frac{P}{A} + \frac{Pe.e}{I} - \frac{M_d.e}{I}\right]$$

(iv)

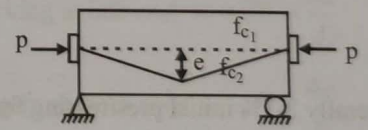


$$\Delta f_s = m\left[\frac{f_{c_1} + f_{c2}}{2}\right]$$

$$f_{c_1} = \frac{P}{A} - \frac{Pe_0.e_0}{I}$$

$$f_{c_2} = \frac{P}{A} + \frac{Pe_0.e_1}{I} - \frac{M_d e_1}{I}$$

(v)



$$\Delta f_s = m\left(\frac{f_{c_1} + f_{c_2}}{2}\right)$$

$$f_{c_1} = \frac{P}{A}$$

$$f_{c_2} = \frac{P}{A} + \frac{Pe.e}{I} - \frac{M_d e}{I}$$

(b) Post-tensioned members: In case of single tendon, there is no loss because the applied prestress is recorded after the elastic

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shortening of the member. Hence, when bars are successively tensioed & anchored, then losses will occur as

(a) When first bar tensioned, no loss

(b) When second bar tensioned, no loss in 2nd but loss in 1st bar

(c) When third bar tensioned, no loss in 3rd but loss in 1st and 2nd bar,

The same concept of averaging will be used when bars are not stretched simultaneously.

3. Shrinkage of concrete

Loss of stress = $\varepsilon_{ss} \times E_s$

ε_{ss} = Total residual shrinkage strain = 3×10^{-4} for pretensioning,

$= \dfrac{2\times10^{-4}}{\log_{10}(t+2)}$ for post tensioning,

E_s = Modulus of elasticity of steel.

t = age of concrete at transfer in days.

2. **Relaxation of steel:** Decrease in stress with time under constant strain. It depends on type of steel, temperature and initial prestress, generally, it is taken as 2 to 5% of initial stress in steel.

4. **Creep of concrete:**

Loss of stress = $m\ \phi f_c$

ϕ = creep-coefficient = $\dfrac{\text{ultimate creep strain}}{\text{elastic strain}}$

$m = \dfrac{E_s}{E_c}$

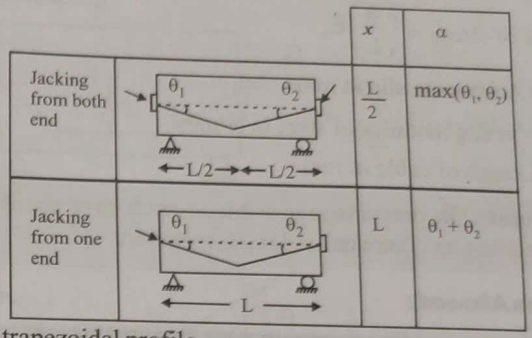
Creep losses are generally 2-3% initial prestressing force.

Creep Coeff.	Day
2.2	7
1.6	28
1.1	365

5. **Frictional losses:**

Loss of stress = Initial stress $(\mu\alpha + Kx)$ μ = Coefficient of friction in curve (Generally 0.25 to 0.55)

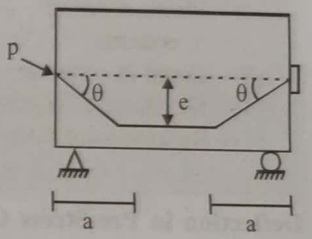
K = Wobble correction factor (0.0015 to 0.0050 per metre length of tendon)



• For trapezoidal profile

Jacking at one end, $\alpha = 2\theta = \dfrac{2e}{a}$

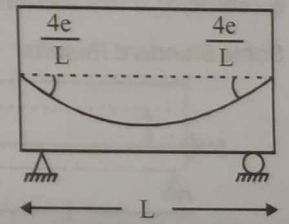
Jacking from both ends $\alpha = \theta = \dfrac{e}{a}$



For parabolic profile,

Jacking at one end, $\alpha = 2\theta = \dfrac{8e}{L}$

Jacking from both ends $\alpha = \theta = \dfrac{4e}{L}$



Special Point: In Pre tensioned members, as there is no concrete during stretching of tendons, hence this loss doesn't occur.

Wobling effect: It is local deviation due to unevenness of duct surface and can not be eliminated.

- In post tensioned members, frictional loss is generated due to curvature of tendon and vertical component of prestressing force.

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6. Anchorage slip:

$$\text{Loss of stress} = \left(\frac{\Delta}{L}\right)E_s$$

Δ = Anchorage slip in mm

E_s = young modulus of steel in N/mm²

L = Length of cable in mm

Special Point: The percentage loss due to anchorage slip is higher for shorter members as compared to longer members.

Total Losses Allowed :

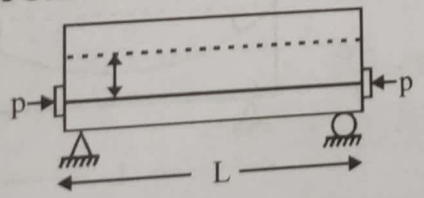
	Total of Loss	Pretensioned	Post tensioned
(1)	Elastic shorting of concrete	3%	1%
(2)	Creep in concrete	6%	5%
(3)	Shrinkage of concrete	7%	6%
(4)	Relaxation of steel	2%	3%
		18%	15%

Deflection in Pre-Stress Concrete

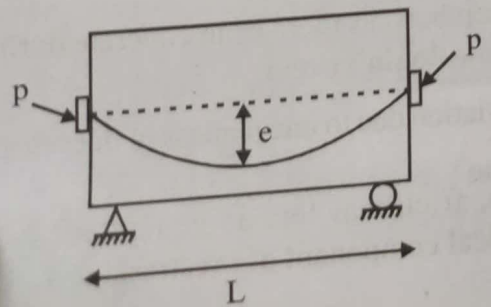
Short term deflection under uncracked condition can be computed using elastic theory by using area moment method (Mohr's method).

Bending moment at any section is the product of prestressing force & eccentricity at that section.

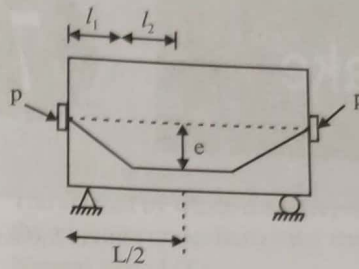
Some Standard Results



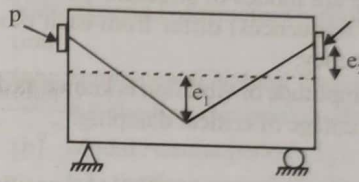
$$\Delta = \frac{-PeL^2}{8EI}$$



$$\Delta = \frac{-5}{48}\frac{PeL^2}{EI}$$



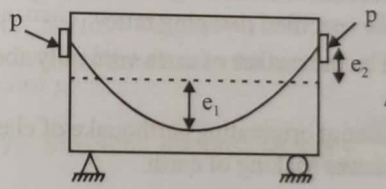
$$\Delta = \frac{-Pe}{6EI}\left(2t_1^2 + 6t_1t_2 + 3t_2^2\right)$$



$$\Delta = \left[\frac{-PL^2}{12EI}(e_1 + e_2)\right] + \left[\frac{Pe_2L^2}{8EI}\right]$$

Special Point: Downward deflection due to self wt or imposed load is

$$\frac{5w}{384}\frac{L^4}{EI}$$



$$\Delta = \left[\frac{-5}{48}\frac{PL^2}{EI}(e_1 + e_2)\right] + \left[\frac{Pe_2L^2}{8EI}\right]$$

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Earthquake 7

Mode → State of vibration

1. Closely spaced modes: These are modes of structure whose natural modes of vibrations (natural frequences) differ from each other by 10% or less of the lower frequency.
2. Damping → Reducing in the amplitude of vibration is known as damping and it is expressed in percentage of critical damping.
3. Critical damping
   Damping beyond which free vibration motion will not be oscillatory.
4. Design basis Earthquake (DBE)
   Means, the earthquake can be expected to occur atleast once during the design life of structure.
5. Design acceleration spectrum
   It is a plot between maximum acceleration as a function of frequency and time period of vibration for specified damping ratio.
6. Epicentre → This is the point on the surface of earth vertically above the focus of Earthquake.
7. Focus → This is the actual point of originating earthquake of elastic waves inside of earth which causes shaking of earth.
8. Importance factor (I)
   It is the structure which is use in designing of structure, that is provided to building according to (importance) functional use.
9. Intensity of Earthquake
   Intensity of earthquake is a measure of strength by how much it shakes the earth and it is indicated by number according to mercalli scale or MSK scale.
10. **Magnitude of Earthquake:** Measured by Ritcher magnitude scale
    It is defined as logarithm to the base of 10 of maximum trace amplitude expression in microns. It register due to earthquake at an epicentral distance of 100 km.
11. Ductility
    Capacity of structure to undergo large inelastic deformation without significent loss of strength or stiffness.
12. Max. considered Earthquake (MCE)
    The most severe earthquake effects the structure acc. to IS code 1893 (Part I)

2002.

13. Modal participation factor (P_K)
    The amount by which mode(K) contributes to the overall vibration of the sturcture under horizontal and vertical ground motion.
14. Natural Period (T)
    Natural period of structure is its times period of undamped free vibration.
    (a) Fundamental Natural Period (T_1)
        It is the first (longest) modal time period of vibration.
    (b) Modal Natural period (T_K)
        It is the time period of vibration in mode (K).
15. Response reduction factor (R)
    It is the factor by which actual base shear force that would be reduced to obtain design lateral force.
16. Seismic Mass
    Seismic weight divided by acceleration due to gravity.
17. Structural response factors $\left(\frac{S_a}{g}\right)$
    It is the factor denoting the acceleration response spectrum of the structure which is subjected to earthquake ground vibration.
18. Zone factor
    It is the factor to obtain design spectrum in the zone in which structure is located, which is - characterised by (MCE) Mod. considered earthquake.
19. Zero Period Acceleration (ZPA)
    Value of acceleration response spectrum for period below 0.03 sec (Frequencies above 33Hz)

Point → Earthquake is not likely to occur simultaneously with wind or max. flood.

- Load Combination (As per IS 1893: 2002 Part I)
  (1) Load factors for plastic design of steel structure.
  - 1.7 (DL + IL) = DL (Dead Load)
  - 1.7 (DL ± EL) = LL (Live load)
  - 1.3 (DL + IL ± EL) = EL (Eathquake load)

  (2) Load factors for limit state design of reinforced concrete and pre stress concrete structure.
  - 1.5 (DL + IL)
  - 1.2 (DL + IL ± EL)
  - 1.5 (DL ± EL)
  - 0.9 DL ± 1.5 EL – In case of critical situation of overturning.
- **Design Acceleration Spectrum**

(1) Our country is classified into four seismic zones. (Zone II, Zone III, Zone IV and Zone V).

Earlier zone I is merged with zone II

2.) The design horizontal seismic coefficient A_h for a structure shall be determined by:

$$A_h = \frac{\left(\frac{Z}{2}\right)\left(\frac{S_a}{g}\right)}{\left(\frac{R}{I}\right)}$$

where Z = seismic zone factor

I = importance factor given in IS 1893 (Parts 1 to 5) for the corresponding structures; when not specified, the minimum values of I shall be,

a) 1.5 for critical and lifeline structures;
b) 1.2 for business continuity structures; and
c) 1.0 for the rest.

R = response reduction factor given in IS 1893 (Parts 1 to 5) for the corresponding structures; and

$\left(\frac{S_a}{g}\right)$ = design acceleration coefficient for different soil types, normalized with peak ground acceleration, corresponding to natural period T of structure (considering soil-structure interaction, if required). It shall be as given in Parts 1 to 5 of IS 1893 for the corresponding structures; when not specified, it shall be taken as that corresponding to 5 percent

- **Value of Z. (Zone factor)**

Seismic zone	II	III	IV	V
Seismic intensity	Low	Moderate	Severe	Very Severe
Z	0.10	0.16	0.24	0.36

- **I = Importance factor**

Depends upon functional use of structure.

It's value is more than school, Railway station than normal residence.

Sl. No.	Structure	I
(1)	(2)	(3)
i)	Important service and community buildings or structures (for example, critical governance buildings, schools), signature buildings, monument buildings, lifeline and emergency buildings (for example, hospital buildings, telephone exchange buildings, television station buildings, radio station buildings, bus station buildings, metro rail buildings and metrorail station buildings), railway stations, airports, food storage buildings (such as	**1.5**

warehouses), fuel station buildings, power station buildings, and fire station buildings), and large community hall buildings (for example, cinema halls, shopping malls, assembly halls and subway stations)

ii) Residential or commercial buildings [other than those listed in Sl No. (i)] with occupancy more than 200 persons **1.2**

iii) All other buildings **1.0**

Some important points:

1. The designer should adopt more values than the given I value.
2. This does not apply to temporary structure like excavation, scaffolding of short duration.
   - R = Response reduction factor
     Characterised by ductile or brittle deformation.

$$Ratio\left(\frac{I}{R}\right) \not> 1.0$$

3. For underground structure and foundation at depth of 30 m or below, the value of A_h will be takes as half of itself. For structure and foundation placed b/w the ground land and 30m, the value of A_h will be linearly interpolated between A_n & it's half ($0.5A_n$).
4. Design Aceleration spectrum for vertical motion may be taken as (2/3) of design horizontal acceleration. $A_v = \frac{2}{3}A_h$

   - Value of $\left(\frac{S_a}{g}\right)$

a) For use in equivalent static method

$$\frac{S_a}{g} = \begin{cases} \text{For rocky or hard soil sites} & \begin{cases} 2.5 & 0 < T < 0.40\ s \\ \frac{1}{T} & 0.40\ s < T < 4.00\ s \\ 0.25 & T > 4.00\ s \end{cases} \\ \text{For medium stiff soil sites} & \begin{cases} 2.5 & 0 < T < 0.55\ s \\ \frac{1.36}{T} & 0.55\ s < T < 4.00\ s \\ 0.34 & T > 4.00\ s \end{cases} \\ \text{For soft soil sites} & \begin{cases} 2.5 & 0 < T < 0.67\ s \\ \frac{1.67}{T} & 0.67\ s < T < 4.00\ s \\ 0.42 & T > 4.00 s \end{cases} \end{cases}$$

b) For use in response spectrum method

$$\frac{S_a}{g} = \begin{cases} \text{For rocky or hard soil sites} & \begin{cases} 1+15T & T < 0.10\ s \\ 2.5 & 0.10\ s < T < 0.40\ s \\ \dfrac{1}{T} & 0.40\ s < T < 4.00\ s \\ 0.25 & T > 4.00\ s \end{cases} \\ \text{For medium stiff soil sites} & \begin{cases} 1+15T & T < 0.10\ s \\ 2.5 & 0.10\ s < T < 0.55\ s \\ \dfrac{1.36}{T} & 0.55\ s < T < 4.00\ s \\ 0.34 & T > 4.00\ s \end{cases} \\ \text{For soft soil sites} & \begin{cases} 1+15T & T < 0.10\ s \\ 2.5 & 0.10\ s < T < 0.67\ s \\ \dfrac{1.67}{T} & 0.67\ s < T < 4.00\ s \\ 0.42 & T > 4.00s \end{cases} \end{cases}$$

- **Value of R (Reduction factor)**

Sl.No.	Lateral Load Resisting System	R
i)	**Moment Frame Systems**	
a)	RC buildings with ordinary moment resisting frame	**3.0**
b)	RC buildings with special moment resisting frame	**5.0**
c)	Steel buildings with ordinary moment resisting frame	**3.0**
d)	Steel buildings with special moment resisting frame	**5.0**
ii)	**Braced Frame Systems**	
a)	Buildings with ordinary braced frame having concentric braces	**4.0**
b)	Buildings with special braced frame having concentric braces	**4.5**
c)	Buildings with special braced frame having eccentric braces	**5.0**
iii)	**Structural Wall Systems**	
a)	Load bearing masonry buildings	
1)	Unreinforced masonry (designed as per IS 1905) without horizontal RC seismic bands	**1.5**
2)	Unreinforced masonry (designed as per IS 1905) with horizontal RC seismic bands	**2.0**
3)	Unreinforced masonry (designed as per IS 1905) with horizontal RC seismic bands and vertical reinforcing bars at corners of rooms and jambs of openings (with reinforcement as per IS 4326)	**2.5**
4)	Reinforced masonry	**3.0**
5)	Confined masonry	**3.0**
b)	Buildings with ordinary RC structural walls	**3.0**

c) Buildings with ductile RC structural walls **4.0**

iv) Dual Systems

a) Buildings with ordinary RC structural walls and **3.0**
RC OMRFs *(see* Note 1)

b) Buildings with ordinary RC structural walls and RC **4.0**
SMRFs *(see* Note 1)

c) Buildings with ductile RC structural walls with RC **4.0**
OMRFs *(see* Note l)

d) Buildings with ductile RC structural walls with RC SMRFs **5.0**

v) Flat Slab - Structural Wall Systems

RC building with the three features given below: **3.0**

a) Ductile RC structural walls (which are designed to resist 100 percent of the design lateral force).

b) Perimeter RC SMRFs (which are designed to independently resist 25 percent of the design lateral force), and preferably

c) An outrigger and belt truss system connecting the core ductile RC structural walls and the perimeter RC SMRFs *(see* Note 1).

NOTE 1- RC and steel structures in Seismic Zones III, IV and V

5. Pecentage of imposed load to be considered in seismic weight calculation

Imposed U.D. floor load	**percentage of imposed laod**
Upto and including 3.0	25
Above 3.0	50

6. Design Seismic Base shear (Total design lateral force) (V_B)

$$V_B = A_h\ W$$

A_h = Design horizontal acceleration

W = Seismic weight of building

7. Fundamental Natural Period (T_a)

(a) Moment resisting frame without brick infil panels (in seconds)

$T_a = 0.075\ h^{0.75}$ for RC MRF building

$T_a = 0.080\ h^{0.75}$ for RC steel composite MRF building

$T_a = 0.085\ h^{0.75}$ for steel MRF building

h = height of building 'm' bending

b) Building with RC structural was:

$$T_a = \frac{0.075h^{0.75}}{\sqrt{A_w}} \geq \frac{0.09h}{\sqrt{d}}$$

where A_w is total effective area (m^2) of walls in the first storey of the building given by:

$$A_w = \sum_{f=1}^{N_w}\left[A_{wi}\left\{0.2+\left(\frac{L_{wi}}{h}\right)^2\right\}\right]$$

where

h = height of building, in m;

A_{wi} = effective cross-sectional area of wall i in first storey of building, in m^2;

L_{wi} = Length of structural wall i in first storey in the considered direction of lateral forces, in m;

d = base dimension of the building at the plinth level along the considered direction of earthquake shaking, in m

N_w = number of walls in the considered direction of earthquake shaking. The value of L_{wi}/h to be used in this equation shall not exceed 0.9.

(c) All other building including moment resisting frame with brick infil panels.

$$T_a = \frac{0.09h}{\sqrt{d}} \text{ seconds}$$

h = height of building

d = Base dimension of building at the plinth level (considered into direction of lateral force).

8. Distribution of design force

Vertical distribution of base shear to different floor levels.

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} w_j h_j^2}$$

Q_i = Design lateral force at floor i, W_i = Seismic weight of floor i

h_i = Height of floor i measured from base, n = No. of storeys in the building.

9. **Dynamic Analysis Method**

1). Linear dynamic analysis shall be performed to obtain the design lateral force (design seismic base shear, and its distribution to different levels along the height of the building, and to various lateral load resisting elements) for all buildings, other than regular buildings lower than 15 m in Seismic Zone II.

2.) The analytical model for dynamic analysis of buildings with unusual configuration should be such that it adequately represents irregularities present in the building configuration.

10. Deformation

Storey drift limitation

→ The storey drift in any storey with partial load factor of 1.0 shall not exceed 0.004 times the height of building

→ There shall be no drift limit for single storey building.

11. Cantilever Projection

(i) Vertical projection (Tower, tanks, parapet chimney, etc.)

Checked for stability for 5 times the design horizontal seismic coefficient $(A_h) = 5A_h$

(ii) Horizontal projection (cornice, balconies) checked for stability for 5 times the vertical coefficient specified.

$$A_v = \frac{2}{3}A_h \qquad = 5A_v = 5 \times \frac{2}{3}A_h$$

So stability $\frac{10}{3}A_h$

12. Compound walls

Compound walls shall be designed for design horizontal coefficient with importance factor

$$\text{I} = 1.0, \text{R} = 1 \;\&\; \left(\frac{S_a}{g}\right) = 2.5$$

Theory Part

1. Regular and irregular configuration

   To performmed in an earthquake, a building should posses four main attributes namely simple and regular configuration and adequate lateral strength, stiffness and ductility.

   Regulr geometry suffer less damage than the building with irregular configuration.

2. Seismic wieght

   1. Seismic weight of floors

      Seismic weight of each floor = Full dead load + imposed load.

      While computing seismic weight. The weight of columns and walls in any storey shall be equally distributed to floors above and below the storey.

   2. Seismic weight of building

      Sum of seismic weight of all floors.

      (A) Plan Irregularity

      (i) Torsional irregularity when max. storey drift is more than 1.2 times the average of storey drift.

      (ii) Re-entrant corner

      When both projection of structure beyond the re-entrant corner are greater than 15% of its plan dimension.

      (iii) Diaphragm Discontinuity

      Cut out area greater than 50% of gross enclosed diaphragm area.

      (B) Vertical Irregularity

      (i) Soft storey

      In which lateral stiffness is less the 70% of storey above. or less than 80% of the average lateral stiffness of the three storeys above.

      (ii) Extreme soft storey

In which lateral stiffness is less than of the three storeys above.

(iii) Weak storey
In which lateral strength is less than 80% of that storey above.

(iv) Mass irregularity
Where seismic weight of any storey is more than 150% of that to its adjacents storeys.

(v) Vertical geometric irregularity
When horizontal dimension of lateral force resistency system in any storeyes more than 150% of that in its adjacent storey.

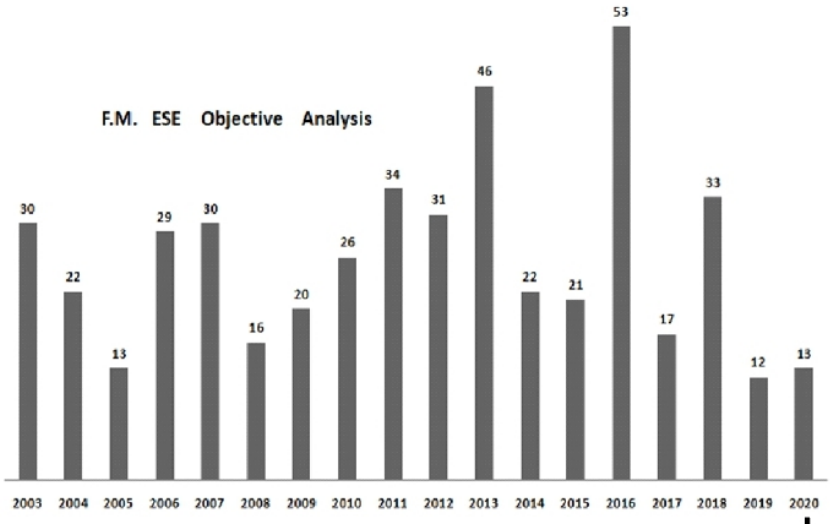
Minimum Design Earthquake Horizontal Lateral Force for Buildings

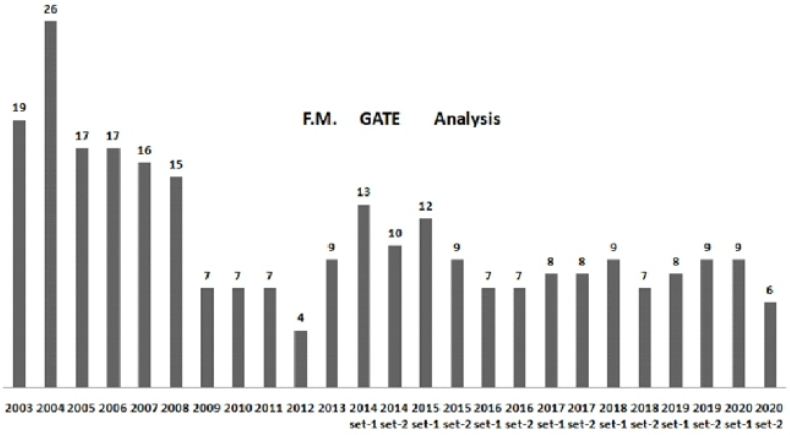
SI. No.	Seismic Zone	**ρ**
		Percent
i)	II	0.7
ii)	III	1.1
iii)	IV	1.6
iv)	V	2.4

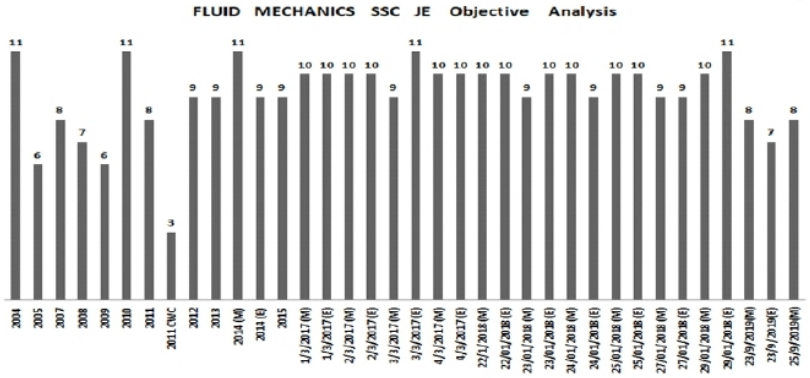
➢ **Important terminologies for earthquake resisting building.**

1. Base dimension (d) → It is the dimension of building at its base in the given direction.
2. Centre of Mass → Point through which resultant of masses of system acts.
3. Centre of stiffness → Point through resultant of the restoring force of a system act.
4. Diaphragm
   It is horizontal system, which transmit lateral force to vertical resisting elements e.g. RCC. floors.
5. Dual system- This system consist of shear walls and moment resisting frame.
6. Moment resisting frame.
   These frames are designed to resist 25% of design base shear.
7. Height of floor (h_i) -Difference in levels of base of building to that floor (i).
8. Shear walls
   It is a wall design to resist the lateral force acting in its own plane.
9. Static Eccentricity
   Distance between centre of mass and centre of rigidity.
10. Storey → Space B/W two adjacent floors.
11. Storey Drift → Displacement of one level relative to the other level above or below.
12. Storey shear → Sum of design lateral forces at all levels above the storey under consideration.

Special point - BIS [IS 1893 (Port I): 2002] has group the country into four seosmic zones viz zone II, III, IV and V.


F.M. ESE Objective Analysis
30 22 13 29 30 16 20 26 34 31 46 22 21 53 17 33 12 13
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020


F.M. GATE Analysis
19 26 17 17 16 15 7 7 7 4 9 13 10 12 9 7 7 8 8 9 7 8 9 9 6
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 set-1 2014 set-2 2015 set-1 2015 set-2 2016 set-1 2016 set-2 2017 set-1 2017 set-2 2018 set-1 2018 set-2 2019 set-1 2019 set-2 2020 set-1 2020 set-2


FLUID MECHANICS SSC JE Objective Analysis
11 6 8 7 6 11 8 3 9 9 11 9 9 10 10 10 10 9 11 10 10 10 10 9 10 10 9 10 10 9 9 10 11 8 7 8
2004 2005 2007 2008 2009 2010 2011 2011 CWC 2012 2013 2014 (M) 2014 (E) 2015 1/1/2017 (M) 1/1/2017 (E) 2/1/2017 (M) 2/1/2017 (E) 3/1/2017 (M) 3/1/2017 (E) 4/1/2017 (M) 4/1/2017 (E) 22/1/2018 (E) 22/01/2018 (M) 23/01/2018 (M) 23/01/2018 (E) 24/01/2018 (M) 24/01/2018 (E) 25/01/2018 (M) 25/01/2018 (E) 27/01/2018 (M) 27/01/2018 (E) 29/01/2018 (M) 29/01/2018 (E) 23/09/2019(M) 23/9/2019(E) 25/09/2019(M)

Properties of Fluid

1

Basic Conversion:

Density (ρ)

$1kg/m^3 = 0.0624\ lb/ft^3$; $1\ lb/ft^3 = 16.018\ kg/m^3$

Unit weight, ($\gamma\ or\ \omega = \rho g$)

Units: N/m^3, kg/m^3 (kg (wt)/m^3);

$1kg/m^3$ (kg(wt)/m^3) $= 9.807N/m^3$ $1N/m^3 = 0.102kg/m^3$

(Force)

1kg wt = 9.807 N (Newton); 1gm wt = 980.7 dynes

$1kg(wt) = 9.807N = 2.204$ lb(wt) $= 9.807 \times 10^5$ dynes

1 N = 0.102 kg wt

1 lb wt = 32.2 poundals

$1N = 0.102kg(wt) = 0.2247$ lb(wt) $= 10^5$ dynes

1 poundal = 13825.5 dynes = 14.102 gm(wt).

(Pressure)

Units: N/m^2 = Pascal (Pa); kg/m^2

$1kg/cm^2 = 10^4\ kg/m^2$

$1kg/m^2 = 9.807\ N/m^2$; = 9.807 Pa

$100kPa = 10{,}200kg/m^2$

$1Pa = 1N/m^2 = 0.102kg/m^2$

$1kPa = 0.01\ kg/cm^2$

1 Standard Atmospheric Pressure = 1.02 kg/cm^2

= 1.013 bar

= 760 mm of Hg

= 101.325 kPa

= 10.33 m water head

$1kg/cm^2 = 98.07kPa$ $100kPa = 1.02kg/cm^2$

- Any substance in gaseous/liquid phase is called as fluid
- Fluid is a substance that deforms (Flow) continually under an applied shear stress.
- Fluid does not have tensile strength, but it has compressive strength only when it is kept in closed container.
- Fluid Static – Study of fluid in rest condition
- Fluid dynamic – study of fluid in motion with/without considering forces.
  (a) Kinetics – study of fluid in motion considering forces.
  (b) Kinematics – study of fluid in motion without considering forces.

Special Point: In solids, stress is proportional to strain but in fluid stress is proportional to strain rate.

Types of fluid -

(a) **Real fluid -**

· Fluids which are not ideal.

Ideal fluid do not exist, so practically all fluid are real.

(b) **Ideal fluid -**

Bulk modulus is infinite.

They are incompressible and do not have viscosity & surface tension.

For an ideal fluid, no shear stresses exist and pressure is same in all directions.

Some Basic fluid properties:

1. Density = $\frac{\text{mass}}{\text{volume}}$ measured in kg/m^3.
2. If relative density < 1, then fluid is lighter than water.
3. The density of water is maximum at 4°C
4. Fathometer is used to measure ocean depth
5. Density of liquid & gas is directly proportional to pressure and inversely to temperature
6. Specific gravity/relative density = $\frac{\text{Density of liquid}}{\text{Density of water at 4°C}}$
7. Specific weight = $\frac{\text{Weight of substance}}{\text{Volume of substance}}$, ($\gamma = \rho g$ in N/m^3)

8. Some Important Relation

1 milibar = 10^{-3} bar =100 N/m^2

1 mm of Hg = 10^{-3} m of Hg = $10^{-3} \times 13.6$ m of water = $10^{-3} \times 13.6 \times 9810$ N/m^2 = 133.42 N/m^2

1 N/mm^2 = 10^6 N/m^2

$$1 \text{ Kgf/cm}^2 = \frac{9.81 \text{ N}}{10^{-4} \text{ m}^2} = 98.1 \times 10^3 \text{ N/m}^2$$

9. $\gamma_{\text{water}} = 9810 \frac{\text{N}}{m^3} = 9.81 \frac{\text{KN}}{m^3}$

10. $\gamma_{\text{mercury}} = 13.6\ \gamma_w$

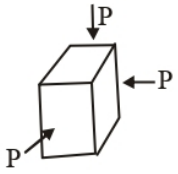
11. Specific volume = $\frac{1}{\text{Density}}$

Special points:

1. Higher temperature, more chances of cavitation.
2. At 100°C, vapour pressure of water = Atmospheric pressure.
3. Air cavitation is less damaging than vapour cavitation.

Bulk modulus: Bulk modulus of elasticity (k) = $\frac{dp}{-\left(\frac{dv}{v}\right)} = \frac{dp}{\left(\frac{d\rho}{\rho}\right)}$

Compressibility (β) = $\frac{1}{\text{K}} = \frac{d\rho}{\rho dp}$



Note:

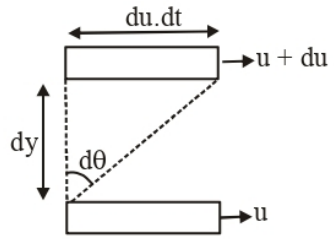
If density does not change with pressure, $\left(\frac{\partial \rho}{\text{dp}} = 0\right)$ then fluid is incompressible

Vapour Pressure

Liquid molecules escaping from the free surface to air is known as vapourisation.

Vapourisation increase with temperature like as for water, vapour pressure at 0°C is 0.063 m while its value is 10.336 m of column of water when temperature is 100°C.

Viscosity: It is the measure of resistance of fluid to its deformation. It is due to the internal frictional forces, which is developed among different layers of fluid when they are forced (external/internal) to move relative to each other.



From above diagram, Shear strain $(d\theta) = \frac{du.dt}{dy}$

Rate of change of shear strain $\frac{d\theta}{dt} = \frac{du}{dy}$ (velocity gradient)

For Newtonian fluids,

$\tau \propto$ Rate of change of shear strain

$$\tau \propto \frac{d\theta}{dt} \propto \frac{du}{dy} \Rightarrow \tau = \mu \frac{du}{dy}$$

Where μ = dynamic viscosity, absolute viscosity or coefficient of viscosity

Dynamic viscosity is the property of a fluid in motion.

$$\text{Unit of } \mu = \frac{NS}{m^2} \text{ or } \frac{kg}{m.s} \text{ or pascal sec (SI)}$$

$$\text{(CGS unit) } \frac{\text{Dyne} - \text{sec}}{cm^2} \text{ or Poise}$$

$$1\frac{NS}{m^2}\text{(SI)} = 10 \text{ poise}$$

$$\text{Kinematic viscosity} = \frac{\text{dynamic viscosity}}{\text{density}} = \frac{\mu}{\rho} \Rightarrow \nu = \frac{\mu}{\rho}$$

$$\text{CGS unit} = \frac{cm^2}{sec} \text{ or stoke}$$

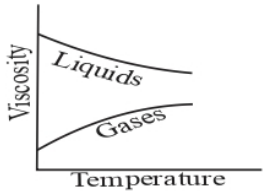
$$\text{SI unit} = \frac{m^2}{sec}$$

$$10^{-4} \text{ m}^2/\text{s (SI)} = 1 \text{ stoke}$$

Special point: $\mu_{water} = 55\ \mu_{air}$, $\nu_{air} = 15.2\ \nu_{water}$ at 20°C, $\mu_{water} = 1$ centipoise at 1°C

Viscosity of liquids is due to cohesion but for gases it is due to molecular momentum transfer among the gas molecules.

Effect of temperature and pressure of fluid's viscosity:



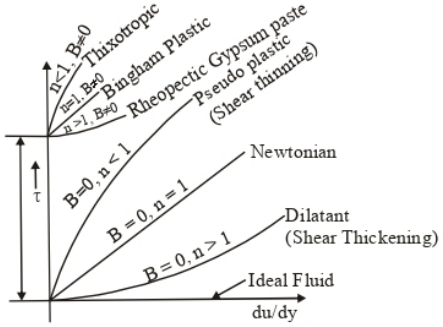
For liquids, μ does not depends on pressure except at high pressure.

For gases also, μ_{gas} does not depends on pressure but as ν is inversely proportional to pressure

Therefore , $\nu_{gas} \propto \dfrac{1}{\text{Pressure}}$

Newtonian and Non-Newtonian fluids

- If $\tau = \mu\dfrac{du}{dy}$ then Newtonian fluids otherwise non-Newtonian



- $\tau = A\left(\dfrac{du}{dy}\right)^n + B$ (General shear equation)
- Slope of the curve gives apparent viscosity.
- Pseduo plastic are shear thinning but Dilatants are shear thickening fluids.
- Study of Non-Newtonian fluid is called Rheology.
- Ex.

(a)	Thixotropic	Ink, ketchup, Enamels etc.
(b)	Bingham plastic	Sewage, Sludge, Drilling mud, Gel, Toothpaste, Cream
(c)	Rheopectic	Gypsum in water & Bentonite slurry.
(d)	Pseudo Plastic	Paint, Paper, Pulp, Blood, syrup, Polymer, Lipstick, Nailpaint
(e)	Dilatant	Quick sand, Sugar in water, Butter

Civil Ki Goli:

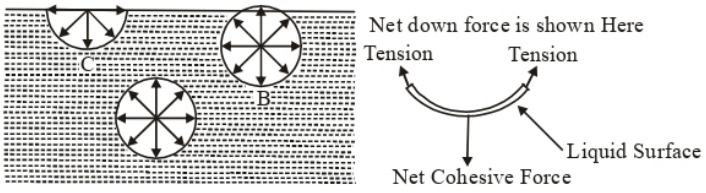
Tu	Bhi	Ruhani	Pakki	Naughty	Dramebaj Hai
↓	↓	↓	↓	↓	↓
Thixotropic	Bingham	Rheopectic	Pseudo	Newtonian	Dilatant

Special Points:

1. Wetting property is due to surface tension.
2. Ideal fluids → No-viscosity → No "No slip" condition
3. No slip condition is due to fluid viscosity.

Surface tension and capillary effect: It occurs at the liquid-gas interface or at the interface of two immiscible liquids while a thin film is apparently formed due to attraction of liquid in the surface which is similar to tension in stretched membrane known as surface tension measured as $\frac{\text{force}}{\text{length}}$ (Unit $\frac{N}{m}$)

- Surface tension is caused by force of cohesion between liquid molecules.



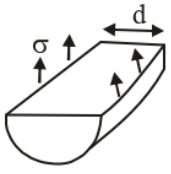
$$\text{Surface tension} = \frac{\text{Work done}}{\text{Change in area to work done}}$$

$\sigma_{water/air}$ 0.073 N/m, At critical point it becomes zero

Then

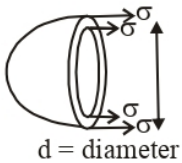
(a) Pressure inside jet $P = \frac{2\sigma}{d}$

P = Gauge pressure



(b) Pressure inside soap bubble $P = \frac{8\sigma}{d}$

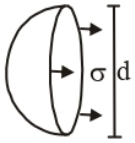
d = diameter.



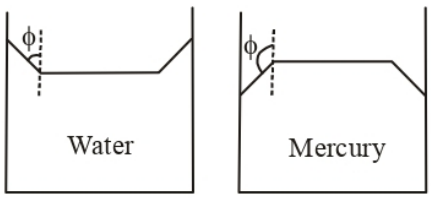
d = diameter

(c) Pressure inside droplet $P = \frac{4\sigma}{d}$

σ = Surface tension



Rise or fall in the surface of liquid when a small diameter (less than 6 mm) tube is inserted into the liquid is called capillary rise or capillary depression respectively.



$\phi < 90°$	Cohesion < Adhesion	Wetting of surface	Concave top surface	Rise in capillary tube
$\phi > 90°$	Adhesion < cohesion	Does not wets the surface	Convex top surface	Drop in capillary tube

$$h = \frac{4\sigma \cos\theta}{\gamma d}$$

θ for water glass = 0°, mercury glass = 128°, Kerosene glass = 26°

Special points

1. Capillary effect is due to Adhesion and surface tension both
2. Water in soil is able to rise a considerable distance above ground water table due to capillary action.
3. When a liquid like Hg is spilled on a smooth horizontal surface, It gathers into droplets because the force of cohesion is more than force of Adhesion.
4. Force of attraction between molecules of different types is called adhesion but in molecules of same type, it is called cohesion.

Pressure and its Measurement

2

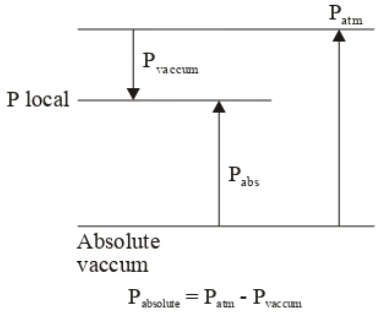
- Normal force exerted by a fluid per unit area is called pressure. It is a scalar Quantity (it has magnitude but no direction).
- **Atmospheric Pressure:** Pressure exerted by atmosphere. It is measured by Barometer. At MSL, atmospheric pressure is 1.01×10^5 Pascal or 1 Bar or 10.3 m of Height of water or 76 cm height of mercury.

Special Point: If head of water is 'h' meter, then equivalent pressure is $\gamma_w h$ and if head of mercury is 'h' m then equivalent pressure will be $\gamma_{Hg} h$

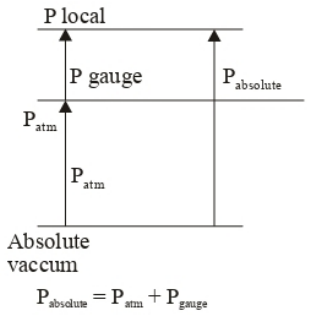
Gauge Pressure: It is the pressure wrt atmospheric pressure as datum. It is measured using Manometer or Bourdon gauge.

- It can be +ve, –ve, zero.

Absolute Pressure: It is the pressure wrt absolute zero or complete Vaccum. It is the actual pressure & measured by Aneroid Barometer.



$P_{absolute} = P_{atm} - P_{vaccum}$



$P_{absolute} = P_{atm} + P_{gauge}$

Special point: 'h' m of water vaccum means pressure of $-h\gamma_w$

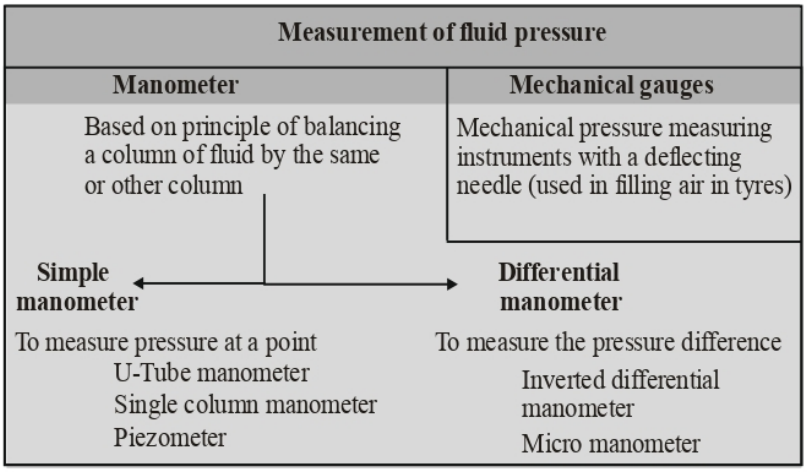
Facts about pressure

1. Longer runway is needed at higher altitude due to reduced drag & lift.
2. Nose bleeding starts at higher altitude because of difference in body's blood pressure and atmosphere pressure.

3. Motor capacity reduces at higher altitude because oxygen available for burning of fuel is less in unit volume of gas.
4. Cooking takes longer time at higher altitudes.

Special Points: As per Pascal's law, pressure applied at the surface a confined fluid increases the pressure throughout by the same amount.
1 atm > 1 bar > 1 kgf/cm^2

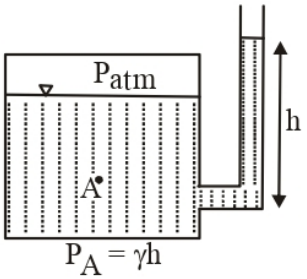
Pressure at a point in a fluid at rest is independents of shape & cross-section of container in which it is kept. It varies in vertical direction & remains constant in horizontal direction (Hydrostatic law).



No.	Type of Manometer	Fluid Types	Pressure measurement
1.	Piezometer	Liquid	Positive (Gauge pressure)
2.	U-tube Manometer	Both liquid & gases	Both positive & Negative Pressure
3.	Inclined Tube Manometer	Gases (for very low pressure)	Both (+ve & -ve) (mostly +ve)
4.	Differential & Inverted Differential	Both liquid & gases	Pressure difference Between 2 points
5.	Bourdon Pressure gauge	Both liquid & gases	It measures pressure at a point

1. Piezometer

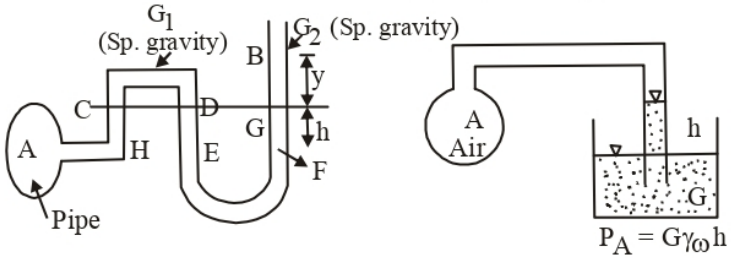
- Use for small & +ve pressure
- Very long column of piezometer is required if pressure is large.
- Diam. of Tube > 10 mm



2. U-Tube manometer

- For large pressure measurement, gas pressure & –ve pressure
- Simple manometer/U-tube manometer can measure both +ve and – ve pressure.

  Pressure at A = Pressure at H = $P_{atm} + G_2\gamma_w y + G_1\gamma_w h$

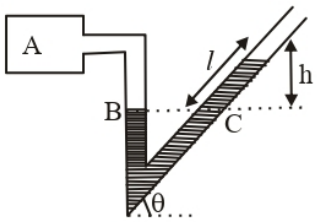


Special Points:

- Liquid in U-tube manometer, should have specific gravity more than the liquid whose pressure is to be measured.
- Manometric Liquid should be completely immiscible (oil & water does not mix) with the liquid whose pressure is to be measured.
- Liquid should have small thermal coefficient & small vapour pressure.
- Mercury is used in Manometer & barometer because of high density, Immiscible & low Vapour pressure.

Special Case: To increase the sensitivity, one leg is inclined.

$P_A = P_B = P_C = G\gamma_w h = G\gamma_w (l \sin\theta)$ measured reading of tube = 'l'

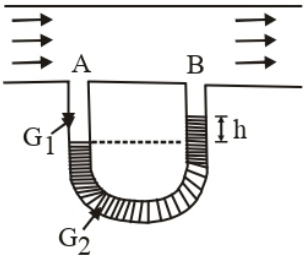


Concept of differential manometer:

$$P_A - P_B = (G_2 - G_1)\gamma_\omega h$$

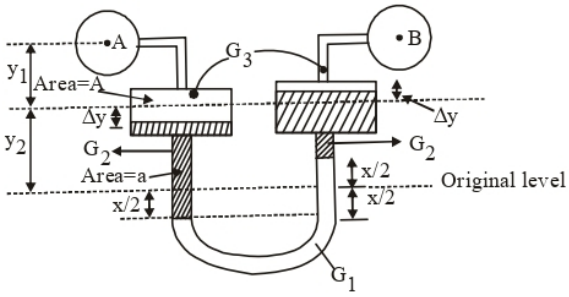
$$P_A - P_B = (\text{head loss})\, G_1\gamma_\omega$$

$$\frac{P_A - P_B}{G_1\gamma_\omega} = \left(\frac{G_2}{G_1} - 1\right)h$$



2. Micromanometer: It measures very small pressure difference or for measuring the pressure difference with high precision.

$$P_A - P_B = (G_1 - G_2)x\gamma_\omega$$



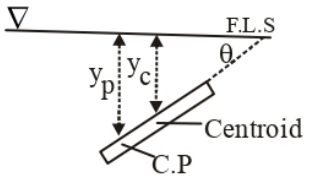
Special points: Multi fluid manometer is used in measuring pressure in a pressurised water tank.

- Mechanical gauges are used for measuring high pressure values which does not requires high precision.

Hydrostatic–Forces

3

Forces at every point on the plane surface can be added algebrically to obtain the magnitude of resultant force on the plane surface.



C.P – centre of pressure

When the surface is Curved, then at every point, the direction of force due to stationary fluid is Normal to the surface

$$y_P = y_C + \frac{I_G \sin^2\theta}{A y_c}$$

y_P = Centre of pressure from liquid surface

I_G = MOI about the centroidal axis

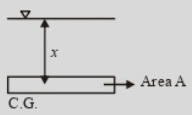
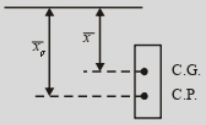
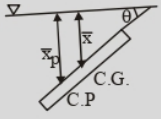
y_C = Centroid from the liquid surface

Special point: Magnitude of the resultant force acting on a plane surface of a completely submerged plate in a homogenous fluid is equal to the product of pressure at centroid of surface & Area 'A' of the surface

$F = P_C A$ and this force acts at y_P. Also $P = \rho g y_c$

- As we go deeper, difference of y_P & y_C will reduce.

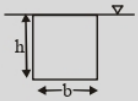
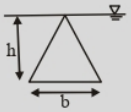
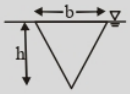
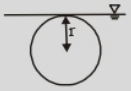
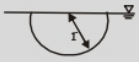
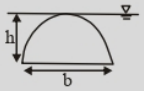
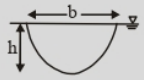
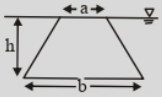
Concept of Pressure

Horizontal Plane Surface	Vertical Plane Surface	Inclined Plane Surface
		

$F = \gamma A\bar{x}$	$F = \gamma A\bar{x}$	$F = \gamma A\bar{x}$
$x_p = \bar{x}$	$x_p = \bar{x} + \frac{I_g}{A\bar{x}}$	$x_p = \bar{x} + \frac{I_g \sin^2\theta}{A\bar{x}}$

$\bar{x}$ & $\bar{x}_p$ are same horizontal plane surface from liquid surface

Special point: In case of vertical surface, when depth of Immersion is very large. Then centre of pressure = Centre of Gravity. As the depth of Immersion increases, distance between centre of pressure and centre of gravity decreases.

Surface	C.G $\bar{x}$	C.P. $\bar{x}_p$
1. 	$\frac{h}{2}$	$\frac{2h}{3}$
2. 	$\frac{2h}{3}$	$\frac{3h}{4}$
	$\frac{h}{3}$	$\frac{h}{2}$
3. 	r	$\frac{5}{4}r$
4. 	$\frac{4r}{3\pi}$	$\frac{3\pi r}{16}$
5. 	$\frac{3h}{5}$	$\frac{5h}{7}$
	$\frac{2h}{5}$	$\frac{4h}{7}$
6. 	$\left(\frac{b+2a}{a+b}\right)\left(\frac{h}{3}\right)$	$\left(\frac{a+3b}{a+2b}\right)\frac{h}{2}$

Hydrostatic forces on the curved surface:

Horizontal Force (F_H): It is the resultant hydrostatic force 'f_x' of curved surface, may be calculated by projecting the surface upon a vertical plane & multiplying the projected area by the pressure at its own centre of area.

Vertical Force (F_V): It is the weight of the liquid contained in the zone bounded by two verticals drawn from the two ends of the curved surface, the curved surface & the free surface (which is applying pressure on the curved surface)

Resultant force (F): $$F = \sqrt{F_V^2 + F_H^2}$$

$$\tan\theta = \frac{F_y}{F_x} = \frac{F_V}{F_H}$$

$\theta \rightarrow$ Angle *b/w* line of action & Horizontal axis

Clear Your Doubt

- **Centre of Gravity-**It is defined as a point through which the whole weight of the body is assumed to be act
- **Centre of mass-**It is the point in a body at which the entire mass may be assumed to be concentrated.
- **Centre of Percussion-**It is the point on an extended massive object attached to a pivot where a perpendicular impact will produce no reactive shock at the pivot.

Buoyancy and Floatation

4

Archimedes Principle: When a body is wholly or partially submerged in a liquid, then the vertical upward force acting on the body (known as Buoyant force) is equal to the weight of the liquid displaced by the immersed part of the body.

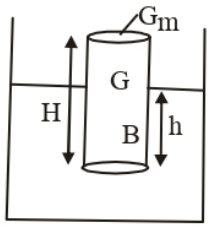
Buoyant force = Net upward force = weight of liquid displaced

Special Points: Point of application of buoyant force is the C.G. of the displaced liquid & it is called centre of buoyancy.

- Buoyant force is independent of distance of body from free surface of liquid and also the density of solid body.
- When a ship moving on sea water and it enters in a river, it is expected to sink a little

Principle of Floatation: A body will float in a liquid, if weight of body is equal to weight of liquid displaced by its immersed part.

$h = G_m H$

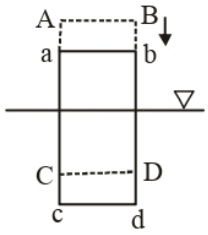


B = Centre of buoyancy at a distance of $h/2$ from base of cylinder.

G = Centre of gravity, at a distance of H/2 from base of cylinder,

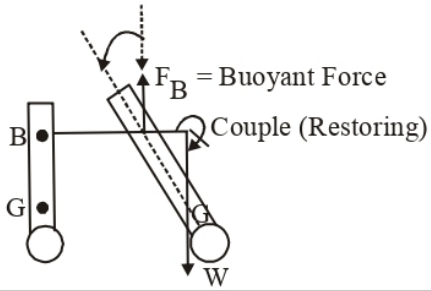
G_m = Specific gravity of material wrt liquid, which should be < 1

Linear Stability: When a small linear displacement of body sets up a restoring force, then the body is in linear stability



Submerged body	Floating body
It remains in neutral equilibrium against linear displacement	It remains in stable equilibrium against vertical displacement & in neutral equilibrium against horizontal displacement

Rotational Stability: When a small angular displacement sets up a restoring couple, then stability is known as rotational stability.

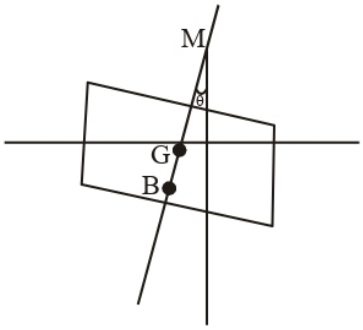


	Submerged body	Floating body
Stable equilibrium	G below B	M above G
		BM > BG
		GM = MB – BG = +Ve
Unstable equilibrium	G above B	M below G
		BM < BG
		GM = MB – BG = –Ve
Neutral equilibrium	G & B coincide	M & G coincide
		GM = 0

Metacentre (M) is the point of intersection of lines of action of buoyant force before and after rotation.

GM = metacentric height

GM = BM – BG



$$\text{Where BM} = \frac{I}{V}$$

I = MOI of top view of the immersed part of the body about longitudinal axis.

- Larger the metacentric height, greater is stability & comfort will decrease.

Time period of oscillation: If a floating body oscillates, then its time period of transverse oscillation wrt metacentre is given by

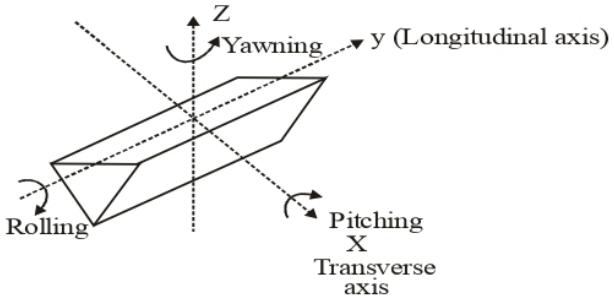
$$T = 2\pi\sqrt{\frac{MK_G^2}{W(GM)}} = 2\pi\sqrt{\frac{K_G^2}{GM.g}}$$

Where K_G Radius of Gyration about centre, W = weight of floating body.

- Larger the time period, more will be the comfort of passenger,
- For cargo / merchant ships, GM is 0.5-1m, comfort & stability both considered.
- For passenger ship, GM is less(0.5-1m), so more comfortable.
- For battle ship, GM is 1-1.5m, Stability is prime consideration.

Movements of a ship:

If a ship is safe in rolling, it must be safe in pitching.



Liquid in Relative Equilibrium

5

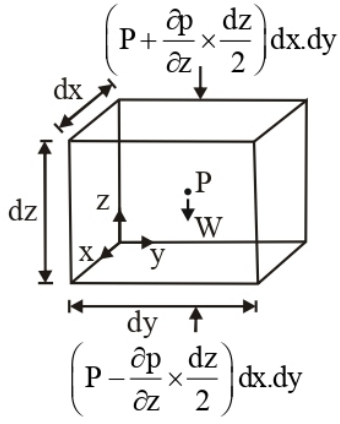
When a liquid is contained in a moving container, then it behaves like as a rigid body (liquid is moving but not flowing)

From Newton's law of motion

$$\frac{-\partial P}{\partial x} = \frac{\gamma}{g} a_x$$

$$\frac{-\partial P}{\partial y} = \frac{\gamma}{g} a_y$$

$$\frac{-\partial P}{\partial z} = \frac{\gamma}{g}(a_z + g) \Rightarrow \text{Euler's equation}$$



Adding above equations,

$$-\left(\frac{\partial P}{\partial x}\hat{i} + \frac{\partial P}{\partial y}\hat{j} + \frac{\partial P}{\partial z}\hat{k}\right) = \frac{\gamma}{g}(a_x\,\hat{i} + a_y\,\hat{j} + (a_z + g)\hat{k})$$

Following are the various conditions:

1. When fluid at rest $a_x = a_y = a_z = 0$

then $\frac{\partial P}{\partial x} = \frac{\partial P}{\partial y} = 0$, $\qquad \frac{\partial P}{\partial z} = -\rho g \Rightarrow P = -\rho g z$

2. When fluid moves in downward direction with constant acceleration ($-a_z$). Then

$$a_x = a_y = 0 \Rightarrow \frac{\partial p}{\partial x} = \frac{\partial p}{\partial y} = 0, \qquad \frac{\partial p}{\partial z} = -\rho(g - a_z)$$

$$P - P_a = \frac{\rho}{g}(g - a_z)h = \gamma h\left(1 - \frac{a_z}{g}\right)$$

3. When fluid moves in upward direction with constant acceleration ($+a_z$). Then

$$a_x = a_y = 0 \Rightarrow \frac{\partial p}{\partial x} = \frac{\partial p}{\partial y} = 0, \qquad \frac{\partial p}{\partial z} = -\rho(g + a_z)$$

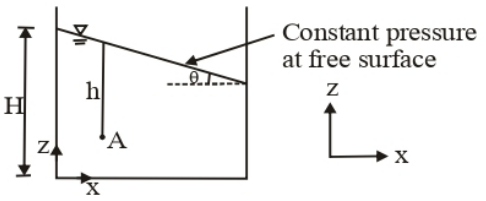
$$P - P_a = -\rho(g + a_z)h = \gamma h\left(1 + \frac{a_z}{g}\right)$$

4. With constant aceleration a_x in x-direction

$$P_A = \rho gh$$

$$\text{Slope } (\tan\theta) = \frac{a_x}{g_{eff}}$$

$$Z = \left(H - \frac{a_x . x}{g_{eff}}\right) \Rightarrow \text{Equation of free surface}$$



Rotation in Cylindrical Container

$$\frac{\partial P}{\partial r} = \frac{\rho V^2}{r} \qquad \ldots(a)$$

$$\frac{\partial P}{\partial z} = -\rho(a_z + g) \qquad \ldots(b)$$

Combining (a) and (b)

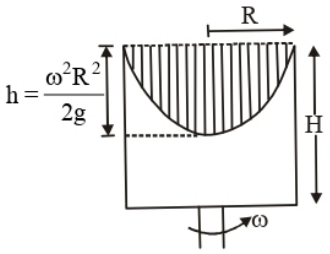
$$dP = \frac{\rho V^2}{r}dr - \rho(a_z + g)dz$$

- **In free vortex motion**, angular momentum remains conserved as external torque is zero, so mvr = constant. In it, bernoulli's equation can be applied.

  So $V \propto \frac{C}{r}$

- So as radius increases, velocity decreases, pressure Increases. Ex: whirlpool in rivers, whirling mass of liquid in wash basin.
- A free Vortex motion is that in which the fluid may rotate without Any external force applied on it.
- In forced vortex motion, fluid is rotated about a vertical axis at constant speed in such a way that every particle has the same angular velocity.
- The surface profile of forced Vortex flow is paraboloid.
- Ex. Rotational Vortex is forced Vortex motion.

  Rotating Cylinder and flow inside Centrifugal pump.
- A force Vortex motion is that in which the fluid mass is made to rotate by means of some external source of power.



$V = r\omega$

$$P = \rho gh = \rho g\left(\frac{w^2R^2}{2g}\right)$$

$$P = \frac{\rho w^2R^2}{2}$$

Hence from (a) as radius increases, velocity increases, pressure decreases. Ex: Flow inside centrifugal pump.

Special point: Rankine Vortex motion is a combination of free and forced vortex motion. For no spilling case, rise above original water level = Fall below original water level.

- Amount of water spilled out = original volume – Remaining volume
- Remaining volume = Volume of cylinder – volume of shaded paraboloid.
- Volume of cylinder = πR^2H
- Volume of paraboloid = $\frac{1}{2}(\pi R^2)\left(\frac{\omega^2R^2}{2g_{eff}}\right)$

Fluid Kinematics

6

Fluid Kinematics: It deals with the motion of the fluids without necessarily considering the forces & moments which cause the motion.

Generally these two approach are used:

- In Lagrangian concept, study of motion of single fluid particle
- In Eulerian concept, study of motion of fluid through a particular section or a control volume

Special point: In F.M., We generally follow Eulerian concept, because it is difficult to keep the track of a single fluid particle.

Types of fluid:

1. **Steady and Unsteady Flow:** At any given location, the flow and fluid properties do not change with time, then its steady flow otherwise unsteady.

$$\frac{\partial V}{\partial t} = 0, \frac{\partial P}{\partial t} = 0, \frac{\partial \rho}{\partial t} = 0 \Rightarrow \text{Steady flow}$$

2. **Uniform and Non-Uniform Flow:** A flow is said to be uniform flow in which velocity & flow both in magnitude and direction do not change along the direction of flow for given instant of time.
3. **Rotational and Irrotational Flow:** When fluid particles rotate about their mass centre during movement. Flow is said to be rotational otherwise irrotational.
   - Flow above the drain having a wash basin is a free vortex motion (Irrotational flow).
   - Rotational Flow $\rightarrow$ Forced Vortex, Flow inside boundary layer.
   - Irrotational Flow $\rightarrow$ Free Vortex, Flow outside boundary layer.
   - In a straight tube of uniform diameter & uniform roughness, the

flow properties does not vary across the length of the pipe. Hence, Uniform flow.

4. **Laminar and Turbulent Flow:** Turbulent flow particles have the random & erratic movement, intermixing in the adjacent layers. Which causes continuous momentum transfer between different layers.

   •A water supply pipe carries water at high speed leading to rapid mixing which causes highly turbulent conditions.

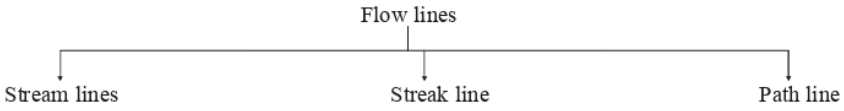
   • In laminar flow, the particles moves in layers sliding smoothly over the adjacent layers

   • Flow of blood in veins and arteries occurs as a viscous flow. Hence, Laminar flow.

5. **One, two or three Dimensional Flow:** If flow parameters varies in one dimension wrt space only, then its 1 D otherwise its 2 or 3 dimension respectively.

$$V = V(x, t) \rightarrow \text{one dimensional}$$
$$V = V(x, y, t) \rightarrow \text{two dimensional}$$
$$V = V(x, y, z, t) \rightarrow \text{three dimensional}$$

6. **Compressible and Incompressible Flow:** In compressible flow density of fluid changes from time to time while in Incompressible flow it remains constant.



- **Stream Line:** There are a set of concentric circle with origin at centre.
- Stream lines neither touch nor cross each other. Line tangent to it give direction of Instantaneous velocity.
- Tracing of motion of different fluid particle.

$$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w}$$ Equation of stream line

- **Streak Line:** It is line traced by series of fluid particles passing through a fixed point. It is formed by continous introduction of dye or smoke from a point in the flow.
- **Path Lines:** It is actual path traced by a fluid particle over a period of time. It is based on lagrangian concept. Two path lines can intersect each other.

Continuity Equation: It is based on principle of conservation of mass. Fluid mass can neither be created nor can be destroyed hence mass of fluid

entering a fixed region should be equal to mass of fluid leaving that fixed region in a particular time.

Various forms of continuity Equation:

Cartesian co-ordinate System:

(*i*) Steady Flow in 1-D, $\rho AV = \text{Constant}$

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

(*ii*) Steady Incompressible in 1-D, $A_1 V_1 = A_2 V_2$

Acceleration of fluid:

$$\vec{V} = u(x,y,z,t)\hat{i} + v(x,y,z,t)\hat{j} + w(x,y,z,t)\hat{k}$$

$$a_x = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} + \frac{\partial u}{\partial t}$$

$$a_y = u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + \frac{\partial v}{\partial t}$$

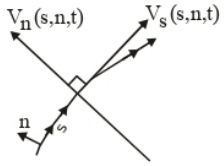
$$a_z = u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} + \frac{\partial w}{\partial t}$$

- Total Acceleration = Convective acceleration with respect to space + local acceleration with respect to time.

Type of flow	Convective Acceleration	Temporal Acceleration
Steady & uniform	0	0
Steady & non-uniform	Exists	0
Unsteady & uniform	0	Exists
Unsteady & non-uniform	Exists	Exists

Acceleration on a stream line

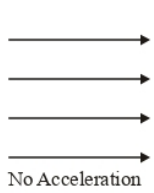
Tangential Acceleration
It occurs due to change in magnitude of velocity. If spacing b/w stream line changes, then tangential acceleration exists



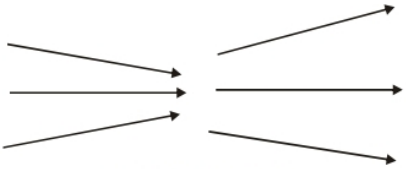
Normal Acceleration
It occurs due to the change in the direction of fluid moving on a curved path

$$a_s = V_s \frac{\partial v_s}{\partial s} + \frac{\partial v_s}{\partial t} \qquad a_n = V_s \frac{\partial v_n}{\partial s} + \frac{\partial v_n}{\partial t}$$

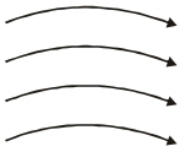
convective tangential acceleration | local tangential acceleration | convective normal acceleration | local normal acceleration



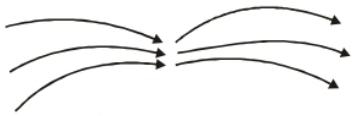
No Acceleration



Tangential Convective Acceleration



Normal Convective Acceleration



Both Normal and Tangential Convective Accelation

Angular Velocity: It is the average of rotation rate of two initially perpendicular lines that intersect at that point.

$$\Omega = \omega_x \hat{i} + \omega_y \hat{j} + \omega_z \hat{k}$$

$$\omega_x = \frac{1}{2}\left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right)$$

$$\omega_y = \frac{1}{2}\left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right)$$

$$\omega_z = \frac{1}{2}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$$

$$\Omega = \frac{1}{2}\begin{bmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ u & v & w \end{bmatrix}$$

Velocity Potential or Potential Function (ϕ): It is the scalar function of space & time in such a way that its negative derivative wrt any direction gives velocity of flow in that direction. It must satisfy Laplace eq.

In Cartesian co-ordinate System, $\phi = f(x, y, z, t)$

$$\frac{-\partial\phi}{\partial x} = u, \frac{-\partial\phi}{\partial y} = v, \frac{-\partial\phi}{\partial z} = w$$

Special Points: If angular velocity is zero, flow will be irrotational.

Vorticity (ξ) = Twice of Angular Velocity

Circulation = Vorticity × Area of loop

Circulation (Γ) = line integral of tangential component of velocity vector along a closed curve.

- Velocity potential exists only for ideal & irrotational flow.
- Equipotential line is the line joining points having same potential function.
- Velocity of flow is in direction of decreasing potential function.

Stream Function (ψ): It is a scalar function of space & time in such a way that its partial derivative wrt any direction gives the velocity component at right angles (in anti clock wise direction) to this direction.

Cartesian co-ordinate system

$$\frac{\partial\Psi}{\partial x} = v, \frac{\partial\Psi}{\partial y} = -u$$

$\Psi_1 - \Psi_2 =$ Discharge per unit width.

Special Points:

(a) If two points lie on same stream line, then ψ will be constant.

(b) If Stream function (ψ) satisfies the Laplace equation, then flow is irrotational otherwise rotational.

$$\text{Laplace equation}, \frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} = 0$$

Cauchy-Riemann Equation: For incompressible irrotational flow

$$u = \frac{-\partial\phi}{\partial x} = \frac{-\partial\psi}{\partial y}, \quad v = \frac{-\partial\phi}{\partial y} = \frac{\partial\psi}{\partial x}$$

Fluid Dynamics

7

- It is the study of motion of fluid along with the forces causing the motion.

Dynamic behaviour of fluid flow is analysed by Newton's 2nd law of motion $\vec{F} = \vec{ma}$

(a) Newton's equation of motion

$$\overrightarrow{F_g} + \overrightarrow{F_P} + \overrightarrow{F_V} + \overrightarrow{F_t} + \overrightarrow{F_c} + \overrightarrow{F_\sigma} = m\vec{a}$$

(b) Reynold's equation of motion

$$\overrightarrow{F_g} + \overrightarrow{F_P} + \overrightarrow{F_V} + \overrightarrow{F_t} = m\vec{a}$$

(c) Navier-stock equation of motion

$$\overrightarrow{F_g} + \overrightarrow{F_P} + \overrightarrow{F_V} = m\vec{a}$$

(d) Euler's equation of motion

$$\overrightarrow{F_g} + \overrightarrow{F_P} = m\vec{a}$$

where,

F_g = Gravity force
F_V = Viscous force
F_t = Turbulence force
F_P = Pressure force
F_c = Compressibility force
F_σ = Surface tension force

Special Points:

- Energy equation can be used to find the pressure at a point in a pipeline using Bernoulli's eq.
- Continuity equation is used to find out the flow rate/velocity betweeen two sections of tapering pipes.
- Euler equation is based on momentum conservation while Bernoulli is based on energy conservation.

- Impulse momentum principle is used to find out the force on a moving vane.
- Concept of moment of momentum (Angular momentum principle) is used in lawn sprinkler problems.

Bernoulli's Equation: It is the integration of Euler's equation of motion along a stream line under steady incompressible flow conditions.

Assumptions:

(*i*) Along Stream line

(*ii*) Effect of friction is negligible (Ideal flow)

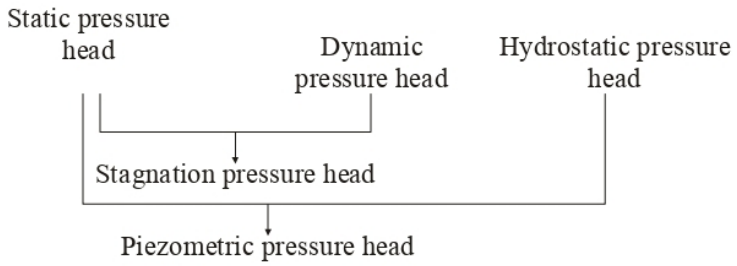
(*iii*) Steady, Incompressible & ir-rotational .

$$\text{Total head } H = \left(\frac{p}{\rho g}\right) + \left(\frac{V^2}{2g}\right) + Z = \text{Constant}$$

$$\text{Piezometric Head} = \left(\frac{p}{\rho g} + z\right)$$

$$\text{Dynamic Head} = \left(\frac{v^2}{2g}\right)$$

$$\text{Stagnation Head} = \left(\frac{p}{\rho g}\right) + \left(\frac{v^2}{2g}\right)$$



$$\frac{P}{\rho} + \frac{V^2}{2} + gz = \text{Constant}$$

$$\frac{\text{Pressure Energy}}{\text{Mass}} + \frac{\text{Kinetic Energy}}{\text{Mass}} + \frac{\text{Potential Energy}}{\text{Mass}}$$

Special Points: When normal acceleration is zero , (when particles move on a straight line), then the piezometric head is a constant.

- Continuity equation is based on the "Principal of Conservation of Mass".
- Free vortex equation is based on "Principal of Conservation of angular momentum".

Kinetic Energy Correction Factor (α)

$$\alpha = \frac{\text{Actual K.E.}}{\text{K.E. Calculated from Average Velocity}}$$

$$\alpha = \frac{\int_A v^3 dA}{AV_{avg}^3} \qquad V_{avg} = \int_A \frac{v\,dA}{A}$$

Momentum Correction Factor (β)

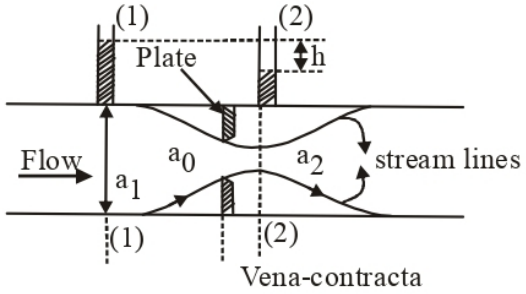
$$\beta = \frac{\text{Actual linear momentum/sec}}{\text{Linear momentum/sec calculated from Average Velocity}}$$

$$\beta = \frac{\int_A v^2 dA}{AV_{avg}^2} \qquad V_{avg} = \int_A \frac{v\,dA}{A}$$

	α	β
Laminar flow between circular pipes	2	4/3
Laminar flow b/w parallel plates	1.543	1.2
Turbulent flow in pipes	1.03 - 1.06	1.015

Applications of Energy Equation:

1. **Orificemeter** - An orifice is called a large orifice if water head is five times the diameter of the orifice.



- It is cheaper & less accurate instrument, measures discharge but has more head losses. Hence $c_d = 0.61 - 0.65$.
- Region of minimum flow area is called Vena-contracta, in it stream lines are assumed to be nearly parallel.

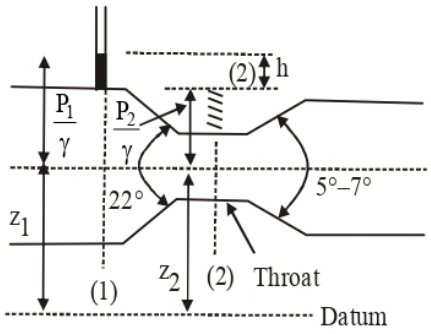
$$c_c = \frac{a_2}{a_0} = \frac{\text{Area of Vena contractra}}{\text{Area of opening}}$$

- $Q_{actual} = c_d \frac{a_1 a_0}{\sqrt{a_1^2 - a_0^2}} \sqrt{2gh}$

Special Point: If the discharge is changed, then the position of Vena-contracta will also change & then stream lineas will not be parallel at sec (2)-(2).

2. Venturimeter

- To find discharge from a large diameter pipe
- Accuracy is quite good & It has much smaller head loss.



- Angle of convergence = 20° - 30° (Generally 22°)
- Angle of divergence = 5° - 7°
- $d \approx \left(\frac{1}{3} \text{ to } \frac{1}{2}\right)D$, *commonly* d = D/2, where d = dia of throat
  D = dia of pipe
- The divergent cone angle in a ventruimeter is generally kept lesser than the convergent cone angle to avoid separation of flow.
- **Principle :** Reduction in Area leads to increase in velocity & decrease in pressure, this pressure reduction is noted & used in Bernoulli to calculate discharge.

  Piezometric head difference $h = \frac{V_2^2}{2g} - \frac{V_1^2}{2g}$

- $Q_{actual} = c_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$

  Where a_1, a_2 cross-sectional areas at section 1 and 2

$\frac{a_1}{a_2}$ = area ratio

$c_d \rightarrow$ discharge coefficient

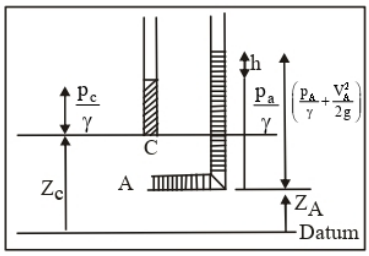
$\frac{a_1 a_2 \sqrt{2g}}{\sqrt{a_1^2 - a_2^2}}$, because this depends only on dimensions of venturimeter, it is called venturi-constant.

- $c_d = \sqrt{\frac{h - h_L}{h}} \approx 0.98 = \frac{Q_{actual}}{Q_{theoretical}}$

Special Point: If in venturimeter, the pipe is not contracted such that $c_c = 1$, then it is termed as Nozzle meter and also used for calculating discharge.

3. Pitot tube:

- Used to mesasure fluid flow velocity, water speed of a boat
- To measure liquid, air & gas flow velocity in certain industrial applications.
- Used to measure ship's speed relative to be water. They are used on both surface ships & submarine.



- It measures the velocity of fluid
- $h_{measured} = \frac{V_A^2}{2g}$

  $V_A = \sqrt{2gh}$
- $V_{A\ actual} = C_V \sqrt{2gh}$

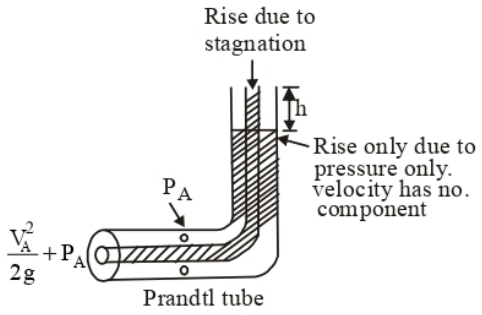
  $C_V = 0.98$ (coefficient of velocity)

Special Points: Anemometer measures gas and air velocity.
Preston Tube is used for Boundary shear stress measurement.

Type of flow meter	Accuracy	Cost	Loss of total head	Typical value of C_d
Venturimeter	High	High	Low	0.95 to 0.98
Orificemeter	Low	Low	High	0.60 to 0.65
Flow nozzle	Intermediate b/w venturimeter & Orificemeter			0.7 to 0.8

4.Pitot Static tube (Prandtl tube)

- Pitot Tube is based on principle of Conversion of Kinetic Head into pressure Head. The point at which velocity reduces to zero is called stagnation Point.
- It measures the piezometric head at the same point where velocity is to be measured.
- Velocity head is indicated by the difference in liquid level between the pitot tube and the piezometer.



$$V_A = C_V\sqrt{2gh},\ C_V = 0.99$$

- It can also used on rough boundaries.
- Velocity head is found out from difference of toal head and piezometric head.

5. Elbow meter or Bend meter Measures discharge

6. Rotameter is used to measure discharge but current meter is used to measure velocity in open channel.

7. Hot Wire Anemometer: It is used for measurement of Instantaneous velocity & temperature at a point in flow.

Special Point :The pirani gauge is a robust thermal conductivity gauge used for measurement of pressure in vaccum system.

Momentum Equation and Application

8

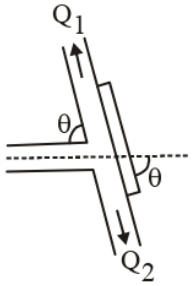
Rate of change of linear momentum in any direction of a body wrt a fixed frame of reference is equal to external forces acting on the body in that direction.

$$\begin{bmatrix} \Sigma F_{x\,\text{external}} \\ \text{on control} \\ \text{volume} \end{bmatrix} = \begin{bmatrix} \text{Net rate of flow} \\ \text{of linear} \\ \text{momentum out} \\ \text{of control volume} \\ \text{in x-direction} \end{bmatrix}$$

Rate of change of Angular momentum in any direction of a body wrt a fixed frame of reference is equal to torque applied on the body in that direction.

$$\begin{bmatrix} \Sigma M_{z\ \text{external}} \\ \text{on control} \\ \text{volume} \end{bmatrix} = \begin{bmatrix} \text{Net torque on control} \\ \text{volume in that direction} \end{bmatrix}$$

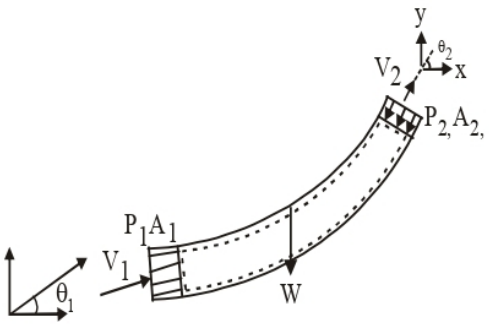
Special case:



$$Q_1 = \frac{Q(1-\cos\theta)}{2}$$

$$Q_2 = \frac{Q(1+\cos\theta)}{2}$$

Force acting on a pipe bend:



In y-direction: $\Sigma F_y = \rho Q(v_2 \sin \theta_2 - v_1 \sin \theta_1)$

$P_1A_1 \sin \theta_1 + P_2A_2 \sin \theta_2 + R_y - W = \rho Q (- v_2 \sin \theta_2 - v_1 \sin \theta_1)$

In x-direction:

$\Sigma F_x = \rho Q(v_2 \cos \theta_2 - v_1 \cos \theta_1)$

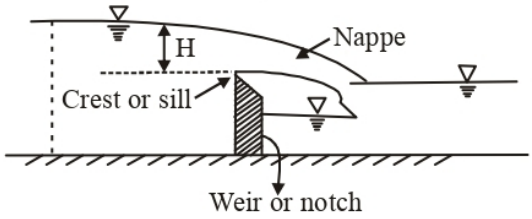
$P_1A_1 \cos \theta_1 - P_2A_2 \cos \theta_2 - R_x = \rho Q(v_2 \cos \theta_2 - v_1 \cos \theta_1)$

Resultant force $R = \sqrt{R_x^2 + R_y^2}$

Weir and Notches

9

Weir	Notch
1. Constructed in an open channel to measure its discharge. 2. It is bigger in size 3. It is concrete or masonary structure.	1. Used for measuring the discharge through a small channel or a tank. 2. It is smaller in size 3. It is gererally metallic plate 4. Useful in model analysis

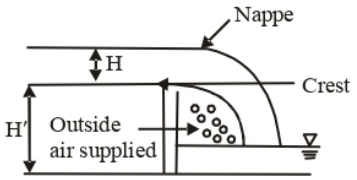


Crest/Sill: The bottom edge of a notch/Top of a weir over which water flows is known as crest/sill.

Classification of Weirs Based on			
Shape of opening	Effect of sides on emerging nappe	Shape of crest	Nature of discharge
Rectangular Trapezoidal Triangular Cipolletti	With end contraction Without end contraction	Sharp edge crested Narrow crested Broad crested Ogee-shaped	Ordinary weir Submerged weir

1. Rectangular sharp-crested Suppressed weir:

- Suppressed – without end contraction.

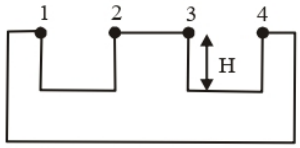


- $Q_{actual} = \frac{2}{3} c_d \, L\sqrt{2g} \; H^{3/2}, \quad c_d = 0.62$

  $H \rightarrow$ depth of water above crest level
- If velocity of approach (V_a) is also considered , then

$$V_a = \frac{Q}{(H + H')L}, \quad h_a = \frac{V_a^2}{2g}, \quad Q = \frac{2}{3} c_d \sqrt{2g} L \left[(H + h_a)^{3/2} - h_a^{3/2} \right]$$

- Effect of end contraction, if not suppressed L is replaced by L_{eft}



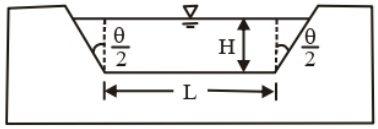
L_{eff} = L – 0.1 nH

n = Number of end contractions (It is 4th in the above diagram)

$$Q = \frac{2}{3} c_d \sqrt{2g} \; L_{eff} \; H^{3/2}$$

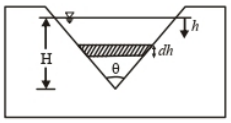
2. Trapezoidal Notch or weir:

$$Q = \frac{2}{3} c_{d_1} \sqrt{2g} \; L \, H^{3/2} + \frac{8}{15} c_{d_2} \sqrt{2g} \; \tan \frac{\theta}{2} H^{5/2}$$



3. Flow over V-Notch or triangular weir:

- End contraction is not consider in this case.



- $Q = \frac{8}{15} c_d \sqrt{2g} \; \tan \frac{\theta}{2} H^{5/2}$ $\qquad c_d = 0.52$

- If we consider velocity of approach then

$$Q = \frac{8}{15} c_d \sqrt{2g}\ \tan\frac{\theta}{2}[(H + h_a)^{5/2} - h_a^{5/2}]$$

Advantages

(*a*) c_d nearly constant with depth.

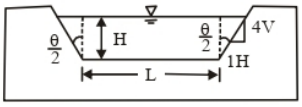
(*b*) Only one dimension is to be measured, therefore more accurate

(*c*) Even for small discharge, high head is obtained. Therefore, no effect. or viscosity and surface tension.

(d)A triangular notch gives much more accurate results in low discharge conditions as compared to conventional rectangular notch.

4. **Cipolletti-Weir:** It is a trapezoidal weir whose slopes are adjusted in such a way that:

- Reduction in discharge due to end contraction in rectangular weir = Increase in discharge due to triangular portion.



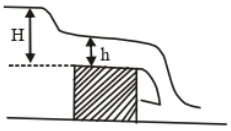
$$\tan\frac{\theta}{2} = \frac{1}{4}, \theta = 28^\circ$$

$$Q = \frac{2}{3} c_d \sqrt{2g}\ L H^{3/2}$$

$$c_d = 0.63$$

5. **Broad Crested weir**

- Consider a Nappe in such a way that stream lines become straight & pressure variation become hydrostatic over the weir.
- $Q = c_d\ L h\ \sqrt{2g(H - h)}$
- In this, flow adjusts itself to give max. discharge at available head H.



- For maximum , discharge

$$h = \frac{2}{3}H \quad Q_{max} = 1.7\ c_d L H^{3/2}$$

$$c_d = 0.85 - 1,$$

h = critical depth as discharge is maximum

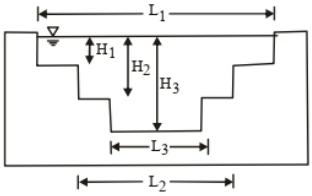
- If Velocity of approach is also considered

  $Q = 1.7\ c_d\ L\ [(H + h_a)^{3/2} - h_a^{3/2}]$

Type of Weir	Discharge Coefficient
Submerged Broad Crested Weir	0.83 – 0.85
Free Broad Crested Weir	0.85 – 1.0

6. Stepped Notch

$$Q = \frac{2}{3} c_d \sqrt{2g} \left[L_1 H_1^{3/2} + L_2 H_2^{3/2} + L_3 H_3^{3/2} \right]$$



7. Proportional weir:

- $Q \propto H$

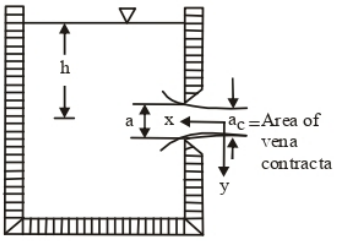
$$Q = K\left(H - \frac{a}{3}\right)$$

$$c_d = 0.6 - 0.65, \quad K = c_d L \sqrt{2ga}$$

- If there are fluctuations in discharge, then there will be less fluctuations in 'H' as compared to rectangular & triangular weirs.

8. Flow through orifice

- Orifice is small opening in tank
- $Q = c_d\ a\ \sqrt{2gh}$

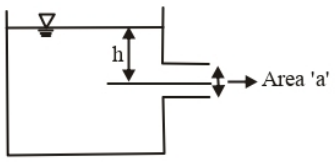


$$c_c = \frac{a_c}{a}, \quad c_d = c_c \times c_v$$

9. Flow through mouth piece

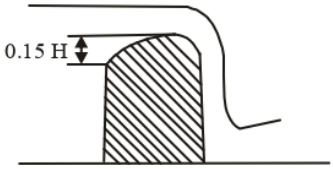
- Mouth piece is short length of tube with length < (2 –3) diameter of orifice.

- $Q = c_d \; a\sqrt{2gh}$, $c_d = 0.82$



10. Ogee spillway

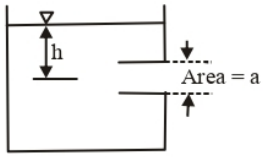
- Profile of the crest is made in such a way that it matches with the shape of water profile over sharp crested weir to avoid development of –ve pressure below nappe (or Adhering Nappe).



$$Q = \frac{2}{3} c_d L \sqrt{2g}\, H^{3/2}, \qquad c_d = 0.62$$

11. Borda's weir

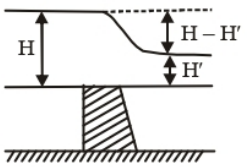
$$Q = c_d a\sqrt{2gh}$$



12. Submerged weir

- When downstream water level is above the crest of the weir, then it is said to be submerged
- Sharp crested weir is more susceptible to submergence than a broad crested weir

- $Q = \frac{2}{3} C_{d_1} L\sqrt{2g}\; (H - H')^{3/2} + c_{d_2} LH' \sqrt{2g\,(H - H')}$



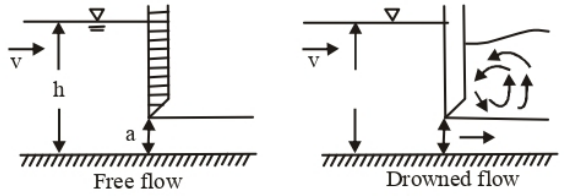
13. Discharge through sluice gate

$$v = \sqrt{2gh}$$

$$Q = c_d a\, L\, \sqrt{2gh}$$

h = Water depth from ground

L = Inside length



Effect on discharge due to error in head measurement

For infinite small errors in head measurement

$$Q = KH^n$$

$$dQ = Kn\, H^{n-1} dH$$

$$\frac{dQ}{Q} \times 100 = n\left(\frac{dH}{H} \times 100\right)$$

% error in discharge = n × % error in head measurement

here $n = 1$ Proportional weir,

$n = 1.5$ rectangular weir,

$n = 2.5$ triangular weir.

Laminar Flow

10

In Laminar flow fluid particles move along the straight parallel paths in layers. It occurs at a very low velocity, & Viscous force predominates the inertial forces. **(Couette flow:** When one plate is moving and other is at rest)

Nature of flow according to Reynold's number (R_e)

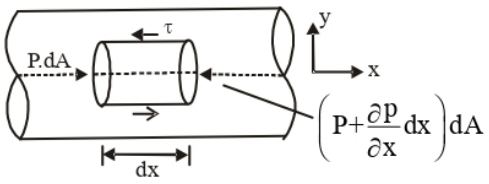
	Laminar	**Transition**	**Turbulent**
Flow in pipe	$R_e < 2000$	$2000 < R_e < 4000$	$R_e > 4000$
Flow between parallel plate	$R_e < 1000$	$1000 < R_e < 2000$	$R_e > 2000$
Flow in open channel	$R_e < 500$	$500 < R_e < 2000$	$R_e > 2000$
Flow through soil	$R_e < 1$	$1 < R_e < 2$	$R_e > 2$

Flow through circular pipe (steady uniform flow)

1. $\frac{dp}{dx} = \frac{d\tau}{dy}$

   x is the direction of flow

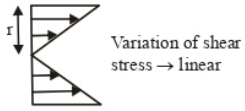
   y is perpendicular to x



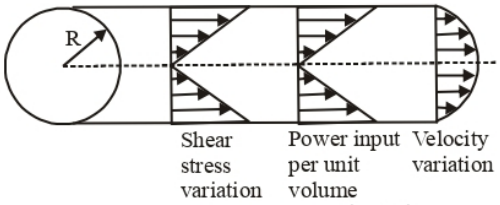
2. $V = V_{max}\left(1-\frac{r^2}{R^2}\right)$

3. $V_{max} = \frac{1}{4\mu}\left(\frac{-dp}{dx}\right)R^2$

4. $\tau = -\frac{r}{2}\left(\frac{dp}{dx}\right)$



5. $\tau_{max} = \frac{2\mu V_{max}}{R} = \left(\frac{P_2 - P_1}{L}\right)\frac{R}{2}$



6. Hagen Poiseuille Formula , $Q = \frac{\pi}{128\mu}\left(\frac{-dp}{dx}\right)D^4$

7. $V_{avg} = \frac{Q}{\pi R^2} = \frac{1}{32\mu}\left(-\frac{\partial p}{\partial x}\right)D^2$, $V_{max} = 2V_{avg}$

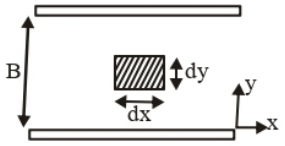
8. $V = V_{avg}$ at $r = \frac{R}{\sqrt{2}} = 0.707\ R$

9. $h_L = \frac{fLV^2}{2gD} = \frac{(4f')LV^2}{2gD}$, ($f$ = friction factor = $\frac{64}{R_c}$, f' = coefficient of friction)

10. $h_L = \frac{32\mu \bar{V}L}{\gamma D^2} = \frac{128\mu QL}{\pi\gamma D^4}$

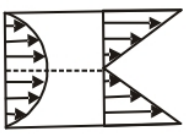
Flow between two fixed parallel plates

1. $u = \frac{1}{2\mu}\left(\frac{-dp}{dx}\right)(By - y^2)$



2. $Q = \frac{1}{12\mu}\left(\frac{-dp}{dx}\right)B^3$

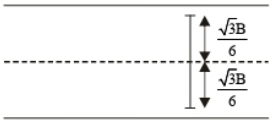
3. $\tau = \mu\frac{du}{dy} = \frac{1}{2}\left(\frac{-dp}{dx}\right)(B - 2y)$



4. $V_{avg} = \frac{Q}{A} = \frac{1}{12\mu}\left(\frac{-dp}{dx}\right)B^2$

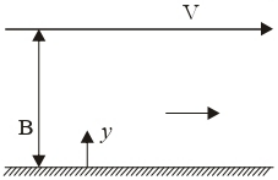
5. $V_{max} = \frac{1}{8\mu}\left(\frac{-dp}{dx}\right)B^2$, $V_{max} = \frac{3}{2}V_{avg}$

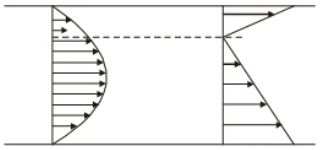
6. $V = V_{avg}$ at $y = \frac{B}{2} \pm \frac{\sqrt{3}B}{6}$



7. $h_L = \frac{12\mu V_{avg} L}{\gamma B^2}$

For couette flow (one plate moving other at rest)





Velocity distribution | Shear stress variation

$$u = \frac{Vy}{B} + \frac{1}{2\mu}\left(\frac{-dp}{dx}\right)(By - y^2)$$

$$\tau = \frac{\mu V}{B} + \left(\frac{-dp}{dx}\right)\left(\frac{B}{2} - y\right)$$

Entrance length: Entrance length in a pipe is the length where boundary layer increases and flow becomes fully developed.

- For Laminar Flow $L = 0.07\ R_e\ D$
- For Turbulent Flow $L_e = 50\ D$

Special Points:

Hele Show flow: Laminar flow between parallel plates

Stoke's Law: Settling of fine particles.

Hagen Poiseuille flow: Laminar flow in Tubes/pipes.

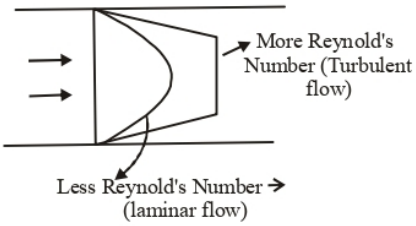
Measurement of viscosity - (a) Rotating cylinder method, (b) Capillary tube method, (c) Orifice type viscometer (Eagler viscometer or Bolt red wood)

Turbulent Flow

11

Turbulent flow results from the instability of laminar flow & due to continuous mixing among different layers. Then momentum transfer occurs which gives rise to addition shear called Turbulent shear.

- For Turbulent flow, the velocity profile will be flatter than that in Laminar flow.



- Shear stress at boundary (τ_w) is much less in Laminar flow as compared to turbulent flow because velocity gradient near the boundary is large in turbulent flow (due to additional shear stress).

Shear stress in turbulent flow

For Turbulent flow		
(1) Boussineq's	(2) Reynold's	(3) Prandtl
$\tau = \eta \frac{d\bar{u}}{dy}$	$\tau = \rho(u'v')$	$\tau = \rho l^2 \left(\frac{du}{dy}\right)^2$
η = eddy viscosity or turbulent mixing coefficient (which depends on flow property) $\frac{\eta}{\rho}$ = eddy kinematic viscosity	u', v' are fluctuating components of velocity in x & y direction respectively	l = mixing length, it is the distance covered by a particle before striking any other particle (or before its momentum is changed)

$$\tau_{Total} = \tau_{Laminar} + \tau_{Turbulent}$$

Hydrodynamically smooth and rough boundary

- If average height of roughness (K) is more than laminar sub layer, it is hydrodynamically rough boundary.
- In hydrodynamically smooth boundaries, average height of roughness (K) is much less than the laminar sub layer (δ').

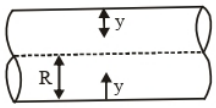
$$\delta' = 11.6\frac{v}{u_*}$$

u_* = Shear velocity = $\sqrt{\frac{\tau_w}{\rho}}$; τ_w = Boundary shear stress

$v \rightarrow$ Kinematic Viscosity

Velocity distribution for turbulent flow in smooth as well as Rough pipe

1. $\frac{u - u_{avg}}{u_*} = 5.75\log_{10}\left(\frac{y}{R}\right) + 3.75$



Here, y is measured from the boundary surface, not from centre.

2. As $\frac{U_*}{U_{avg.}} = \sqrt{\frac{f}{8}}$, $\left(\frac{U_{max}}{U_{avg}}\right) = 1 + 1.33\sqrt{f}$

3. $U = U_{max}$ at $y = R$, So $\left(\frac{U_{max} - U_{avg}}{u_*}\right) = 3.75$

4. $\frac{1}{7}$ th power law of velocity distribution for smooth pipes

$$\frac{u}{u_{max}} = \left(\frac{y}{R}\right)^{\frac{1}{7}} \text{ (As per Nikuradse)}$$

5. In pipe flow, $\tau_w = \frac{dp}{dx}\left(\frac{R}{2}\right)$, $\frac{R}{2}\left(\frac{\Delta P}{L}\right) \Rightarrow \frac{R}{2L}(\gamma h_L)$

$$\frac{\tau_w}{\rho} = \frac{R}{2L}(gh_L) = \frac{R}{2L}g\left(\frac{fV^2}{2gD}\right) = \frac{D}{4L}g\left(\frac{fV^2}{2gD}\right)$$

$$\frac{\tau_w}{\rho} = \frac{f}{8}V^2, \sqrt{\frac{\tau_w}{\rho}} = u_* = \sqrt{\frac{f}{8}}V_{avg}$$

Friction factor '*f*' for Turbulent flow (Artificial Roughnes)

1. **For smooth pipes**

(*a*) $f = \dfrac{0.316}{(R_e)^{1/4}},\ 4000 < R_e < 10^5$

Special Point: For laminar flow $f = \dfrac{64}{R_e}$ circular pipe

(*b*) $f = 0.0032 + \dfrac{0.221}{(R_e)^{0.237}},\ 5\times10^4 < R_e < 4\times10^7$

(*c*) $\dfrac{1}{\sqrt{f}} = 2\log_{10}\left(Re\sqrt{f}\right) - 0.8,\ 5\times10^4 < Re < 4\times10^7$ (Nikuradse)

2. **For Smooth Commercial pipes**

$$\frac{1}{\sqrt{f}} - 2\log_{10}\left(\frac{R}{K}\right) = 1.74 - 2\log_{10}\left[1 + 18.7\frac{R/K}{R_e\sqrt{f}}\right]$$

3. **For Rough pipes**

$$\frac{1}{\sqrt{f}} = 2\log_{10}\left(\frac{R}{K}\right) + 1.74,\ R \rightarrow \text{Radius of pipe}$$

$\left(\dfrac{R}{K}\right) \rightarrow$ Relative Smoothness

Dependence of friction factor			
Transition flow	**Laminar flow**	**Turbulent flow**	
		Smooth pipe	Rough pipe
$f = g(R_e, k)$ Reynold's no & average height of Roughness	$f = g(R_e)$ Only on Reynold's Number	$f = g(R_e)$ Only on Reynold's number	$f = g(k)$ Only on average height of roughness

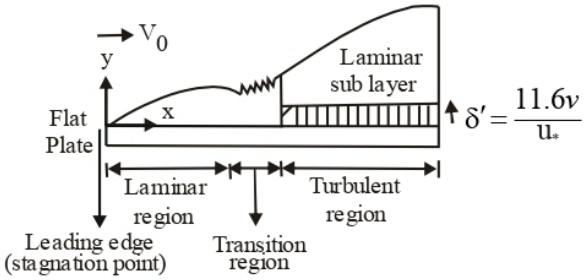
Laminar flow	Turbulent flow
In it fluid layer moves in straight line.	Fluid flow in zig-zag manner
Occurs when fluid flow with low velocity & in small diameter pipes	Occurs when fluid flow with high velocity & in large diameter pipes
Shear stress depend only on viscosity	Shear stress depends on density
Fluid flow is very orderly	There is mixing of different layers

Boundary Layer Thickness

12

It is the region in the immediate vicinity of the boundary surface in which the velocity of flowing fluid increases gradually from zero at the boundary surface to the velocity of the main stream.

- Flow outside the boundary layer has Ir-rotational characteristic but that within the boundary layer is rotational characteristic.
- It was developed by Prandtl in 1904
- Valid for infinitely large medium of real fluid & not for ideal fluid.



Essential boundary conditions:

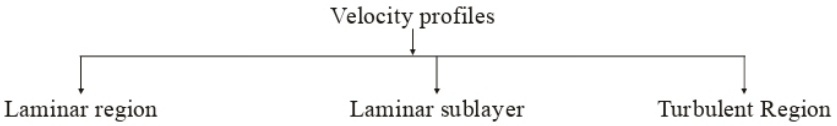
1. $x = 0, \delta = 0$
2. $y = \delta, u = 0.99V_0$
3. $y = 0, u = 0$
4. $y = \delta, \frac{du}{dy} = 0$

Desirable boundary conditions: At $y = \delta, \frac{du}{dy} = 0, \frac{d^2u}{dy^2} = 0$

Salient points regarding boundary layer:

1. As the roughness of plate increases, length of laminar region decreases
2. With increase in velocity, boundary layer thickness decreases but with increase in viscosity boundary layer thickness increases.
3. +ve pressure gradient increases boundary layer thickness but reduces the length of laminar region.

4. $R_{ex} = 5 \times 10^5$ is called critical Reynold's number.
   If $R_e < R_{ex}$ then laminar boundary layer region in case of flat plates
   $R_e > R_{ex}$ then Turbulent boundary layer region, in case of flat plates
5. On a smooth plate, in turbulent layer region, there is very thin layer adjacent to the boundary where the flow remains laminar. This region is called laminar sub layer.



$$\frac{u}{u_0} = \left(\frac{y}{\delta}\right)^2 \qquad \frac{u}{u_0} = \left(\frac{u_* \times y}{\nu}\right) \qquad \frac{u}{u_0} = \left(\frac{y}{\delta}\right)^{1/7}$$

Boundary layer Thickness (δ): It is the distance form the boundary surface in which velocity reaches 99% of the free stream velocity.

At $y = \delta$, $V = 0.99\ V_0$

Displacement Thickness (δ^*) : It is the distance by which boundary should be shifted in order to compensate for the reduction in mass flow rate on account of boundary layer formation.

$$\delta^* = \int_0^{\delta} \left(1 - \frac{V}{V_0}\right) dy$$

V_0 = Free stream velocity

V = Velocity at any distance y from the boundary

Reduction in mass flow rate per unit width = $\rho\ \delta^* V_0$

Momentum Thickness (θ): It is the distance by which boundary should be shifted in order to compensate for the loss of momentum due to formation of Boundary layer.

$$\theta = \int_0^{\delta} \frac{V}{V_0}\left(1 - \frac{V}{V_0}\right) dy$$

Energy thickness (δ_E)

It is the distance by which boundary should be shifted in order to compensate loss of energy due to boundary layer formation.

$$\delta_E = \int_0^{\delta} \frac{V}{V_0}\left(1 - \frac{V^2}{V_0^2}\right) dy$$

Loss of energy due to boundary layer formation = $\frac{\rho V_0^3}{2}\delta_E$

Special Points:

- Shape factor = $\frac{\delta^*}{\theta}$
- $\delta^* > \delta_E > \theta$

FRICTION COEFFICIENT

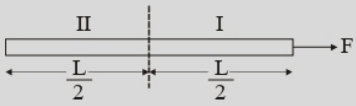
Local skin friction coefficient

Average drag coefficeint

$C_{fx} = \frac{\tau_0}{\left(\frac{\rho V_0^2}{2}\right)} = \frac{\text{Wall shear stress}}{\text{Dynamic pressure}}$, $C_{f_{avg}} = \frac{\text{(Drag Force on plate)}}{\frac{\rho V_0^2}{2} \times area\ of\ plate} = \frac{\text{Avg. wall shear stress}}{\text{Dynamic pressure}}$

Special Point :

If Boundary layer is laminar through out



$\frac{\text{Drag force on I half}}{\text{Drag force on II half}} = 1 + \sqrt{2}, > 1$

Blassius experiments results/when velocity profile is not given

	Laminar	Turbulent	Transition region
	$R_0 < 5 \times 10^5$	$5 \times 10^5 < R_e < 10^7$	$10^7 < R_e < 10^9$
δ	$\frac{5x}{\sqrt{R_{ex}}}$	$\frac{0.376x}{(R_{ex})^{1/5}}$	$\frac{0.22x}{(R_{ex})^{1/6}}$
C_{fx}	$\frac{0.664}{(R_{ex})^{1/2}}$	$\frac{0.059}{(R_{ex})^{1/5}}$	$\frac{0.37}{(\log_{10} R_{ex})^{2.58}}$
C_{favg}	$\frac{1.328}{\sqrt{R_{eL}}}$	$\frac{0.074}{(R_{eL})^{1/5}}$	$\frac{0.455}{(\log_{10} R_{eL})^{2.58}}$

Special Points :

- In laminar region $C_{fx} \propto \frac{1}{\sqrt{x}}$, but in turbulent region $C_{fx} \propto \frac{1}{x^{1/5}}$ So, τ_0 decreases more repidly in laminar region than in turbulent region.
- In Laminar region $\delta \propto \sqrt{x}$, while in turbulent region $\delta \propto x^{4/5}$. So δ increases more rapidly in turbulent region than in laminar region

Drag froces on a plate which has both Laminar and Turbulent regions

$$\text{Drag force} = C_D \times \frac{\rho V^2_0}{2} \times \text{Area}$$

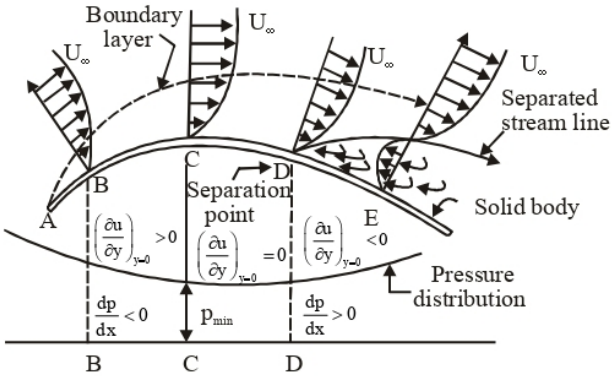
Separation of Boundary layer

$\left(\frac{du}{dy}\right)_{y=0} = 0$ is called separation point

$\left(\frac{du}{dy}\right)_{y=0} > 0$, Attached flow

$\left(\frac{du}{dy}\right)_{y=0} < 0$, Already separated flow

Separation of flow occurs in turbines, pumps, aerofoils, open channel transitions etc:



Effect of pressure gradient on boundary layer separation.

- In the region ABC of curved surface, the area of flow decrease & so the velocity increases. Hence, the flow get accelerated in the region & the pressure decreases in the direction of flow.

- Therefore, $\frac{dp}{dx} < 0$, and the entire boundary layer moves forward.
- Along the region CDE of curved surface, the area of flow increases & so velocity of flow decreases in the fluid.
- The pressure is minimum at point C.
- To delay the point of separation, a tripwire is mounted near the leading edge of body.
- Due to decrease of velocity, $\frac{dp}{dx} > 0$. Therefore, in the region CDE, the velocity of flow goes on decreasing because the kinetic energy of the layer is used to overcome the frictional resistance of the surface. The combined effect of +ve pressure gradient & surface resistance decrease the momentum of the fluid.
- A condition comes, when the momentum of the fluid is unable to over come the surface resistance & the boundary layer starts separating from the surface at point D.
- D/s of the point D, where the flow takes place in the reverse direction & the velocity gradient becomes –ve.
- So, the +ve pressure gradient helps in boundary layer separation.
- Large turbulent eddies are formed at D/s of the point of separation. The region is called the turbulent wake.

Consequences of boundary layer separation

(*a*) Separation of boundary layer increases flow losses in case of internal flow like pipes.

(*b*) There is increase in pressure drag if there is boundary layer separation in case of external flow

Methods to control separation

1. Rotating boundary in flow direction
2. Stream lining of the body.
3. Suction of fluid from boundary layer.
4. Supplying additional energy form blower
5. Providing a bypass in the slotted wing
6. Accelerating the fluid in boundary layer by injecting fluid.
7. Providing guide blades on bends.

Dimensional Analysis and Model Studies

13

Dimensional homogeneity: It states that every term in an equation when reduced to its primary (fundamental) dimensions must contain identical powers of each dimension.

Dimensions of Few Physical Quantities

(*a*) Kinematic Quantities:

1. Angular velocity	T^{-1}
2. Vorticity	T^{-1}
3. Angular acceleration	T^{-2}
4. Kinematic viscosity	L^2T^{-1}
5. Stream function	L^2T^{-1}
6. Circulation	L^2T^{-1}

(*b*) Dynamic Quantities:

1. Specific weight	$ML^{-2}T^{-2}$
2. Surface tension	MT^{-2}
3. Modulus of elasticity	$ML^{-1}T^{-2}$
4. Dynamic viscosity	$ML^{-1}T^{-1}$
5. Bulk modulus	$ML^{-1}T^{-2}$
6. Angular momentum	ML^2T^{-1}

Methods of Dimensional Analysis

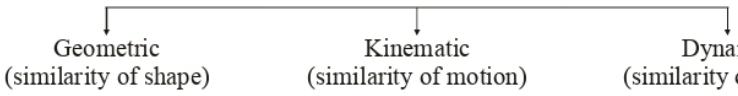
(*a*) Rayleigh's Method:

- It does not provides any information regarding the number of dimensionless groups to be obtained as a result of dimensional analysis.
- It is used for determining the expression for a variable which depends upon maximum of 3 to 4 variables.

(*b*) Buckingham's π-theorem: If there are *n* no. of variables in a dimensionally homogenous equation & these variables contain *m*

fundamental dimensions, then the no. of dimensionless groups which can be formed shall be *(n-m)*.These dimensionless groups are called π-terms.

Similitude : To achieve similarity between the flow in the model & its prototype, every dimensionless parameter referring to that conditions in the model must have the same numerical value as the corresponding parameter referring to the prototype



Special points: For kinematics similarity, Geometric similarity must exist & for dynamic similarity both Geometric & kinematic similarity must exist. These are necessary conditions but not sufficient conditions (if kinematic similarity exists, then geometry similarity will be definitely there while geometric similarity exists then kinematic similarity may or may not exist). (also similar for dynamic similarity)

- A model can be larger than prototype.
- Normally larger models are made when:

(a) Flow field is very small.

(b) Flow velocity is very large.

Forces acting of Fluid mass

1. Inertia Force $(F_i) = \rho L^2V^2$
2. Gravity Force $(F_g) = \rho L^3g$
3. Pressure Force $(F_p) = PL^2$
4. Viscous Force $(F_v) = \mu VL$
5. Surface tension Force $(F_\sigma) = \sigma \times L$
6. Elasticity force $(F_e) = KL^2$

Dimensionless-Paramters

Compressibility force are predominant when mach no ≥ 0.3

$0.3 <$ Low subsonic, 0.3-0.8 $\rightarrow$ High subsonic, 0.8-1.2 $\rightarrow$ Transonic, 1.2-5.0 $\rightarrow$ Supersonic, 5-10 $\rightarrow$ Hypersonic, 10 -25 $\rightarrow$ High Hypersonic

Number	Equation	Uses
Reynolds No.	$\frac{F_i}{F_v}=\frac{\rho VL}{\mu}$	Aeroplanes, submarines, pipe flow
Eulers No.	$\sqrt{\frac{F_i}{F_p}}=\frac{V}{\sqrt{\frac{p}{\rho}}}$	Cavitation problem, water hammer problem, high pressure flow in pipe
Mach No.	$\sqrt{\frac{F_i}{F_e}}=\frac{V}{C}$	Aerodynamic testing, rocket, missile
Froude No.	$\sqrt{\frac{F_i}{F_g}}=\frac{V}{\sqrt{gL}}$	OCF, spillway, weir , Harbour model
Weber No.	$\sqrt{\frac{F_i}{F_\sigma}}=\frac{v}{\sqrt{\sigma/\rho L}}$	Blood in arteries and veins, rising bubble, seepage through soil capillary rise, study of droplet, flow over weir for small head

	Reynold's law	**Fraude's law**
Time Ratio (T_r)	$\frac{\rho_r L_r^2}{\mu_r}$	$\frac{\sqrt{L_r}}{\sqrt{g_r}}$
Velocity Ratio (V_r)	$\frac{\mu_r}{L_r\rho_r}$	$\sqrt{L_r}\times\sqrt{g_r}$
Acceleration Ratio (a_r)	$\frac{\mu_r^2}{\rho_r^2 L_r^3}$	g_r
Power Ratio (P_r)	$\frac{\mu_r^3}{\rho_r^2 L_r}$	$\rho_r L_r^{3.5} g_r^{1.5}$
Force Ratio (F_r)	$\frac{\mu_r^2}{\rho_r}$	$\rho_r L_r^3 g_r$
Discharge Ratio (Q_R)	$\frac{\mu_r L_r}{\rho_r}$	$\rho_r L_r^{2.5} g_r^{0.5}$

River model law (Distorted model law)

(*a*) Vertical scale ratio (L_{rv}) = $\frac{H_p}{H_m}$

(*b*) Horizontal scale ratio (L_{rH}) = $\frac{L_p}{L_m} = \frac{B_p}{B_m}$

(*c*) Velocity ratio (Vr) = $\sqrt{L_{rv}}$

(*d*) Area ratio (A_r) = $L_{rv} \times L_{rH}$

(*e*) Discharge ratio (Q_r) = $L_{rH}.L_{rv}^{3/2}$

Model / Prototype Laws for

(*a*) Head ratio (H_r) = $N_r^2\ D_r^2$, (where D_r = diameter ratio)

(*b*) Discharge ratio (Q_r) = $N_r\ D_r^3$, (where N_r = rotational speed ratio)

(*c*) Power ratio (P) = $\rho_r\ N_r^3\ D_r^5$

Pipe Flow

14

Practically, all the flow in the pipes is turbulent in nature.

Head loss

Frictional loss
Major loss → (80 – 90)%

Losses in pipe fittings
Minor loss →(10 – 20)%

- Major loss in pipe due to friction is given by Darcy–Weisbach equation.

Major Losses

(*a*) Darcy's weisbach equation

$h_f = \frac{f L V^2}{2gD}$, $f = 4f'$, (f = friction factor, f' = coefficient of friction)

(*b*) Chezy's formula

$$V = C\sqrt{RS}$$

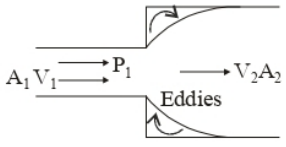
$$R = \frac{A}{P} = \frac{\pi}{4}\frac{D^2}{\pi D} \Rightarrow R = \frac{D}{4}$$

$$\text{Slope } (S) = \frac{h_L}{L}$$

By equating both the above equations , we can get $C = \sqrt{\frac{8g}{f}}$

Minor losses

(*a*) Due to sudden expansion

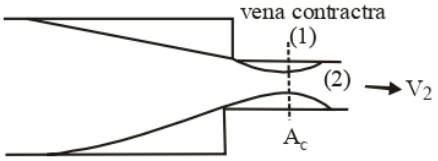


$$h_L = \frac{(V_1 - V_2)^2}{2g} = \frac{V_1^2}{2g}\left(1 - \frac{A_1}{A_2}\right)^2$$

A_1 = Area of smaller diameter pipe
A_2 = Area of bigger diameter pipe
V_1 = Velocity of smaller diameter pipe

$$h_L = K\frac{V_1^2}{2g} \qquad \text{Where } K = \left(1 - \frac{A_1}{A_2}\right)^2$$

(*b*) Losses due to sudden contraction



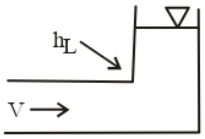
$$h_L = \frac{(V_c - V_2)^2}{2g} = \frac{KV_2^2}{2g} = \frac{0.5V_2^2}{2g}$$

where $K = \left(\frac{1}{C_c} - 1\right)^2$, $C_c = \frac{A_c}{A_2}$

Special Points:

- Momentum equation and Bernouilli's equation are uses in derivation of losses
- Loss in expansion is much higher than loss in contraction
- Losses are always expressed in terms of velocity of smaller diameter pipe.

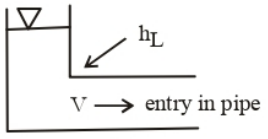
(*c*) Exit loss (due to impact)



$$h_L = \frac{KV^2}{2g}$$

Special Point: In exit loss due to impact, K is the kinetic energy correction factor. For Laminar , its K = 1 & forTurbulent, its K = 1.

(*d*) Entry loss



$$h_L = \frac{0.5V^2}{2g}$$

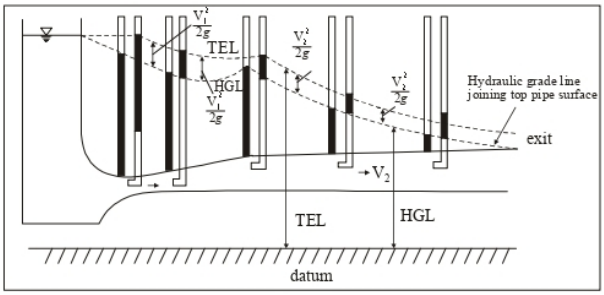
(*e*) Loss due to pipe fittings and bends

$$h_L = \frac{KV^2}{2g}$$

Type of fitting	K
Standard Tee	1.8
Standard Elbow	0.9
45° Elbow	0.4
90° Bend T (Sharp)	1.2
Gate valve (half open)	5.6
Angle valve	5.0
Foot valve of pump	1.5

Hydraulic gradient line and Total energy line

Line joining the points of piezometric head $\left(\frac{P}{\gamma} + z\right)$ at various points in a flow is called HGL.



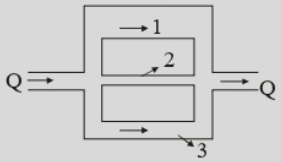
Line joining the points of total energy $\left(\frac{P}{\gamma} + \frac{V^2}{2g} + z\right)$ at various points in a flow is called TEL.

Special Points:

- HGL may rise or fall in the flow direction, depending upon the velocity head (which varies with the area of cross section)
- TEL always fall down. But if there is a pump or turbine placed in the flow, then there will be sudden rise or fall repectively
- TEL is horizontal in case of idealised Bernoulli's flow as losses are zero.

Pipe connections

Parallel connection

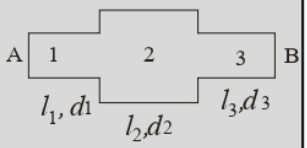


Same head loss

$$Q = Q_1 + Q_2 + Q_3$$

$$h_{L_{AB}} = h_{L_1} = h_{L_2} = h_{L_3}$$

Series connection



Same discharge

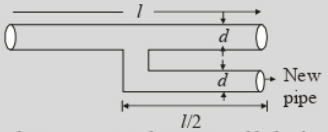
$$h_{L_{AB}} = h_{L_1} + h_{L_2} + h_{L_3}$$

$$Q = Q_1 = Q_2 = Q_3$$

Equivalent pipe: A pipe which can replace existing compound pipe while carrying same discharge under same losses. For series connection equivalent pipe of length 'L' and diameter 'D' will be

$$\frac{L}{D^5} = \frac{l_1}{d_1^5} + \frac{l_2}{d_2^5} + \frac{l_3}{d_3^5}$$

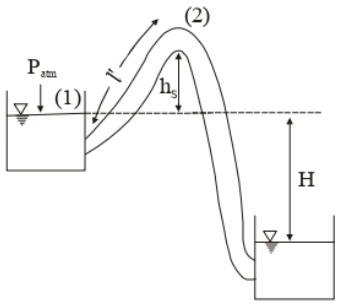
Special Point: Increase in discharge by adding a pipe of same diameter in mid way of a pipe but keeping that head constant is 26.53%



In pipe flow of municipal water supply, a parallel pipe is Installed mainly for increasing the discharge .

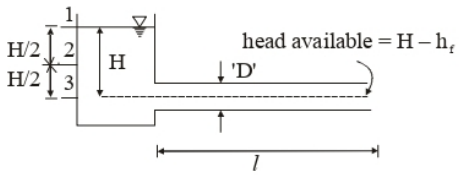
Flow through siphon:

- A pipe which rise above its hydraulic grade line has –ve pressure & is known as siphon.



Special point: For No vapourisation $P_s > P_{vaporization}$, otherwise vapours will form & flow will be stopped.

Power transmitted through pipe



$$\text{Efficiency } (\eta) = \frac{H - h_f}{H}$$

Power $(P) = Q\ \gamma(H - h_f)$

For max power $\frac{dP}{dQ} = 0,\ h_f = \frac{H}{3}$

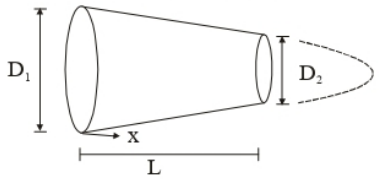
$\eta_{max} = 66.67,\%$, min. power lost = 33.33%

- Time required to empty the reservoir $\int_0^H \frac{dh}{\sqrt{h}} = \int_0^T \sqrt{\frac{2g}{K}} \times \frac{a}{A} dt$, here K is head loss constant.
- Time required to empty the top half of tank form 1 to 2 be t_1 & for bottom half from 2 to 3 be t_2 , then $t_1 = 0.414\ t_2$

Special point: It Nozzle of area 'a' attached at exit, then for maximum efficiency $\frac{fla^2}{DA^2} = \frac{1}{2}$ where A corresponds to area of diameter D.

Special case of head loss

Loss of head due to friction in tapering pipe



$$h_f = \int_0^L \frac{fQ^2 dx}{12.1(D_1 - kx)^5}$$

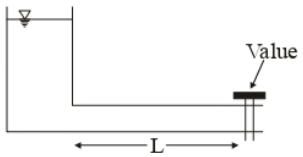
$$K = \left(\frac{D_1 - D_2}{L}\right)$$

Water hammer Pressure: Sudden/rapid closure of valve in a pipe carying flowing liquid destroys the momentum of flowing liquid & sets up a high pressure wave. This pressure wave travels with the speed of sound & causes hammering action in pipe called Knocking/water hammer.

- Surge tanks are used to absorb the Increase in the pressure due to water hammer phenomenon.

Velocity of Pressure Wave (c)

In Rigid Pipe



In Elastic Pipe

$$C = \sqrt{\frac{K}{\rho}}\left(\frac{1}{1+\left(\frac{D}{t}\right)\left(\frac{K}{E}\right)}\right)^{\frac{1}{2}}$$

$$C = \sqrt{\frac{K}{\rho}}$$

D = diameter of pipe, K = Bulk modulus of Liquid, t = thickness of pipe

ρ = mass density of liquid, E = modulus of elasticity of material,

Water hammer pressure = ρ VC

- Time period for complete cycle of water hammer pressure = $\frac{4L}{C}$

Critical time equations $T_0 = \frac{2L}{C}$

Water hammer pressure

Rapid closure
$T \le T_0$

Slow/gradual/closure

$T_0 << T$

$T_0 < T \le 1.5T_0$

Special Point : Equations used in solving branching of pipes connecting reservoirs of different levels are (*a*) Darcy weisbach equation, (*b*) Bernoulli's equation (*c*) Continuity equation.

Hardy-Cross method of solving closed loop pipe networks.

1. It is a trial & error solution
2. Flow rate at the entry of any junction must be equal to flow out of each junction.
3. Loss of head due to flow in clockwise direction must be equal to loss of head due to flow in anti clockwise direction.

$$\text{Modification in discharge } \Delta Q = \frac{-\Sigma r Q^n}{\Sigma \left| r n Q^{n-1} \right|}$$

where $h_f = rQ^n$ & ΔQ is algebrically added.

Various Instruments Used in Measurement

Device	Measurement
Venturimeter	Discharge or rate of flow
Flow nozzle	Discharge or rate of flow
Orifice & mouthpiece	Discharge or rate of flow
Rotameter	Discharge or rate of flow
Bendmeter	Discharge or rate of flow
Hydrometer	Density or specific gravity
Hygrometer	Moisture
Pyrometer	Solar radiation
Pycnometer	Water content & specific gravity
Hot wire anemometer	Air & gas velocity
Current meter	Velocity in open channel flow
Barometer	Local atmospheric pressure
Pitot tube	Fluid velocity
Notches & weir	Discharge or rate of flow through small channels

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9

HYDRAULIC MACHINE

Contents

1. Turbines
2. Hydraulic Pumps

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Turbines

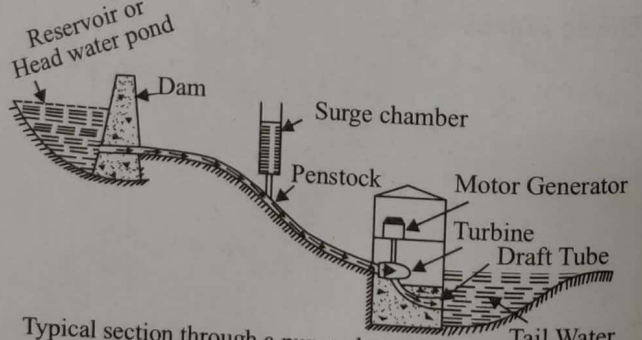
1

Essential Components of Hydro Electric Power Plant:

- Hydraulic Turbine: It is most important part of Hydroelectric plant, as it is a hydraulic machine which converts hydraulic energy into mechincal energy inturns is converted to electric energy.
- The mechanical energy so developed is supplied to the generator coupled to the runner which then generate electrical energy.

Surge Tank: It is a reservoir fitted at some opening made on a long pipe line to receive the rejected flow when the pipeline is suddenly closed.

- It also helps in absorbing the sudden pressure rise due to closing of value when load on turbine is reduced thus elminating water hammer effect.
- When it is not possible to provide forebay we provide surge tank to absorb pressure fluctuation.
- It reduces the distance between the turbine and free surface.



Typical section through a pumped storage plant

Classification according to energy available at input

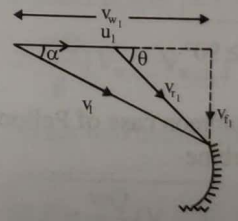
	Impulse turbine	Reaction Turbine
1.	Input energy is only kinetic energy	1. Input energy is kinetic energy + pressure energy
2.	Pressure remains constant throughout the working & which is equal to atmospheric.	2. pressure drop takes place.
3.	Useful for high head & low disshcrge	3. Useful for low head & high discharge
4.	Degree of reaction is zero.	4. Degree of reaction not zero.
5.	No draft tabe	5. Draft tube is present.
6.	Example Pelton wheel	6. Example (i) Francis Turbine (ii) kaplan & propeller Turbine.

Turbine Name	Type	Type of Energy	N_s (MKS)	Head	Discharge	Direction of flow
Pelton wheel turbine (Single jet)	Impulse	Kinetic	10-35	High (250 to 1000m)	Low(Q<1000 LPM)	Tangential
Peloton wheel turbine (multiple jet)	Impulse	Kinetic	35-60	High (250 to 1000 m)	Low	Tangential flow runner
Francis Turbine	Reaction	Kinetic + Pressure	60-300	Medium (60 to 150 m)	Medium (1000-10000) LPM	Inward Radial Mixed flow (Modern Francis)
Kaplan & Propeller turbine	Reaction	Kinetic + Pressure	300-1000	Low (< 30 m)	High(Q>10000LPM)	Axial flow

Velocity Diagram

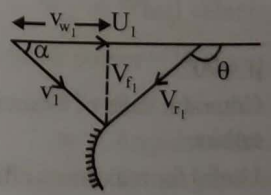
1. At Inlet

(a)



- $\text{Tan}\,\theta = \dfrac{V_{f1}}{V_{w1} - U_1}$
- $\theta < 90°$
- Forward vanes
- Common case of Francis Turbine

(b)



- $\theta > 90$
- Backward vanes
- $\tan(180° - \theta) = \dfrac{V_{f_1}}{U_1 - V_{w_1}}$

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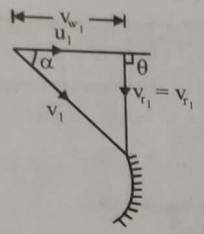
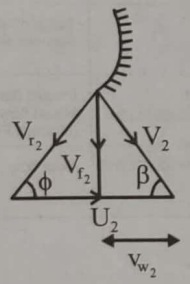
(c)



- $\theta = 90^\circ$
- Radial vanes
- $U_1 = V_{w_1}$
- $V_{F_1} = V_{r_1}$
- $\boxed{\tan\theta = \frac{V_{f_1}}{V_{w_1}}}$

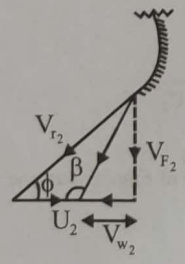
2. At Outlet

(a)



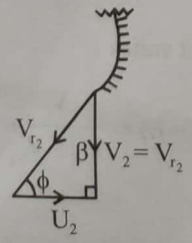
- $\beta < 90^\circ$
- V_{w_2} is in the direction of U_2.

(b)



- $\beta \geq 90^\circ$
- Common case of Pelton wheel turbine

(c)



- $\beta = 90^\circ$
- Common case of Francis turbine
- Useful for maximum efficiency

Here β = guide vane angle between V_2 and U_2 at outlet.
α = guide vane angle between V_1 and U_1 at Inlet.
ϕ = Runner vane angle between V_{r_2} and U_2 Outlet.
θ = Runner vane angle between V_{r_1} and U_1 at outlet.
V_2 & V_1 = Absolute velocity for water of outlet & Inlet respectively.

u_1 & u_2 are relaive velocities at intet and outlet respectively
V_1 & V_2 are tangential, also called circumferential velocity at intlet and outlet respectively.

Francis Turbine

1. Powers

(i) Hydraulic power (water power) $\boxed{H.P = wQH}$ in kW

$= \frac{\rho QH}{75}$ in HP

w(γ) = Spacific weight = ρg
1.HP = 736 watt (Metric H.P)
1.HP = 746 watt (British H.P)
H = Head = $H_g - H_F$
H_g = Gross Head, H_F = Friction loss.

(ii) Runner power $\boxed{R.P = rQ[V_{w_1}U_1 - V_{w_2}U_2]}$

$= \frac{wQ}{g}[V_{w_1U_1} - V_{w_2U_2}]$

(a) for maximum efficiency $V_{w_2} = 0$.

$$\boxed{R.P = \frac{wQ}{g}(V_{w_1U_1})}$$

V_{w2} = Whirl velocity at Outlet, V_{w1} = Whirl velocity at intet.

(iii) Shaft power = $\boxed{S.P = \tau\omega}$

S.P = R.P – Mechanical friction losses
w = Angular velocity of shaft
τ = Torque produced by shaft

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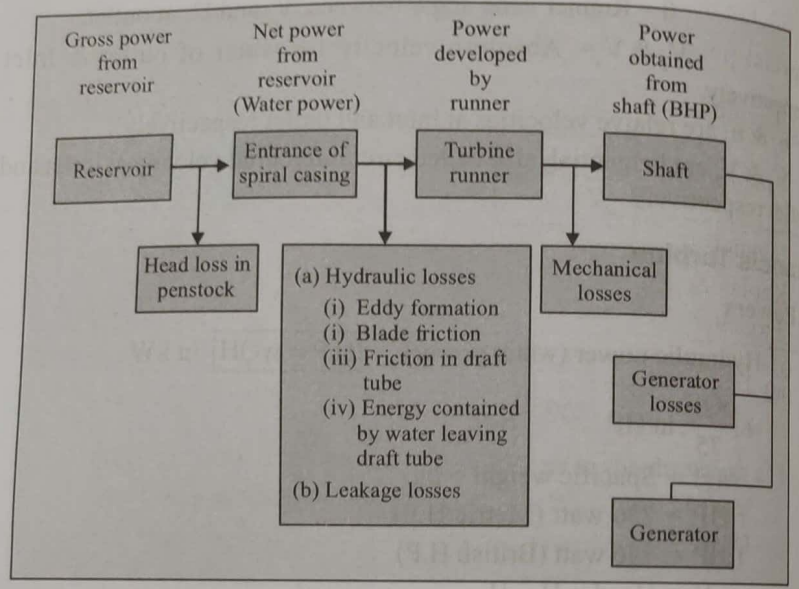
Special point: In Francis Turbine H.P > R.P > S.P

2. Efficiency



For Reaction Turbine

(i) Hydraulic efficiency = $\eta_h = \frac{R.P}{H.P}$

$$\eta_h = \frac{(V_{w_1}u_1 - V_{w_2}u_2)}{gH}$$

(ii) Volumetric efficiency = $\eta_{vol} = \frac{Q - \Delta Q}{Q}$

ΔQ = Change in discharge (m^3/s), Q = Discharge (m^3/S)

(iii) Mechanical efficiency = $\eta_m = \frac{S.P}{R.P} = (1 - \frac{loss}{R.P})$

(iv) Blade efficiency = $\eta_b = \frac{v_1^2 - v_2^2}{v_1^2}$

V_1 & V_2 are absolute velocity of water at inlet and outlet respectively

(v) Overall efficiency. = $\eta_o = \eta_h.\eta_m.\eta_v.\eta_b$

3. Design Parameter of Francis Turbine

(i) $\frac{D_1}{D_2} \simeq 2$ D_1 & D_2 are dia of intel and outlet respectively.

(ii) For maximum efficiency $V_{w_2} = 0$.

Special point:

Turbine	Speed ratio	Flow ratio	No. of vanes
Pelton	0.4–0.5	0	$15 + \frac{m}{2}$
Francis	0.6–0.9	0.15–0.3	25 to 30
Kaplan & Propeller	1.8–2.5	0.6–0.9	3 to 8

(iii) $A_{f_1} = (1-k)\pi D_1 B_1$ $\quad A_{f_2} = (1-k)\pi D_2 B_2$

K = Vane thickness coefficient $\simeq 5\%$

A_{f_1} & A_{f_2} are area of flow at intel and outlet respectively.

B_1 & B_2 are width of plate at inlet and outlet respectively.

D_1 & D_2 are diameter at inlet and outlet respectively.

(iv) Width ratio = $\eta = \frac{B_1}{D_1} \simeq 0.1$ to 0.45

(v) $R = \frac{\frac{P_1}{\gamma} - \frac{P_2}{\gamma}}{\left(\frac{V_{w_1}u_1 - V_{w_2}u_2}{g}\right)}$ (For max. efficiency) $R = \frac{\frac{P_1}{\gamma} - \frac{P_2}{\gamma}}{\left(\frac{V_{w_1}u_1}{g}\right)}$

(vi) Head = $H = \frac{V_2^2}{2g} + \frac{V_{w_1}U_1}{g}$ (Master Formula)

Assumption, $V_{w_2} = 0$, $\frac{P_2}{\rho g} = 0$,

Special Points:

- For turbine : water power > Runner power > shaft power
- For pump : Shaft power > Impeller power > Water power

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4. Model Relationship for Turbine

Dimensional Parameter	Diamensionless Parameter
1. $N_S = \frac{N\sqrt{P}}{(H)^{5/4}}$	1. $N_s = \frac{\omega\sqrt{\frac{P}{\rho}}}{(gH)^{5/4}}$
2. $C_Q = \frac{Q}{ND^3}$	2. $C_Q = \frac{Q}{\omega D^3}$
3. $C_H = \frac{H}{N^2D^2}$	3. $C_H = \frac{gh}{\omega^2D^2}$
4. $C_P = \frac{P}{N^3D^5}$	4. $C_P = \frac{P}{\rho\omega^3D^5}$

Here, N_S = Specific speed, C_Q = Discharge coefficient
C_H = Head coefficient, C_p = Power coefficient

w – Angular speed = $\frac{2\pi N}{60}$, N – No. of revolution/minute

H – Head (m), P – Power

Special Points: Fluid Path

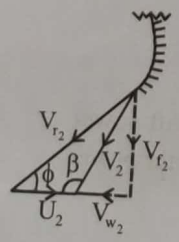
(a) Pelton (Impulse): Head race (Dam) → Penstock → Nozzle → Bucket (Blades) → Runner → Tail race

(b) Reaction turbine (Kaplan & francis): Head race → Penstock → Casing → Guide vanes → Moving vanes → Runner → Draft tube → Tail race.

Pelton Wheel Turbine

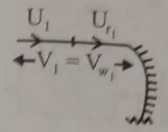
1. Velocity Triangle

(i) At outlet



- $\beta > 90°$
- $V_{r_2} = kV_{r_1}$
- $k = 1$
- k = Friction factor
  For frictionless vane
- $|V_{r_2}\cos\phi| = |U_2| + |V_{w_2}|$

(ii) At Inlet



$V_1 = V_{w_1}$

$V_{f_1} = 0$

Here, $\alpha = 0°$

$\theta = 0°$

2. Power

(i) Jet power or k.E/sec or jet $= \frac{1}{2}\rho Q v_1^2 = \frac{1}{2}\cdot\frac{wQ}{g}V_1^2$

(ii) Hydraulic power H.P = WQH ....(kW), $= \frac{\rho QH}{75}$ ...(H.P)

(iii) Runner power R.P = $\frac{wQ}{g}[V_{w_1} + V_{w_2}]U$

(iv) Shaft power, S.P = R.P – Mechanical friction losses.

Special point: H.P > K.E/sec.of jet > R.P > S.P

3. Efficiencies

(i) Nozzle efficiency : $\eta_{nozzle} = \frac{\text{k.E/sec of jet}}{\text{H.P available of base of nozzle}}$

$= \frac{V_1^2}{2gH} = C_V^2 \left[\because v_1 = C_v\sqrt{2gH}\right]$

(ii) Hydraulic efficiency = $\eta_h = \frac{\text{R.P}}{\text{k.E/sec of Jet}}$

$\eta_{nozzle} = \frac{2\left[V_{w_1} + V_{w_2}\right]U}{V_1^2}$

$= \frac{2(V_1 - u)(1 + k\cos\phi)u}{V_1^2}$

Maximum hydraulic efficiency $\eta_h|_{max} = \frac{(1 + k\cos\phi)}{2}$

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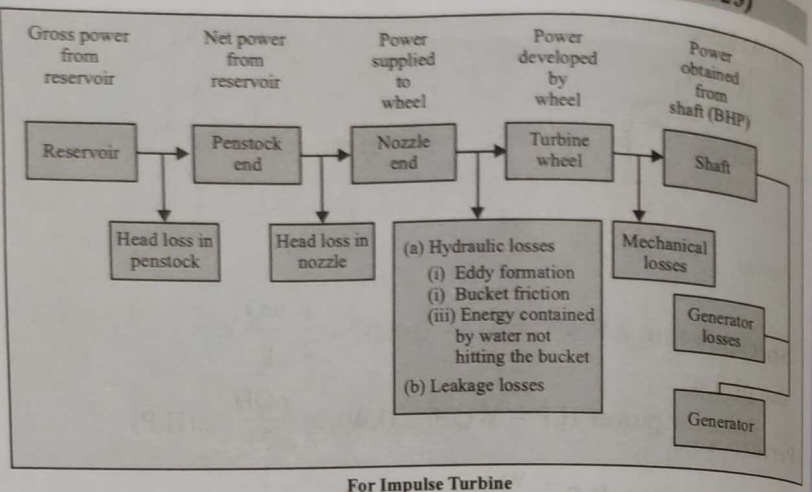

For Impulse Turbine

(iii) Mechanical efficiency = $\eta_m = \dfrac{S.P}{H.P}$

(iv) Overall efficiency = $\eta_o = \dfrac{S.P}{H.P} = \eta_{nozzle.}\ \eta_h.\eta_{mechanical}$

4. Design Criteria

(i) Jet ratio = $m = \dfrac{D}{d} = (11 \text{ to } 15)$

D = Diameter of pitch circle, d = Diameter of jet.

(ii) $\text{No.of jet} = \dfrac{\text{Total discharge through penstock}}{\text{Discharge through each jet}} \not> 6$

(iii) Number of vanes = $n = \left(15 + \dfrac{m}{2}\right)$ (Tygon formula)

= 18 to 25

Kaplan and propeller trubine (Axial Flow reaction turbine)

1. Discharge = $Q = A_{F_1}.V_{F_1} = A_{F_2}.V_{F_2}$, $A_{F_1} = \dfrac{\pi}{4}(D_0^2 - D_b^2)$

2. $U_1 = U_2 = \dfrac{\pi DN}{60}$

where $D = D_b$ at inner edge, $D = D_o$ at expressed edge

$D = \dfrac{D_o + D_b}{2}$ at mid point

D_b = Dia of hub or boss, D_o = Outer dia of runner

Special Point: The analysis of velocity triangle, powers, Are Similar to that of francis turbines. In this case generally $\theta > 90°$ and $V_{w_2} = 0$.

Performance of Turbines/ Unit Quantities

- **Unit Speed (N_u):** $N_u = \dfrac{N}{\sqrt{H}}$
- **Unit Discharge (Q_u):** $Q_u = \dfrac{Q}{\sqrt{H}}$
- **Unit Power (P_u):** $P_u = \dfrac{P}{H^{3/2}}$
- **Specific Speed (N_s):** $(N_S)_T = \dfrac{N\sqrt{P}}{H^{5/4}}$
- **Dimensional formula of a turbine:** $M^{1/2}T^{-5}L^{-1/4}$
- **Model Laws of Turbines**
  - $\left(\dfrac{H}{D^2N^2}\right)_m = \dfrac{H}{(D^2N^2)_P}$
  - $\left(\dfrac{Q}{D^3N}\right)_m = \left(\dfrac{Q}{D^3N}\right)_P$
  - $\left(\dfrac{P}{D^5N^3}\right)_m = \left(\dfrac{P}{D^5N^3}\right)_P$

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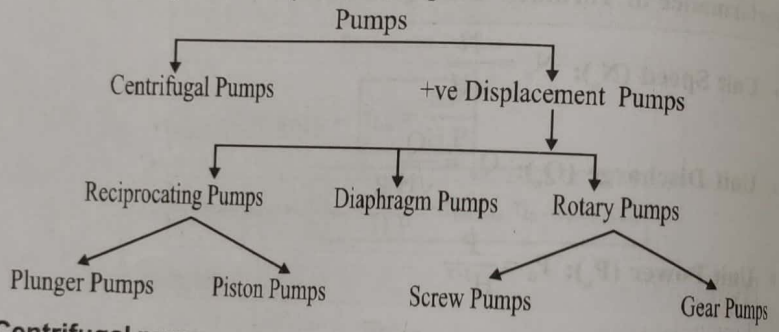
Hydraulic Pumps

2

- **Pump:** It is a mechanical device to increase the pressure energy of a liquid.
- Pumps are used to raising fluid from a lower to higher level & not used as main component of hydroelectric plant.

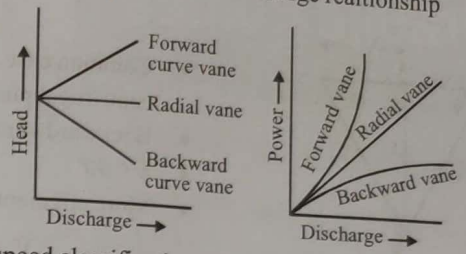


Centrifugal pump

- It is reverse of inward flow reaction turbine. It works on principle of forced vortex motion. It has high discharging capacity and can be used for lifting highly viscous liquids e.g. sewage water, chemicals etc.
- Priming is an operation in which liquid is completely filled in the chamber of pump so that air or gas or vapour from the portion of pump is driven out & no air pocket is left.
- Priming in centrifugal pump can be done by the any one of the following method
  (a) automatic or self priming
  (b) Priming with suction or vacuum pump
  (c) priming with jet pump
  (d) priming with separator
- In volute pump cross sectional area results in developing a uniform velocity throughout the casing & free vortex is formed.
- Hydraulic RAM (It work on the principle of water hammer) is a device used to lift small quantity of water to a larger height when a large quantity

is available at smaller height. It does not need any external power like electricity.

- Head Vs discharge and Power Vs discharge realtionship



- Specific speed classification of pumps

FLOW DIRECTION	SPEED	DIMENSION SPECIFIC SPEED
Radial	Low	10-30
	Medium	30-50
	High	50-80
Mixed Flow		80-160
Axial Flow		160-450

Types of Pump	Range of Head
Low head pump	upto 15m head
Medium head pump	15 m to 40 m
High head pump	above 40 m

- Specific speed $(N_s) = \dfrac{N\sqrt{Q}}{(H_m)^{3/4}}$

  It may be defined as the speed in revolution/minute of a geometrically similar pump of such a size that under corresponding conditions it would deliver 1 liter of liquid/second against of a head of 1m.

  For multi stage $(H_m) = \dfrac{\text{Total head}}{\text{No. of stage}}$

- For optimum effieiency impeller should be designed in such a way that whirl velocity at inlet is zero. (Discharge should enter in the pump radially $(V_{w_1} = 0)$)

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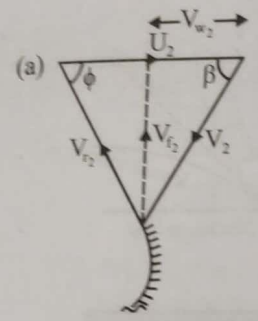
- **Velocity Triangle**

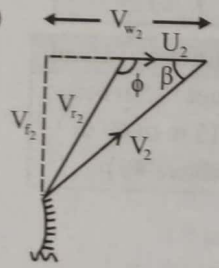
(i) At Outlet

(a)



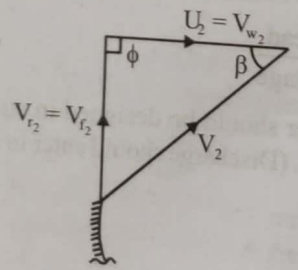
- Common case of centrifugal pump.
- Backward vanes
- $\phi < 90^\circ$
- More effecient
- $\tan \phi = \dfrac{V_{f_2}}{U_2 - V_{w_2}}$
- $V_{w_2} = V_2 \text{Cos } \beta.$
- $V_{F_2} = V_2 \sin \beta.$

(b)



- $\phi > 90^\circ$
- Forward vanes
- $\tan (180^\circ - \phi) = \dfrac{V_{f_2}}{(V_{w_2} - U_2)}$
- $V_{w_2} = V_2 \cos \beta$
- $V_{f_2} = V_2 \sin \beta$

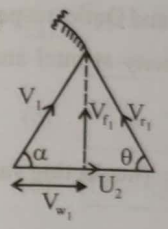
(c)



- $\phi = 90^\circ$
- Radial vanes
- $U_2 = V_{w_2}$
- $V_{r_2} = V_{F_2}$

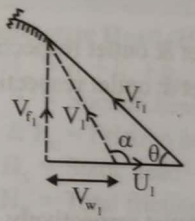
(ii) At Inlet

(a)



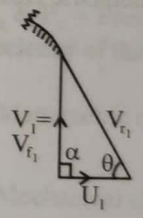
- $\alpha < 90^\circ$
- $\tan \theta = \dfrac{V_{f_1}}{U_1 - V_{w_1}}$
- V_{w_1} in the direction of U_1
- $V_{w_1} = V_1 \cos \alpha$
- $V_{F_1} = V_1 \sin \alpha$

(b)



- $\alpha \geq 90^\circ$
- $\tan \theta = \dfrac{V_{f_1}}{|U_1| + |V_{w_1}|}$
- V_{w_1} in the opposite direction of U_1

(c)



- $\alpha = 90^\circ$
- $V_{w_1} = 0$
- $\tan \theta = \dfrac{V_{f_1}}{U_1} = \dfrac{V_1}{U_1}$

Where, θ = Impeller vane angle of inlet (Angle b/w V_{r_1} and U_1)

ϕ = Impeller vane angle of outlet (Angle b/w V_{r_2} and U_2)

β = Angle b/w V_2 and U_2 or outlet (Blade Angle)

α = Angle b/w V_1 and U_1 at Inlet (Blade Angle)

V_2 & V_1 = Absolute velocity of water at outlet & Inlet respectively.

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= Absolute velocity of water at inlet

V_{r_1} & V_{r_2} are relative velocity of water at Inlet and Outlet respectiveyly

U_1 & U_2 are tangential (circumferential) velocity at intel and Outlet respectively.

- **Design parameters of pump**

1. (a) A_{f_1} = Area or flow at inlet = $\pi D_1 B_1$, (neglecting vane thickness)
   = (1-k) $\pi D_1 B_1$
   where, K = Vane thickness coefficient $\simeq 5\%$

   (b) A_{f_2} = Area of flow of outer = $\pi D_2 B_2$, (neglecting vane thickness)
   = (1–k) $\pi D_2 B_2$
   where, D_1 & D_2 = Dia of Impeller of Inlet & outlet respectively
   B_1 & B_2 = Width of impeller of inlet & outlet respectively
2. Number of vanes may be 6 to 12.
3. Discharge = $\boxed{Q = A_{f_1} V_{f_1} = A_{f_2} V_{f_2}}$

   V_{f_1} & V_{f_2} is velocity of flow a inlet & Outlet respectively.
4. Speed ratio = $\boxed{\phi = \frac{U_2}{\sqrt{2gH_m}}}$, where H_m = Manometric Head.
5. Flow ratio = $\boxed{\psi = \frac{V_{f2}}{\sqrt{2gH_m}}}$
6. If $D_2 = 2D_1$, then $\boxed{D_2 = \frac{10.23}{\omega}\sqrt{H_m}}$
7. $\boxed{\omega = \sqrt{\frac{8gH_m}{D_2^2 - D_1^2}}}$

   ω = Angular speed in rad/sec = $\frac{2\pi N}{60}$

- **Powers In Pump**

(i) Shaft power = $\boxed{S.P = T\omega}$

$$\omega = \frac{2\pi N}{60} \text{ rad/sec.}$$

(ii) Impeller power

(a) $\boxed{I.P = \frac{wQ}{g}[V_{w_2} U_2 - V_{w_1} U_1]}$

(b) $\boxed{I.P|_{max} = \frac{wQ}{g}[V_{w_2} U_2]}$ [Why $V_{w_1} = 0$]

(c) $\boxed{I.P = S.P - \text{Mechanical Frictional losses}}$

(iii) Manometric power = $\boxed{M.P = wQH_m}$ (kW)

$$= \frac{\rho Q H_m}{75} \text{ (H.P)}$$

Special point: S.P > I.P > M.P

- **Manometric Head (H_m)**

(i) $H_m = h_s + h_d + h_{fs} + h_{fd} = H_S + H_d$
h_s = Suction head, h_d = delivery head
h_{fs} & h_{fd} = Friction head loss in suction & delivery pipe respectively
H_S = Static head = $h_s + h_d$.
H_F = Total friction loss = $h_{fs} + h_{fd}$.

(ii) $\boxed{H_m = \frac{P_d}{\rho g} - \frac{P_s}{\rho g} \text{ or } \frac{P_d}{\gamma} - \frac{P_s}{\gamma}}$

P_d & P_S = Pressure in delivery & suction pipe.

- **Effeciency of the Pump**

(i) Manometric efficiency = $\boxed{\eta_{man.} = \frac{M.P}{I.P}} = \frac{gH_m}{(V_{w_2} U_2 - V_{w_1} U_1)}$

(ii) Mechanical efficiency = $\boxed{\eta_{mech.} = \frac{I.P}{S.P}}$

(iii) Volumetric efficiency = $\boxed{\eta_{vol} = \frac{Q - \Delta Q}{Q}}$

(iv) Overall efficency = $\boxed{\eta_o = \frac{M.P}{S.P}}$

$\eta_o = \eta_{mech} \cdot \eta_{vol} \cdot \eta_{max}$
$\eta_o = \eta_{mech} \cdot \eta_{man}$
[where η_{vol} is neglected]

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- **Model Relationship for Pumps**

Dimensionless Parameter	Dimensional Parameter
(i) $C_H = \frac{gH}{\omega^2 D^2}$	(i) $C_H = \frac{H}{N^2 D^2}$
(ii) $C_P = \frac{P}{\rho\omega^3 D^5}$	(ii) $C_P = \frac{P}{N^3 D^5}$
(iii) $C_Q = \frac{Q}{\omega D^3}$	(iii) $C_Q = \frac{Q}{ND^3}$
(iv) $N_S = \frac{\omega\sqrt{Q}}{(gH)^{3/4}}$	(iv) $N_S = \frac{N\sqrt{Q}}{(H)^{3/4}}$

Where, C_H = Head coefficient, C_P = Power coefficient
C_Q = Discharge coefficient, P = Power
N_S = Specific speed of pump

- Overall efficiency of pump $(\eta_o) = \frac{C_Q . C_H}{C_P}$
- Net Positive Suction Head (NPSH) $= \left(\frac{P_{atm}}{\rho g} - h_s - h_{fs}\right) - \frac{P_v}{\rho g}$

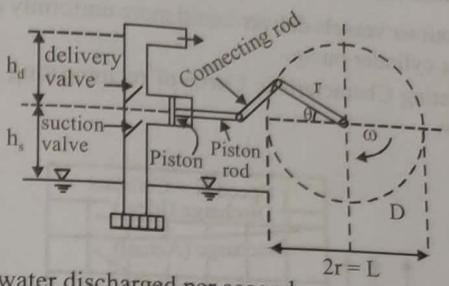
where, $\frac{P_v}{\rho g}$ = Vapour presure head $\simeq$ 2.5 m at 20°C for water and 10.3 m at 100°C for water

$\frac{P_{atm}}{\rho g}$ = Atmospheric pressure head $\simeq$ 10.3 m at MSL

- Thomas Cavitaion Number $(\sigma) = \frac{NPSH}{H}$
- Critical Thomas number $(\sigma_c) = 1.042(H)^{4/3}$
- For no cavitation $\sigma \geq \sigma_c$ or NPSH $\geq \sigma_c H$.

Reciprocating pump

These are used to lift water anainst high head at low descharge.



Volume of water discharged per second.

$$Q = \frac{ALN}{60} m^3/sec$$

A = Area of cylinder (in m^2), N = Crank speed (in rpm)
L = Length of cyliner (in m)

- If the head against which water is to be lifted is
  $H_s = (h_s + h_d)$
  h_d = delivery head, h_s = suction head
- Work done per second = $\gamma Q(h_s + h_d)$
- To increase discharge & to maintain it more uniform, double acting reciporcating pumps are used.

$$Q = \frac{2ALN}{60}$$, hence power also gets doubled.

- Slip in Percentage is given by

$$\% \text{ slip} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100 = \left(1 - \frac{Q_{act}}{Q_{th}}\right) \times 100$$
$$= (1 - c_d) \times 100$$

where C_d = coefficient of discharge

Slip in negative when (a) delivery pipe is small & suction pipe is long

(b) Pump is running at very high speed.

- **Air Vessel** is used to obtain continuous supply of water at uniform rate, to save a considerable amount of work (Percentage of work saved is 84.8% when single acting pump with air vessel is used but this saving is only 39.2% when air vesel is used in double acting pump) & to run the pump at a high speed without separation.
- Main adavantage of multicylinder pumps are that the pump even

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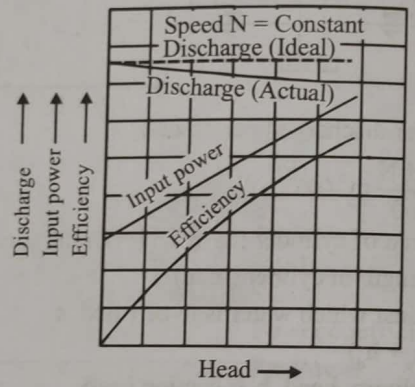
without air vessels deliver liquid more uniformly as compared to single cylinder pump.

- Operating Characteristic Curve of reciprocating Pump is given below.



- Pumps in series: Q = Constant, Increase Head, Total $H_m = n H_m$
- Pumps in parallel: H_m = Constant, Increase discharge, Total Q = n Q
- **Indicator diagram** is the graph between the pressure head in the cylinder & the distance travelled by the piston flow inner dead centre for one complete revolution of the crank, work done by pump is proportional to the area of indicator diagram.

Property	Centrifugal pump	Reciprocating pump
Flow	Continuous and smooth	Fluctuating and pulsating
Maintenance cost	Less	More
Running Speed	Can run at high speed	Cann't run at high speed
Starting torque	More	Less
Wear and Tear	Less	More
Efficiency	Less	More
Floor area	Smaller	Large
Suction and delivery valve	Not necessary	Necessary
Cost	Less	Four times of C.P.
Mechanism	Impeller	Piston
Discharge	High	Low
Priming	Required	Not required
[illegible]dem	Cavitation	Water seperation

10

OPEN CHANNEL FLOW

Contents

1. Introduction
2. Uniform – Flow
3. Energy-Depth Relationship
4. Gradually Varied Flow
5. Rapid Varied Flow

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(a) $V_{avg} = V_{0.6}$ (Less Better)

(b) $V_{avg} = \frac{V_{0.2} + V_{0.8}}{2}$ (Much Better)

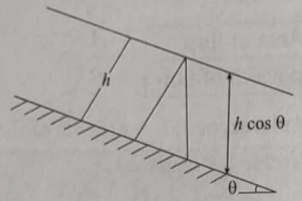
where $y_0 \rightarrow$ Depth of flow.

(c) $V_{avg} = K.\ V_s$

Where $V_s \rightarrow$ Surface Velocity

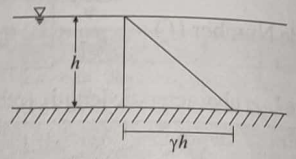
$K \rightarrow$ Coefficient (0.8 – 0.95)

Pressure distribution



Large slope

$\boxed{P = \gamma h \cos\theta}$



Small slope

$\boxed{P = \gamma h}$

Specific force : Sum of pressure force & momentum flux per unit "unit weight" of the fluid at a section.

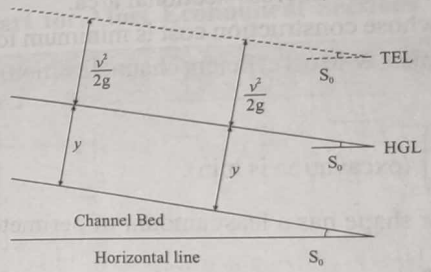
$$\boxed{\text{Specific force} = \frac{P + M}{\gamma}}$$

It is assumed to be constant if the channel is horizontal & frictionless.

Uniform – Flow

2

Depth of flow corresponding to the slope of bed will be Normal depth.



Measurement of Velocity:

1. Chezy's equation

$$\tau_0 = \gamma R S_0\ \tau_0 = K\left(\frac{\rho V^2}{2}\right),\ V = C\sqrt{RS}$$

where

τ_0 = Average shear stress on the wetted area under uniform flow condition.

S_0 = Slope of channel bed = slope of HGL = Slope of TEL

R = Hydraulic radius, K = Constant depending on roughness

Special points: τ_0 is independent of Viscosity.

Dimension of $C = L^{1/2} T^{-1}$, Dimension of $n = L^{-1/3} T^{1}$

2. Manning's equation

$$\boxed{V = \frac{1}{n} R^{2/3} S_0^{1/2}}$$

- Strikler's Formula $n = \frac{d_{50}^{1/6}}{21.10}$, $d_{50} \rightarrow$ in meters

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Meyer's Formula $n = \frac{d_{90}^{1/6}}{26}$, d_{90} → in meters

Special point: Relationship between c, n, f

$$c = \sqrt{\frac{8g}{f}} \quad f = \left(\frac{n^2}{R^{1/3}}\right) 8g$$ f = Darcy's friction factor (Dimensionless)

Economical channel section:

(i) The efficient section is the one whose discharge carrying capacity is maximum for a given cross-sectional area.

(ii) A section whose construction cost is minimum for a given discharge.

- Most Economical & Most efficient channel section, perimeter should be minimum.

$\left(\because Q \propto \frac{1}{P^{2/3}}\right)$ (excavation is min).

- Semi-Circular shape has a least amount of perimeter for a given area.

Circular section

$$A = \frac{r^2}{2}(2\theta - \sin 2\theta) \quad P = 2r\theta$$

$$\frac{dA}{d\theta} = r^2(1 - \cos 2\theta)\frac{dp}{d\theta} = 2r$$

(1) For maximum velocity

$$v = \frac{1}{n} A^{2/3} S^{1/2}, \text{ Put } \frac{dv}{d\theta} = 0$$

$$\tan 2\theta = 2\theta$$

$$\boxed{2\theta = 257°\,27'56''} \quad \boxed{d = 0.81D}$$

(2) For maximum discharge

$$Q = \frac{1}{n} A^{5/3} S^{1/2}, \text{ Put } \frac{dQ}{d\theta} = 0$$

$$\boxed{2\theta = 302°\,22'} \quad \boxed{d = 0.938D}$$

Special point: From Chezy's equation

- For condition of Maximum Discharge $2\theta = 308°$, $\frac{d}{D} = 0.95$
- For condition of Maximum Velocity $2\theta = 257°\,27'$, $\frac{d}{D} = 0.81$
- For Condition of Maximum Velocity $2\theta = 257°\,27'$, $\frac{d}{D} = 0.81$

Chart for Most Economical Sections

Gedmetrical Parameters	Rectangular	Triangular	Trapezoidal
Diagram			
Condition for most Economical	$y = \frac{B}{2}$	m = 1, θ = 45°	$B = \frac{2y}{\sqrt{3}}$ $m = \frac{1}{\sqrt{3}}$ θ = 60° Hor. θ = 30° Vert.
Area	$A = B.y = 2y.y$	$A = my^2$	$A = (B + my) \times y$
	$A = 2y^2$	$A = y^2$	$A = \left(\frac{2y}{\sqrt{3}} + \frac{1}{\sqrt{3}}y\right) y = (\sqrt{3})y^2$
Perimeter	$P = 4y$	$p = 2\sqrt{2}y$	$P = 2\sqrt{3}y$
Hydraulic Radius (R = A/P)	$R = y/2$	$R = \frac{y}{2\sqrt{2}}$	$R = \frac{y}{2}$
Top width (T)	$T = 2y$	$T = 2y$	$T = \frac{4y}{\sqrt{3}}$
Hydraulic Depth $\left(D = \frac{A}{T}\right)$	$D = y$	$D = y/2$	$D = \frac{3}{4}y$

In trapezoidal section, most economical trapeziodal section should be half of regular hexagon.

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Energy-Depth Relationship

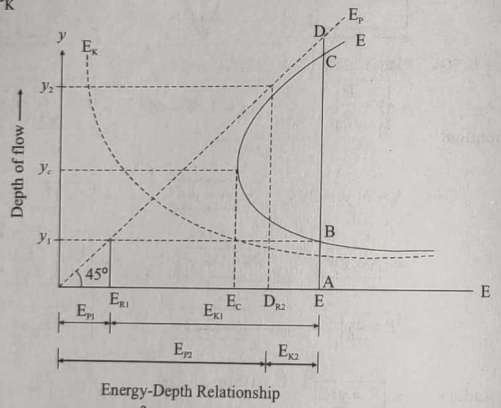
3

Specific energy: Total energy at a section with respect to the channel bed as datum.

$$\boxed{E = y + \alpha\frac{V^2}{2g}}$$ (For Small slope)

α = K.E correction Factor

$E = E_p + E_K$



Energy-Depth Relationship

E_K = Kinetic energy = $\frac{V^2}{2g}$, E_p = Potential energy = y

For a given Kinetic energy (E), there are two possible depth of flow y_1 and y_2. These are called Alternate depth.

Special points: At Critical Flow condition,

$$\boxed{\frac{Q^2T}{gA^3} = 1}$$ T = Top width, A = Area of x-section

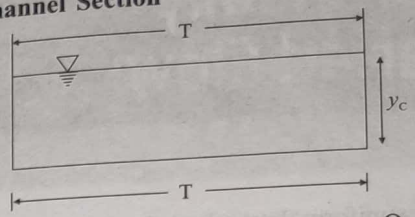
(*a*) For a given discharge, specific energy is minumum

(*b*) Specific Force is also minimum for a given discharge.

(*c*) For a given specific energy, discharge will be maximum.

Calculation of critical depth

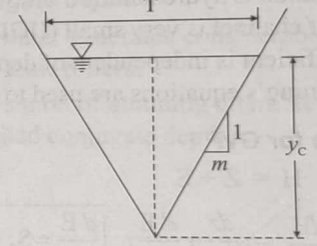
1. Rectangular Channel Section



$y_c = \left(\frac{q^2}{g}\right)^{1/3}$ q = discharge per unit width (B) = $\frac{Q}{B}$

$F_r = \frac{V}{\sqrt{gy_a}}$, $E_c = \frac{3}{2}y_c$

2. Triangular Channel Section



$F_r = \frac{\sqrt{2}V}{\sqrt{gy_e}}$, $y_c = \left(\frac{2Q^2}{gm^2}\right)^{1/5}$, $E_c = \frac{5}{4}y_c$

Special point: For Parabolic Section $E_c = \frac{4}{3}y_c$.

Channel Transition: This topic should be coverd from standard books.

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4 Gradually Varied Flow

It is a **Steady**, Non uniform flow, where depth of flow varies gradually from section to section along the length of the channel.

Assumptions in GVF:

1. Energy Correction Factor (α) = 1
2. Flow is Steady (Constant discharge)
3. Prismatic channel (Slope & Shape constant)
4. Pressure distribution is hydrostatic
5. Bottom Slope of channel is very small (HGL will lie at free surface).
6. Roughness coefficient is independent of depth.
7. Chezy's & Manning's equations are used to determine energy slope.

Differential Equation for GVF

(i) $$H = Z + E$$

$$\frac{dH}{dx} = \frac{dz}{dx} + \frac{dE}{dx}, \quad \boxed{\frac{dE}{dx} = S_0 - S_f}$$

(ii) $$H = Z + y + \frac{V^2}{2g}$$

Again differentiating wrt x $\boxed{\frac{dy}{dx} = \frac{S_0 - S_F}{1 - F_r^2}}$ $F_r = \frac{Q^2 T}{gA^3}$

5 Rapid Varied Flow

Hydraulic Jump (Standing/Shock Wave) is formed when water moving at super critical velocity in a relatively shallow stream strikes water having large depth & sub critical velocity.

Applications of hydraulic jump are as desalination of sea water, to aerate polluted stream, energy dissipator (main purpose) to mix chemicals, to reduce the uplift pressure.

Sequent depth or conjugate depth:

During hydraulic jump, water generates considerable disturbances in the form of eddies & reverse flow rollers.

Because of this, falls shorts of attaining alternate depth (y_3) & attain's another depth ($y_2 < y_3$) called conjugate depth.

Momentum equation for the jump:

$$\boxed{A\bar{y} + \frac{Q^2}{gA^3} = \text{constant}} \quad \boxed{\frac{P + M}{\gamma} = \text{constant}}$$

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Hydraulic jump in horizontal frictionless rectangular channel

(1) $\frac{y^2}{2}+\frac{q^2}{gy}=$ constant

(2) $\frac{y_2}{y_1}=\frac{1}{2}\left(-1+\sqrt{1+8F_1^2}\right)$ where $F_1^2=\frac{q^2}{g\,y_1^3}$

(3) $\frac{2q^2}{g}=y_1y_2(y_1+y_2)$

(4) Efficiency of jump $\eta_{jump}=\frac{E_2}{E_1}$

$\eta_{jump}=1-$ Relative energy loss

(5) Energy loss $E_L=\frac{(y_2-y_1)^3}{4y_1y_2}$

(6) Relative Energy loss

$$\frac{h_L}{E_1}=\frac{\left(-3+\sqrt{1+8F_1^2}\right)^3}{2\left(2+F_1^2\right)\left(\sqrt{1+8F_1^2}-1\right)}$$

$$\frac{h_L}{y_1}=\frac{\left(\frac{y_2}{y_1}-1\right)^2}{4\left(\frac{y_2}{y_1}\right)}\quad\frac{E_1}{y_1}=1+\frac{F_1^2}{2}$$

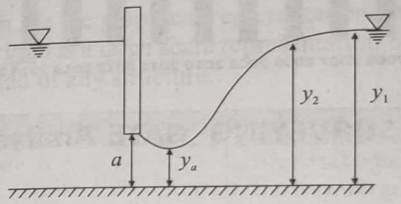
(7) Length of jump $L_j=6.9\,(y_2-y_1)$

(8) $F_2^2=\frac{8F_1^2}{\left(-1+\sqrt{1+8F_1^2}\right)^3}$

Types of Jump: It depends on the Froude's number of the incoming (upstream end).

	Fr	E_L/E_1	Water surface
Undular	1-1.7	≈ 0	Undulating
Weak	1.7-2.5	5–18%	Small rollers form
Oscillating	2.5-4.5	18–45%	Water moving in random manner
Steady	4.5-9	45–70%	Roller & jump action
Strong	≥ 9	≥ 70%	Very rough & choppy

Location of jump:



y_t = tail water depth
y_0 = depth of flow at vena-contracta
y_2 = conjugate depth

(a) $y_t=y_2$ Free hydraulic jump.
(b) $y_1<y_2$ Free repelled jump.
(c) $y_t>y_2$ Submerged or drowned jump.

Special point: Energy loss is less in submerged jump.

- Energy Dissipators
  - (a) Chute Block for splittings & aeration of flow
  - (b) Baffel block for providing addtional resistance to flow.
- Stilling Basin is a structure in which a Hydraulic Jump used for Energy Dissipation.

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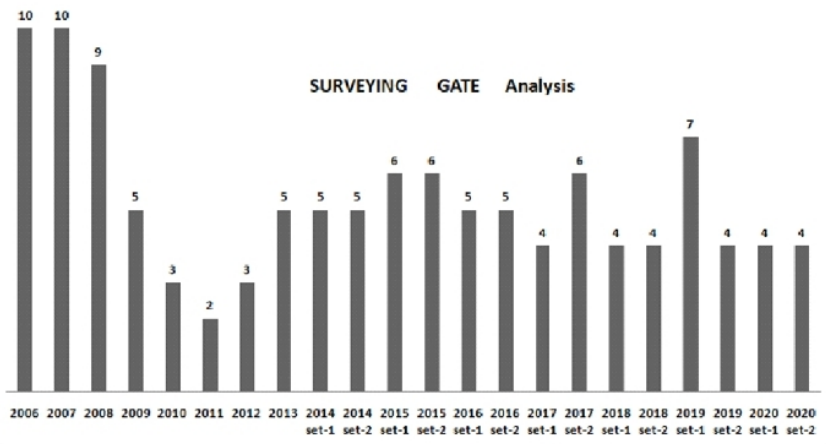
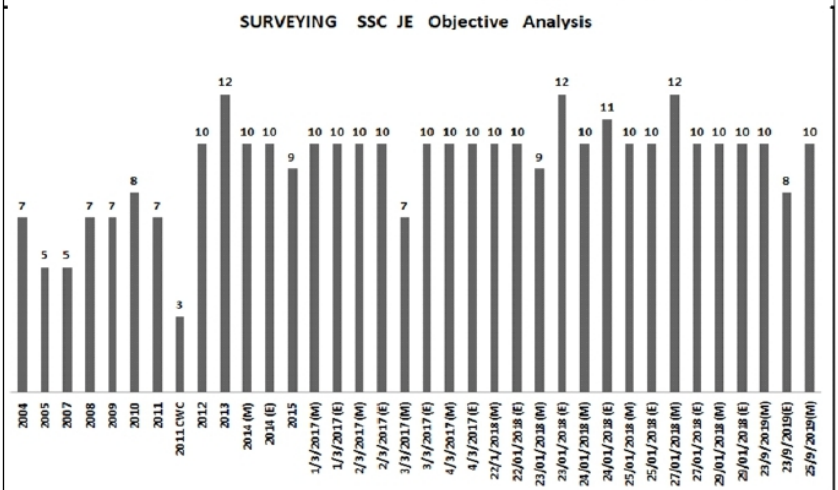
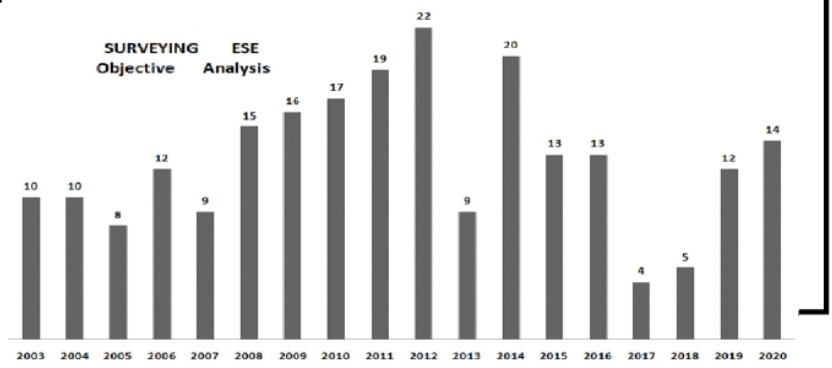

SURVEYING GATE Analysis
10 10 9 5 3 2 3 5 5 5 6 6 5 5 4 6 4 4 7 4 4 4
2006 2007 2008 2009 2010 2011 2012 2013 2014 set-1 2014 set-2 2015 set-1 2015 set-2 2016 set-1 2016 set-2 2017 set-1 2017 set-2 2018 set-1 2018 set-2 2019 set-1 2019 set-2 2020 set-1 2020 set-2


SURVEYING SSC JE Objective Analysis
7 5 5 7 7 8 7 3 10 12 10 10 9 10 10 10 10 7 10 10 10 10 10 9 12 10 11 10 10 12 10 10 10 10 8 10
2004 2005 2007 2008 2009 2010 2011 2011 CWC 2012 2013 2014 (M) 2014 (E) 2015 1/3/2017 (M) 1/3/2017 (E) 2/3/2017 (M) 2/3/2017 (E) 3/3/2017 (M) 3/3/2017 (E) 4/3/2017 (M) 4/3/2017 (E) 22/1/2018 (M) 22/01/2018 (E) 23/01/2018 (M) 23/01/2018 (E) 24/01/2018 (M) 24/01/2018 (E) 25/01/2018 (M) 25/01/2018 (E) 27/01/2018 (M) 27/01/2018 (E) 29/01/2018 (M) 29/01/2018 (E) 23/9/2019(M) 23/9/2019(E) 25/9/2019(M)


SURVEYING ESE
Objective Analysis
10 10 8 12 9 15 16 17 19 22 9 20 13 13 4 5 12 14
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

Fundamentals of Surveying

1

- The headquarter of Survey of India is located in dehradun (1767).
- Both Plan & Map are the graphical representations of the features on horizontal plane. Plan is a large scale representation but map is a small scale representation of any structure.

Geodetic Survey	Plane Survey
It is done for fixing widely spaced control points.	It is done for Engineering projects.
Geodetic surveying is done by Department of National Survey of India.	Use for small area.
Large areas of earth's surface involved	Earth surface is assumed to be flat.
Curvature arc of earth is consider.	Line joining two points is a line.
	It is less accurate.

Special Points : Plane survey can safely be used when the extent of area is less than 260 Sq km.

- The difference in the length of an arc & its subtended chord on earth's surface for a distance of 18.5 km is about 10 mm.(but some books also recommended 15.2 mm, which is not right as per exam point)
- The earth is an oblate spheroid, the length of equatorial axis being 12,756.602 km & polar axis 12,713.168 km. The polar axis (12713.168 km) is shorter than the equatorial axis (12756.602 km) by about 43 km (0.34 %).
- The length of an arc of 1.2 km on earth's mean surface is only 1 mm more than the straight line connecting those two points.
- The average radius of earth is taken 6370 km for all calculations point of view.

Classifiaction of Surveying Based on Purpose

(*i*) **Topographical Survey:** It is conducted to obtain data & to make a map indicating inequalites of land surface. Topographic Survey is done to determine the Natural features of a Country. Scale range is 1 : 25000 to 1 : 1000000.

(*ii*) **Hydrographic Survey:** It is conducted on or near water bodies. Marine survey is also one of it's type.

(*iii*) **Engineering Survey:** It is used for design & construction of new routes (roads & railways). Also used to calculate for route alignment.

(*iv*) **Geological Survey:** It is conducted to obtain data of different strata of earth's surface for the purpose of geological studies.

(*v*) **Cadastral Survey :** It is used to produce plans of property boundries for legal purpose. The revenue chain is used in cadastral surveying. Also called public land survey.

(*vi*) **Astronomic Survey:** It is conducted for determination of azimuths, latitudes, longitudes, local time etc. at various places on the earth by observing heavenly bodies. Absolute location of a point on earth surface is obtained by it.

Classification based on instrument used -

Chain surveying , Compass surveying, Theodolite survey, Levelling survey, Contouring, EDM survey, Photogrammetric survey, Tacheometric survey.

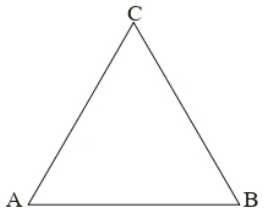
Special Points:

- Archaeological survey is done to collect information about old & nelic structures.
- Reconnaissance Survey is a kind of preliminary survey which is performed to find out method of survey to be adopted & its rough cost.
- Correct Sequence of Surveys
  (a) Traffic Survey
  (b) Reconnaissance Survey
  (c) Preliminary Survey
  (d) Detailed Survey/Location Survey

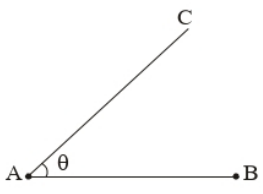
Principles of Surveying

(*i*) **Work from Whole to Part:** So as to localise the error & prevent their accumulation.

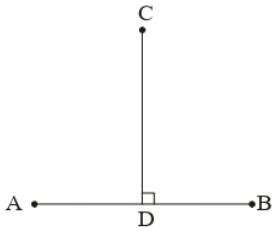
(*ii*) **Locate a Point by Atleast two Measurements:** Locating at point C.



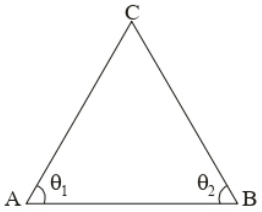
(*a*) By measuring AC and BC



(*b*) By measuring AC and angle θ



(*c*) By measuring CD at right angle to AB while AD & BD is known.



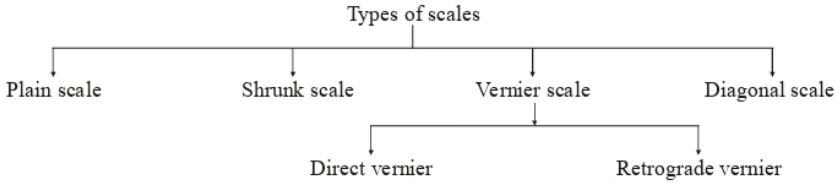
(*d*) By measuring θ_1 and θ_2 (Compass method)

Scale of a map: It is the fixed ratio that every distance on the plan bears with corresponding distance on the ground.

- Engineer scale 1 cm = 30 m

Representative fraction (R.F.) = $\frac{1}{3000}$

$$\boxed{\text{Representive fraction (RF)} = \frac{\text{Map distance}}{\text{Ground distance}}}$$



(*i*) **Plain Scale:** It is used to measure two dimensions only.

(*ii*) **Shrunk Scale**

$$\boxed{\text{Shrunk Scale} = \text{Original scale} \times \text{Shrinkage factor (SF)}}$$

Shrinkage Ratio (SR) or (SF) =

$$\frac{\text{Shrunk length}}{\text{Original length}} = \frac{\text{Shrunk RF}}{\text{Original RF}} = \frac{\text{Shrunk Scale}}{\text{Original Scale}}$$

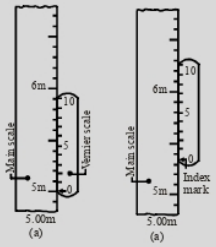
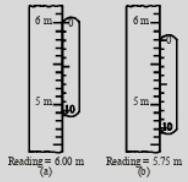
Special Points:

1. $\frac{1}{100}$ Scale is larger RF than $\frac{1}{1000}$ scale.
2. Graphical Scales are much better than Numerical scales.

Error due to use of Wrong Scale

(*i*) Correct length $= \dfrac{\text{RF of wrong scale}}{\text{RF of correct scale}} \times \text{Measured length}$

(*ii*) Correct area $= \left(\dfrac{\text{RF of wrong scale}}{\text{RF of correct scale}}\right)^2 \times \text{Measured area}$

Direct Vernier	Retrograde Vernier
• Reading increases in a direction to that of the main scale.	• Reading increase in a direction opposite to that of the main scale.
• It has the divisions which are slightly shorter than those of the main scale	• It has the divisions which are slightly longer than those of the main scale.
•  Direct Vernier $nv = (n-1)s$	•  Retrograde Vernier (nv = (n + 1)s)

$$\text{Least count of Vernier Scale} = \frac{s}{n}$$

S = Value of one smallest division of main scale

n = No. of division on the vernier

Diagonal Scale: It is possible to measure in three dimensions such as meters, decimeter, centimeters & unit, tenth, hundreds.

Generally used scales for measurement purpose are :

S.N.	Type of Scale	Scales	R.F. value
1.	Cadastral map	1 cm = 5 m to 0.25 km	$\frac{1}{500}$ *to* $\frac{1}{5000}$
2.	Topographical map (a) Buildings	1 cm = 2.5 km 1 cm = 10 m or less	$\frac{1}{1000}$ *or less*
	(b) Town planning	1 cm = 50 m to 100 m	$\frac{1}{5000}$ *to* $\frac{1}{10,000}$
	(c)Location map	1 cm = 50 m to 200 m	$\frac{1}{5000}$ *to* $\frac{1}{20,000}$
	(d) Small Scale Topographic Survey	1 cm = 0.25 km to 2.5 km	$\frac{1}{25,000}$ *to* $\frac{1}{2,50,000}$
	(e) Mines	1 cm = 10 m to 25 m	
	(f) Forest Scale	1 cm = 0.25 km	
3.	Preliminary survey of rails & roads	1 cm = 10 m to 60 m	

Speical Point: A good draughtsman can plot a length to within 0.25 mm.

Errors and mistakes

- Errors arise due to physical conditions of the instrument like temperature at the time of measurement & human eye's limitation.
- Mistakes are caused by misunderstanding of the problem, poor judgement or carelessness & these can be corrected only if discovered.

$$\boxed{\begin{aligned}&\text{Error} = \text{Measured value} - \text{True value}\\&\text{Correction} = \text{True value} - \text{Measured value}\end{aligned}}$$

Hence Correction = - Error

Most Probable Value → The value that has more chances of being the correct value.

$$E_S = \pm\, 0.6745\sqrt{\frac{\Sigma V^2}{(n-1)}},\ (E_S = \text{Probable error of single observation})$$

$$E_m = \pm 0.6745\sqrt{\frac{\Sigma V^2}{n(n-1)}} = \frac{E_S}{\sqrt{n}},\ (E_m = \text{Probable error of mean observation})$$

Error in chaining: Errors in chaining are classified as follows:

1. Compensating errors (Random errors)

2. Cumulative errors (systematic errors)

Cumulative errors (systematic errors)

- These are proportional to the length of the line & may be positive or negative.
- These are the errors which are liable to occur in the same direction & tend to accumulate.

Compensating errors (Random errors)

- These are proportional to the square root of the length of the line.
- These are the errors which are liable to occur in both the directions & tend to compensate.

Cases	Errors
In correct length of tape	Cumulative + or –
Tape not stretched horizontally	Cumulative +
Error due to sag	Cumulative +
Tape not stretched, tight & straight, but both ends in line	Cumulative +
Error due to temperature	Cumulative + or –
Variation in pull	Cumulative + or –
Error in marking tape lengths	Compensating + or –
Disturbing arrows after they are set	Blunder
Errors in reading the tape	Mistake
Incorrect counting of tape length	Blunder
Careless holding & marking	Compensating + or –

Units of Measurement

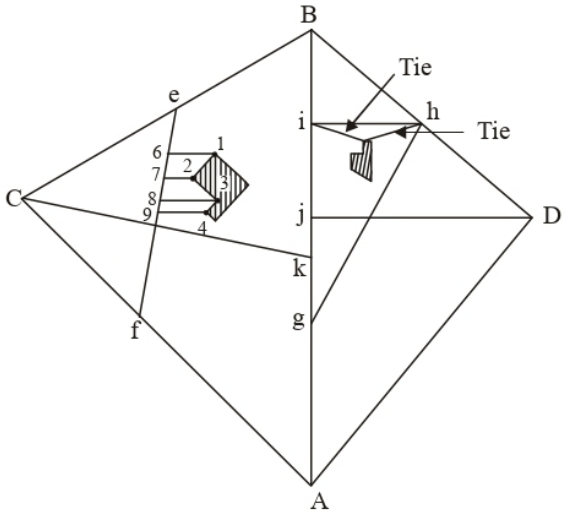
1 ft. = 0.3 m	1 mile = 1.609 km
1 yard = 3 ft	1 acre = 43560 sq. ft.
1 hectare = 2.471 acre	1 Nautical mile = 1.852 km

Linear Measurement

2

Chain surveying is suitable only for areas of small extent on open ground.

Terms Used in Large Survey Area



(*i*) Main station : It is a point in chain survey where two sides of triangle meet. In above figure, A, B, C, D are main stations.

(*ii*) Base line: It is the longest survey line from which direction of all other survey lines are fixed. In above figure, AB is the base line.Colby apparatus is used for the measurement of Base lines.

(*iii*) Main survey line: Chain line joining two main survey stations. In above figure, AD, DB, BC, CA, BA are main survey lines.

(*vi*) Tie station or subsidiary station: Station on survey line joining main stations. It is helpful for locating interior details. In above figure, e, f, g, h, i are the tie stations.

(*v*) Proof line or check line: It is provided to check the accuracy of the field work. In above figure, Ck & Dj are check lines.

(*vi*) Offsets: These are lateral measurement made w.r.t. chain line which may be oblique or perpendicular in nature.

(*vii*) Chainage: It is the distance measured along the main survey line in direction of progress of work.

Special Points:

- Double line field book is most commonly used for recording ordinary chain survey work.
- The book in which length chain or tape measurement are recorded is called Field book
- Standard dimensions of a field book are 20 cm x 12 cm
- Single line field book is used for very large scale work where more details are to be entered

Well Conditioned Triangle: Triangle in which all intersections of lines are clear. Angle's between the lines for clear plotting purpose. Intersections should be 30° to 120°. The best angle is 56° 14' for this condition.

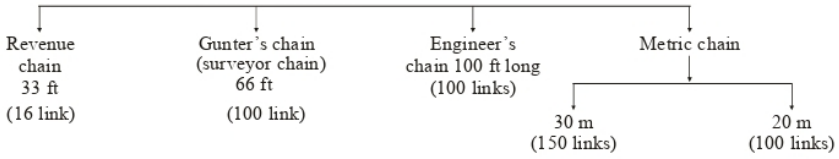
An equilateral triangle is the most appropriate well conditioned triangle.

Equipments Used for Measuring Lines

(*i*) Surveying chain: It is used where very high accuracy is not required

A chain consist of a number of large links made up of galvanized mild steel wire of 4 mm diameter.

To easy the reading of fraction of a chain length without difficulty, brass tallies (tags) are attached to the chain at some fixed interval.



Special Points: As per IS specifications, every metre length of the chain should individually be accurate to within ± 2mm when measured under a tension of 80 Newton (8 kg).

(a) 1 mile = 80 Gunter's chain, (b) 1 acre = 10 × (Gunter's chain)^2

(c) The overall length of chain should be within the limits given below

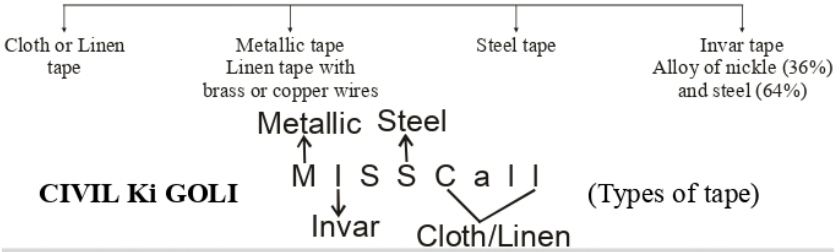
(i) 20 m ± 5 mm for 20 m chain, (ii) 30 m ± 8 mm for 30 m chain.

(*ii*) Arrows: These provides a check over the length of line as entered in the field notes.Length of arrow - 400mm with 5mm tolerance.

(*iii*) Offset rod: Similary to ranging rod with a stout open hook at the top.

(*iv*) Pegs: To mark definite points on ground temporarily.

(*v*) Tapes:



Special Point: Invar tape is used for work of highest precision such as measurement of a base line in triangulation survey

(*vi*) Ranging rods: To locate intermediate points such that these points lie on straight lines joining the end stations. The process of locating a number of points on a long survey line is called ranging / ranging out. Ranging rod are 30 mm in diameter & 2 or 3 m in length.

Direct Measurement

(a) **Passometer** is an electromechanical & portable instrument, which count the number of paces/velocity of the body movement.

(b) **Pedometer** count each step taken by a person by detecting the motion of the person's hand/hip. It is better for vertically measurement.

(c) **Pacing** = Average number steps × distance of one step, (1 pace = 80 cm)

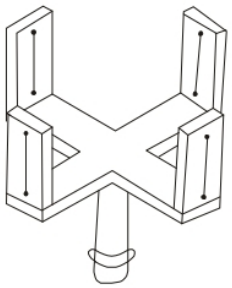
(d) **Speedometer** - It is use in automobile vechiles.

(e) **Odometer** - It is an instrument that measure the number of revolutions of a wheel.

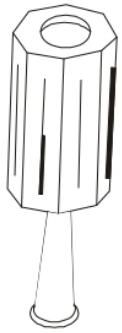
Equipments for Measurement of Right angles

(*i*) Cross staff

Open cross staff



French cross staff



- Accuracy of the french Cross Staff is less than that of an open cross staff. But french cross staff can be set out at an angles of 45° & 135°.

(*ii*) Optical Square: Pocket instrument, more convenient & accurate than a cross staff.

- Optical Square is used to establish two Points at right angle. The principal used is of Double reflection. So, Angle between two mirrors is 45°.

(*iii*) Prism Square: It has two reflecting surfaces fixed at 45°. No adjustment is required in it.

Special Points:-

- It is easier to work downhill while stepping than to work uphill.
- Simple clinometer : For measuring the angle of slope of the ground.

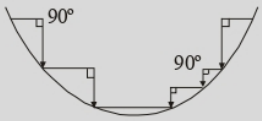
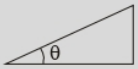
Equipments for Establishing Intermediate points

Ranging - The process of establihing the intermediate points on a straight line is known as ranging or ranging out in surveying.

There are 3 methods of ranging out - (a) Direct ranging, (b) Indirect ranging (repeated alignment), (c) Random line method .

Direct ranging with a line ranger - Line ranger consists of two right angled isosceles triangular prisms placed one above the other.

Linear Measurement with Chain

On smooth level ground	On sloping ground	
using chain, pegs & arrows after establishing intermediate points	Stepping 	Along slope Using Abney level 

Correction in Chain Measurement

(*i*) **Standardisation Correction**

Correct length =

$$\text{Actual length of chain} \times \frac{\text{Length reported to be measured}}{\text{Nominal length of chain}}$$

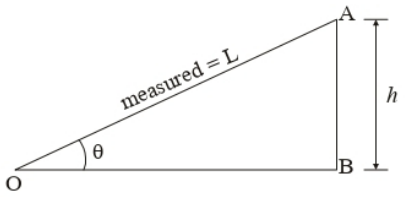
Correction = True length – Measured length

(*ii*) **Slope Correction**

(*a*) When slope θ is measured

Correction = L cos θ – L

= – L (1–cos θ)



(*b*) When AB is measured

$$\text{Correction} = \frac{-h^2}{2L}$$

Special Point: Slope correction is always negative. If higher power is not neglected, The Correction increase by $\boxed{\frac{h^4}{8L^3}}$

Degree of Accuracy in Chaining:

For measurement with chain on rough or hilly ground (1 : 250), under average condition (1 : 500), under tested chain (1 : 1000), with invar tape , thermometer, spring balance (1 : 10000), with steel tape, plumb bob, chain pins (1 : 1000).

Corrections in Tape Correction

(*i*) Standardisation correction: Same as chain correction.

(*ii*) Slope correction : Same as chain correction.

(*iii*) Pull correction is (C_p):

$$\boxed{C_p = \left(\frac{P - P_s}{AE}\right)L}$$

P = Applied pull, P_s = Standard Pull, A = Area of cross section

L = Length of tape

E = Modulus of elasticity = 2.1×10^5 N/mm^2 for steel tape

= 1.54×10^5 N/mm^2 for Invar tape

Special Point: If pull is more than standard pull, correction will be positive

(*iv*) Temperature Correction (C_t):

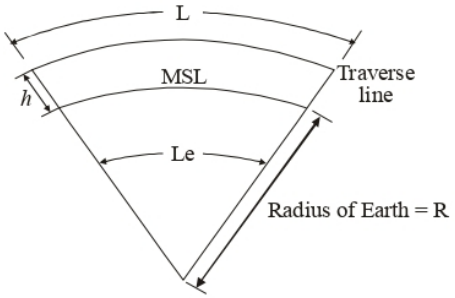
$$\boxed{C_t = \alpha(T_m - T_o)L}$$

T_o = Standardisation temperature

T_m = Mean Temperature, α = Thermal coefficient

(*v*) Mean sea level correction

$$\boxed{C_h = \frac{-Lh}{R}}$$



(*vi*) Sag Correction (C_s)

$$\boxed{C_s = -\frac{w^2 l^3}{24 p^2}}$$

p = Applied pull

w = Weight of tape per unit length in N/m

l = Length of tape suspended between supports

Order of field work in chain surveying

(*a*) Reconnaissance, (*b*) Marking of stations

(*c*) Running survey lines, (*d*) Taking offsets

Obstalces in chaining

- Forest, Hill - Obstacle to ranging but not chaining
- Small pond, small bend in river - Obstacle to chaining but not ranging
- A big building - Obstacles to both chaining & ranging

Compass-Surveying

3

The method of establishing control points by taking linear & angular measurements is called traversing.

Types of Traversing:

Open Traverse: An open trasverse starts from a station & closes on another station whose location is unknown. It is used in areas for road, railway line etc.

Closed Traverse: It starts from a station & closed either on the same station or another station whose location is already known.

Special Point: Error's in closed traverse can easily be detected, adjusted & balanced but in open traverse it is not possible. So it should be avoided.

Defference Between Traverse Surveying & Chain Surveying

Chain Surveying	Traverse Surveying
Requires only linear measurements	Requires both linear & angular measurements.
Therefore, relatively easier	Therefore, requires skilled personnel.
Check lines are required in chain Surveying	Check lines are not required because accuracy of the framework can be checked by the methods of adjustments
Accuracy is low	
. The framework consists of triangles.	Frame work consists of a series of connected lines
Used when area to be surveyed is small, ground is flat	Uses when area involved is large
	Accuracy is good

Meridian: The direction of line is defined by the horizontal angle which the line makes with the reference angle line. That reference line is called meridian.

(i) True Bearing	(ii) Magnetic Bearing
• It is measured with true north in clockwise direction. • It does not change with time since true meridian at a point is fixed.	• It is measured with magnetic north in clockwise direction. • It changes with time since magnetic poles are not fixed in position.
• It is the horizontal angle between the true meridian & the line.	• It is the horizontal angle which line makes with the magnetic north.
• It is determined by astronomical observation	• It is determined by prismatic compass or surveyor's compass

(*iii*) **Arbitrary Meridian:** It is the meridian which is taken in any convenient arbitrary direction.

(*iv*) **Grid Meridian:** For survey of a country, the Meridian passing through the central place is generally taken as a reference meridian for the whole country. This type of reference meridian is called grid meridian.

Bearing: It is the horizontal angle which the line makes with the meridian

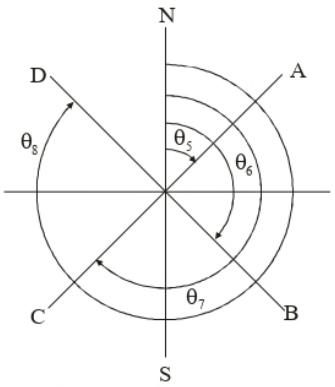
Types of bearing - (a) Magnetic, (b) True, (c) Grid , (d) Arbitrary

- Magnetic bearings are used for small, less important surveys.
- True bearing of a line (also known as Azimuth) does not change with time & can be re-established even after hundreds of years.

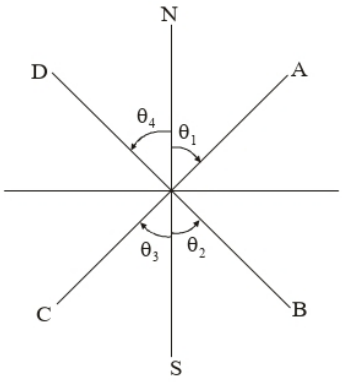
Designation of bearing

Quadrantal Bearing System: It is the acute angle which the line makes with the meridian. Measured from North point or South point whichever is closer & always less than 90°. Surveyor compass have quadrantal bearing system.

Whole Circle Bearing System: It is the horizontal angle between the line & the north end of the reference meridian in clockwise direction. It varies between 0° to 360°. Prismatic compass have whole circle bearing system.



Whole circle Bearing (WCB)



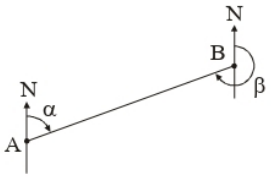
Quadrantal Baring (QB)

Reduced Bearing: When WCB is more than 90º, it is reduced to the corresponding angle less than 90º

WCB	RB	Quadrant
0º–90º	WCB	NE
90º–180º	180–WCB	SE
180º–270º	WCB–180	SW
270º–360º	360–WCB	NW

Fore Bearing: (FB): The bearing of line in the direction of the progress of survey.

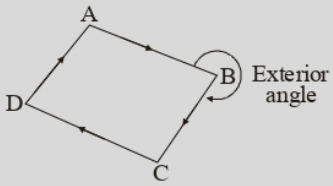
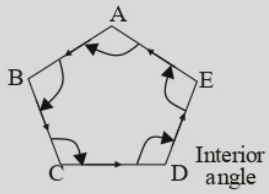
Back Bearing (BB): The bearing of line in the opposite direction of the progress of survey.



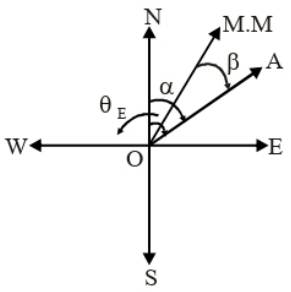
Line	FB	BB
AB	α	β
BA	β	α

$$F.B = B.B \pm 180°$$

Included Angle: When two line meet at a point, the angle between them is included angle. It is angle measured in the clockwise direction from the preceding line of a traverse to the forward line.

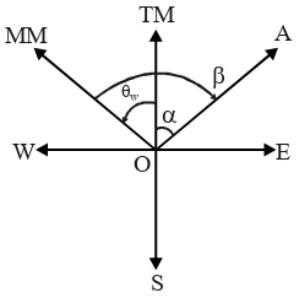
In clock-wise traverse, included angle is exterior angle	In anti-clock wise traverse, the included angle is interior angle
	

Magnetic Declination: The horizontal angle which the magnetic meridian makes with the true meridian is called declination or magnetic declination at that point.



Eastern Declination

T.B. = M.B. + declination



Western Declination

M.B. = T.B. + declination

(*a*) **Agonic Line:** It is line passing through points of zero declination.

(*b*) **Isogonic Line:** It is Line passing through the points on earth surface at which the declination is same at given time.

Variation of magnetic declination			
Secular variation	**Annual variation**	**Diurnal variation**	**Irregular variation**
Due to over a long period of time due to gradual shift in earth's magnetic field.	Due to revolution of earth around the sun. (Yearly)	Due to rotation of earth about its own axis. It's more at pole, in day & summer time.	Due to magnetic disturbances in earth's magnetic field.

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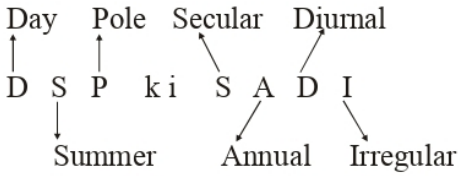


Local Attraction: It is the attraction of the magnetic needle to a local magnitic field other than earth's magnetic field. It may be due to wrist watch, parking wire, belt, pen etc.

F.B.-B.B. $\neq 180^{o}$ (local attraction exist)

$$\text{Sum of external included angles} = (2N + 4) \times 90^{o}$$

& internal angle = $(2N - 4)\ 90^{o}$

where N = No. of sides of the closed traverse.

Dip: It is the angle made by the lines of magnetic force with the earth's surface.

Magnetic needle becomes horizontal at equator but becomes vertical at magnetic poles.

Special Point: Lines joining points of same dip are called Isoclinic but of zero dip are called aclinic.

Prismatic Compass	**Surveyor Compass**
• Smaller in size (85 - 110 mm diameter)	• Bigger (circular box of size 150 mm diameter)
• Broad Needle with aluminium ring is used	• Measurement quadrantal bearings.
• Sighting of the object & reading of the bearing are done simultaneously	• First Object is sighted & then reading of bearing is taken by moving around the looking down from glass cover.
• Agate cap is fitted with prismatic compass	
• Temporary Adjustment Centering, Levelling, focussing.	• Temporary Adjustment Centering & Levelling.
• Tripod is not essential	• Tripod is essential
• Graduation is inverted because we have to see them through prism.	• Graduation is erect because we can seen from it top.
• Readings are in W.C.B., having 0^{0} at south, 90^{0} at West, 180^{0} at North & 270^{0} at East	• Edge bar type magnetic needle is used, which is also act as index.
	• It has 0^{0} at N & S, 90^{0} at E & W (Q.B.System).

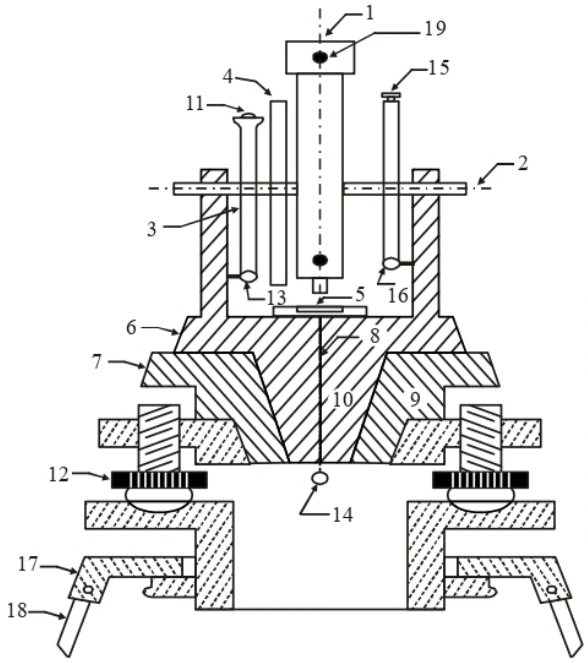
Special Points: Least count of Prismatic Compass is 30', surveyor compass 15', vernier scale - 0.1mm, micrometer - 0.01 mm, theodolite (20" & 15 second), for levelling staff - 5 mm.

Theodolite

4

It is an instrument used for measuring horizontal & vertical angles in surveying.

- A simple circular curve can be set out using two theodolite method. In this method, only angular measurements are taken with the help of two theodolite instruments.
- Size of theodolite is defined by lower graduated circle.
- Non-transit theodolite can not be rotated through 180° in vertical plane.



1. Telescope
2. Trunnion axis
3. Vernier frame
4. Vertical circle
5. Plate level
6. Upper plate
7. Lower plate
8. Inner axis
9. Outer spindle
10. Inner spindle
11. Altitude bubble
12. Levelling screw
13. Clip screw
14. Hook
15. Vertical clamp screw
16. Vertical tangent screw
17. Tripod
18. Tripod leg
19. Target sight

Basic Definitions

(*i*) Centering: It is process of setting up the instrument exactly over the station mark with the help of plumb bob.

(*ii*) Face left: When vertical circle is on the left hand side of observer.

(*iii*) Face right: When vertical circle is on the right hand side of observer.

Line of collimation	Line of sight
It is an imaginary line passing through the intersection of cross hair & the optical centre of objective	A straight line along which an observer has unobstructed vision.Line joining the optical centre of the objectives to point of intersection of cross hair

Note: - When sighting a point, the line of sight is remaining horizontal, then line of sight is called as line of collimation.

(*iv*) Axis of level tube: It is the line tangential to the longitudinal curve of the level tube at its centre.

(*v*) Vertical axis: It is the axis about which telescope can be rotated in horizontal plane. Also called azimuth axis.

(*vi*) Horizontal axis: It is the axis about which telecope is rotated in vertical plane. Also called trunnion axis.

(*vii*) Telescope Normal: When vertical circle on left side & bubble is up.

(*viii*) Telescope Inverted: When vertical circle on right side & bubble is down.

(*ix*) Swinging: Revolving the telescope in the horizontal plane about its vertical axis.

(*x*) Lining in: It is the process of establishing intermediate points with the helps of theodolite on a given straight line whose ends are intervisible.

(*xi*) Balancing in: It is the process of establishing intermediate points with the help of theodolite on a given straight line whose ends are not intervisible.

(xii) Double Sighting: In this process, horizontal or vertical angle is measured twice, once in telesocpe normal condition & other in the inverted condition.

(xiii) Transiting: It is the operation of revolving the telescope by 180° in a vertical plane about its horizontal axis. Transiting is also called plunging/reversing.

Special Points:

(*a*) Line of collimation is perpendicular to the horizontal axis.

(*b*) Line of collimation is being parallel to the axis of the altitude level, when it is horizontal and vertical circle reads zero.

(*c*) Horizontal axix perpendicular to the vertical axis.

Temporary Adjustments of a Theodolite (in Order)

(*a*) Setting, (*b*) Centering
(*c*) Levelling, (*d*) Focussing the eye piece,
(*e*) Focussing the objective.

Permanent Adjustment of a Theodolite (in order)

(*a*) Plate level test, (*b*)Cross-hair ring , (*c*) Collimation in Azimuth test
(*d*) Spire test : It is use to check if horizontal & vertical axis are being perpendicular or not.
(*e*) Bubble tube adjustment, (*f*)Verticle circle test

Special Topic: Comparision Between Method of Repetition and Reiteration

(*i*) Reiteration method is preferred in triangulation, where no. of angles are taken at one station only.
(*ii*) Repetition method is preferred for single angle measurement
(*iii*) Following error's are eliminated in repetition method:
(*a*) Error due eccentricity of Verniers & centres is eliminated by reading both the Verniers.
(*b*) Error due to inaccurate graduations on the main scale is eliminated by taking the reading on the different parts of the circle.
(*c*) Error due to line of sight & horizontal axis being out of adjustment is eliminated by taking both face reading.
(*d*) Error due to inaccurate bisection of signal is eliminated by taking more number of observations.
(*e*) Other errors are also minimised by dividing the cumulative angle value with the number of observation.

The parts of a telescope are as follows.

- Objective is a lens towards the object.It provides a real inverted image in front of the eyepiece in the plane of cross hairs.
- Focusing Screw is used to adjust the focus.The magnification power of eyepiece is managed by the focusing screw.
- Eyepiece is a lens near the eye which is used by observer's eye to view the distant object.It have magnifying glass which magnify the observing image & the cross hairs of diaphragm..
- Diaphragm is provided infront of the eyepiece.
- It conisist of cross hairs made up of dark metal which are arranged in perfect perpendicular positions.
- These cross-hairs are used by the eye piece to bisect the objective through objective lens.

Traversing

5

A traverse is a series of connected lines whose length & direction are measured in field. In traversing, two types of measurements are need:

Angular measurement	Linear measurement
(a) Loose needle method	(a) Taping or chaining
(b) Fast needle method	(b) Tacheometric method
(c) Method of deflection angle	(c) Electronic distance measuring instrument (EDMI)
(d) Method of direct angle	
(e) Method of included angle	

Accuracy order: Coordinate method > Method of included angle > fast needle method > Loose needle method.

Angle Misclosure: It is equal to the difference between actual sum of measured angles & the theoretical sum of included angles:

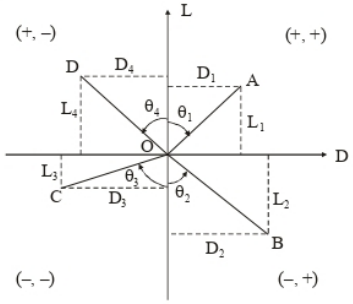
Sum of internal angles of a traverse = $(2N - 4)\times 90^\circ$

Sum of external angles of a traverse = $(2N + 4)\times 90^\circ$

Permissible angle misclosure = $K\sqrt{N}$, N = Number of sides of traverse

K = Depends on theodolite least count, accuracy desired & no. of repetitions (Gernerally consider 20").

Latitude and Departures: The orthographic projection of a line on meridian & on the axis perpendicular to the meridian is called latitude & departure respectively.



Line	Latitude	Departure
OA	$+L_1 \cos\theta_1$	$+L_1 \sin\theta_1$
OB	$-L_2 \cos\theta_2$	$+L_2 \sin\theta_2$
OC	$-L_3 \cos\theta_3$	$-L_3 \sin\theta_3$
OD	$+L_4 \cos\theta_4$	$-L_4 \sin\theta_4$

Checks in Traverse

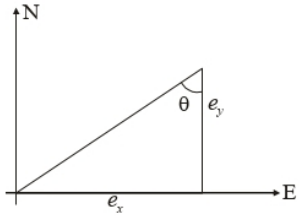
Closed Traverse (Loop)	Open Traverse (Link)
(*i*) Algebric sum of latitude $\sum L = 0$,	(*i*) Algebric sum of latitude = Difference in the latitude of final & initial control points.
(*ii*) Algebric sum of Departure $\sum D = 0$,	(*ii*) Algebric sum of Departure = Difference in the departures of final & initial control points.

If in closed traverse $\sum L \neq 0$, So $\sum L = e_y$ & $\sum D \neq 0$ so $\sum D = e_x$

Therefore, Error of closure $\boxed{e = \sqrt{e_x^2 + e_y^2}}$

Direction of closing error $\boxed{\tan\theta = \frac{e_x}{e_y}}$

Special Point: The sign of e_y & e_x will define the Quadrant in which closing error will lie.



$$\boxed{\text{Relative error of closure} = \frac{\text{Error of closure}}{\text{Perimeter of traverse}} = \frac{e}{P}}$$

Special point: Relative error of closure is also called relative accuracy or degree of accuracy.

Following are the methods for adjustment of traverse -

(*i*) Arbitrary method: It is based on the discretion of the surveyor & based on field conditions.

(*ii*) Bowditch rule: It is used where lengths & angles are measured equally

precise. Also known as compass rule.

Error in latitude of any line = Total error in latitude (e_y)

$$\times\left(\frac{\text{Length of that line}}{\text{Traverse perimeter}}\right),\ C_L = e_L \times \frac{l_1}{\Sigma l}$$

Similarly for departure of that line

Error in Linear Measurement $\propto \sqrt{l}$

Error in Angular Measurement $\propto \frac{1}{\sqrt{l}}$

(*iii*) **Transit rule:** It is used where Angular measurements are more precise than the linear measurement.

Error in latitude of any line

$$= \frac{\text{Total error in latitude } (e_y) \times \text{Numerical value of the latitude of that line}}{\text{Arithmetic sum of all latitudes}}$$

$$C_L = e_L \times \frac{L}{\Sigma L}$$

Similarly for departure of that line, $C_D = e_D \times \frac{D}{\Sigma D}$

(*iv*) Graphical method: It is based on Bowditch rule used for theodolite traverse with low accuracy.

(*v*) Axis method: In it, corrections are applied only to length & angles are measured very preciesely.

Triangulation: It is a network of triangles which are used for control network in which only one base line is measured & remaining sides are only determined by measuring angles.It is suitable for hilly area where direct measurement of distance is not possible.

- Satellite station is an auxillary theodolite station taken near an inaccessible main station.
- Laplace station is a triangulation station at which astronomical observations are also made.
- Main characteristic of Triangulation station is that they should be intervisible from each other.

Types of Triangulation		
Primary triangulation Most accurate Highest grade Use for testing defence, space vehicles	**Secondary triangulation** Strengthens the network made by primary triangulation	**Tertiary triangulation**

Signals : These are small devices which are used to define the exact location of a triangulation station so that it can be easily observed from the other stations or places.

Height of signal & distance are related as :

$$h \text{ (in cm)} = 13.3\ D \text{ (in km)}$$

Signal Types :

(a) Opaque Signal- Less accurate, for short distances (less than 30 km), can be use during day time only.

(b) **Luminous Signal-** More accurate, used for geodetic survey, for large distances (more than 30 km), can be use during night time only. It is of two types -

(i) **Sun Signal-** Also called Heliotrope, which reflect the sun rays towards the instrument station.

(ii) Night Signal- Used for making observations at night. Ex. magnesium lamps with parabolic reflectors etc.

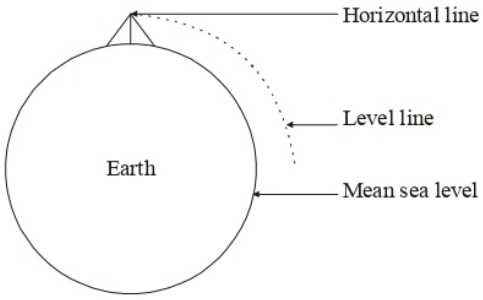
Trilateration: All sides of each triangles are measured in the field itself. Angles are indirectly calculated from the lengths of the sides of triangle.

Special Point: Accuracy of shape is measured in terms of strength of figures & its value depends upon No. of observed directions, No. of geometric conditions & magnitude of distance.

Levelling

6

- A level line is the one that is at a constant height relative to MSL. It must be a curved line.



- The value of MSL at datum is obtained by averaging the elevations of high & low tides (for a period of nearly 19 years) and in India, it is measured wrt Bombay port.
- The vertical distance between datum level & assumed point is called elevation

Bench Marks (B.M.): Any point whose elevation is definitely known can be used as bench mark. The degree of precision required for establishment of bench marks is $\pm 4\sqrt{k}$

Following are the various **types of Benchmark -**

- (a) GTS (great trignometrical survey) benchmark is taken wrt Bombay Port with 1 degree latitude & 1 degree longitude
- (b) Temporary BM - It is established temporary for a day's work.
- (c) Permanent BM - It is established by P.W..D. or S.O.I. (survey of India).
- (d) Arbitrary BM - Arbitrary considered for levelling small area.

Following are **different methods of levelling -**

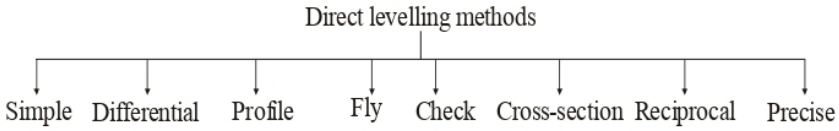
(a) **Direct levelling-** It is also known as spirit levelling.In it, spirit level is

attached to the telescope of levelling instrument. It is most common method of levelling.

(b) **Indirect levelling**- (i) Barometric levelling : It is quick method. In it, elevations are determined by change in atmospheric pressure.

(ii) Trignometric levelling : In it, vertical elevations are calculated by measuring horizontal distances & elevation angles.

(iii) Hypsometric levelling : In it, difference of elevation is calculated by noting the temperature at which water start boiling.



(*i*) **Differential Levelling** is used when points are situated quite apart. Also known as compound levelling.

(*ii*) **Check Levelling** is done for checking the already obtained elevations.

(*iii*) **Profile Levelling** is done for the purpose of determining the elevations of the ground surface along a fixed line. Also known as longitudinal levelling.

The Level obtained in profile levelling are done for plotting the longitudinal section which are required for various works like as fixing the gradients, determining the earthwork quantities etc.

(*iv*) **Fly Levelling** is done where rapidly but low precision is required. Generally used in reconnaissance.

(*v*) **Cross-section Levelling** is done to determine the difference of ground surface along the lines normal to the centre line.

(*vi*) **Precise Levelling** is done where high accuracy is desired.

(*vii*) **Reciprocal Levelling** is done where points are situated quite apart & it is not possible to set up the instrument mid way between the points. Ex:- Two more points located on opposite banks of a river/ pond.

Major components of level : (a) Telescope, (b) Bubble tube.

Optical Defects of Lens

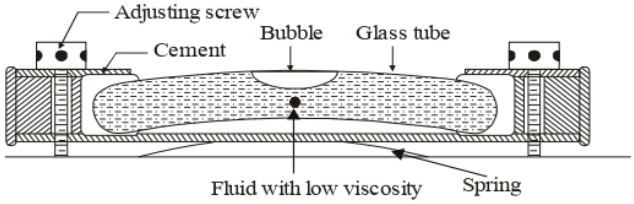
(*i*) Spherical Aberration: It occurs as the rays incident on the edge of the lens are refracted more than rays incident on the centre of the lens.

(*ii*) Chromatic Aberration: It occurs due to dispersion of light. White light is split into different colour components. The violet ray is refracted most and the red least. Due to this, blurred & coloured image is formed.

Special Points: An aplantic combination of lens (two identical plano convex lenses) is free from spherical aberration. Most commonly used eye piece is the Ramsaden eye piece.

An achromatic combination (convex lens of crown glass & concave lens flint glass) is free from chromatic aberration

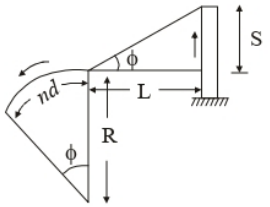
Level Tube: Sensitivity of level tube is expressed in terms of the angle in seconds substended at the centre by an arc of the level tube equal to one division of the tube.



Where, R = Radius at centre at bubble tube

Sensitivity of level tube can be increased by increasing radius, diameter of tube, length of tube and decreasing the temperature, viscosity of liquid, the roughness of the inner wall of the tube.

Determination of sensitivity



$$\phi = \frac{nd}{R} = \frac{S}{L}$$

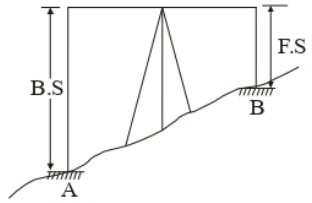
$$\boxed{\phi = \frac{d}{R} = \frac{s}{nL}\text{Radian}}$$

Special Point:- Dumpy level is less accurate & consumes large time in levelling. So generally not preferred nowadays.It is advantageous when several observations are to taken from one set of instrument. It is mostly used in direct levelling.There are the two types which are commonly used for levelling purposes named automatic level & tilting level.

- When there is windy condition in the field, the plumb bob may start swinging, in such case centering is done using optical plummet.

Procedure of Levelling

R.L. of A = may be B.M



H.I. = RL of A + (BS)

RL of B = H.I. – (FS)

$$RL\ of\ B = RL\ of\ A + BS - FS$$

Special Points:

Change Point: where back sight & fore sight is taken.

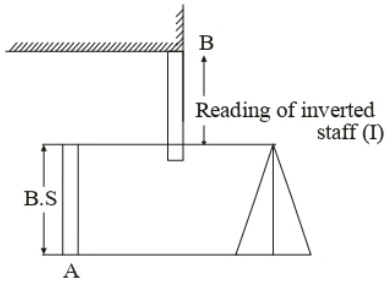
First reading made on a point of known reduced level is always a Back sight reading.

Readings are Booked in the level book two methods– Rise and fall method, Height of instrument method.

Rise and Fall Method	Height of Collimation method
1. Arithmetic check Σ(Back sights) – Σ(fore sights) = Σ(Rise) – Σ(fall) = Last RL – first RL	1. Arithemetic check Σ(BS) – Σ(FS) = Last RL – first RL
2. Check for intermediate reading is done using ΣRise – Σfall	2. Reduction is easier in it.
3. It is well suited for determining the differences of levels of two points where precision is required.	3. Collimation method is most suited for longitudinal/cross-sectional levelling & Contouring.

Inverted Staff: When the point whose elevation is to be found is much above the line of collimation, the staff is placed inverted with its zero end touching the point. The inverted staff reading is booked in the relevent column of the level book with a –ve sign. It is used to find RL at ceiling.

(RL of soffit (B) =RL of A + BS at A + I

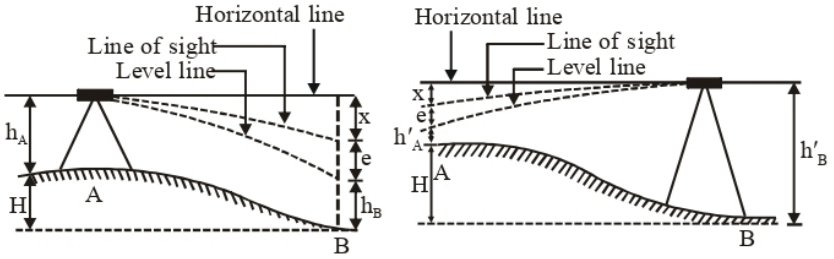


Effect of Curvature of Earth and Refraction

- **Curvature:** $C_C = -\frac{d^2}{2R} = -0.0785d^2$.
- **Refraction:** $C_r = \frac{1}{7}\left(\frac{d^2}{2R}\right) = 0.0112\ d^2$.
- **Final Combination Correction:** $C = C_c + C_r = -\frac{6}{7}\left(\frac{d^2}{2R}\right) = -0.06728d^2$
- **Distance of Visible Horizon**

  $d = 3.85\sqrt{h}$, d = in km and h = in meter.

Reciprocal Levelling: It eliminates the error's due to curvature of earth, refraction & collimation, error in instrument adjustment.



When instrument is set up at A
Reading on staff at A = h_A
Reading on staff at B = h_B

When instrument is set up at B
Reading on staff at A = h'_A
Reading on staff at B = h'_B

In it, e = error due to curvature & refraction & x = error due to inclined line of sight

$\boxed{h_A - h_B = h'_A - h'_B}$ If instrument is correct.

$$\boxed{H = \frac{(h_B - h_A) + (h'_B - h'_A)}{2}}$$

Where 'H' is the true difference of R.L. between A & B.

True Readings

Instrument is at	Reading of A	Reading of B
A	h_A	$h_A + H$
B	$h'_B - H$	h'_B

Techeometry

7

It is an optical distance measurement method. Generally used for rough or steep grounds where accuracy is less while chaining (taping)

Tacheometer: Transit theodolite fitted with Stadia diaphragm.

(*i*) Telescope is fitted with an anallactic lens.

(*ii*) Additive constant (*c*) should be zero.

(*iii*) Multiplying constant (K) should be 100,

(*iv*) Eyepiece has high magnification power.

Subtense Bar: It is used in measuring both horizontal & vertical distances in places where chaining is impossible. It is also called horizontal stave.

Stadia Rod: Also called vertical Stave. It is a 5–15 m long graduated rod in decimals of metre.

Methods of tacheometry -

(a) **Tangential method** - In it, observations are made for vertical angles & staff intercepts are obtained with cross wires only. Stadia wires are not used at all.It is faster than stadia hair method but less accurate.

(b) **Range finding -** It is used to find out the horizontal distance & direction of a line without going to far end of the line. The equipment used is known as range finder.

(c) **Stadia method -** (i) Fixed hair method - In it, parallactic angle is kept fixed & the staff intercept is varied.

(ii) Moveable hair method - It is also called subtense method .

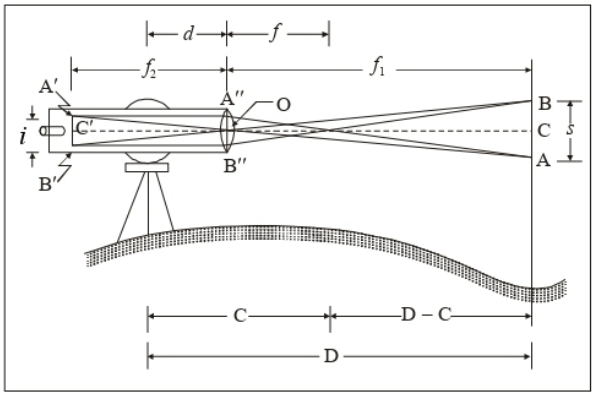
Fixed hair system: In this system the vertical distance between the upper and lower stadia hair is fixed and this fixed distance is called as stadia interval (I).

- The stadia diaphragm consist of two stadia hairs at equal distances.

Principle of Stadia Method

$$\boxed{D = KS + C}$$

D = Horizontal distance between staff & vertical axis of tacheometer



S = Staff intercept

$$K = \frac{f}{i},\ C = f + d\ ,\ \text{(where } \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}\text{)}$$

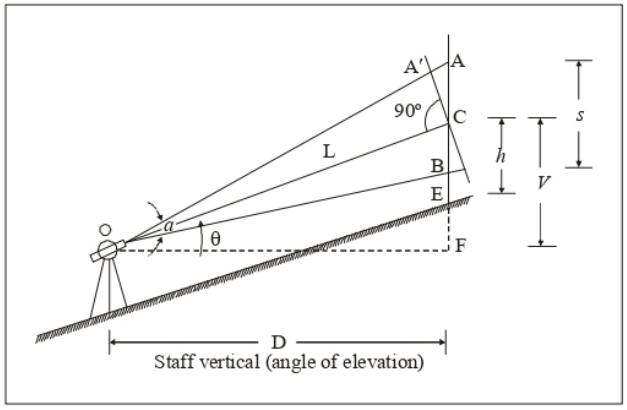
i = Interval between the stadia hairs of the Diaphragm

d = Horizontal distance between optical center O & vertical axis of techeometer.

Additive contstant C, range from 0.3 to 0.6 (for external focussing telescope) & 0.08 to 0.2 (for internal focussing telescope) & taken as 0.

Distance and Elevation Formula for Inclined Sights

(*i*) When staff is vertical



Elevation of staff station when elevation angle θ = HI + V – h

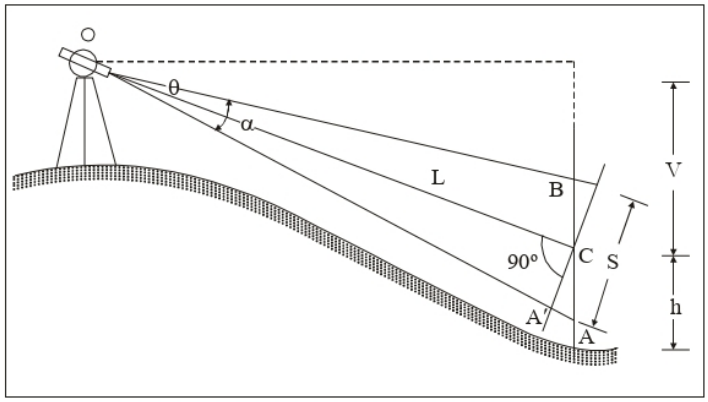
L = KS cos θ + c

$D = L \cos\theta = ks \cos^2 \theta + c \cos\theta$

Elevation of Staff Station when elevation angele is $\theta = HI + V - h$

Elevation of Staff Station when depression angele is $\theta = HI - V - h$

(*ii*) When staff is normal



Angle of depression

(a) Line of sight at an angle of depression

$L = Ks + c$

$D = (Ks + c) \cos\theta - h \sin\theta$

Elevation of Staff Station when depression angle is θ

$= HI - V - h \cos\theta$

(b) Line of sight at an angle of elevation

$L = Ks + c$

$D = (Ks + c) \cos\theta + h \sin\theta$

Elevation of Staff Station when elevation angle is θ

$= HI + V - h \cos\theta$

Plane-Table Surveying

8

It is an instrument used for surveying by a graphical method in which the field work & plotting are done simultaneously.

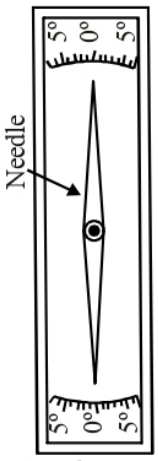
Principle Used: Unknown point of interest can be established by measuring its directions from the known points.Parallelism is the principle of plane table as used in surveying.

Accessories Used:

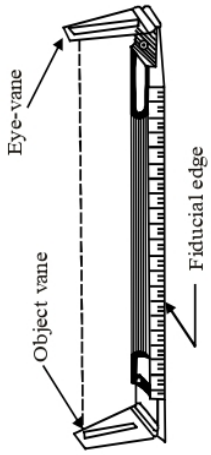
(*a*) Plane Table Board

(*b*) Tripod: To support the plane table board

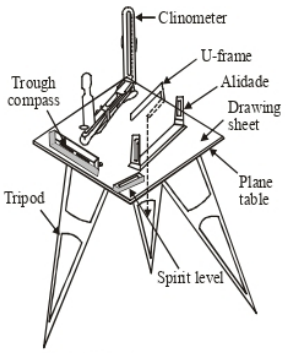
(*c*) Trough compass:It is used to locate N-S direction. Trough compass is 15 cm long.



Trough compass



Alidade



Plain table with accessories

(*d*) Spirit level/level tube: It is used to make plane table board horizontal.

(*e*) Alidade: It is used for sighting the objects & drawing the lines.Plane Alidade for horizontal & telescopic Alidade for inclined line of sight.

(*f*) Plumbing fork : It is used for centering of plane table.

(*g*) Indian clinometer:It is used to determine the difference of elevations of two points by measuring the inclination of line of sight.

(*h*) Drawing sheet.

Special Points:

(i) Telescopic alidade is used in plane Table surveying for further measurements of Horizontal & vertical distances directly.

(ii) The size of plane table is 60 cm × 50cm, 75 cm × 60cm or 100 cm × 75cm

Temporary Adjustments in Plane Table

(*a*) Surface of board should be perpendicular to the vertical axis of the instrument.

(*b*) The two vanes (object vane & eye vane) should be perpendicular to the base of the alidade.

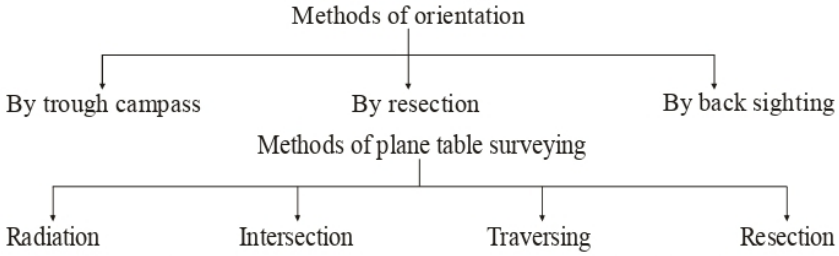
(*c*) The fudicial edge of the alidade should be a straight line.

Setting up the Plane Table

(*i*) Levelling: It is the operation of bringing the plane table in a horizontal plane.

(*ii*) Centering: It is the process of bringing the plotted station point exactly over the ground station. For small scale mapping, an error in centering of about 30 cm is permissible.

(*iii*) Orientation: It is the process of keeping the plane table parallel to the positon, it occupied at the first station.



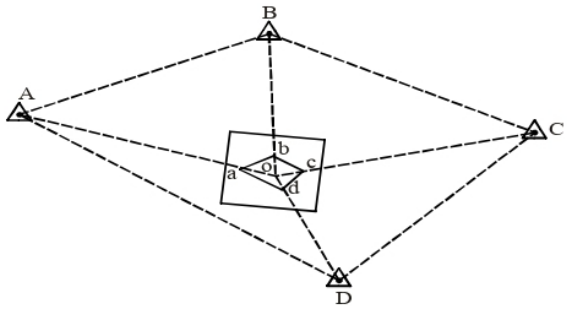
(*a*) **Traversing:** Generally used when a narrow strip of terrain is to be surveyed. Ex- Survey of road, Railway etc. It is used for both open & close traverses.

(*b*) **Resection method:** It is employed when the plane table occupies a position not yet plotted on the drawing sheet. It is commonly used for establishing instrument station

(*c*) **Intersection:** It is used when the base stations are visible & accessible but the other stations are only visible but not accessible. It is most suitable for hilly area & also known as graphical triangulation

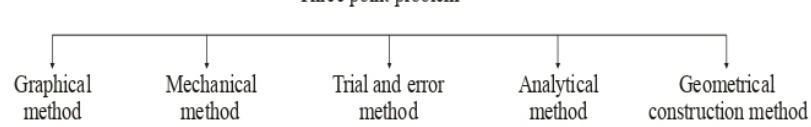
(*d*) **Radiation:** It is suitable when area to the surveyed is small & all the required stations to be plotted are clearly visible & accessible from

the instrument station.This method is similar to theodolite or compass traversing.



Two Point/Three Point Problem: Three point problem is better than two point problem because it is simple & accurate.

It consist of locating the position of plane table station on the drawing sheet by observation of two/three well defined points which are visible & already plotted on the plane table.



Special Points:

1. Most rapid method of orientation by the three point method of plane Tabling is the Trial & error method.
2. The fix of a plane Table from known points is good if the middle station is Nearest.

3.Traversing & resection methods are use for locating the instrument station whereas Intersection & Radiation methods are use for plotting the details.

Difference between two & three point problem

Two Point Problem	Three Point Problem
To fixing plain table station two well	To fixing plain table station three well
Accuracy is not Good	Give more accurate result
More labour required compare to three point problem	Less labour required compare to 2- point
More time is required	Less time required

Contouring

9

Contour: It is an imaginary line passing through the points of equal elevation on the earth surface.

Contour Interval: Vertical distance between consecutive contour. It is desirable to have constant contour interval through the map. Generally 1-15 m. It depends on following factors:

(a) Scale of map $\propto \frac{1}{\text{C.I.}}$ (b)Nature of the country

(c) Purpose of map-for more details small C.I. (d) Time and funds $\propto \frac{1}{\text{C.I.}}$

$$\text{Contour interval} \propto \frac{1}{\text{Flatness of ground}} = \frac{25 \text{ (in meter)}}{\text{No. of cm in per km}}$$

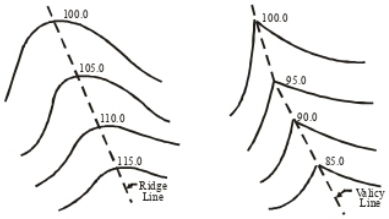
Characteristics of Contour

(a) A zero meter contour line represents the coastal line. When no value is represented, it indicates a flat terrain.

(b) Equally spaced contours represents uniform slope.

(c) A watershed or ridge line contour crosses the valley contour at right angle. Generally the contours are not visible on the grounds excepts in the case of shore lines.

(d) Two contours intersect each other only in case of overhanging cliff or a cave penetrating a hill side.

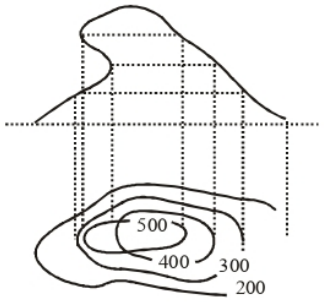


(a) (b)

(e) Direction of steepest slope is along the shortest distance between the contours.

(f) Two contour lines having same elevation can not unite & continue as one line.

(g)



A set of close contour with higher figures inside & lower figure outside represent a hill while with those having lower figures inside & higher figures outside represent lakes or depressions.

Applications: Determination of intervisibility, Route location, Drainage area, Site of structures, Capacity of reservoir, earthwork estimates.

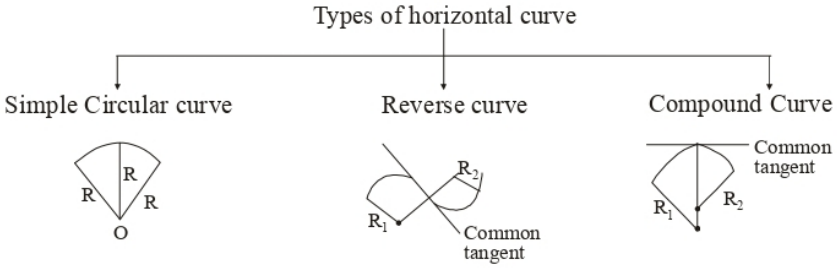
Special Point: A very steep slope is scrap & a high scrap is known as crag.

- **Methods of contouring**
  - (a) Direct Method :-
    - (i) When the survey area is small & sufficient time available (slow method)
    - (ii) When greater accuracy is required
  - (b) Indirect Method :-
    - (i) For engineering works, we use this method generally.
    - (ii) In this method, we draw the contour of any reduce level using the Inter polation with the help of some fixed point.

  Following are **Indirect method**:-
  - (a) By square method:- used for small area & also called spot levelling.
  - (b) By cross- section method:- used for railway line, road line, canal alignment.
  - (c) By tacheometer method:- used in hilly area
- **For Interpolation**, following methods are used.
  - (a) By Estimation methods, (b) By Graphical methods
  - (c) By arithmatical methods (by compution method): It is best method/ most accurate.

Curves

10



Horizontal curve: It is a curve in plane to provide change in direction to the central line of a road. It is provided at the point where two straight lines intersect in the horizontal plane. Generally circular in nature.

Vertical curve: Due to changes in grade in the vertical alignment, it is necessary to introduce vertical curve at the intersections of different grades to smoothen out the vertical profile & hence ease off the changes in gradient for the fast moving vehicles.Generally parabolic in nature.

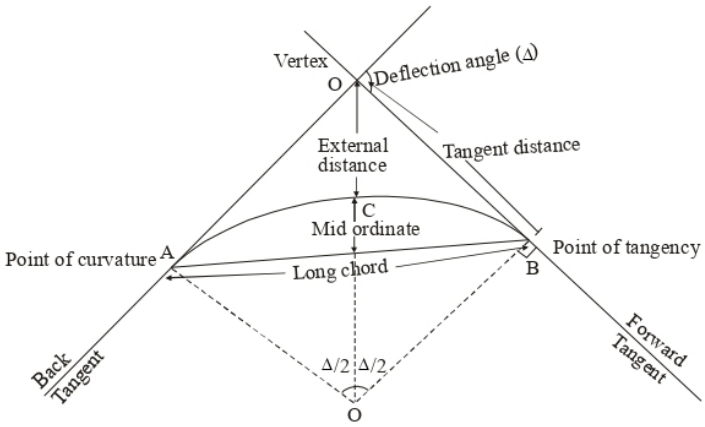
Reverse curve: It is a combination of two simple circular curves having opposite direction joining at common tangent point.

These are used in hilly terrains and in railway siding as cross over.

Reverse curves are used when either the two straights are parallel or their angle of intersection is too small.

Transition curve: When a vehicle travelling on a straight road (infinite radius) enters a curve of finite radius.Then, it is suddenly subjected to the centrifugal force which causes shock & sway. For avoiding this, it is necessary to provide a transition curve at the beginning of the circular curve, (having a radius equal to infinity at the end of the straight end) & gradually reducing the radius to the radius of circular curve where the curve begins.

Horizontal Circular Curve



Degree of Curve: It is the angle substended at the centre by an arc or chord of a specified length.

- Chord definition is used in case of railways.
- Arc definition is used in case of highways.

Arc definition → 30 m arc, 20 m arc

Chord definition → 30 m chord, 20 m chord

$$R = \frac{1719}{D} \qquad R = \frac{1146}{D} \qquad R = \frac{15}{\sin D/2} = \frac{1719}{D} \qquad R = \frac{10}{\sin D/2} = \frac{1146}{D}$$

Elements of a Simple Circular Curve

(*i*) Length of curve (l): Length of ACB

$$l = \left(\frac{2\pi R}{360}\right)\Delta$$

(*ii*) Tangent length/ Tangent distacne:

$$T = R \tan\left(\frac{\Delta}{2}\right)$$

(*iii*) Chainage of tangent points:

(*a*) Chainage of A = Chainage of Vertex – Tangent distnace

(*b*) Chainage of B = Chainage of A + length of curve

Special Point: Chainage of B ≠ Chainage of Vertex + Tangent distance

(*iv*) Length of long chord (L)

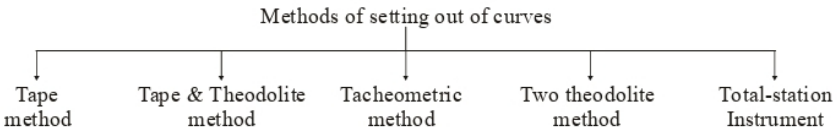
$$L = 2R \sin\left(\frac{\Delta}{2}\right)$$

(*v*) External distance or Apex distance (E) :

$$E = R\left(\sec\frac{\Delta}{2} - 1\right)$$

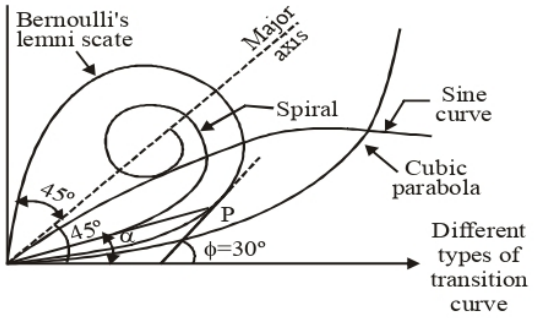
(*vi*) Mid-ordinate (*m*)

$$M = R\left(1 - \cos\frac{\Delta}{2}\right) = R \text{ versine } \frac{\Delta}{2}$$



Special Point: In horizontal curves to avoid inconvenience to slow moving vehicles, the maximum value of the centrifugal ratio for roads is specified as 1/4 & for railway tracks, it is 1/8.

Bernoulli's Lemniscate: It is special type of transition curve which is generally used when angle of deflection is very large.It is easy to set out in the field & rate of change of acceleration is uniform throughout the length of transition curve.



- It is objectionable in Railways but allowed on highways.
- Curve closely resembles a clothoid for a polar angle upto 5^0.
- It is symmetrical, so it can even be used when curve is transitional throughout without a circular curve between the two transition curves.

Field Astronomy 11

- On 21st or 22nd Septmber, sun crosses the equator from North to South & it is called first point of Libra (also known as Autumnal equinox).
- On 21st March, sun crosses the equator from South to North & it is called first point of Aries. On this day & night are equal. (Also known as vernal equinox).
- The angular distance of any plane. North or South of equator is called Latitude (θ).

$$\boxed{c + \theta = 90^\circ}$$

- The measured angle between pole to zenith point for any place is called co-latitude (c).
- The angle between meridian of a place from a fixed meridian is called longitude.
- The angular distance from horizon, measured on a vertical circle passing through the body is called Altitude (α).

$$\boxed{\alpha + z = 90^\circ}$$

- The angular distance of body from Zenith is called Co-Altitude (z) or Zenith distance.
- The angular distance of a body from the plane of celestial equator, measured along declination circle is called Declination (δ).

$$\boxed{\delta + p = 90^\circ}$$

- Angular distance of heavenly body form pole is called co-declination (p)
- The angular distance measured Eastward from first point of Aries is called right ascension (R.A.).
- The angle between observer's meridian & declination circle passing through the body is called Hour Angle (H). It is measured from South in Westward direction.

Terrestrial Latitude and Longitude

(a) Axis of the earth: Axis joining the North & South Pole of the earth.

(*b*) Equator: The great circle perpendicular to axis of the earth.
(*c*) Latitude: The vertical angle above or below equator.
(*d*) Longitude: The horizontal angle between great circle passing through place & standard meridian.
(*e*) Meridian: Any great circle whose plane passes through the axis of earth.

Special Point: Prime meridian or standard meridian is a meridian passing through Greenwich.

(*vi*) Parallel of latitude: Parallel of latitude through a point is a small circle passing through that point & parallel to equator.

$$1 \text{ Nautical mile} = 1.852 \text{ km}$$

Celestial Latitude and Longitude System

- Celestial longitude is the horizontal angle measured from first point of Aries to the east.
- Celestial latitude is the vertical angle measured above or below arc of ecliptic.
- **Time:** The interval lapsed between any two instants.

The various time measurements used by astronomers are:

(*a*) **Sidereal Time:** It is the hour angle of first point of Aries (*r*) measured westward at any instant. Measured according to positional stars in sky.

LST = Right Ascension (RA) of the observer's meridian = RA of a star + HA of star

- The interval of time which elapses since the upper transit of first point of Aries over observer's meridian is known as local side real time of the place (L.S.T.)

(*b*) **Mean Solar Day:** It is the interval of time between two successive lower transit of mean sun.

- The hour angle of the mean sun recorded westward from 0 to 24 hours is known as local mean time.
- The instant when the mean sun crosses the local meridian at its upper transit is known as local mean noon.

(*c*) **Apparent Solar Time:** The interval of time which lapses between two successive lower transit of centre of sun over meridian of the place is called apparent Solar day.

The measurement of time based on dailly apparent motion of the sun round the earth.

(*d*) **Standard Time:**Indian standard meridian which passes from Allahabad is at 5 hours 30 minutes East of Greenwhich

It is the time of the watch. Standard meridian of a country is generally selected such that it lies at an exact number of hours from Greenwich.

IST longitude is 82°30' E.

Standard time (ST) = LMT $\pm$ Difference of longitude converted to time

Equation of time = Apparent solar time – Mean solar time

Conversion of Time:

Longitude	360°	15°	1°C	15'	1'	15″
Time	24 hours	1 hours	4 minute	1 minutes	4 second	1 second

- Local apparent time = local mean time + equation of time.
- Sidereal time
  = Mean solar time + Acceleration
  = Mean solar time + 9.8565 see per hour of given mean solar time.
- Mean solar time
  = sidereal time – retardation
  = sidereal time – 9.8296 seconds per hour of given sidereal time
- LST at LMM = GST at GMM

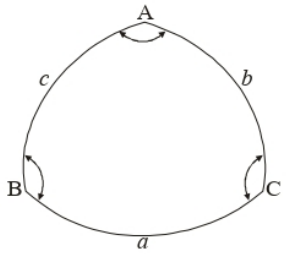
  $\pm$ 9.8565 sec. per hour of longitudinal $\left(\frac{W}{E}\right)$
- LST at LMT = LST at LMM + SI from LMM
  SI (sideral time interval) = LST at LMT – LST at LMM
- LST at LMN = GST at GMN

  $\pm$ 9.8565 sec. per hour of longitude $\left(\frac{W}{E}\right)$
- Equation of Times: Difference between apparent solar time & mean solar time at any instant is known as the equation of time.

1 Tropical year = 365.24422 mean solar days
1 sidereal year = 366.2422 sidereal days

Spherical triangle: If a, b, c are sides of spherical triangle, then A is angle formed at centre of sphere by arc BC or A is angle between two great circle passing from AB & AC.

Properties of Spherical Triangle



(*i*) Any angle is less than π.

(*ii*) $\pi < (A + B + C) < 3\pi$

(*iv*) If sum of any two sides is equal to π angle, then the sum of angles opposite them is also equal to π.

(*iii*) Sum of any two sides > third side.

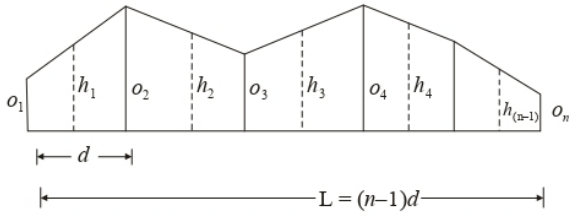
(*vi*) Area of spherical triangle = $\frac{\pi R^2}{180} \times E$, where spherical excess (E) = (A + B +C)– 180.

(*v*) The smaller angle is always opposite to the smaller side.

Measurement of Area and Volume

12

Measurement of Area



$h_1, h_2 ... h_n$ are offsets at mid point of each division.

(*a*) Average ordinate rule

$$\text{Area} = \frac{o_1 + o_2 + o_{n+1}}{n+1} \times nd, \quad \text{Area} = \frac{nd\sum_{i=1}^{n} O_i}{n+1}$$

(*b*) Trapezoidal rule: $A = d\left(\frac{o_1 + o_n}{2} + o_2 + o_3 + ... + o_{n-1}\right)$

Where o_1 & o_n are end ordinates.

Trapezoidal rule is more accurate than the Mid-ordinate rule and Average ordinate rule.

(*c*) Mid-ordinate rule

Area = $(h_1 + h_2 + ... + h_n)\, L$

(*d*) Simpson's one-third rule

$$A = \frac{d}{3}[(o_1 + o_n) + 4(o_2 + o_4 + ... + o_{n-1}) + 2(o_3 + o_5 + ... + o_{n-2})]$$

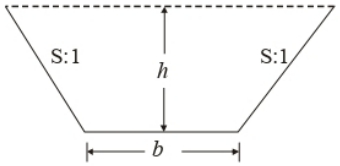
Special Points: Simpson's Three Point formula

$$A = \frac{d}{3}[h_1 + 4h_2 + h_3]$$

- This rule is more accurate than previous rules & based on assumption that the figures are trapezoidal.
- It should be clear that this rule is applicable only when No. of divisions of area is even.
  (*a*) Short length of boundries between two adjacent ordinates is a parabolic arch.
  (*b*) If there are even no. of offsets, then area upto the second last segment is calculated by Simpson's rule & for the last segment trapezodal rule is used.

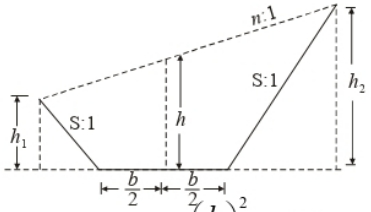
Measurement of Area of Cross-section

(*a*) Level section



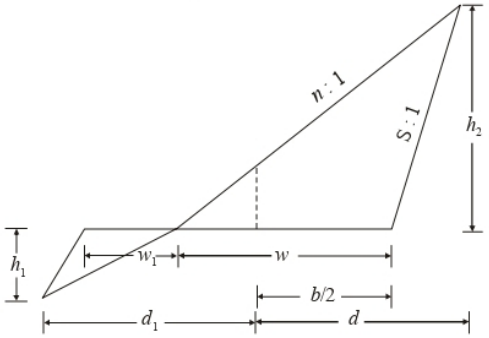
From above diagram, Area = $(b + Sh)\, h$

(*b*) Two-level section



From above diagram, Area = $\dfrac{s\left(\dfrac{b}{2}\right)^2 + n^2\left(bh + sh^2\right)}{n^2 - s^2}$

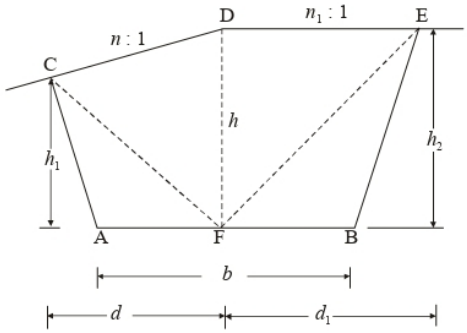
(*c*) Side hill (two level section)



$$\text{Embankment Area} = \frac{\left(\frac{b}{2} - nh\right)^2}{2(n-s)}$$

$$\text{Excavation Area} = \frac{\left(\frac{b}{2} + nh\right)^2}{2(n-s)}$$

(*d*) Three level section



$$\text{Area} = \frac{b}{4}(h_1 + h_2) + \frac{h}{2}(d + d_1)$$

Volume Mesurement

(*a*) Prismoidal formula (Simpson's rule is used) : Valid for odd no. of offset.

$$V = \frac{L}{3}((A_1 + A_n) + 4\,(A_2 + A_4 + \ldots + A_{n-1}) + 2\,(A_3 + A_5 + \ldots + A_{n-2}))$$

(*b*) Trapezoidal formula

$$V = \left[\frac{A_1 + A_n}{2} + A_2 + A_3 + \ldots A_{n-1}\right] L$$

$A_1, A_2, A_3 \ldots A_n$ are the end consecutive areas & L is the distance between them

Special Point: In case if only prismoidal rule is to be applied, then the area halfway between the sections is interpolated by averaging the dimensions of the end sections & not by averaging the end areas.

Some Important Instruments Used in Survey

- As compared to engineer's level, Abney level is precise
- Abney level is the improved type of clinometer
- An instrument which measures the distance between two points by means of a laser geodimeter
- Eidograph is an mechanical plotting instrument used to redraw maps at a smaller or larger scale. It has the same function as a pantograph.
- Observation can be taken in the night by instrument called tellurometer

Instrument	Use
• Hand Level	• To trace contours.
• Abney Level	• To measure slope, take cross section, to find gradient.
• Box Sextant	• To measure horizontal & vertical angle in chain survey and plane table survey
• Indian Pattern Clino-Meter	• To determine elevation difference between two points.
• The Pantagraph	• Used to reduce or enlarge the maps.
• Optical square/Cross Staff	• To set out 90° angle.
• Planimeter	• Instrument used to measure area very accurately.
• Ceylon Ghat Tracer.	• To measure slope & to set-out gradient.
• Clinometer	• Angle measuring Instrument
• Cardiograph	• Improved version of pantagraph.

Total station used for:

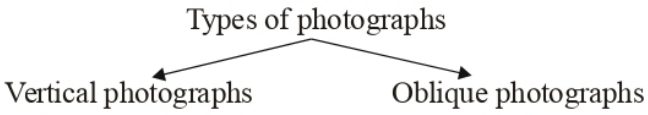
(a) Establishing horizontal control.
(b) Establishing vertical control.
(c) Remote object height determination.

- In the total station, the angles & distances are recorded in the digital form.It has all facilities of tacheometer operated electronically.It is operated through the control panel.
- A smart station is used to indicate a total station with an itergrated GPS module.
    - **Levelling staff** are of two types:-

Self reading staff :- It can be read directly by the level man through the telescope. Smallest Sub Division is -0.005 m. They are also three types-
(i) Solid Staff, (ii) Telescope staff, (iii) Folded staff (used in our country)
Target Staff:- In this staff , level man direct the staff man to move the target up and down until it bisects by the line of sight. Minimum sub division is 0.001 m. Its height - 4m, thickness - 18 mm, width - 75 mm.

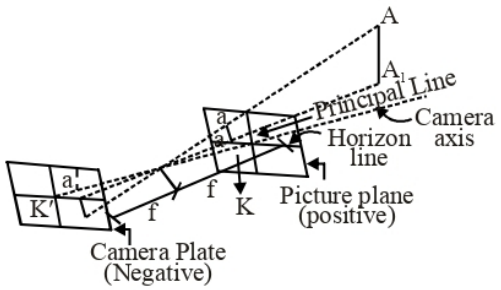
Photogrammetry 13

- It is the science of obtaining information about physical objects through process of recording, measuring & interpreting of photographes of the area.
- Terrestrial photorammetry:
  In it, photographs are taken from a fixed position on or near the ground.
- Aerial photogrammetry:
  In it, photographs are taken from a camera mounted in an aircraft flying over the area.
- The number of satellites involved in the orbit for the GPS survey technique are 24
- No. of sattellite use to locate (Latitude, longitude, altitude) = 4
- No. of sattellite use to locate (Latitude, longitude) = 3
- Comparators are used for accurate measurement of distance on photograph
- Stereo comparators are used for measurement on an overlapping stereo pair of photographs.
- Mono-comparator is used for measurement on one photograph at a time



Important Definitions

- **Camera Axis:** Line passing through centre of camera lens perpendicular both to camera plate (Negative) & picture plane (photograph)



- **Principal point:** K or K′ point on intersection of camera axis with either picture plane or the camera plate.
- **Picture Plane:** It is the positive plane perpendicular to camera axis.
- **Focal length (f):** It is the perpendicular distance from centre of camera lens to either to picture plane or camera plate. It satisfy the relation.

$$\frac{1}{f}=\frac{1}{u}+\frac{1}{v}=\frac{u+v}{u.v}\ ,\ f=\frac{uv}{u+v}$$

- **Principal plane:** It is a plane which contain principal line & optical axis.
- **Oblique photograph:** Photograph taken from air with axis of camera tilted from vertical area called oblique photograph, these are of two type.
- **High Oblique Photograph:** If tilt is more in such a way that horizon is shown in the photograph.
- **Low Oblique photograph:** An oblique photograph that does not show the horizon.
- **Nodal point:** It is either of two points on the optical axis of a lens so located that when all object distances are measured from one point & all image distances are measured from other. They satisfy the simple lens relation.

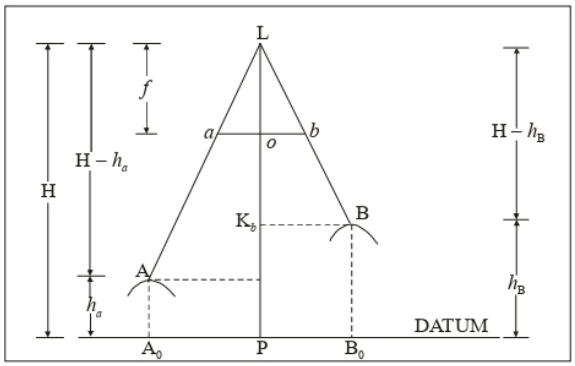
$$\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$$

- **Convergent photograph:** Low oblique photographs which are taken with two cameras exposed simultaneously at successive exposure stations, with their axes tilted at a fixed inclination from vertical, in such a way that forward exposure of first station from a stereo pair with backward exposure of next station, these photographs are called 'Convergent Photographs'.

Special Point: Map is an orthographic projection but an aerial photograph is a central projection.

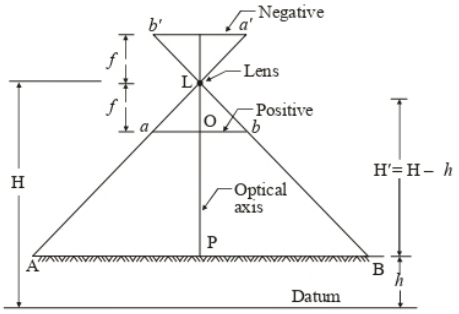
Scale of Vertical Photograph

(*a*) Datum scale



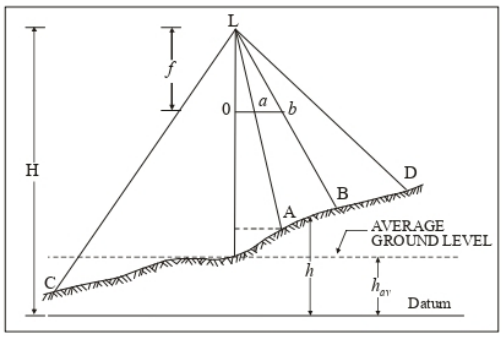
$$S = \frac{f}{H}$$

(*b*) Flat terrain



$$S = \frac{f}{H - h} = \frac{ab}{AB}$$

(*c*) Average scale



$$S = \frac{f}{H - h_{avg}}$$

$$X_A = x_a\left(\frac{H - ha}{f}\right),\ Y_A = y_a\left(\frac{H - h_b}{f}\right)$$

Where Ground coordinates are

(X_A, Y_A): Ground co-ordinates f = focal length of lens

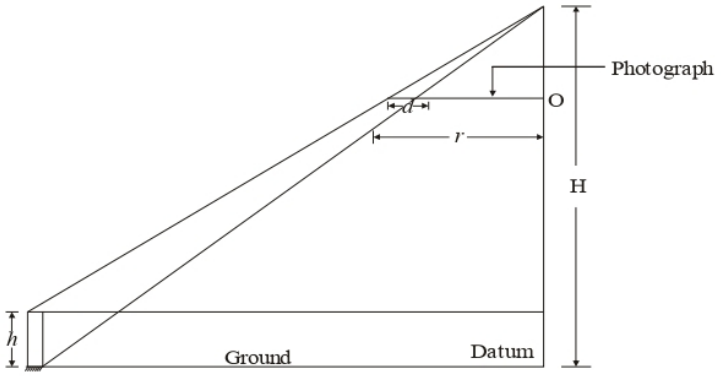
(x_a, y_a): Photo co-ordinates h_A elevation of point A above datum

H = flying height

Map	Aerial photograph
Orthogonal projection.	Perspective projection
Selected details.	Vast details shown.
More clarity due to use of symbols.	Less clarity due to no use of symbols.
Constant scale.	Scale varying due to varying elevation.

Relief displacement on a Vertical Photograph

When the ground is not horizontal, the scale of the photograph varies from point to point. The ground relief is shown in perspective on the photograph. Therefore every point on the Photograph is displaced from true orthography position. This displacement is called relief displacement.



d = Relief displacement

H = Flying height above the datum

h = Height of the object above datum

r = Radial distance of the image of the top of object

$$d = \frac{rh}{H}$$

Overlap in the Photographs

- Longitudinal overlap = 55 to 65%
- Lateral Overlap = 15 to 35%
- For maximum rectangular area, to be covered by one photograph, the rectangle should have the dimension in the flight to be one-half the dimension normal to the direction of flight.
- W = 2B, W = 1.22H , W = width of ground % overlap = 60% in longitudinal direction

Calculation of Flying Height of a Vertical Photograph

(*a*) When photo coordinates are (x_a, y_a), & (x_b, y_b), focal length is *f*, elevation of points above ground is h_a & h_b respectively, then distance between points on the photograph will be

$$AB = \sqrt{\left[\frac{x_b}{f}(H - h_b) - \frac{x_a}{f}(H - h_a)\right]^2 + \left[\frac{y_b}{f}(H - h_b) - \frac{y_a}{f}(H - h_a)\right]^2}$$

(*b*) When focal length is '*f*' & scale of photographs '*s*' then

$H' = \frac{f}{s}$, Where H' = flying height above ground

Required Number of Photographs

Ground Area = A , Area covered by one photograph = a

Side lap = P_s, Longitudinal overlap/end lap = P_l

Length of photograph in direction of flight = *l*

Scale of photograph = *s*

width of photograph normal to the direction of flight = *w*

(*a*) $$N = \left[\frac{L_1}{(1 - P_l)\frac{l}{s}} + 1\right]\left[\frac{W_1}{(1 - P_w)\frac{w}{s}} + 1\right]$$

L_1 = Length of ground to be covered

W_1 = Width of ground to be covered

(*b*) $$N = \frac{AS^2}{(1 - P_l)(1 - P_s)wl}$$

Crab and Drift

Drift is the lateral shifting of the photograph. It is generally due to wind. The crab is generally introduced to avoid drift.

Crab of a photograph is the angle formed between the flight line & edges of the photograph in the direction of flight.

Map-projection			
Conformal projection	**Equal area projection**	**Equidistant projection**	**Azimuthal projection**
Angle between any pair of short line is correctly represented	Areas represented correctly, while shape may not be same	In it, distances are represented correctly from one central point	

Special Point: In tilted photographs, these angles completely define the angular orientation of that photograph. These are tilt (t), swing (s) & azimith (a)

Theory of Errors

14

True value of the quantities (angles & distances) is impossible to determines as some type of errors always occurs in every measurement.

Types of errors -

(a) Gross errors (mistakes) - These occurs due to inexperience/carelessness of the surveyor.

(b) Systematic (cumulative) errors - These can be calculated & corrected easily. These are of same magnitude & nature in the same conditions.

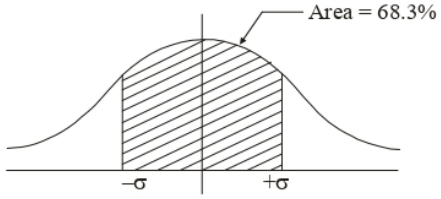
(c) Accidental (random) errors - Also called compensating errors. These occurs due to lack of perfection in the human eye. These obey the law of chance.

Special Point: In this chapter we consider that mistakes & systematic errors have been eliminated & only accidental errors are left to be eliminated.

Laws of Accidental Error

It follows normal probability distributin curve (also called as Gaussian distribution)

Error = Measured value – True value
Residual = Measured value – Most probable value



$$y = \frac{1}{\sqrt{2\pi}\sigma} e^{-0.5(v/\sigma)^2}$$

v = residual

y = frequency of occurance of the residual or variation

Special Points: Smaller the value of standared deviation, the greater is the precision.
Standard deviation is also called root mean square error of the measurement.

Indices of Precision for Observations of equal Weight

(*a*) Standared deviation (σ): For accessing the precision of a set of observations.

$$\sigma = \pm\sqrt{\frac{\Sigma v^2}{n-1}}$$

(*b*) Standard error of the mean (σ_m)

$$\sigma_m = \pm\frac{\sigma}{\sqrt{n}}$$

(*c*) Variance (σ^2): It is used as a measure of dispersion or spread.

$$\sigma^2 = \frac{\Sigma v^2}{n-1}$$

(*d*) Standard error of single observation (σ_1)

$$\sigma_1 = \pm\sqrt{\frac{\Sigma v^2}{n-1}}$$

(*e*) Most probable error

$$e = \pm 0.6745\,\sigma = \pm 0.6745\sqrt{\frac{\Sigma V^2}{(n-1)}}$$

(*f*) Maximum error: If any measurement deviates from mean by more than ± 3.29σ, then that measurement is considered as mistake & it can be rejected.

(*g*) Different percentage error:

(*a*) 90% error (E_{90}) = ± 1.645 σ

(*b*) 95% error (E_{95}) = ± 1.96 σ

(*c*) 99.7% error ($E_{99.7}$) = ± 3.0 σ

Definition of Weight: It is always express in number. It is a measure of relative trust worthiness of the set of observations. The larger the precision of an observation, the larger will be its weight.

Rules of Weight Allocation

(*a*) The weights are taken inversely proportional to the variance or square of standard deviation

(*b*) Weights are sometimes allocated by personal judgement depending on field prevailing & environmental conditions (lower weights allocated to observations in difficult terrain).

(*c*) The weights of the quantities measured in similar conditions are assigned in direct proportion to the number of times (*n*) the quantity is measured.

(*d*) Weight of level line is taken as inversely proportional to the length (L) of the route. Hence,

$$\frac{w_1}{w_2} = \frac{L_2}{L_1}$$

Laws of Weight

(*a*) If the no.of observations (*a, b, c* ....) of a particular quantity have unit weight (1), then the value of quantity will be the arithmetic mean of observation.

(*b*) Weight of observation *a* is w_1 & weight of observation *b* is w_2.

$$\text{Weight of } a \pm b = \frac{1}{\frac{1}{w_1} + \frac{1}{w_2}} = \frac{w_1 w_2}{w_1 + w_2}$$

(*c*) Weight of observation *a* is w_1 . If the observation is multiplied by factor K, then

$$\text{Weight of K}a = \frac{w_1}{k^2}$$

(*d*) The weight of the weighted arithmetic mean is equal to the sum of individual weights. $(w_1 + w_2 + w_3)$

(*e*) If the equation is multiplied by the own weight, then the weight of resulting equation is equal to the reciprocal of the weight of that equation.

(*f*) Weight of an equation remain unchanged if the equation is added or subtracted from a constant.

(*g*) Weight of an equation remains unchanged if all signs of equations are changed

Indices of Precision for Observations of Different Weights

(*a*) Standard deviation of weighted observations (σ_w)

$$\sigma_w = \pm\sqrt{\frac{\Sigma(wv^2)}{n-1}}$$

(*b*) Standard error of the mean of the weighted observations (σ_m) is

$$(\sigma_m)_w = \pm\frac{\sigma_w}{\sqrt{\Sigma w}}$$

(*c*) Most probable error of the mean $(E_m)_w$

$$(E_m)_w = \pm 0.6745\ (\sigma_m)_w$$

Theory of Least Square: The most probable value is that value which makes the sum of squares of the residual to a minimum value.

(*a*) If the observations have equal weight, so Σv^2 = minimum

(*b*) If the measurements are of unequal weights, so $\Sigma w(v^2)$ = minimum

Methods of least square adjustments are

(*a*) Method of correlates or condition equations method

(*b*) Normal equation method

12 Hydrology

1. INTRODUCTION

- Hydrology is the science of occurrence, circulation & distribution of water of the earth and its atmosphere.
- Evaporation from ocean contributes 90% of the atmospheric moisture
- In the ocean, about 9% more water evaporates than that falls back as ppt.
- Average Annual rainfall over whole of India is 119 cm
- Chemical symbol for Ice as per UNESCO is H_2O
- A total of 14% of Heat is received by atmosphere from Direct Sunlight but a total of 34% of Heat is received by atmosphere from Earth.

Conduction: The Transfer of Heat through the molecules of matter in Any Body

Interception : Short term retention of rainfall by vegetation.

Infiltration: Movement of water into the soil of the earth's surface.

Evaporation: It is the conversion of liquid to the vapour phase

Precipitation: It is the deposition of water on the Earth's surface in the form of rain, snow, hail, frost & so on..

Transpiration: It is the soil moisture taken up through the roots of a plant & discharged into the atmosphere through evaporation. It occurs during photosynthesis

Runoff: It is the volume of water drained by a river at the outlet of a catchment

Percolation : Movement of water from one soil zone to lower soil zone.

(Infiltration + Depression storage + Interception) = (Rainfall - Runoff)

Hydrological Budget Equation

$$\text{Inflow} - \text{Outflow} = \text{Storage}$$

$$P - R - G - E - T = \Delta S$$

P = Precipitation
R = Runoff
E = Evaporation
T = Transpiration
G = Net Ground water flow
ΔS = Net increase in storage

$$\text{Residence time} = \frac{\text{Volume of water in a phase}}{\text{Average flow rate in the phase}}$$

Avg. Residence time of ocean is larger than that of global ground water.

Instruments used in measurement

1.	Relative humidity	Psychrometer
2.	Humidity	Hygrometer
3.	Temp and Humidity	Thermohygrometer
4.	Capillary potential	Tensiometer
5.	Wind velocity	Anemometer
6.	Rainfall depth	Ombrometer/Pluviometer
7.	Evapotranspiration	Lysimeter
8.	Evaporation	Atmometer
9.	Transpiration	Phytometer
10.	Hydraulic conductivity	Permeameter
11.	Infiltration capacity	Rainfall simulator

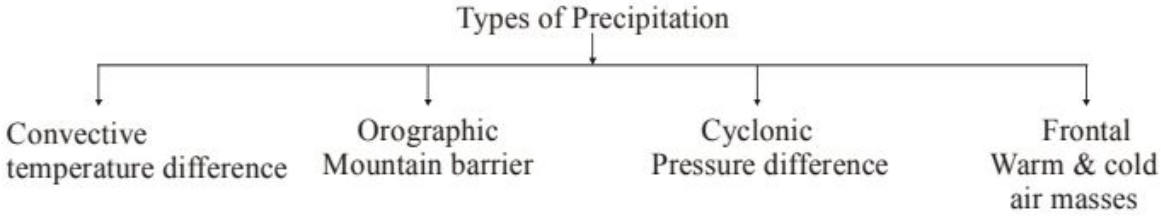
Isopleth : A line drawn on map along which the value of a particular phenomenon is uniform.

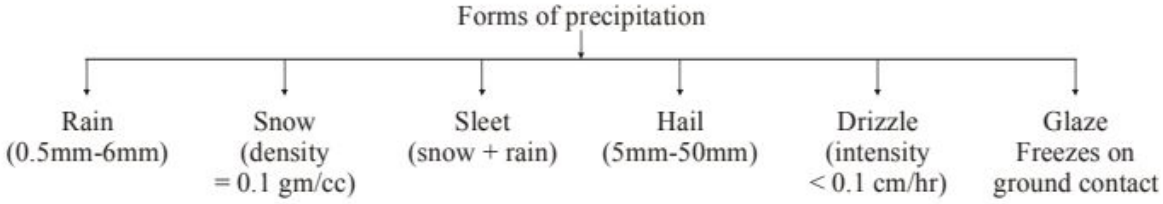
	Name	Isopleth
1.	Isobar	Pressure
2.	Isobath	Depth in sea
3.	Isohaline	Salinity
4.	Isohels	Sunshine
5.	Isohyets	Rainfall
6.	Isonif	Snowfall
7.	Isotherm	Temperature
8.	Isopleths	Evapotranspiration

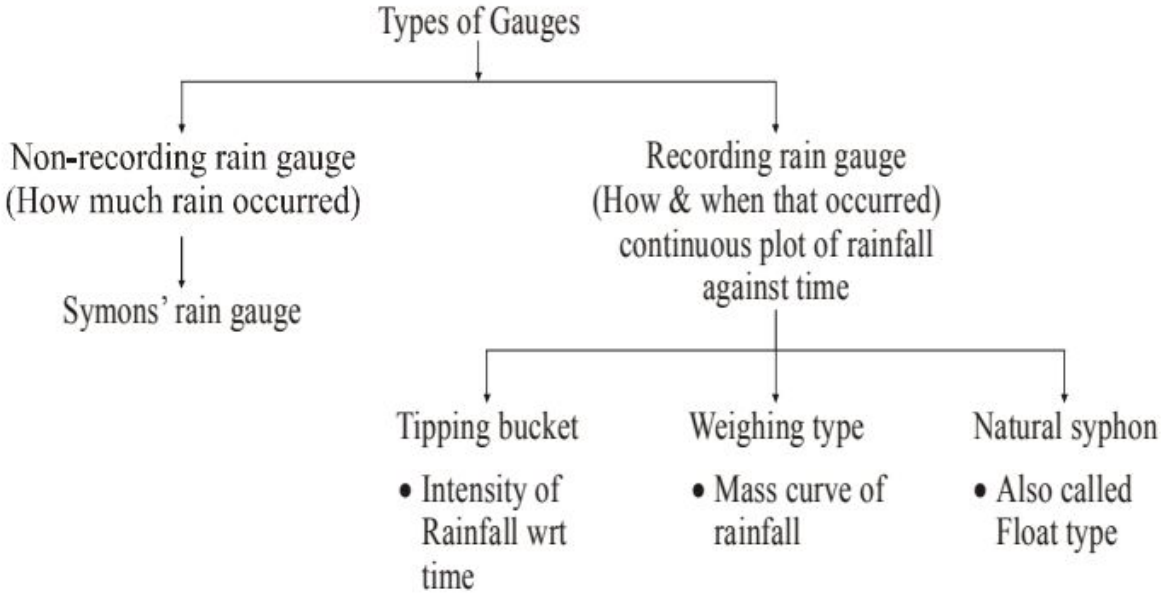
Special Point:- Isochrone is a line on map which connect points having equal time of travel of the surface run off to catchment outlet.

2. PRECIPITATION AND MEASUREMENT

Fall of water in **various forms** on the earth from the clouds.







Rain gauge is use to measure the rainfall depth at any station. Also called ombro meter, Pluviometer & Hyetometer.

The various type of precipitation gauge used are broadly classified as

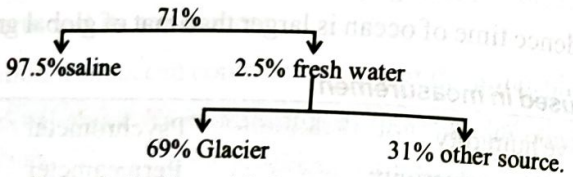
(a) Non–recording gauge

(b) Recording gauge

Precipitation and Measurement

2

- 71% of Earth's area is covered with water.



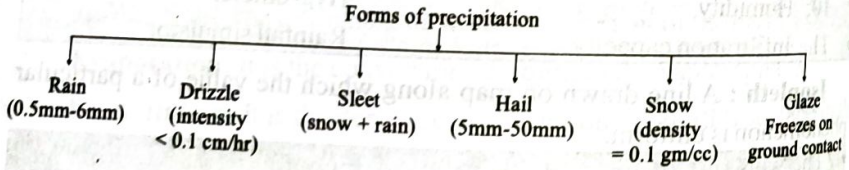
Various types of precipitation- (a) **Orographic**- Due to mountain barrier

(b) **Cyclonic**- It occurs due to pressure difference

(c) **Convective** - It occurs due to heating of air (temperature difference)

(d) **Frontal** - It is a type of cyclonic precipitation, which occurs due to warm & cold air masses.

- Monsoon is due to S-W wind
- Fall of water in various forms on the earth from the clouds.



Type of Rain	Intensity
Light Rain	Upto 2.5 mm/hr.
Moderate Rain	2.5 - 7.5 mm/hr.
Heavy Rain	> 7.5mm / hr

- If rainfall in a day $\geq$ 2.5 mm, the day is called rainy day.
- For uniformity, the rainfall is measured every day at 8:30 am (IST) and is recorded as the rainfall of that day.
- Most common rainfall in India is due to Orographic ppt.
- **Raingauge** is use to measure the rainfall depth at any station. Also called ombro meter, Pluviometer & Hyetometer.

Following requirements which has to be statisfied prier to Installment of raingauge.

(a) Raingauge must be installed on level surface.

(b) Raingauge must be surrounded by open fenced area of 5.5 × 5.5 m.

(c) Raingauge must be installed at a distance of atleast 30 metre or twice the height of building from the nearby objects.

(a) Non-recording gauge

- They measure how much rain occured. The non recording gauge used in India is the Symon's gauge.

(b) Recording gauge

It produce a continuous plot of rainfall against time & provide valuable short duration data on intensity & duration of rainfall for hydrological analysis of storms. The commonly used recording gauge are:

1. Tipping Bucket Type raingauge gives data on the Intensity of rainfall

- The main advantage of this type of instrument is that it gives an electronic pulse output that can be recorded at a distance from the raingauge. It is use in Hilly or inaccesible region.

2. Weighing-bucket type:

- Also used to calculate water content of snowfall.
- The catch from the funnel empties into a bucket mounted on a weighing scale. The weight of the bucket & its contents are recorded on a clockwork-driven chart.
- The weighing type is suitable for measuring all kinds of precipitation (rain, sleet etc.)
- It gives a plot of the accumulated rainfall against the elapsed time, mass curve of rainfall (accumulated precipitation against time).

3. Natural syphon type:

- It is also known as float type gauge.
- It is adopted as standard recording type rain gauge in India. It has diameter of 127 mm.
- In it, the rainfall collected by a funnel shaped collector is lead into a float chamber causing a float to rise. It gives plot of the mass curve of the rainfall.
- As the float rises, a pen attached to the float through a level system

records the elevation of the float on a rotating drum driven by a clockwork mechanism.

Special Point: Rainfall simulator type Infiltrometers give lower values than the flooding type infiltrometers. This is due to the effect of rainfall Impact & turbidity of the surface water present in the former.

Recently, the indian meteorological department using fibreglass reinforced polyester raingauges, which is an improvement over the Symon's gauges.The IS: 5225- 1969 gives details of these new raingauges.

Rain gauge Network density = Area covered per gauge

As per I.S :4987 –1968	One station per
Hilly Areas	130 km²
Moderately Elevated Area	260–390 km²
In Plains	520 km²

Special Point: As per WMO, 10% of the gauge stations should be self recording type.

Adequacy of Rain Gauge Stations

1. Mean Rainfall $P_m = \dfrac{P_1 + P_2 + ... + P_n}{n}$

   Where n = total number of rain gauge station

   P_1, P_2 = rainfall recorded at stations 1 and 2 etc.

2. Standard deviation

$$\sigma_{n-1} = \sqrt{\frac{(P_1 - P_m)^2 + (P_2 - P_m)^2 + ... + (P_n - P_m)^2}{(n-1)}}$$ if $n < 30$, then σ_{n-1}

   Otherwise σ_n

3. Coefficient of variation $C_v = \dfrac{\sigma_{n-1}}{P_m}$

4. Optimum number of stations $N = \left(\dfrac{C_v}{\varepsilon}\right)^2$

   ε = Allowable degree of error (Generally $\varepsilon = 0.1$)

Average Annual Precipitation: It is average Value of annual rainfall values for last 35 yrs.

Normal Precipitation: It is average Value of rainfall 30 yrs data of particular date or month.

Estimation of Missing Data

1. Arithmetic mean method: It is used when normal precipitation of the selected stations is within 10% of that station with missing data

$$P = \frac{P_1 + P_2 + ... + P_n}{n}$$

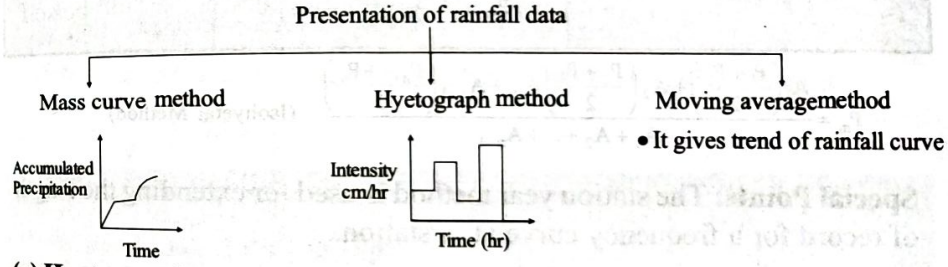
2. Normal ratio method : It is used when normal percipitation of the selected station is beyond 10% of that of station with missing data.

$$\frac{P_x}{N_x} = \frac{1}{n}\left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + ... + \frac{P_n}{N_n}\right)$$

P = Precipitation

N = Normal precipitation

Inconsistency of Records: It is corrected by double mass curve in which previous records are made consistent with present day enviroment & land use conditions.



(a) Hyetograph: It is a plot of the average intensity of rainfall against the time interval.

- The area under a hyetograph represents the total precipitation received in the period.
- The hyetograph is derived from the mass curve & is generally represented as a bar chart.

(b) Mass curve of rainfall: It is a plot of the accumulated precipitation against time.

- These are used in extracting the information on the duration & magnitude of a storm
- Storage capacity of a reservior can be fixed by mass curve method.
- Double mass curve technique is use to check & correct the inconsistency of ppt. records.

Arithmetic Mean Method	Thiessen Polygon	Isohyetal
• Least accurate but quick • Use where uniform distribution of rainfall occur • Rain gauges only inside catchment area $P_m = \frac{P_1 + P_2 + ... + P_n}{n}$	• Consider rain gauge outside catchment also • Topographical influence not taken • Prependicular bisectors of triangles made by joining rain guages $P_m = \frac{P_1A_1 + P_2A_2 + ... + P_nA_n}{A_1 + A_2 + ... + A_n}$	• Most accurate • Very slow & laborious method • Required large number of raingauge

$$P_m = \frac{A_1\left(\frac{P_1+P_2}{2}\right) + A_2\left(\frac{P_2+P_3}{2}\right) + ... + A_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{A_1 + A_2 + ... + A_{n-1}}$$ (Isohyetal Method)

Special Points: The station year method is used for extending the length of record for a frequency curve at a station.

- Accuracy of finding average depth by various methods follows the order. Arithmetic mean < Thiessen polygon < Isohyetal method.

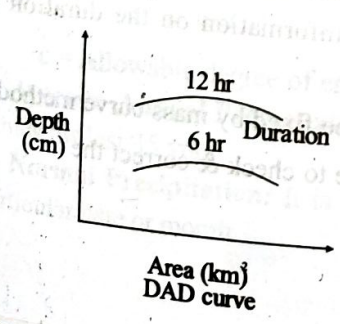
Depth Area Duration Curve

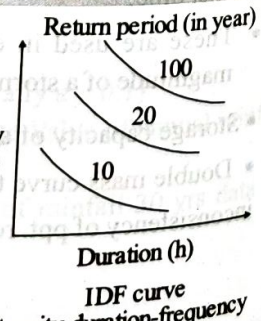
$\bar{P} = P_o e^{-KA^n}$

$\bar{P}$ = Average depth, A = Area

P_o = Highest storm at storm centre

Special Point: Depth decrease with Increase in Area.





Flow duration curve (Discharge frequency curve) is a curve plotted between stream flow Q and % of time the flow is equalled or exceeded. It is used to study the variability of stream flow over a water year.

$PMP = \bar{p} + K\sigma$

Probable Maximum Precipitation

$\bar{p} \rightarrow$ Mean annual rainfall series

Clear Your Confusion

Evaporation Vs. Transpiration: Transpiration is that water requirement of plant which is necessary for the metabolism of plant during its growth period.

Evaporation is a phenomenon of liquid, by which liquid molecules at free surrface continuously changed into gaseous phase (vapour).

The depth of water consumed in both evaporation (from stem & leafs) and transpiration during use of evapotranspiration.

Rainfall intensity accordding to **British ministry of health formula,**

$$I = \left(\frac{760}{t+10}\right)$$

Where I - mm/hr, t - Minute.

Abstractions from Precipitation

3

Abstractions are Evaporation (E), Interception (I), Transpiration (T), Depression storage (DS) and Infiltration (IL).

Evaporation: Dalton's law

$E_l = K\ (e_w - e_a)$

E_l = Rate of Evaporation (mm/day),

e_a = Actual air vapour pressure (mm),

e_w = Saturation vapour pressure (mm)

Special Points:

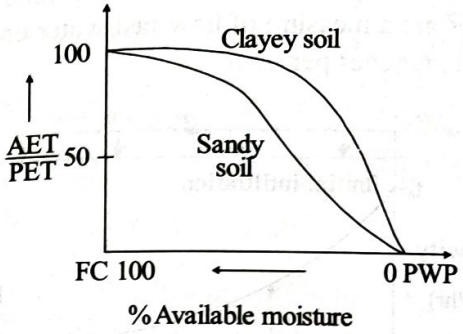
1. Evaporation increases with decrease in atmospheric pressure.
2. Highest rate of evaporation from deep water bodies is in winters
3. Evaporation from sea water is less than fresh water due to salinity

Measurement of Evaporation

Evaporimeter	Empirical Formulae Meyer's Formula	Analytical Methods
Concept of pan coefficient (C_p) Lake evaporation = C_p ×pan evaporation C_p=0.7 class A Land pan = 0.8 ISI/US GS floating pan	$E_l = k_m\ (e_w - e_a)\left(1+\frac{u_9}{16}\right)$ k_m - Coeff. of size of water body u_9 = monthly mean wind velocity at 9m above the ground k_m = 0.36 (Large deep of water) k_m = 0.5 (Shallow, small water) $u_h = ch^{1/7}$	Water Budget Equation (Hydrological continuity) Mass transfer (Theories of turbulent mass transfer) Energy Balance (law of conservation of energy)

Special Point: Lake evaporation can be reduced by reducing the surface area or by chemical films of cetyl Alcohol (Hexadecanol) or stearyl Alcohol (octadecanol) or by providing mechanical cover.

- Estimation of PET is done by Penman's Equation & Blaney Criddle formula



AET → Actual Evapotranspiration

PWP → Permanent wilting point

PET → Potential Evapotranspiration

FC → Field capacity

Penman equation.

$$PET = \frac{A(H_N) + E_a\gamma}{A+\gamma}$$

γ → Psychometric constant = 0.49 mm of mercury /°C

E_a → parameter including wind velocity & saturation deficit

H_n → Net radiation of evaporable water per day (mm)

PET → Daily potential evapotranspiration

A → Slope of the saturation vapour pressure Vs temperature curve at the mean air temperature

- Penman's Equation is based on energy balance & mass transfer
- **Blaney-criddle formula**

$$PET = 2.54\ k \sum \frac{P_h T_f}{100}$$

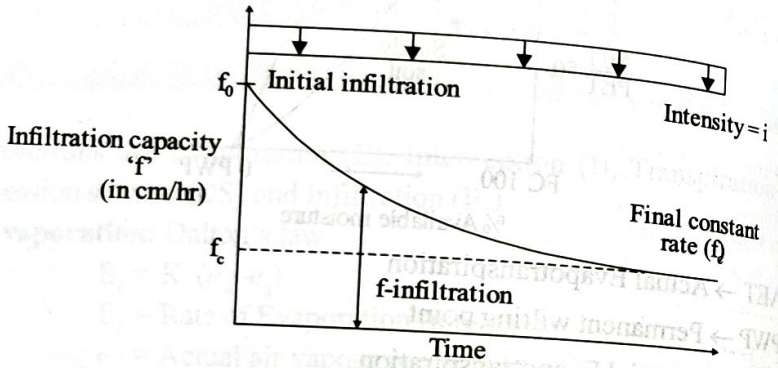
K = Empirical coefficient

T_f = Mean monthly temp in °F

P_h = Monthly % of annual day time hrs

Horton's Infiltration Curve

Infiltration is the process by which water on the ground surface enters the soil. Infiltration rates are a measure of how fast water enters the soil & are generally expressed in inches per hour



General Equation, $f = f_c + (f_o - f_c)e^{-\alpha t}$

$f = f_c$, if $i > f_c$

$f = i$, if $i < f_c$

ϕ Index	W- Index
Average rainfall above which the rainfall volume is equal to run off volume	It excludes DS & Interception loss
$\phi = \frac{P-R}{t}$	$W = \frac{F}{t} = \frac{P-R-S}{t}$

(*a*) Rainfall Intensity – W-index = Effective Rainfall Intensity + Depression Storage + Interception

(*b*) Rainfall Intensity – ϕ Index = Effective Rainfall Intensity

Special points: (W – index $\leq$ ϕ – index)

(Infiltration + Depression storage + Interception) = (Rainfall - Runoff)

Latent heat of vaporisation of water is 585 cal./gm.

Stream Flow Measurement

4

Stage : Height of the water surface in the river above some arbitrary datum.

In small streams of Shallow depth, & observer stands in water, current meter held at a suitable depth this arrangement is called wading.

Measurement of stage			
Automatic		Manual	
Float gauge recorder	Bubble gauge	Staff gauge Below Water Surface	Wire gauge Above Water Surface

- Current meter: It is the mechanical device to measure velocity of stream. It is caliberated in Towing Tank.
- Most relilable and accurate measurement of stream flow during floods is current meter.
- Current meter method is commonly used for measuring velocity of flow of river.

$V = a N_s + b$

a, b = Current meter constants.

N_s = Number of revolutions per sec

- Velocity distribution in the vertical section across stream is logarithmic Following are the **various methods for velocity measurement.**

(a) Average velocity for moderately deep stream

$$\overline{V} = \frac{V_{0.2d} + V_{0.8d}}{2}$$

(b) For shallow stream of depth up to 3 m

$$\overline{V} = V_{0.6d}$$

(c) In rivers having flood flow

$$\overline{V} = K.V_s$$

Measurement of discharge -

(i) Indirect method - Slope area method

$$K = \frac{1}{n} AR^{2/3}$$

$$A = \frac{A_1 + 2A_3 + A_2}{4}$$

$$P = \frac{P_1 + 2P_3 + P_2}{4}$$

$$R = A/P$$

A_3, P_3 – Area perimeter of intermediate Sections

(ii) Direct methods - Following are direct method for discharge measurement :

(a) Ultra-sonic method

(b) Moving boat method - It is use for large rivers

(c) Electromagnetic method

(d) Area velocity method

(e) Dilution technique

Runoff & Drought

5

- Hydrograph: Discharge in a stream plotted against time chronologically

$$\text{Runoff Coefficient} = \frac{\text{Runoff}}{\text{Rainfall}}$$

- Both direct run off hydrograph & effective rainfall hyetograph represent the same quantity (rainfall excess) but in the different units
- The area of effective rainfall hyetograph Multiplied by the catchment area give the total runoff volume

Classification of hydrograph -

(a) Short term hydrograph - Flood hydrograph

(b) Long term hydrograph - Monthly, seasonal and annual hydrograph.

Classification of rivers -

(A) Based on location of reach - Mountain rivers, Rivers in flood plains., Delta rivers, Tidal rivers

(B) Classification of alluvial rivers based on stability - Stable meandering rivers, Aggrading rivers, Degrading riversr

(C) Based on plan-form - Straight rivers, Meandering rivers, Braided river

- Ist June in India is considerd the beginning of the water year.
- Long term hydrographs are used in calculating surface water potential of stream, Reservoir studies & drought studies.

Aquiclude: It is a geological formation, which is highly porous but not permeable due to very small size of pores.

Example: Clay

Aquitard: It is a formation through which only seepage is possible & therefore, yield is insignificant compared to an aquifer.

Example: Sandy Clay

Aquifer: It is a saturated formation of earth material which not only stores water but yields, in sufficient quantity easily due to its high permeability.

Example: Deposits of Sand & Gravel.

Aquifuge: It is a geological formation which is neither porous nor permeable.

Example: Massive compact rock without any fracture.

List - I	List - II
Specific yield	Volume of water drained by gravity per unit drained volume of aquifer
Specific retention	Volume of water retained per unit volume of aquifer
Specific storage	Volume of water released from unit volume of aquifer for unit decline in piezometric head

Specific yield + Specific retention = Porosity

The performance of a well is measured by its specific capacity, which is the discharge of the well per unit drawdown.

Runoff characteristics of stream		
Perennial	**Intermittent**	**Ephemeral**
Carries flow throughout the year	Limited contribution from GW	No base flow contribution Lasting for a very short time

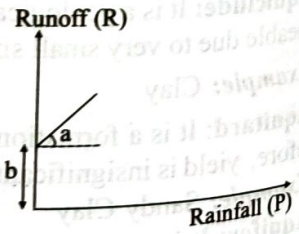
Special Point: Influent Streams are those which raise the "GWT" and become ephemeral but Effluent streams are those in which water comes from nearby high "GWT".

Rainfall Runoff Relationship

$$R = aP + b$$

$$a = \frac{N\Sigma PR - (\Sigma P)(\Sigma R)}{N\Sigma P^2 - (\Sigma P)^2}$$

$$b = \frac{\Sigma R - a\Sigma P}{N}$$



Coefficient of correlation

$$r = \frac{N\Sigma PR - (\Sigma P)(\Sigma R)}{\sqrt{\left((N\Sigma P^2 - (\Sigma P)^2\right)\left((N\,\Sigma R^2 - (\Sigma R)^2)\right)}}$$

Khosla's formula for Monthly Runoff: It is indirectly based on Water - budget equation & developed for small catchment

Runoff = Rainfall – losses

Losses = 0.48 (mean monthly Temp (T_m))

$$\text{Index of Wetness} = \frac{\text{Rainfall in a year}}{\text{Average Annual rainfall}} \times 100$$

% Rain deficiency = 100% – Index of wetness

- River forecast is short range forecast & it is most reliable but this gives an advance warning of 12-40 hr. only.
- Hydrological forecast is medium range forecast. In this rainfall-runoff relationships are used to predict flood levels with a warning of 2-5 days.
- Meteorological forecast is long range forecast & it is least reliable but this gives maximum time for advance notice.
- The drainage density is the average length of the streams per unit drainage area within the basin.

Droughts (deficiency in precipitation)

- As per **Indian meterological department** -

Decrease from normal precipitation	Classfication
< 25%	No drought
26 – 50%	Moderate
> 50%	Severe

Agriculture Drought- It occurs when the soil moisture & rainfall are inadequate during the growing season. There will be extreme crop stress & wilt conditions.

$$\text{Aridity Index} = \frac{PET - AET}{PET} \times 100$$

Where , AET = Actual Evapotranspiration

PET = Potential Evapotranspiration

AI Anomaly	Classification
0 (or-ve)	Non arid
1–25	Mild
26–50	Moderate
> 50	Severe

Special Point: A year in India is considered to be drought year if area affected by moderate/severe drought is more than 20% of total area of country.

Clear Your Doubt

Recurrence Interval : Recurrence Interval (T) is time period after which peak flood discharge is likely to be equal or exceeded. It is also known as return period. Let the maximum flood discharge recorded at a bridge site is 200 cumec & on an average, this peak value occurs once in 50 years, then recurrence interval is called 50 years.

Flood frequency : It represents annual exceeding probability (AEP) which is inverse of return period.

$$f = \frac{1}{T} \times 100$$

Where, T - Recurrence interval or return period

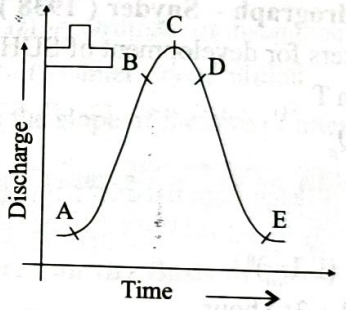
If Return Period is 100 year, it mean that flood discharge can be equal or exceed after 100 years.

$$f = \frac{1}{100} \times 100$$

100 year flood having 1% flood frequency.

Hydrograph 6

- Rainfall excess (Suprarain) = Total rainfall - ϕ
- Effective rainfall = $\frac{\textit{Direct runoff volume}}{\textit{Area of Catchment}}$



Attenuation: When flood hydrograph is routed through a reservoir awing to the storage effect, the peak of the out flow hydrograph will be smaller than that of the inflow hydrograph. This reduction in the peak value is called 'Attenuation'.

AB – Rising limb – It depends on intensity, duration & distribution of rainfall

DE – Recession Falling limb – It depends on catchment characteristics

BCD – Crest segment

Shape of the flood hydrograph generally depends on (*a*) Distribution of rainfall (*b*) Size of catchment (*c*) Direction of storm movement (*d*) drainage density (*e*) Rainfall intensity (*f*) Rainfall duration (*g*) catchment shape(*h*) Slope

Unit Hydrograph: A hydrograph of Direct runoff resulting from 1 cm of effective rainfall applied uniformly over a basin area at a uniform rate during a specified period of time (D-*hr*).It is given by Sherman

Limitations: Area between (2 - 5000) km², No large storage, precipitation in the form of rainfall only.

Assumptions : Time Invariance & Linear Response

S-Curve hydrograph: Hydrograph of direct runoff resulting from a continuous effective rainfall of uniform intensity $\frac{1}{D}$ cm/hr.

$$Q = A\frac{1}{D}Km^2 - cm/hr = 2.778\frac{A}{D}m^3/sec$$

D = Duration (hr), A = Area (km²)

Synthetic unit hydrograph (SUH) : It is made for ungauged basin areas Basin parameters & unit hydrograph parameters of the ungauged, hydrometeorologically homogenous area are selected to basin parameter.

Synthetic unit hydrograph – Snyder (1938)

Following parameters for development of SUH:

(*i*) Basin time width T

(*ii*) Peak discharg Q_p

(*iii*) Lag time t_p

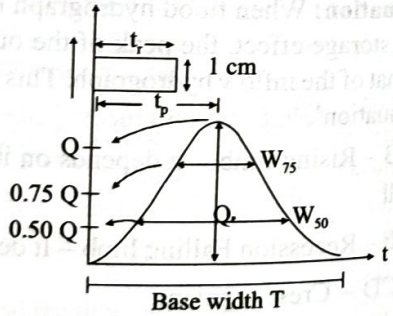
$$t_p = C_t\ (L.L_{ca})^{0.3}$$

$$T = (72 + 3t_p)\ \text{hour}$$

$$t_r = \frac{t_p}{5.5}$$

$$Q_p = \frac{2.78\,C_p A}{t_p}$$

C_t = 1.35 to 1.65



t_r = Standard duration of effective rainfall

A = Area in Km²

L = Basin length along the water course

L_{ca} = Centroid distance form gauging point

W_{75}, W_{50} = width of SUH at 75% & 50% of peak discharge

$$\left(\frac{W_{50}}{W_{75}} = 1.75\right)$$

- Instantaneous Unit hydrograph: Unit hydrograph of Infinite small duration
- It is independent of rainfall Characteristics & depends only on catchment characteristics.
- Clark model showed that IUH may be obtained by routing the rainfall excess & Clark model based on time area histogram.

$$u(t) = \frac{1}{i}\frac{dS}{dt}$$

S = Ordinate of S-curve

$u\ (t)$ = Ordinate of instantaneous hydrograph

i = Intensity of rainfall

- Ordinate of IUH is the slope of S-curve of intensity 1 cm/hr

Special Point: Linear reservoir is one in which storage ∝ outflow discharge

Classification of Rivers on the Basis of Flood Hydrographs -

The rivers may be classified on the basis of stage & nature of their flood hydrograph, into the following two types:

(i) **Virgin Rivers.** In arid zones (deserts), a river water may completely dry before it joins another river or the ocean. Such type of river is known as virgin river. After flowing for a some distance from its source, the water of such river disappears due to high percolation or excessive evaporation. There are various virgin rivers in the States of Kutch & Rajasthan in India.

(ii) **Flashy Rivers.** If the flood rise & flood fall in a river is sudden, then it is called flashy rivers. In these rivers, the flood flows, occur suddenly, and rise & fall of water level is very quick. The flood hydrographs are very steep, indicating floods, all of a sudden.

- A tidal river is a river whose flow and level are influenced by tides.
- Braided rivers are a type of river that form a network of many branches within a channel. They often form when the bed load sediment is high as compared to the suspended load. Fast flow & steep gradients char-

acterize braid

Floods & Flood Routing

7

(a) **Standard Project flood (SPF):** Flood from most severe combination of the meteorological & hydrological conditions excluding extremely rare combination.

(b) **Maximum Probable flood (MPF):** It includes the extremely rares catastrophic floods & is usually confined to spillway design of very high dams the SPF is generally around 80% of the MPF for the basin.

(c) **Maximum flood:** Correspond to peak flow obtained from Observed data.

(d) **Design flood:** It is adopted for design of Hydraulic structure like spillways, flood banks, bridge openings etc. It is the max. flood that any structure can sefely pass.

Probable maximum Precipitation (PMP): Greatest or extreme rainfall of a given duration that is physical possible over a station.

Selecting Design Flood: Central Water Commission

Spilway for projects with Storage > 60 M m^3	PMP & PMF
Pick up wiers	Return period of 100 or 50 years
Aqueducts	
(a) Waterways	T= 50 years
(b) Foundation free board	T = 100 years
Permanent barrage & minor dams with storage < 60 M m^3	SPF

Special Points: Gumbel's method is used for estimation of design flood for a particular return period.

Khosla's theory is used for design of weir & barrages on permeable foundation.

The design period usually adopted for dam is 25-100 years, wells 5 years, distribution system 35 to 45 years.

Empirical Formula's for flood peak

(a) Dicken Formula used in Central & Northern parts of the country.

$Q_P = C_D A^{3/4}$, $Q_P \rightarrow m^3/sec$, $C_D \rightarrow 6$ to 30 , $A \rightarrow km^2$

(b) Inglis Formula used in western ghats of Maharashtra

$$Q_P = \frac{124\,A}{\sqrt{A + 10.4}}$$

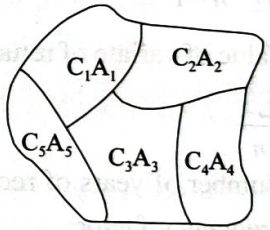
(c) Ryves Formula used in Tamil Nadu, Parts of Andhra Pradesh & Karnataka.

$Q_P = C_R A^{2/3}$, $C_R \rightarrow$ Ryves coefficient

Rational Method

$$Q_P = C\,i\,A$$

Where C = Runoff coefficient = $\frac{\text{Runoff}}{\text{Rainfall}}$



$$C_{eq} = \frac{C_1A_1 + C_2A_2 + \ldots + C_nA_n}{A_1 + A_2 + \ldots + A_n}$$

i = Intensity of Rainfall, depends on time of concentration (t) & Return period of rainfall.

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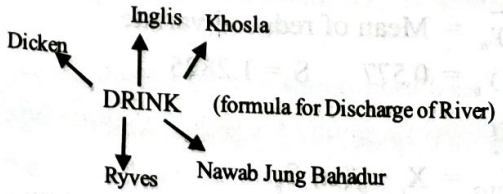


Time of Concentration (Kirpich Equation)

$$t_c = 0.01947\ L^{0.77}\ S^{-0.385}$$

S = Slope of Catchment

L = Maximum length of travel by water

Special Point: Rational formula is found to be suitable for peak flow prediction in small catchment upto 50 km² in area.

Estimation of Design flood for a particular return period: Gumbel's method

- It is based on extrapolation for large return period

$$X_r = \bar{X} + K\sigma_{n-1}$$

$$\sigma_{n-1} = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$$

X_r = Value of variate of return period T

$$\bar{X} = \frac{\Sigma x}{n}$$

n = Number of years of record

K = Frequency factor

$$k = \frac{y_T - \bar{y}_n}{S_n}$$

y_T = Reduced variate $y_T = -\ln \ln\left(\frac{T}{T-1}\right)$

S_n = Standard deviation reduced variate

$\bar{y}_n$ = Mean of reduced variate

For $n > 50$ $y_n = 0.577$ $S_n = 1.2825$

Confidence Limit

$$X_{1/2} = X_t + f(\alpha)\ S_e$$

$f(\alpha)$ = function of confidence probability 'α'

α in percentage	50	68	80	90	95	99
f(α)	0.674	1.0	1.282	1.645	1.96	2.58

S_e = Probable error = $\frac{b\sigma_{n-1}}{\sqrt{n}}$

where k = frequency factor, $b = \sqrt{1+1.3k+1.1k^2}$

Risk-Reliability

Return period refers to the inverse of the probability of exceedance of an event.

Probability of exceedance is P, Return period $T = \frac{1}{p}$

Probability of Non occurrence $q = 1 - p$

Risk → Probability of exceedance atleast once = $1 - q^n$.

Assurance/Reliability → Probability of Non-occurrence = q^n.

Probability of exceedance of m times in n years = ${}^nc_m p^m q^{n-m}$

Probability of exceedance or exactly one time in n years = ${}^nc_1 pq^{n-1}$

Special Point: 100 years flood discharge > 50 years flood discharge.

Flood routing

It is the technique to determine the flood hydrograph at a section of a river by utilizing the data of flood flow at one or more upstream sections.

The basic techniques used in flood routing are :

(i) **Lumped routing** -

It is hydrologic routing & we use continuity equation in it.

In it, we find out the discharge as a function of time at any given location.

(ii) **Distributed routing** -

It is hydraulic routing and we use continuity & momentum equation in it.

In it, we find out the discharge as a function of time & space.

Effective storage = Useful storage + surcharge storage - valley storage

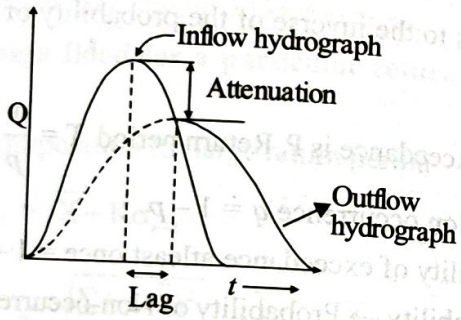
Reservoir Routing: It is done by

1. Goodrich method (Graphical method)
2. Standard 4th order Ranga-kutta method (Numerical method)

3. Modified pul's method (Graphical method)

$$\left(\frac{I_1+I_2}{2}\right)\Delta t-\left(\frac{Q_1+Q_2}{2}\right)\Delta t=S_2-S_1$$

In an uncontrolled outlet of a level pool routing following inflow & outflow hydrographs will be achieved



Lag: Time difference in two peaks

Special Points: Storage is maximum at point of intersection.

- The peak of outflow hydrographs will occur at the point of intersection of inflow & outflow hydrograph.
- The flood absorption capacity of a reservoir is the storage between FSL and MWL

Channel Routing: Storage is function of both inflow & outflow

Muskingum equation

- It is most widely used Hydrological channel routing method.
- It involves the concept of wedge and prism storage.

$$S=K\,[x\,I^m+(1-x)\,Q^m]$$

Where , S = Storage of channel

k = Storage time constant, has dimensions of time, & approximately equal to the time of travel of flood wave through channel reach.

x = weighting factor, depending on shape of wedge

I = Inflow, Q = Outflow

m = 0.6, for artifical channel (Generally Rectangular channel)

m = 1 for natural channel

$$S_2-S_1=k\,[x\,(I_2-I_1)+(1-x)(Q_2-Q_1)] \quad \text{...(a)}$$

$$S_2-S_1=\left(\frac{I_1+I_2}{2}\right)\Delta t-\left(\frac{Q_2+Q_1}{2}\right)\Delta t \quad \text{...(b)}$$

From (a) and (b),

$$Q_2=C_0I_2+C_1I_1+C_2Q_1$$

$$C_0=\frac{-kx+0.5\Delta t}{K-Kx+0.5\Delta t}$$

$$C_1=\frac{Kx+0.5\Delta t}{K-Kx+0.5\Delta t}$$

$$C_2=\frac{K-Kx-0.5\Delta t}{K-Kx+0.5\Delta t}$$

$$C_0+C_1+C_2=1$$

Life of Reservoir due to Silting: Every river carries certain amount of sediment load. Sediment particles try to settle down to the river bottom due to the action of gravitational force, but sediment may be kept in suspension due to upward currents in the turbulent flow, which may overcome the gravity force. Thus bigger suspended particles & most of the bed load, gets deposited in the head reaches of the reservoir. Fine particles may travel some more distance & may finally deposit further down in the reservoir, the deposition of the sediment will automatically reduces the water storing capacity of the reservoir, & if this process of sediment deposition continues for a long time, a stage is likely to reach when the whole reservoir may get silt up & it become useless. If silting is not controlled, then dam become useless before its expected service life.

Trap efficiency of Reservoir: Life of reservoir will be more if Trap efficiency is low. It is the ability of reservoir to trap & retain incoming sediments.

$$\text{Trap efficiency} = f\left(\frac{\text{Capacity of reservoir}}{\text{Total inflow } of\ water}\right)$$

Tunnel Engineering

17

It is an engineering structure, artificial gallery, passage or roadway beneath the ground, under the bed of a stream or through a hill or mountain.

Open cuts:

- It is open to sky passage excavated through huge soil mass of obstacle like hill, run in required direction to connect.
- Open cuts are provided up to depth 18m economically, if more than 18m depth.Tunneling is preferred. (60 feet)
- For highways, tunneling is preferred to open cut if the depth of open cut exceeds 15m.
- It will require less time & cost for construction as compared to tunnels.

Advantages of tunnel

(*a*) For carrying public utilities like water, gas, railway lines or roads etc.

(*b*) Lesser maintenance &operating cost.

(*c*) Aerial warfare & bombing of cities have given important values to tunnel.

(*d*) Cost of hauling is decreased due to lighter grades, possible in tunnels.

Classification of Tunnels			
Based upon Purpose		**Based upon construction material**	**Based on Position or Alignment**
Traffic	**Conveyance**		
Railway	Hydro Electric power tunnel	Tunnel in hard Rock	Saddle or Base tunnel
Pedestrain	Sewer tunnel	Tunnel in Quick Sand or loose sand	Off spur tunnel
Highway	Water supply tunnel	Open cut tunnel	Spiral tunnel
			Slope tunnel

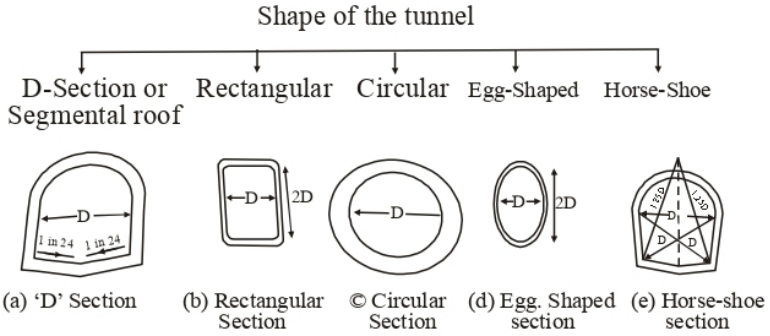
According to Alignment

(a) OFF - Spur Tunnels
- Short length tunnels to negotiate minor local obstacles, is very high projections on the way, which cannot be followed with permitted

(b) Slope Tunnels:
- Tunnel constructed in sleep hills for economic and safe operations of roads and railways.

(c) Saddle or Base Tunnels:-
- Tunnel constructed in the valleys along the natural slope till slope does not exceed ruling gradient

(d) Spiral Tunnels:
- Tunnel provided in narrow valley in the form of loops in the interior of mountain so as to increase length of tunnel to avoid steep sloper



(*i*) **In Rock tunnels:** It is suitable for subway/Navigation channel.

(*ii*) **Egg shaped** section is used in **sewers** as it maintains required self cleansing velocity. It provide least crosectional area at bottom.

(*iii*) Rectangular section is suitable only in case of hard rocks.

(*iv*) **Circular section:** It is most suitable for sewer & water carriage. It is best suited for materials without cohsion (Quick sands) where the pressure acts normal to the line of profile.

(*v*) Horse shoe shape is best suited for traffic purposes. It is most popular for tunnel.
- It is suitable for soft rock but difficult to construct.

Investigations in tunnel construction

Information collected are

(*i*) Origin of soil mass.
(*ii*) Location of faults, folds etc.
(*iii*) Temperature of soil near by.
(*iv*) Hydrology in surrounding proposed tunnel site.
(*v*) Presence or foul gases.
(*vi*) Bearing capacity of soil mass at proposed site.

Sequence of operation

(*a*) Locating centre line on ground.
(*b*) From centre line to inside tunnel.
(*c*) For required grade at the bottom of tunnel.
(*d*) Checking tunnel cross-section.

Grades in tunnels

- Grades in tunnel should be lesser than surface grade.
- It is not favorable to continue tunnel approach grades in tunnel especially in railway.
- For Tunnels > 300m length, grade should be provided below 75% of the ruling gradient.
- In order to maintain desired shape of tunnel the C/S must be check at regular 2m to 3m interval.

Setting of centre line		
Curve linear tunnel (a) Method of tangent offsets (b) Method of chords & deflection angles	Long tunnels By triangulation using micrometer & transit theodolite	Short tunnels Theodolite using wooden stakes

- Setting out is defined as marking the centre line or alignment of any construction work on ground.
- It is done indirectly in different stages using theodolites.
- Modern way of providing horizontal control on ground surface is by running an open traverse between two ends of proposed tunnel by using theodolite of precision and laser unit pole.
- Laser pole unit is used to define a thin visible vertical plane upto large height.

- This plan is bisected by theodolite for measurement of traverse liner.
- Lengths of survey lines are measured by direct method of stepping with invar or steel tapes.
- Weisbach triangle method is used to connect two ends of an underground tunnel.
- Tunnel alignment is carried out by Triangulation.
- For transfer of centre line from surface to underground, shafts are to be constructed at regular interval of 500 m along traverse line.

Shafts

There are vertical wells sunk along the centre line of tunnel to permit excavation, removal of excavated material & to provide adequate ventilation during construction.

Advantages of shafts :

(1) They help in correct alignment and to carry the centre line into the tunnel proper.
(2) They can be used as pumping shafts in case of large influx of water.
(3) They afford outlets for excavated material and means of access into the tunnel for building materials.
(4) They greatly expedite the work by adding two faces per shaft for driving.
(5) In long tunnels, they afford ventilation and are useful for exhausting smoke & foul air out of the tunnel.

Size of shafts

It depends on following factors :-

1. Quantity of muck to be handled
2. Size of muck car
3. Space required to carry pipes & wires and nature of hoisting system
4. Nature of equipment used in tunneling process
5. No. of labours
6. Eventual use of the shaft

Types of shafts: According to location and position :-

1. Shafts over centre-line :-

- These have advantage of hoisting out the materials easily from the tunnel.

2. Side shafts :-
   - These are shifted on one side of centre-line.
   - A transverse gallery or a pilot tunnel or passage is required for connecting it with main tunnel.
   - The turning of machinery at sharp curve of the gallery is the greatest drawback of this shaft.

According to alignment

1. Vertical shafts:
   - Laid in vertical direction only as they easy to construct and cheap.
2. Inclined shafts :-
   - For small depth, inclined shaft with suitable gradient of 45° or less are constructed to achieve removal of muck by gravity.

According to time of filling material

1. Permanent shafts:
   - These are left open even after construction of tunnel and helps in providing ventilation.
2. Temporary shafts:
   - The shaft to be excavated can be refilled if its sole purpose is to get information is called temporary shafts.
   - They are located in valley.
   - Mainly provided for the supply of construction material and for the removal of muck.

Protection round shaft opening:

- It is usual to construct 900 mm high wall around the edge of the shaft opening, to form a protective fencing.
- This prevents surface water flowing down the shaft.

Drilling Equipments		
Percussion Drills	Fusion piercing	Abrasion Drills
• Drills Breaks rock by impact due to repeated blows • Tripod drill for very hard rock	• Produces mixture of oxygen & flux bearing fuel like as kerosene at the end of blow pipe	• Grinds rock due to abrasive effect • Can drill upto 100 m.

Blasting

It is the operation perform to loosen rock so that it may be excavated or removed from its existing position.

Theory of blasting	Cut		Type of Explosives
Impact Abrasion Fusion & vapourized Chemical reaction Thermally induced spalling	Initiat blast must release suitable amount of rock & free face for blast to follow		Straight dynamites Ammonia dynamites Amonia gelatine Water gels Blasting agents Semi-gelatine
	Angle cut	Burn cut	

For blasting, type of explosive used may be:

1. Ammonia dynamites: two types are as :
   (a) High velocity High density (HVHD)
   (b) Low velocity low density (LVLD)
2. Straight dynamites:
   - Not suitable for rocks because poor fume chart.
3. Ammonia gelatin: can be fired in presence of water.
4. Blasting agents:
   - Ammonia Nitrate (NH_4NO_3) 94.5% + fuel oil 5.5% or other carbonaceous matter is used as blasting agent.
   - It is low in cost & safe but highly sensitive to water.
5. Semi - gelatine: This can be used in water better than above.

6. Slurries or water gels:

→ Recently developed and have high % NH_4NO_3 in aqueous solution. They have resistance to water.

- A good blast with good yield obtained if cut hole inclined at 45° to face.

Methods of Tunneling		
In Hard Rock	**In soft Rock**	
	Without Timber	**With timber**
Cantilever car dump Full face method Heading and bench method Drift method	Linear plate method Shield method Compressed air tunneling	Austrian method Fore poling method Needle beam method Belgian method Army method English method German method American method

Method of tunnelling in rock:

1. Drift Method:

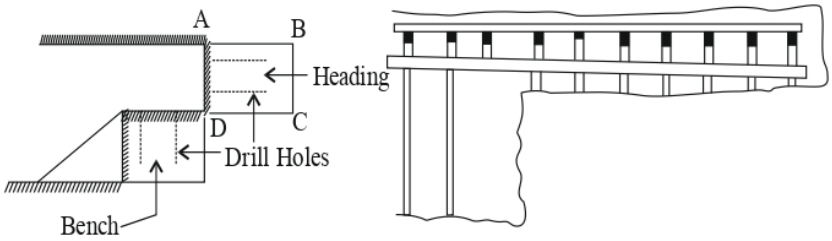
- It consists driving small sized beading, centrally at top or botton of face, which is later enlarged by widening and benching.
- It is suitable for large size tunnels in difficult or incompetent rock (hard rock).
- Top drift method is popular & involves operation as :-
  (a) Boring and blasting a top centre of drift, end to end.
  (b) Widening and enlarging the drift.
  (c) Benching in stages.
- This method also known as multiple drift method.
- **Advantages:**
  1. A small preliminary section for the full length has been accurately drives, which economise construction.
  2. During heading work, mucking work goes on undsitrubed.

3. Elaborate supporting platforms are not necessary for drilling open.
4. It provides good ventilation for workers.

- **Disadvantages:**

1. The enlargment can not started until central hole constructed for full length
2. Extremely costly
3. Mucking tracks required to shift frequently, bench to bench

2. Heading and Benching Method:



Heading and benching method

- This method involves the drilling of the top portion in advance of bottom portion.
- If rock is hard & self-supporting, the top heading advances ahead by one round over the bottom, so that heading & benching follow each other.
- If rock is badly broken, the top heading will need support & bench will afford platform for this, in such case heading is excavation & supported to the full length or part length before benching started.
- For full face method excavation is divided into 3 sections & the first operation in this method relates to excavation being done along the perimeter.
- Heading is always ahead of benching by convenient length & formed by excavating full width above spraining line.
- In one blast, one Heading & one Benching are blasted with few seconds time lag.
- Less quantity of explosive required as compared to full face method.

- It is generally suitable for soft rock tunnelling of medium/average size.
- It is advantageous such that drilling and mucking is done simultaneously.
- Removal of muck from heading is difficult.

3. Cantilever car dump method:

- This method provides an improved arrangement of throwing muck from bench to the floor of the tunnel.
- Two plate girders about 23m length & 1.8 c/c distance.
- A belt-conveyor is fitted with no. of jack and running on plate girders.
- The ends of plate girders project beyond the full face of the bench & front ends are suitable supported by means of struts from the top of the tunnel.

4. Full face method:

- It is convenient adopted for tunnel of small cross section area through stable and self-supporting rocks and whole section/full face attacked at a time.
- This tunnel is continous.
- At present techniues shield & tunnel boring machine (TBM) are popular and well suited for full face excavation in different ground condition and various shapes and sizes.
- It is popular due to result of equipment developement.
- It useful when diameter < 6m & face area < 19 m^2. As further increase in dia & area resuts in difficult construction & costly.
  - **Advantages:**
    1. Simplicity as minimum equipments are required.
    2. Easily and speedy complection.
    3. Minimize the total magnitude of ground disturbance and settlement.
    4. The mucking track laid once for full operation.

Mehtods of tunnelling in soft grounds

1. Forepoling method:

- This is probably the only system which could be advocated for running ground & similar soils.

- The process is slow and required skilled labours.
- Tunnels of small dimensions, for laying sewers, gas pipes etc, at ordinary depth advantageously constructed by this method
- Forepoles or spikes, horse head etc. are used for supporting.

2. Army method or case method:

- It is discovered by US Army for construction of small tunnel at fairly shallow depth.
- It is mainly used for laying under ground sewers.
- It is simple and economical as only few planks and jocks are required.
- Also done with unskilled labour with any difficulty.
- The drawback of this method is only that its use is limited for construction of short tunnels of small cross section.

3. Needle beam method:

- Suitable for firm ground & Brick lining.
- 3m to 4m length advanced per day.
- Needle beam = 5m to 6m length

• Large no. of jacks are required.

4. American method :

- It is suitable for large sized highway or railway tunnels.
- It does not required heavy timbers, involves simple operation.
- However unsuitable for tunnels of flat bottom.

5. English method :

- It involves the use of a lot of timber and frequent shifting for heavy timber logs back and forth is greatest disadvantage of this method.
- Other disadvantage is, the mason & excavators to work alternatively and this the process required more time as compared to other methods.
- If the soil is unstable, the excavation of full section will increase danger of caving.

• Advantages.

- Simple method of hauling can be adopted.
- The lining is built in one piece from foundation to the crown and it thus, grants strong & homogeneous construction.

6. Compressed air method:

- It is most suitable for clays.
- In this working is done under pressure.
  (i) When working zone pressure $\leq$ 1.25 kg/cm^2, working hours = 8 hrs & breathing internal = 4 hrs.
  (ii) Wen P > 1.5 kg/cm^2, working = 4 hrs & breathing interval = 2 hrs.
- In it, vol. of free air provided is 6 m/min / m^2 of face area.

7. Belgium method :

- Advantages :-
  (a) Use lighter timber section.
  (b) Completing first the construction or roof arch which is exposed to the greatest pressure and then constructing the side walls and the invert.
  (c) Starting of work from different points simultaneously.
  (d) Reduction in cost as the muck cars can be taken upto the farthest end in the centre trench.
- Disadvantages :
  (i) Settlements and cracks in arch masonary due to the system of underpinning of the built arch, particularly when the avoidable subsidence of the soil may takes place.
- But settlement is reduce by using R.C.C arches.

8. Austrian method:

- In it, a centre is taken for full height of tunnel and it is then widened to full face to permit short sections of the masonry to be completed.
- Adopted for long tunnels at great depths.

9. German method:

- In this method of supporting the roof & sides, three drifts are employed - one at the crown & two at the bottom along the wall.

10. Liner plates method:

- It is suitable & used when the strata is sub-aqueous
- Standard sized pressed steel plates, plain or corrugated are used to support the soil and the work is carried on in short lengths corresponding.

- Liner plates are generally made 400 mm × 900 mm with 50 mm flange on all 4 sider.
- When diameter of tunnel $\geq$ 3m, stiffening of the liner plates for tunnels becomes necessary to withstand pressure.

11. Shield tunnelling:

- Shield is a metal cylinder of hard steel plates bent to required curvature and thickness, by rivetting 2 to 3 plates with counter sunk headed rivets.
- Shield is an equipment which acts as bridge with roof for workers to work on extension of lining on one hand and face of attack on other hand.

Hauling of Muck

It is the operation of loading & removing excavated or hosted materials and then dumping it at predetermined sites. it is done to make enough working room & final cleaning of bottom to place inverts. It is either done by hands or machines.

Ventilation in tunnel			
Natural Ventilation	**Mechanical Ventilation**		
Due to the difference in inside & outside temperature	Exhausting	Blowing	Combination of Blowing & exhausting

(i) Blowing or Plenum process

- In it, fresh air is blown by blower fans.
- It is not employed for tunnel more than few hundred metres long

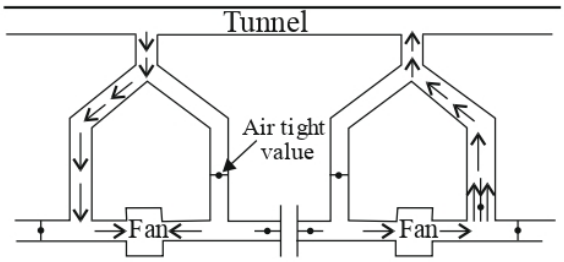
(ii) Exhausting

- It involves extraction of the vitiated (spoil) air from the tunnel by means of one or more exhaust fans.
- Fresh air being drawn into the tunnel through its portal 'or' through inlet shafts.

(iii) Combination of blowing and exhausting

- The most efficient ventilation system depend upon the combination of blower and exhaust fans.

Immediately after blasting, exhausted system is used to drop smoke & gases and during rest of the time, it is reversed and supplies fresh air alongwith blowing system.



Ventilation in tunnels

Special point: A light intensity of 260 lumens/ m^2 in the working area is considered satisfactory in tunnelling operations.

The empirical formula commonly adopted to obtain a working station is

T = 82D

D = Diameter of tunnel in m

T = Thickness of lining in mm

But this thickness is limited to a minimum of 230 mm irrespective of the material used for lining. A thumb rule for obtaining approximate thickness of the tunnel lining is to keep 25mm thickness of lining for every 300 mm of the bore diameter of the tunnel.

- For constructing the tunnel, the preferred tool to excavate very soft ground, is water jets.

Bridge Engineering 18

Codes used for Bridge Design:

1. IRC - 5 - Code of practice for specification of Bridge.
2. IRC - 6 - 2010 - Loads & stress. (L.S.M.)
   (Old Code - IRC - 6 - 2000 - (W.S.M.)
3. IRC - 21 - Code of practice for cement concrete (L.S.M)
4. IRC - 22 - for composite structure
5. IRC - 78 - for foundation design

- Bridge is an arrangement made to cross an obstacle in the form of a low ground or a stream or a river or over a gap without closing the way beneath.
- Required for the passage of railways, roadways footpaths and even for carriage of fluids.

Components of bridge

1. Sub-Structure

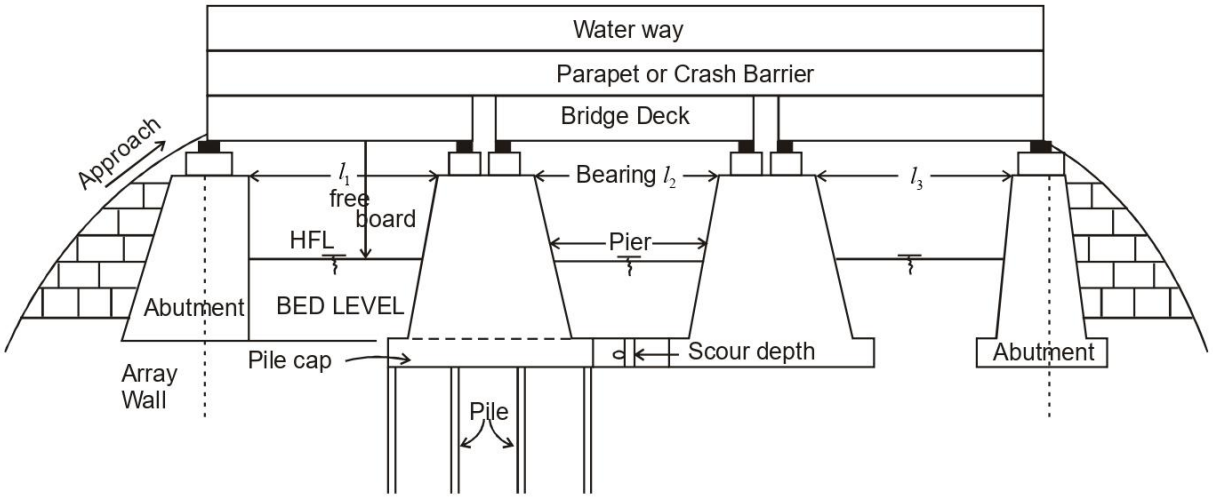
- Component of bridge upto the level of bearing.
- Consists of piers, abutments, wing walls and foundations for the piers, abutments and wing walls.

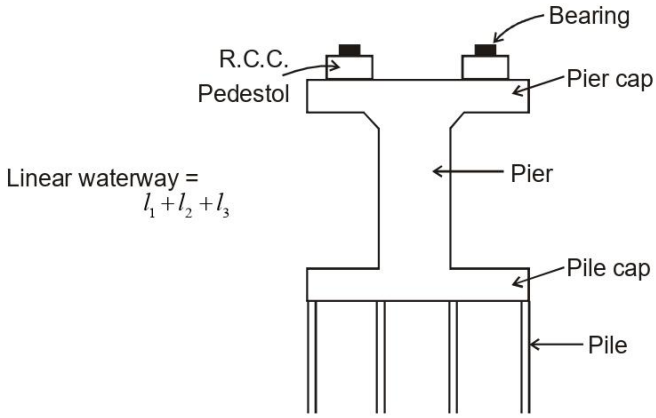
2. Super Structure:

- Component above the level of bearing.
- Consist of beams, girders, arches and cables, parapet walls. Flooring, guard stones, hand rails etc.

3. Adjoining Structure:

- Component like approaches, guard stones, bearing, river training work, apron etc.





Classification of Bridge

1. **According to span**
   - (i) Culvert
   - (ii) Minor Bridge
   - (iii) Major Bridgeiv) Long span bridge
2. **According to Masonary**
   - (i) Timber
   - (ii) Masonary
   - (iii) Iron & Steeliv) Prestressed
3. **According to loading** I.)Class A ii.) 70 R loading (Permanent Bridges)
   iii.)Class AA iv.)Class B (Temporary Bridge)

Loading on Bridge as per IRC - 6 - 2010

(1) D.L.
(2) Live Load
(3) W.L.
(4) Earthquack Load
(5) Earth Pressure
(6) Centrifugal force
(7) Water current
(8) Impact load
(9) Longitudinal force
(10) Snow load

According to Railway:

1. **Major bridges:** Total waterways more than 18m or having any span of clear waterways of 12 m or over.
2. **Minor bridges:** Total waterways < 18 m or any span of clear waterway < 12 m.
3. **Important bridges:** Total major bridge of total water ways ≥ 18 m. or 110 m^2.

Special Points:

1. Culvert - span < 6m
2. Minor Bridge - 6 - 30 m
3. Major Bridge - 30 - 120 m
4. Long span Bridge - above 120m

Cross-drainage structures for the purpose of investigates.

1. Culverts and minor bridges having linear waterways upto 30 m.
2. Major bridges having linear waterways excluding 30 m but on stable rivers and canals.
3. Important bridges having linear waterways excluding 30 m but on major rivers which present some problems of stability.

Identification of bridges

- IRC : 7–1971
- Expressed in fraction number. $\frac{a}{b}$
- a $\rightarrow$ Km in which the structure situated.

- b → Km-wise serial number of structure e.g. Fourth cross-drainage structure in 9th Kilometre.
- $\frac{9}{4}$
- Number of structure is inscribed near the top of left hand side parapet.
- Structre having railing without parapet separate pillars are constructed insiribed the structure number.

  ex. between 4th and 5th culvert in 30 mor. km any new culvert are to be introduced (i.e. between km stone 9 and 30), then new culvert will be designated as

  $= \frac{30}{4-1}, \frac{30}{4-2}$ etc.

Ideal Bridge requirement:

- Should be efficient and effective.
- Economical
- Esthetically sound.
- Safety and convience.

Priminary and final project report:

1. Catchment area map:
   - prepared from topographical maps of SOI.
   - Drawn to a scale of $\frac{1}{50000}$
   - Indicates catchment area to contribute water at site.
2. Contour plan:
   - According, IRC, distance concered by plan on either side of site for catchment area of:

     3 km^2 – 100 m

     15 km^2 – 300 m

     > 15 km^2 – 1500 m
3. Cross-Sections:

Horizontal Scale = Not less than $\frac{1}{1000}$

Vertical Scale – not less than $\frac{1}{100}$

4. Index map:

   Small river – 1 : 50,000

   Large river – 1 : 25000

5. Longitudinal Section:

   - Plotted with horizontal scale not less $\left[\frac{1}{2500}\right]$
   - Vertical Scale $\leq \frac{1}{1000}$

6. **Soil profile:**
   - For culvert and minor bridge – Simple soil investigation.
   - Major – Adopted investigation upto depth equal to 1.5 times the proposed width of foundation below the proposed bottom of foundation.

Traffic requirements of highway bridges:

1. Alignment:
   - Small bridge – Adopt small skew angle bridge.
   - Long bridge – Square crossing with suitable approaches.
2. Central Verge:
   - Used to separate traffic of two direction.
   - Should be ≤ 1200 mm.
3. Footpath:
   - For movement of pedestrains.
   - For Rural areas: Min width 1500 mm can taken 108 person per minute.
   - Increased at rate of 600 mm for every additional capacity of 54 per. per minute.

4. Roadway width:

Type of traffic	Min width (cm)
1. Vehicular traffic	
– Single lane	425
– Two - lane	750
– Multi lane	350 for every lane over two lane.
2. Cycles	
– Without overtaking	200
– With overtaking	300

Roadway width can be decided from following:

Vehicles: 1000 veh. per hour per lane width of 3750 mm.

Cycles: 3600 cycles per day for 2-lane [2000 mm]

5. Safety Kerbs:
   - 600 mm × 225 mm either side of roadway.

6.

Sight distance	Design speed	Length
– Village road (VR)	150 kmph	160 m
– Other district Road	165 kmph	180 m
– MDR	180 kmph	110 m
– National and State highway	100 kmph	150 m

Length of bridge:

- Distance between inner face of two abutments length of bridge L = (n × *l*) + (n – 1) × b

  n = number of span

  l = Clear span

  n – 1 = total number of piers.

  b = width of pier.

  Some important points:

- Bridges are design for flood occurring once in 100 years.
- Design culverts for flood occuring once in 20 years.
- Slab deck used for short span such as culverts.

- Tee beam and slab deck – Medium span (10 m – 20 m Range)
- Prow string girder type – Road bridge span range 25 – 35 m

"Sub Structure"

- Abudments
- Piers
- Wing Walls

1. Abutments:

– end support of a bridge.

– Retain earth filling and transmit the reaction of super-structure.

Types

(a) Abutment with wing walls:

(i) With straight wing wall

– Adopted for railway or street crossing.

– Unsuitable for bridge with waterway.

(ii) With splayed wing wall

– Suitable for bridge with waterway because it gives smooth entry and exit.

(iii) With return wing walls

– U-abutments

– Unsuitable for river or stream subjected to heavy floods.

(b) Abutment without wing walls:

(i) Without wing wall straight abutments.

– Useful for without waterway or negligible waterway.

(ii) T-abutment:

- Recommended face batter for different height:

Height	Face batter
upto 16 m	Vertical
16m to 12 m	1 in 24
12 m to 18 m	1 in 12
Above 18 m	1 in 16

- **Dimensions of an abutment**

(i) Height: Fixed up by the difference between the bed level of river banks and the formation level of road.

(ii) Batter: See above table:

Trantwine's Formula: Batter on earth side = 1 in $\frac{24 \times \text{rise}}{\text{span}}$

(iii) Top width:

$$\text{Top width E} = \frac{r}{5} + \frac{a}{10} + 0.60$$

r = radius of soffit (m)

a = rise in m

(iv) Length = Overall width of bridge including footpaths.

2. Piers

- Intermediate support of a bridge.

Dimensions

(i) Batter

- 1 in 12 to 1 in 24

  Low pier – greater value

  high pier – smaller value

(ii) Height:

Same as in Abutments

– However, sufficient free board or clearance to the extent of about 1000 mm to 1500 mm maintained.

(iii) **Length:** Equal to width of bridge (excluding cantilever phojections) plus width of cut water and case water.

(iv) **Top width:**

- depend upon span.
- Should be sufficient to accomodate two bearing for the pier with a clearance of about 150 mm.
- Usually min width about 750 mm.

Culvert and Causeways

Waterways of a Culvert

General principles–

(i) Assumed should be flowing half full when approach channel wide and narrow.

(ii) Adequate cushion above the top of culvert.

(iii) Velocity through culvert limited to 150 cm/sec.

Area of Water way

1. For catchment area upto 40 hac.
   a. A = 0.09 C – Suitable for deccan condition and perm. velocity of about 3000 mm/s.
   b. A = 0.029C – for North Gujarat condition per Velocity about 1500 mm/sec.
2. Catchment area from 40 to 280 hac.
   a. A = 0.05 C + 1.63 → Suitability same as above for a.
   b. A = 0.0255 + 1.63 → Suitability same as above for b.

   A = Area of waterway

   C = Catchment area.

Type of Culvert

1. Arch culvert

- Adopted for span 2 m to 6 m.

2. Box culvert:

- Height rarely exceeds 3 m.
- Individual span ranging from 1 m to 4 m.
- >6m, greater thickness required, hence become uneconomical.

3. Pipe Culvert:

- Diameter of pipe ≤ 300 mm.
- Used for low discharge, say upto 10 m^3/sec.
- Cost from pipe – Suitable 750 mm.
- RCC pipes – Suitable upto 1800 mm.

9. Slab Culvert:

– Simple slab culvert – Suitable upto 2.50 m

– Deck type – upto 8 m.

Bridge loading standards

- First loading standard (IRC : 6) in India was published by Indian Road Congress in 1958.
- IRC Bridge loading standards.
- IRC class AA loading:

Impact Factors

1. For Road Bridges:

(i) Indian road congress:

(a) For class A and B loading:

$$I = \frac{A}{B + L} \rightarrow \text{Length}$$

A = Constant for RCC bridge = 4.5

for steel bridge = 9.0

B = Constant, for RCC bridge = 6.0

for Steel bridge = 13.5

- For Span, less than 3m-

  I = 0.5, for R.C. bridge.

  = 0.545, for Steel bridge.

  For span exceeding 45 m.

  I = 0.088 for R.C. bridge = 0.154 for Steel bridge

(b) For class AA or TOR loading:

Span < 9 m,

(i) For trackled vehicles – 25% of span upto 5 m linearly reduced to 10% for span of 9 m.

(ii) For wheeled vehicles – 25%

For Span ≥ 9 m;

- For trackled vehicle – R.C. bridges, 10% upto span 40 m.

  For steel bridge, 25% for span upto 23 m.

2. AASTHO Loadings: $\bar{d} = \frac{50}{L + 25}$

Some Important Formulae:

1. **Marriman's formula:**

$$h_a = \frac{V^2}{2g}\left[\left(\frac{A}{Ca}\right)^2 - \left(\frac{A}{A_1}\right)\right]$$

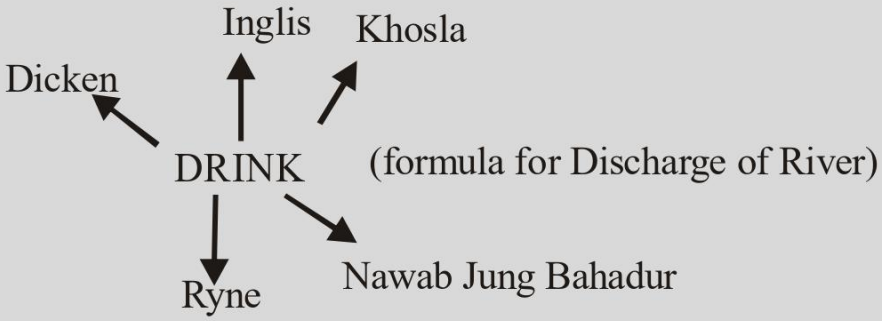
2. **Molesworth formula:**

$$h_a = \frac{V^2}{17g} + 0.015\left[\left(\frac{A}{Ca}\right)^2 - 1\right]$$

Where, A = Natural Waterway, A_1 = Linear Waterway

C_a = Contracted Area

CIVIL Ki GOLI



1. **Dicken's formula:** $Q = CA^{3/4}$ (C: Constant, A: Area of catchment)

This formula is applicable in North India

2. **Ravey's formula:** $Q = CA^{2/3}$

Applicable in South India

3. **Ingli's formula :** $Q = 123.2\sqrt{A}$

Applicable in Maharashtra Region

4. **Nawab Jung Bahadur's formula :** $Q = \frac{123.2\sqrt{A}}{\sqrt{A + 10.36}}$

Applicable in North & South India

"Bearing"

The device, which are provided over the supports of bridge to accomodate the changes in the main girders due to delfection. Temperature, vertical movement due to sinking of supports, Shrinkage, prestressing creep, etc. and to transmit the load from the super structure to the substructure in such a way that the bearing stresses induced in the sub-structure are within permissible limit.

Types of Bearing

1. **Cement Mortor pad:**
   - Fixed bearing for road girder bridge of small spans.
   - 30 mm thick cement grout pad (1 : 1)
   - Dower bars of 25 mm designed to take up the longitudinal forces in shear.
2. **Expansion bearing:**
   - It allows angular as well as longitudinal movement of the girder.
3. **Knuckle Bearing:**
   - Provide only for angular movement of the girder.
4. Rocker and Rouer bearing:
   - This bearing is generally recommended when length of span exceed about 15 m or 50.
5. **Rocker bearing:**
   - For span greater than 20 m or 50, a rocker bearing is provided at one end and at other end roller and rocker bearing.
   - Allows only free angular movement of the main girder.
6. **Rubber bearing:**
   - Synthetic Ruber like neophene can be successfully used.
   - In form of layer of Rubber plate.
   - Thicken plate at one end and thinner plate at other end, then former acts as free bearing and latter as fixed bearing.
7. **Neoprene bearing**

Books from **CIVIL Ki GOLI** Publication

1. Civil Booster: It is a Handbook which include **23 subject** of civil engineering . **Civil Capsule and Civil Engineering Rocket Chart** are free with it.

2. Civil Capsule: It is a type of **CIVIL Engineering Pocket Dictionary**. It can be used during travelling, office time etc for **quick revision**.

3. CIVIL Engineering Rocket Chart: It is a 2 × 3 feet **wall chart of Civil Engineering** Subjects. You can revise whole Civil Engineering within 1-2 hour from it, which is required during last time preparation of any exam.

4. CIVIL Ki GOLI :

This book has Qualitative questions combination of previous years of **IES, IAS, Gate, SSC-JE, PSU's, Various AE/JE Exams of states.** This book has **Topic wise questions** of each subject.

Each topic has divided into four levels:

(A) Level-1 (Basic Theory Questions)

(B) Level-2 (Theory Base Conceptual questions)

(C) Level-3 (Numerical Questions)

(D) Level-4 (Confusing Questions)

Note- Its solution is available in separate book named **Detailed solution of CIVIL Ki GOLI Book.**

19

RAILWAY ENGINEERING

Contents

1. Basic of Railway and Rail Joints
2. Sleepers and Track Fasteners
3. Ballast and Track Alignment
4. Track Stresses and Creep
5. Geometric Design of the track
6. Points and Crossings
7. Railway Station and Station Yard
8. Signalling and control Systems
9. Traction and Tractive Resistance

Basic of Railway & Rail Joints

1

- George Stephenson (father of railway) of England succeeded in running the first train on 27th September 1825 between Stockton and Darlington with steam engine.
- In the world India Railways are next only to Russian Railways under a single management.
- Tejas train is first Private train of India (2019).
- First train (four coaches and one steam engine) were run in India on 16th April 1853 between Boribunder (Mumbai) and Thane.

Rail: These act as a continuous girders carrying axle loads made up of high carbon steel which convert moving wheel loads of train into point load, which then acts on sleepers.

Requirement of Rails:

(*a*) Rails are tested by falling weight test/tup test.
(*b*) Maximum wear of head allowed is 10 mm
(*c*) Rails are manufactured by open hearth or duplex process.
(*d*) Minimum tensile strength needed 72 kg/mm^2.

Properties	Flat Footed Ralls	Bull Headed Rails or Double Headed rails
1. Laying and Relaying	Fitting is simpler. So, these can be easily laid or relaid.	Laying or relaying is difficult.
2. Strength and Stiffness	These have more strength & stiffness for same weight.	These have lesser stiffness & strength for same weight.
3. Initial cost	Fastenings are lesser and cheaper. So initial cost is less.	Fastening are more and costly. So initial cost is high.
4. Maintenance cost	It has less maintenance cost.	It requires heavy maintenance cost.

Special Points:

1. Double Headed rails were used in the beginning.
2. Flat footed rails also known as Vignole's rails and these rails are designed by weight of rail per unit length. These are most commonly used in India.
3. 52 kg rail (52 kg/m F.F) is suitable upto 130 kmph & 60 kg rail is suitable upto speed of 160 kmph.
4. Flat footed rails is commonly used in India.

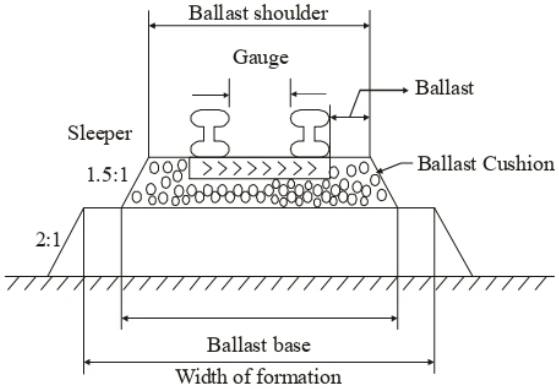
Length of Rail: Rails of larger length are always preferred because they will have less no. of joints. Rail length of 12.8m for BG tracks & rail length of 11.89 m for MG track are used in Indian railways.

Special Point: $\frac{\text{wt. of Rail}}{\text{wt. of Iocomotive}} \approx \frac{1}{510}$

When wear of head exceeds 5% of total weight, then rail must be replaced.

Permanent way (Railway Track)

- The combination of rails, fitted on sleepers and resting on ballast & subgrade is called railway track or permanent way.
- It is Semi-elastic in nature due to packing of ballast cushion.



Major Defects of Rail			
Corrugated/Roaring Rails	**Kinks in rail**	**Hogged rail**	**Buckling of rail**
Minute depression on the Surface of rails Created where brakes applied or train start	(occur due to loose packing of joints and uneven wear)	Created due to impact action of wheel at the end of rail, had get bend.	Occur due to temperature (specially summer) when there is insufficient gap b/w two end joints.

Gauges in Railway Track: It's the clear distance between inner faces/ running faces of two track rails.

Broad Gauge = 1.676m

Narrow Gauge = 0.762m

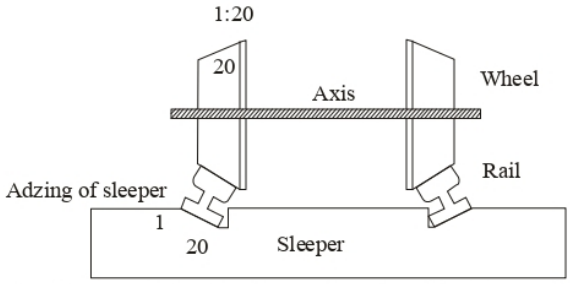
Meter Gauge = 1.0 m

Light gauge (Feather track) = 0.610 m

Standard gauge = 1.435m (Delhi metro) (In generally UK and USA)

Coning of wheels: Wheels of the train are made at a slope of 1:20. Which is known as conning of wheels. It reduces the wear & Tear of wheel flanges & also prevent the wheels from slipping.

Adzing of sleepers: Also called tilting of rails. For effective use of coning of wheels, the rails are also laid at the slope of 1 in 20 on the sleepers.



Rail Joints: Are needed to hold together the adjoining ends of the rail. They are the weakest part of the track. It's strength is 50% of strength of rail.

Types of Rail joints					
Supported	**Suspended**	**Bridge**	**Compromise**	**Expansion**	**Welded**
Rail ends rests on a single sleeper, called joint sleeper	Rail ends are projected beyond sleepers, called shoulder sleeper	Projected rail ends are connected by a flat or corrugated plate	Two different rail sections are joined by fish plates.	Gap is provided for thermal expansion	Most perfect & strongest type of Joints.

Welded Rails: Rails are welded to provide sufficient restrain at the ends of rail & better degree of fixity of rail to the sleeper.

Special Point:

Breathing length: minimum length of rail required to be welded at the end of track, so the portion of rail between welded rail does not undergo any thermal expansion or contraction.

Sleepers and Track Fasteners

2

Sleepers (Rail road lines) are the members which support the rail & are laid transverse to it. They act as elastic medium for providing longitudinal and lateral stability to the track & distributed load from rail to ballast.

- **Classification of sleepers on material basis -**

(a) Wooden (timber) sleeper

(b) Concrete sleeper - (i) Reinforced concrete, (ii) Prestressed concrete

(c) Metal sleeper - (i) Cast iron sleeper, (ii) Steel sleeper

- Wooden sleepers are best sleepers but they have life of 12–15 years.
- Sal & Teak wood are most commonly used for sleepers.Box heart or Ekka wood must be used for the construction of sleepers. Creosting & Burnettising are done to incease life of wodden sleepers.
- Serviceable portion of the spiked wooden sleepers is cut & used with tie bars in station yards is known as check sleepers.
- Check sleepers are not used on a track having running traffic.
- Steel Trough sleepers maintain the two tracks at the same level.
- Central Standard Trail no. 9 (CST-9) sleeper was standrised by Track Standard Committee. It can be used upto a speed of 130 kmph & most widely used in Indian Railways.
- C.I. Sleeper's life is about 35–50 years.Their overall cost & cost of Maintenance is low as compared to Wooden sleepers but scrap value is high while their Initial cost is high.
- C.I sleepers are used more than steel sleepers as they are less prone to corrosion.
- C.I sleepers can be used with every type of ballast but are not suitable for track circuiting.
- Steel sleepers are light in weight, require less no. of fasteners but get easily rusted/ corroded.
- Concrete sleepers have high track modulus, therefore used for developing high speed tracks due to best absorbing capacity of shock.But they have very poor scrap value.

- In prestress concrete sleepers, Generally M55 and M60 are used & there are suitable for Track circuiting.But heavy damages occurs due to derailment of trains.

Special point - Track circuiting is used to find out the location of a train on track & also to find spacimg between two traains on the same track.

Composite Sleeper Index (C.S.I): It is used to measure the mechanical strength of timber. Minimum CSI for track sleeper (783), crossing sleeper (1352), bridge sleeper (1455).

$$\boxed{\text{CSI} = \frac{\text{S} + 10\,\text{H}}{20}}$$

S = strength Index H = Hardness Index (Measured at 12% moisture content)

Track fasterners:

(*a*) **Fish plates:** Thse are used for connecting one rail to the next rail. Also use to resist heavy transverse shear. Minimum 4 fish bolt are required to connect 2 fish plate.The buckling occurs if fish plates are bolted so tightly that rails are not allowed to slip/expansion.

(*b*) **Spike:** It is used to hold rail on wooden sleepers. Dog spikes are used for wooden sleepers with flat footed rails.

(*c*) **Chair:** It support bull headed rails on sleepers. Slide chairs are used to hold stock Rail & tongue rail.

(d) **Keys:** It fix rails to chairs on metal sleepers. Morgan key (18 cm long & tapered 1:32) is most commonly used for CI chairs & steel sleepers.

(*e*) **Bolts:** Dog/Hook bolt is used where sleepers rest directly on steel girder.Fish bolts are used to resist heavy tranverse shear.

(*f*) **Bearing plate:** It is used below F.F rails to distibute load over wooden sleeper.These are not used in concrete sleepers & metal sleepers. Saddle plates are used to strengthen the steel sleepers.These are rectangular plates of either MS or CI. They do not required adzing of sleepers,

Sleeper density: No. of sleepers per rail length It is N + x

where N = rail lengh (13 for BG)

x = varies b/w 3 to 7

For BG sleeper density is N + 5 (18 sleepers/rail)

Squaring of Sleeper: Adjusting ballast under the sleepers to space them parallel to each other. It is a maintenance process. It is done by Crow bar.

Ballast and Track Alignment

3

Ballast: It is high Quality crushed stone with desired specifications placed immediately beneath the sleepers

Function of Ballast

1. It held the sleepers in position & prevent longitudinal and Lateral movements due to Dynamic loads.
2. It give some elasticity to track and provides Good drainage.
3. Good Ballast should absorb minimum water.

Special Points:

- Size of Ballast varies from (1.9 – 5.1) cm. For wooden sleeper (5.1cm), Steel sleeper (3.8cm) & at switches & crossings (2.54cm).
- Quantity of Ballast is more on curves with super elevation.
- In India, this width is kept in between 38 to 43 cm from end of sleepers.
- The ballast above packing which surrounds the sleeper, is loosely filled called Boxing.
- The process of ramming the ballast under the sleeper is called packing.
- The loose ballast between the two adjacent sleepers is known as Ballast crib.

Types of ballast

(*a*) Broken stone: Best material as ballast, has maximum stability.Igneous Rock such as Granite, Quartzite make good ballast material.

(*b*) Sand: It provides good drainage & silent track.

(*c*) Gravel or River pebble or shingle: They are smooth & round, so poor packing and interlocking. Gravel ballast gives better performance in soft formation.

(*d*) Ashes or Clinder : They have excellent drainage property, Excellent ballast material for station yards & but it is corrosive in nature.

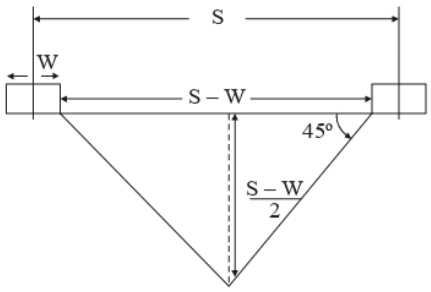
(e) Brick ballast : It is fairly good for drainage.

Depth of ballast-Section

Minimum depth of Ballast layer = D_{min}

$$\boxed{D_{min} = \frac{S - W}{2}}$$

Where S - Sleeper spacing, W - Width of sleeper, D - Depth of ballast.



Width of ballast: On straight track it is sleepers length + 2 × 300 mm at top which work out to be 3.35 m for BG, 2.25m for MG & 1.83m for NG. The side slope is 1.5 horizontal to 1 vertical.

Survey works for alignemnt of track.

(*a*) Traffic survey
(*b*) Reconnaissance survey
(*c*) Preliminary survey
(*d*) Detailed or location survey

Track Stresses and Creep

4

Track Modulus (m)

- Track Modulus is Index for stiffness resistance to deformation of permanent way.
- Load per unit length of the rail required to produce unit deformation or depression in the track.
- For calculation of Track modulus, Initial load is 4 tones for BG track & 3 tones for MG Track.

Special Point: Elastic theroy is used to define track modulus

Stresses on the rail: Torsional stresses are developed due to eccentric vertical loads but maximum shear stress below the contact surface of rail & diesel locomotive is 36.25 kg/mm^2

Creep of the rail: It is the longitudinal movement of rail wrt sleepers in a track and its value varies from 0-16 cm.

Theories of creep		
Wave Action theory	**Percursion theory**	**Drag theory**
Vertical reverse curve Wave motion is set up by moving loads of wheel	Due to horizontal component of the resultant impact force at the rail end	Drag of driving wheel of locomotive have opposite effect wrt. direction of creep.

Measurement of Creep

- Maximum permitted creep on BG track is 150 mm
- Creep should be measured at an Interval of about 3 month.
- No creep should be permitted on points & crossings.

Prevention of creep:

(*i*) Using steel sleepers
(*ii*) Pulling back rails to original position
(*iii*) By providing sufficient crib ballast & anchors

Factors affecting creep of the rail:

(*i*) Alignment of track: Observed greater on curves than tangent railway track.

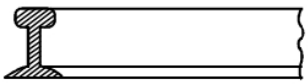
(*ii*) More creep in the direction of heaviest traffic.

(*iii*) Type of rails: Old rails have more creep than new rails.

(*iv*) Grade of track: More creep in downward steep gradients.

Crushed head:

- Crushed heads are those which have either sagged or flattened.

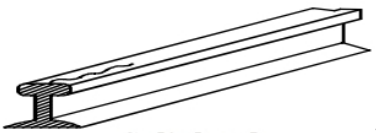


Crushed head

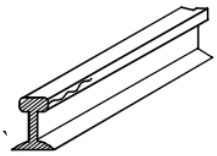
- Besides the defect of manufacture, crushed head are due to
  (a) Weak supports at the rail ends. This weak end support may be due to loose fish bolts.
  (b) Flat spots on wheels which are developed due to skidding of wheels.
  (c) Slipping of wheels.

Split heads:

- In it, cracks occur in the middle of the head or pieces are split from the side to the end of the head.



Split head



Horizontal fissure

- It occurs due to cavity formed during manufacturing or shrinkage of metal when the metal is not closely welded together.

Horizontal fissures:

- These are developed in the rail head.
- They are more in the form of a fracture & develop gradually.

Geometric Design of the track

5

- Generally, the maximum Gradient allowed is known as Ruling Gradient & It is the gradient allowed so that engine can haul the load with its maximum capacity. In hilly region (1:100 - 1:150) & plain region (1:150 - 1:250) .
- In pusher gradient, a pusher or helper engine is used. For B.G. Track of Western Ghats pusher gradient is of 1:37. Generally used in hilly areas.
- In India, the minimum gradient provided on the station yards to drain out off water is 1:400 to 1:1000.
- Momentum gradient is steeper than ruling gradient & comes only after a falling gradient.

Grade compensation: Due to curvature on the grade, the gradients on the curves are to be reduced to reduce the resistance in motion of train.

	% per degree of curve
BG	$0.04/\left(\frac{70}{R}\right)$
MG	$0.03/\left(\frac{52.5}{R}\right)$
NG	$0.02/\left(\frac{35}{R}\right)$

- High carbon steel is used to make rails must be resistant to fatigue or surface cracking. The aim is for the steel to have a long fatigue life. Rail steel is chosen to achieve a balance between fatigue life & wear resistance. If the steel is too hard, it will allow cracks to develop on the surface

Safe speed of train as per Martin's Formula			
For low speed (<100 kmph)			For High speed (>100 kmph)
Transition curve		Non-trasition curve	$V_{max} = 4.58\sqrt{R}$ (BG)
on BG & MG	on NG	80% of speed on transition curve.	
$V_{max} = 4.35\sqrt{R-67}$	$V_{max} = 3.6\sqrt{R-6.1}$		

Degree of Curve:

For 30m chain	$\frac{1720}{R}$
For 20m chain	$\frac{1150}{R}$

As per Indian Railways.

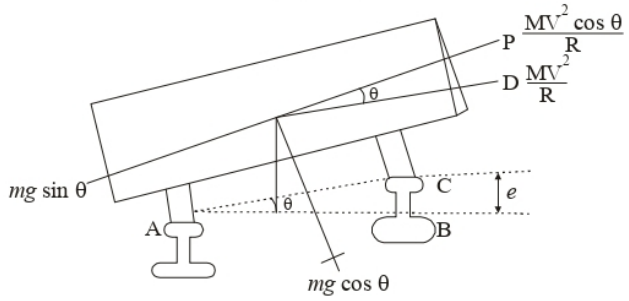
	Maximum degree of curve	Minimum radius
BG	10°	175 m
MG	16°	109m
NG	40°	44m

Super elevation or cant

$$\tan\theta = \frac{e}{G} = \frac{v^2}{gR}$$

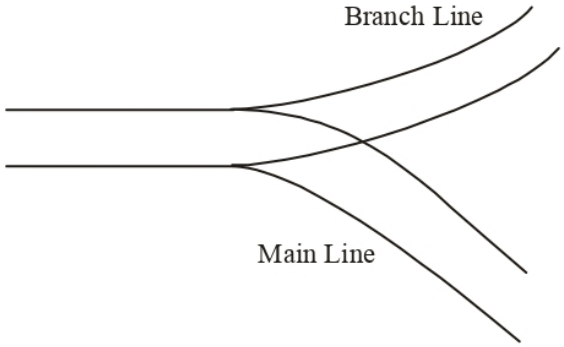
$$\boxed{e = \frac{Gv^2}{127R}}$$

V in kmph, R in m, G → Gauge (in m)

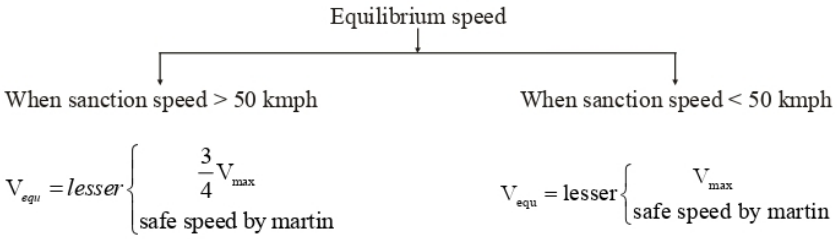


- The maximum value of superelevation is (1/10)th to (1/12)th of the Gauge.
- When the loads, pressure on both rail is equal. Then, the cant provided is known as Equilibrium cant.

- **Negative superelevation** - When the main line lies on a curve & has a turnout of contrary flexure leading to a branch line, then the superelevation necessary for the average speed of trains running over the main line curve cannot be provided. In such cases, the branch line curve has a –ve superelevation & so speed on both tracks must be restricted, particularly on the branch line.



Negative Superelevation



$$\text{Weighted average speed} = \frac{\sum N_i V_i}{\sum N_i}$$

N_i Number of train's having speed V_i

Maximum limit of super elevation

Equilibrium Speed

Track	Speed< 120 kmph	> 120 kmph
BG	16.5cm	18.5 cm
MG	10 cm	
NG	7.6 cm	

- **Cant deficiency** - It is the difference between the equilibrium cant necessary for the maximum permissible speed on a curve & the actual cant provided (on the basis of average speed of trains).
- Cant deficiency is limited due to -

(a) Extra pressure & lateral force on outer rail.

(b) Higher cant deficiency gives more discomfort to passengers.

- The allowable cant deficiency for BG is 75mm, for MG 50mm & for NG 40mm.
- **Cant Excess** - It occurs when a rail travels round a curve at a speed less than the equilibrium speed. It is the difference of actual cant & theoretical cant required for such lower speed. The maximum cant excess for BG is 75mm & for MG is 65mm.

Types of Transition Curve

- Transition curve is introduced in between the circular portion of track & straight track at both ends.
- Cubic parabola (also called Froud's curve) is used as transition curve & Transition curve are early set out by offset method.
  (a) Spiral curve is used in Highways
  (b) Bernoulli's Lemniscate satisfy the requirement of Transition curve upto deflection angle of 30.

Transition Curve:

(*a*) Equation of deflection of cubic parabola $y = \frac{x^3}{6RL}$

(*b*) Deflection angle $\theta = \tan^{-1}\left(\frac{1}{3}\tan\phi\right)$

(*c*) Spiral angle $\phi = \tan^{-1}\left(\frac{x^2}{2RL}\right)$

(*d*) Shift $s = \frac{L^2}{24\,R}$

Length of transition curve

From 1st method -

$$L = \max\begin{cases} 7.2e \\ 0.073eV_{max} \\ 0.073D\,V_{max} \end{cases},$$

where e = S.E in cm, V_{max} in kmph, D = cant deficiency in cm

From 2nd method - Maximum of following

(*i*) Railway board formula

$$L = 4.4\sqrt{R}$$

where L, R (in m)

(*ii*) Rate of change of super elevation

$$L = 3.6e$$

(*iii*) Change of radial acceleration

$$L = \frac{3.28V^3}{R}, \quad V \rightarrow \text{m/sec}$$

Maximum speed based on length of transition curve

(L in m, e in mm)

Speed < 100 kmph: $V_{max} = \frac{134L}{e} = (134\ L/D)$

Speed > 100 kmph: $V_{max} = \frac{198L}{e} = (198\ L/D)$

Gauge widening on curves

$$\boxed{W_e = \frac{13(B+L)^2}{R}}\ \text{cm}$$

B – Rigid wheel base in meters, (For BG = 6 m, For MG = 4.88m)

R – Radius of curve (in m)

$$\boxed{L = 0.02\sqrt{h^2 + Dh}}$$

L = Lap of flange (in m), D = Diameter of wheel

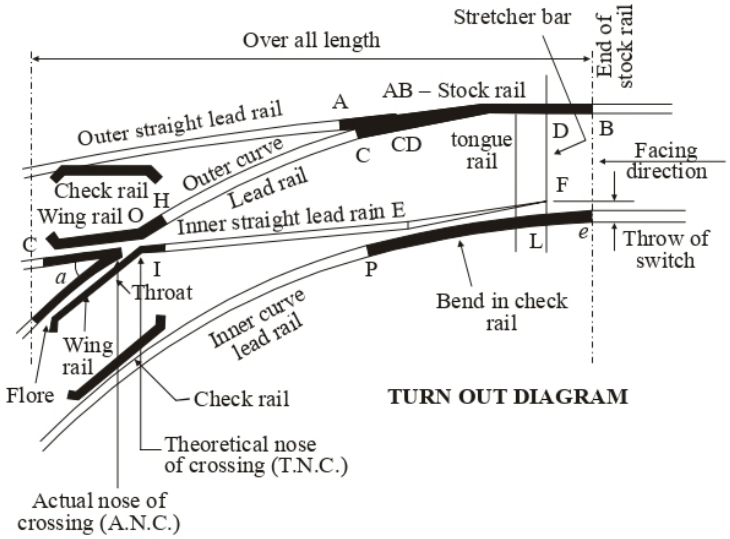
h = Depth of wheel flange below rails , W_c = Widening of gauge

- Due to rigidity of wheel when the outer wheel of rear axle does not follow the same path as by front axle, there is always a gap with the outer rail. So, curve gague is a bit wide need but should not be more than required.

Points and Crossing

6

- Track circuiting is done in order to find out the location of a train on track. It also tells the spacing between two trains on the same track.
- **Turnout:** It is the combination of points & crossing which enables a back either a branch line or siding to take off from main track.
- Points crossings are weak kinks in the track where vehicles are suceptible to derailment.
- High mangaese steel are used to make material (Steel) for points & crossing.
- Check Rails are provided on the opposite side of the crossing for guiding one wheel of the vehicle & thus to check the tendency of other wheel to climb over the crossing.
- On the curves, check rails parallel to Inner rail can be Introduced to control wear.
- Check-rails are used if the degrees of curves is more than 8° for BG and more than 14° for MG.
- The correct sequence for a train when it passes a Turn out from the facing direction is Toe of switch, Tongue rail, Lead rail & crossing.
- A tongue rail is tapered having toe at one end & heel at the other end.
- The position of the straight alignment against which the tongue rail fits is known as stock Rail.
- Crow bars are used to raise sleeper to a desired height & also use in replacement of track.
- Claw bar to remove dog spikes out of sleepers.
- Rail Tongue to lift & carry rails.
- Wire claw or ballast fork to clean & spread the Ballast.
- Wing rails help in channelising the wheels in their proper routes.
- Guard rails are extra rails provided over bridges to prevent damage.
- Treadle bar is used for Interlocking points & signals.



Special Points:

- Lock bar is provided so that point may not be operated while train is on it.
- Maximum axle load in India are 28.56 tonnes for BG & 17.34 tonnes for MG.
- Realignment of straight Track is done by using crow bar & Track liners.

Turn out consists of

(*a*) 2 points or switches
(*b*) (1 pair) of stock rails
(*c*) An acute angle crossing/ V crossing.
(*d*) A pair of check rails - 2
(*e*) 4 lead rails - 2 straight & 2 curve lead rails.

Important Points of Switch:

(*i*) Flange way clearance: It is the distance between adjacent faces of tongue rail & stock rail at the heel of switch. It is provided as :

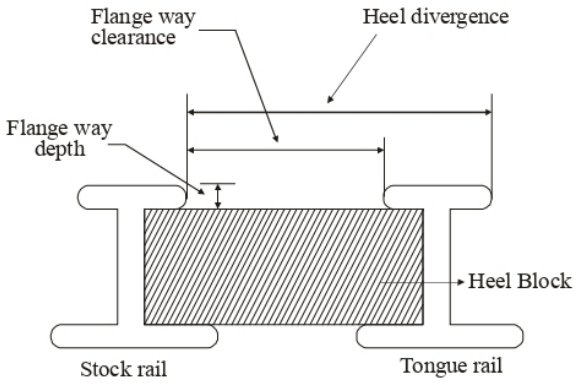
(a) In 1 in 12 crossing , it is 6.3 cm, (b) In 1 in 8.5 crossing, it is 6.6 cm

(*ii*) Flange way depth: It is vertical distance b/w top of rail to heel block.

(*iii*) Heel divergence: It is the distance between running faces of stock rail & tongue rail at the heel of switch.In India, it is provided as :

(i) In Broad Guage : 13.3 cm to 13.7 cm

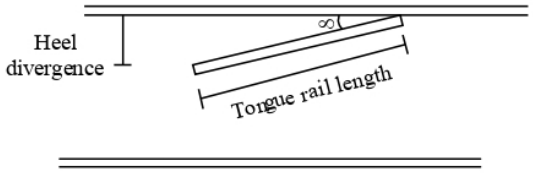
(ii) In Meter Gauge : 12.1 cm to 12.7 cm, (iii) In Narrow Gauge : 3.8 cm



(*iv*) Throw of switch: It is the maximum distance by which toe of tongue rail moves sideways. For BG (9.5 cm) & MG/ NG (8.9 cm)

(*v*) Switch angle: It is the angle between running faces of stock rail & tongue rail when tongue rail touches the stock rail.

$$\alpha = \frac{\text{Heel divergence}}{\text{Length of tongue rail}}$$



Crossing angle:

$$\text{No. of crossing (N)} = \frac{\text{The spread at the leg of crossing}}{\text{The length of corssing T.NC.}}$$

T.N.C. Theoretical Nose of Crossing

Methods to calculate crossing angle 'N'		
Cole's method (right angle triangle method)	**Centre line method**	**Isosceles triangle method**
 $N = \cot\alpha$ Used in Indian Railway	 $\alpha = 2\cot^{-1}(2N)$	 $\sin\left(\frac{\alpha}{2}\right) = \frac{1/2}{N}$

Design of Turnout:

(*a*) Curve lead: It is the distance measured along stock rail between TNC and toe of switch

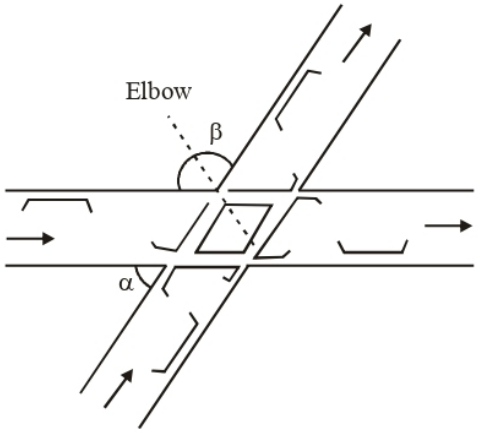
Curve lead = lead + switch lead

(*b*) Lead: It is the distance between TNC and heel of switch measured along stock rail

(*c*) Switch lead: It is the distance between heel of the switch and toe of the switch. It is measured on stock rail.

Diamond crossing: When curved track or straight traks of the same or different gauges cross each other at an angle less than 90°, a diamond shape is formed. Therefore, this crossing is known as diamond crossing.

Diamond crossing at Nagpur is a double diamond railway crossing.



The salient features of diamond crossing are:

(a) It consists of 2 acute angle crossings , 2 obtuse angle crossings & 4 check rails.

(b) Indian Standards specify the limit of flattest diamond to be 1 in 10 for BG tracks & 1 in 8.5 for other tracks.

(c) The length of the gap between two noses of an obtuse crossing increases as the acute angle of crossing decreases.

(d) Diamond crossings should be avoided as far as possible on curves because they necessitate restriction on speed.

Railway Station and Station Yard

7

- Minimum length of passenger platform is 180 m for all gauges.
- Sidings provides temporary storage for wagons.
- Dyanamometer car is helpful in collecting the Information about the Railway Track Condition.
- Turn Table has arrangement for Turning the direction of the engine of locomotive.

Sidings: When a branch line from main line or a loop line terminates at a dead end with a buffer stop or sand hump.

Station yard: It is a system of track laid for receiving, storing, sorting & dispatching of new vehicles etc.

Types of station yard - (a) Passenger, (b) Locomotive, (c) Goods, (d) Marshalling

Passenger yard: It includes the passenger platforms & a number of tracks where idle trains can be accommodated, examined & cleaned.

Goods yard: It include the platform useful for loading & unloading goods.

Marshalling yard: It is considered as "the heart that pumps the flow of commence along the track & main function of marshalling yard are reception, sorting & (departure) reforming into desiganation wise of goods trains. It may be flat yard, hump yard or gravitational yard.

- Flat yard is used when limited land is available on plains.
- Nowdays practise is to use Hump yards because shunting operations are done more quickly than flat/Gravitational yards.

Locomotive yard: These are the yards where locomotives are housed & where all the facilities like coaling, watering, repairing cleaning oiling are provided for servicing of the Locomotives.

Special points - Drop pit is used to remove the wheels of an engine.

- Turn table is used for changing the direction of locomotive such as triangle.
- Scotch blocks is used to separate all the sidings & shunting lines from through running lines.

Signalling and control Systems

8

Absolute block system or space interval system is extensively used in India.

Classification of Signals - Based upon

(a) **Operational** characteristics - Detonating, hand & fixed signals.

(b) **Functional** characteristics- Shunting (disc or ground) , warner, coloured light & semaphore (stop) signals.

(c) **Locational** characteristics - Reception signals like as home & outer signal, Departure signal like as starter & advance starter signals.

(d) **Special** characteristics - Calling on, routing, point indicator & repeater (co-acting) signals.

(*i*) Detonating signals are used in foggy & cloudy weather. These are placed on rails which explode with when train passes over them.

(*ii*) Warner signal: A semaphore signal at entrance to station is combined with a warner system.It is painted with yellow, not red.

(*iii*) Stop/semaphore signal: If arm is horizontal, then it indicates stop or danger indication. If arm is inclined at 45- 60 degree, it is said to be off position meaning to proceed.

(*iv*) Shunting signals are used in station yards in shunting operation.

(v) Home Signal (Due to its location at the Door of station it is called as Home signal) has bracketed arms which which line is to be used.

(*vi*) Repeater or co-acting signal's are provided where driver's vision is obstructed. A duplicate arm of smaller size is placed at a suitable position on the same post.

(*vii*) Calling on signals are very much useful with repair work.

(*viii*) Routing signals are provided where no of lines exist at a station taking off different locations from main line.

(ix) Fixed signals are generally a semaphore type, fixed at a place.

(x) The starter signals mark the limit upto which trains stopping at a station come to a stand or halt.

Special Points: Outer signal is placed minimum to 0.54km & 0.40km away from station yard on BG and MG tracks respectively.

- Detonator must be placed on the rails atleast 400-500m ahead of signals.
- The height of the centre of arm of semaphore signal is kept 7.5m above the ground.

Traction and Tractive Resistance

9

Tractive effort: Pull applied by engine on driving wheel

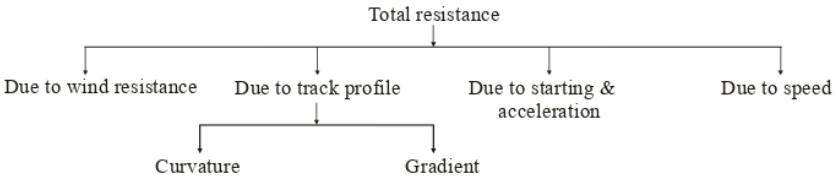
Hauling Capacity: Maximum value of frictional force due to driving wheels. It indicate the power of locomotive engine.

$$\text{Hauling Capacity (H.C.)} = \mu W = \mu w n$$

μ = friction coefficient

n = no. of pair of driving wheels

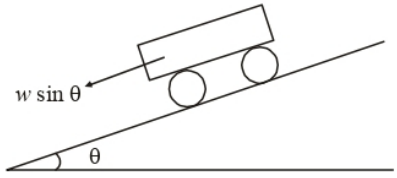
w = weight on driving axle, W = total weight on driving wheels



Resistance due to train resistance

$R_T = 0.0016\ w + 0.00008\ wv + 0.0000006\ wv^2 + w \tan\theta$ (due to gradient) + 0.0004 DW (due to curve)

V = Speed of trains in kmph, w = wt. of train in tonnes



Special Points:

- For moving train

  Tractive Resistance > Hauling capacity > Total resistance

- For solving Numerical problems, we take. Tractive effort = Hauling capacity = Total resistance

21

APPLIED MECHANICS

Contents

1. Basic Fundamental
2. Velocity & Projectile Motion
3. Friction
4. Force
5. Work, Power & Energy

Basic Fundamental

1

- Units and Measurements
- Vector and Scalar Quantity
- Newton's Law of Motion
- Friction
- Rectilinear Motion
- Projectile Motion
- Circular Motion
- Simple Harmonic Motion.

Fundamental and derived quantities.

- Large number of physical quantities and every quantity needs a unit.
- Fundamental quantities are only seven in number.

	Quantity	SI Unit	Symbol
1.	Length	meter	m
2.	Mass	Kilogram	kg
3.	Time	Second	s
4.	Electric Current	Ampere	A
5.	Thermodynamic temperature	Kelvin	K
6.	Amount of Substance	Mole	mol.
7.	Luminous intensity	Candela	Cd.

Special points: Two supplimentary unit.

(i) Plane angle – radian rad.

(ii) Solid angle – Staradian St.

CGS System: Units of length, mass and time are centimetre (cm), gram (g) and second(s) respectively.

Force – dyne

Work – erg.

FPS system: Units of length, mass and time are foot, pound and second.

Force – poundal.

SI Prefix:

Power of 10	Prefix	Symbol
6	mega	M
3	Kilo	K
–2	Centi	C
– 3	Mili	m
– 6	Micro	μ
– 9	nano	n
– 12	pico	p

Vector and scalar quantities

- Any physical quantity is either a scalar or a vector.

Scalar

- Scalar quantity completely can be described by its magnitude only.

  e.g. Mass, Volume, density etc.

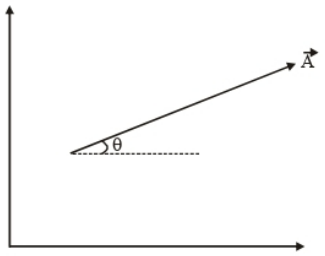
Vector

- A physical quantity in addition to magnitude it has a specified direction.
- Obeys the law of parallelogram of addition eg: Displacement, velocity, acceleration etc.

Note: Electric current in a wire shown by a direction but it is not a vector quantity.

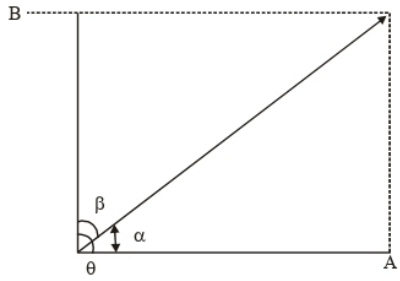
Reason: It does not obey the law of parallelogram of vector addition.

Representation of Vector



1. The parallelogram Law:

$\vec{R}$ = Resultant of $\vec{A}$ and $\vec{B}$



$$\tan\alpha = \frac{B\sin\theta}{A + B\cos\theta}$$

$$\tan\beta = \frac{A\sin\theta}{B + A\cos\theta}$$

According to parallelogram law

Magnitude of $\vec{R}$ is given by:

$$R = |\vec{R}| = \sqrt{A^2 + B^2 + 2AB\cos\theta}$$

if $\theta = 0°$; $R = A + B$ = Max.

$\theta = 180°$; $R = A - B$ = Min.

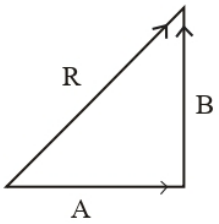
$\theta = 90°$; $R = \sqrt{A^2 + B^2}$

2. The Triangle Law:

"If the tail of one vector be placed at the head of other, their sum $\vec{R}$ is drawn from the tail end of first to the head of other.

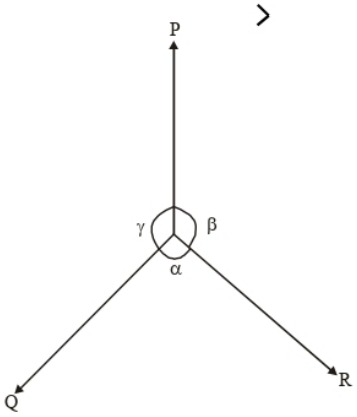
$\vec{R} = \vec{A} + \vec{B}$

Sine Rule:



Lami's Theorem $\Rightarrow \frac{P}{\sin\alpha} = \frac{Q}{\sin\beta} = \frac{R}{\sin\gamma}$

It states that if three coplaner forces acting at a point be in equilibrium, then force is proportional to the sine of the angle between the other two forces.



Special Points:

- The law of parallelogram of the forces cannot be proved theoretically
- The Triangle Law and the polygon Law of Forces are not fundamental laws. they are only derived laws.

Velocity & Projectile Motion

2

Rectilinear Motion

- Motion in a straight path.

Distance and displacement:

Distance: When a particle is moving its successive position in general may lie on a curve, the curve is then called as the path of the particle the total length of the path followed by the body is called the distance travelled by the body.

- Scalar quantity.

Displacement:

- The directional distance between final and initial position of the particles.
- It is a vector quantity.

Speed

- Speed is the rate at which a moving body describes its path. Path may be curve or straight line.

  Average Speed, $V = \frac{\Delta s}{\Delta t}$

  If the interval of time Δt is infinitisimally small approaching to zero. This ratio is called instantenous speed.

  Instantenous speed $= \underset{\Delta t \to 0}{lt} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$

- Speed is scalar quantity.

Velocity:

- Rate of change of position.

  Average velocity, $\vec{V} = \frac{\Delta \vec{r}}{\Delta t}$

Also, instantenous velocity, $\vec{V} = \underset{\Delta t \to 0}{Lt} \frac{\Delta \vec{r}}{\Delta t} = \frac{d\vec{r}}{dt}$

- It is a vector quantity.

Acceleration:

- Rate of change of velocity.
- The change in either magnitude or direction or both of them.

Average acceleration $\vec{a}_{avg.} = \frac{\Delta \vec{v}}{\Delta t}$

Note: If an object moves along straight line without change in direction, in a given time interval.

(i) It's displacement and distance travelled are equal.

(ii) It's average speed and velocity are equal.

Distance ≥ |displacement|

Speed ≥ | Velocity|

Uniform motion

- Motion is uniform if,
  - (i) Velocity is non zero.
  - (ii) Acceleration is zero.
  - (iii) Direction and velocity do not change.
- An object moves along a straight line. Half the time with V_1 and rest with V_2.

Average velocity = $\frac{V_1 + V_2}{2}$

- While moving half distance with V_1 and rest with V_2

Average velocity = $\frac{2V_1V_2}{V_1 + V_2}$

Relative Motion

1.



Moving in opposite direction,

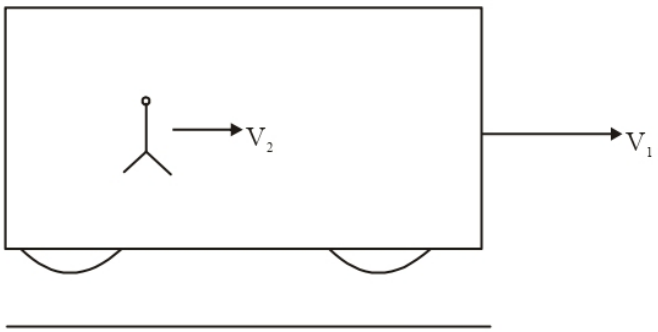
relative speed = $V_A + V_B$

2. Moving along same direction,



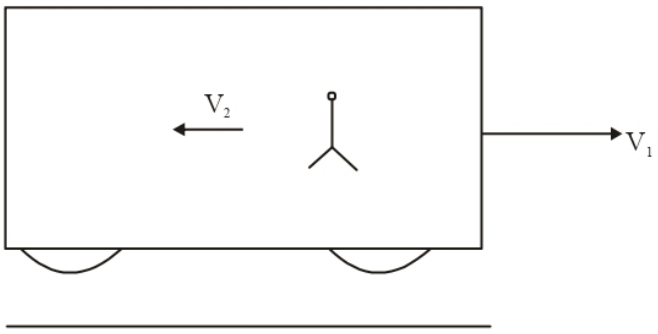
Relative Speed = $|V_A - V_B|$

Resultant motion



$V_R = V_1 + V_2$

Resultant velocity of man wrt ground.



$V_R = V_2 - V_1$

Equation of Motion: Straight line with uniform acceleration.

1. $V = u + at$
2. $S = ut + \frac{1}{2}at^2$

3. $V^2 = u^2 + 2as$
   - in a given interval of time

     $\bar{V} = \frac{\text{initial velocity + final velocity}}{2}$
   - Displacement = (Average velocity) × time

Important point:

1. Average velocity during first t seconds–

   $= u + \frac{1}{2}at$
2. For a body starting from rest (u = 0) with uniform acceleration, the ratio of distances convered in ts, 2ts, 3ts etc is 1 : 4 : 9 etc.
3. A body starting from rest with uniform acceleration covers distances in the ratio 1 : 3 : 5 (odd numbers) in consecutive equal internal of time.
4. Distance traversed by the particle in the nth second of its motion:

   $S_n = u + \frac{1}{2}a(2n-1)$

Vertical motion under gravity.

1. Body released from rest–
   A point object is released from rest from a point at height h.

   – Time taken to reach ground = $\sqrt{\frac{2h}{g}}$
   - Velocity with which it strikes ground = $\sqrt{2gh}$.
2. Body thrown vertically upward:
   A point object is thrown vertically upward with velocity u.

   time of ascend = $\frac{u}{g}$

   time of descend = $\frac{u}{g}$

   time of flight = $\frac{2u}{g}$

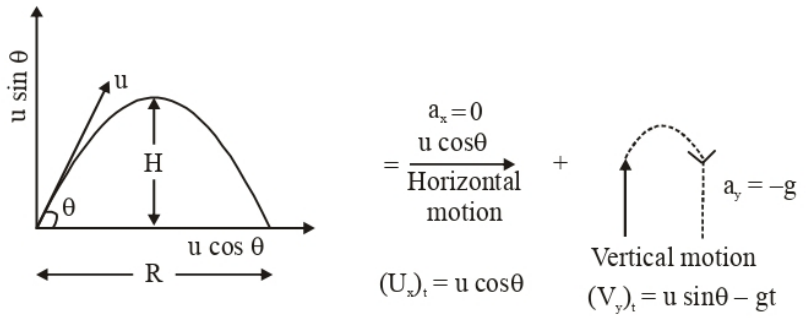
$V^2 = u^2 - 2gh$, $V = 0$ at highest point

$u^2 = 2gh_{max}$

$$\Rightarrow h_{max} = \frac{u^2}{2g}$$

Projectile Motion

- It is two dimentional motion with constant acceleration.



1. Time of flight:

   The displacement along vertical direction is zero for the complete flight.

$$\Rightarrow \quad S = ut - \frac{1}{2}gt^2$$

$$\Rightarrow \quad 0 = (u\sin\theta)t - \frac{1}{2}gt^2$$

$$\Rightarrow \quad t = \frac{2u\sin\theta}{g}$$

2. Horizontal Range (R):

   $R = u_x.t$

$$\Rightarrow \quad R = u\cos\theta.\frac{2u\sin\theta}{g}$$

$$\Rightarrow \quad R = \frac{u^2\sin 2\theta}{g}$$

3. Max. Height (H):

   At highest point velocity component equal to zero.

$V^2 = u^2 + 2as \Rightarrow 0 = u^2 \sin^2\theta - 2gH$

$$\Rightarrow \quad H = \frac{u^2 \sin^2\theta}{2g}$$

4. Resultant velocity:

$$\vec{V} = v_x\hat{i} + v_y\hat{j} = u\cos\theta\hat{i} + (u\sin\theta - gt)\hat{j}$$

$$|\vec{V}| = \sqrt{u^2\cos^2\theta + (u\sin\theta - gt)^2}$$

and $\tan\alpha = V_y/V_x$

Important Points

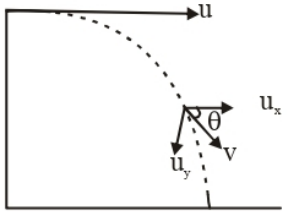
- For max. Range $\theta = 45°$

$$R_{max} = \frac{u^2}{g}$$

- We get the same range for α and $(90 - \alpha)$ but in both cases, max. heights attained by the particles are different.
- Equation of Trajactory:

$$y = x\tan\theta - \frac{gx^2}{2u^2\cos^2\theta}$$

Projectile throw Parallel to the horizontal from some height:



1. Time of flight (T): $T = \sqrt{\frac{2h}{g}}$
2. Range (R): $R = u\sqrt{\frac{2h}{g}}$
3. Velocity at general point P(x, y):

$$V = \sqrt{u_x^2 + v_y^2}$$

$u_x = u$, $u_y = gt$ (downward).

Circular Motion

- When a particle moves in plane such that its distance from a fixed point remains constant, motion with respect to that fixed point is called as circular motion.

1. Angular velocity (W):

   W_{av} = Average Angular velocity

   $$W_{av} = \frac{\text{Angular displacement}}{\text{Total time taken}} = \frac{\theta_2 - \theta_1}{t_2 - t_1} = \frac{\Delta\theta}{\Delta t}$$

   - Angular displacement is scalar but angular velocity is Pseudo vector.
   - SI unit rad/s, dimention $[T^{-1}]$
   - $w_{av} = \frac{2\pi}{T}$ (T-Time period)
   - $w_{av} = 2\pi f$ (f-frequency)
   - $w_{av} = \frac{2\pi n}{t}$ (n-rotations)

2. Angular Acceleration:

   $$\bar{\alpha}_{av} = \frac{\vec{w}_2 - \vec{w}_1}{t_2 - t_1} = \frac{\Delta\vec{w}}{\Delta t}$$

   If $\alpha = 0$; Motion is called uniform

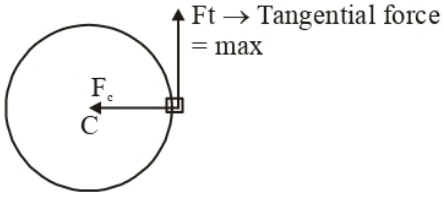
   - Unit rad/s^2
   - Dimention = $[T^{-2}]$.
   - Speed and angular velocity Relation

     $$\vec{V} = \vec{w} \times \vec{r}$$

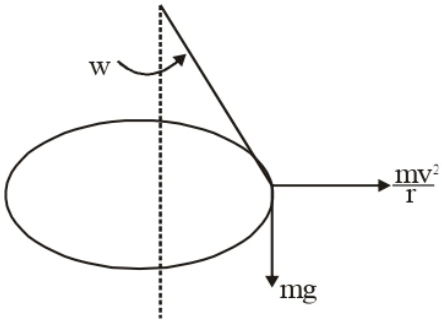
     Position w.r.t. centre of circular motion.

3. Centripetal Force (F_c): At constant speed, the net force acting on the body is along the inside normal to the path of the body, called centripetal force.

   $$F_c = ma_c = \frac{mv^2}{r} = mw^2r$$



4. Centrifugal Force:
   - Magnitude equal to centripetal force.
   - Always directed radialy outward.
   - $\frac{mv^2}{r}$



   - When a body is rotating in circular path and the centripetal force vanishes, body would leave the circular path.

Special Point: Lame's constant

$$\mu = \frac{E}{2(1+\nu)}, \lambda = \frac{E\nu}{(1+\nu)(1-2\nu)}$$

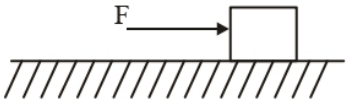
- Constants which relate stress to strain in an isotropic, elastic material.
- Depends upon temperature and material.

Friction

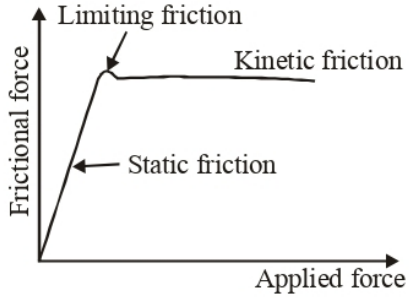
3

- Comes into play between two surfaces whenever there is relative motion or a tendency of relative motion between them.
- It opposes the relative motion between two surfaces in contact.

Types of Friction	
Static	**Kinetic**
It acts between Surface in contact but not in relative motion, opposes the tendency of relative motion	It acts between surface in contact which are in relative motion. It opposes the relative motion between surfaces.



- Dynamic friction (kinetic friction) is the friction between surfaces which acts between the body moves relative to one another.
- In Static friction body tends to move when a force is applied on it (the bodies are not moving relative to each other).
- Generally, the order of friction forces are:



Limiting friction force > Maximum static friction force > Dynamic friction force

Note Coefficient of friction is the ratio of friction force to the normal force which is acting to the normal of frictional force surface

Law of Static friction

- It is independent of area of contacting surfaces.

$f_{s\,max} \propto N$

f_s max $= \mu_R N$, (N-Normal reaction, μ_s- Co-efficient of static friction)

$0 \le f_s \le \mu N$

- When F exceeds f_s block starts moving and frictional force decreases to a constant value f_k.

f_k is kinematic friction.

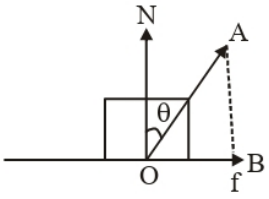
$f_k = \mu_k N$

μ_k-Co-efficient of kinematic friction.

Angle of friction

- Angle made by the resultant force with the vertical is known as the angle of the friction in ΔOAB,

$$\tan(90-\theta) = \frac{AB}{OB} \Rightarrow \cot\theta = \frac{AB}{OB}$$



$$\Rightarrow \tan\theta = \frac{OB}{AB} \Rightarrow \theta = \tan^{-1}\left(\frac{OB}{AB}\right)$$

Force

4

Newtons Law of Motion

Force:

A pull or push which changes or tends to change the state of rest or of uniform motion or direction of motion of any object is called force.

- It is a vector quantity.
- unit – $\frac{kg.m}{s^2}$ (MKS)

  dyne and $\frac{g-cm}{s^2}$ (CGS)

  $1\ N = 10^5$ dyne.

Effect of resultant force:

1. May change only speed.
2. May change only direction of motion.
3. May change both speed and direction of motion.
4. May change size and shape of body.

Contact forces:

- Tension, Normal reaction, Friction etc.
- Forces that act between bodies in contact.

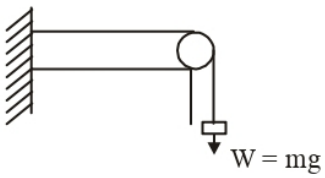
Field Forces:

- Weight, electrostatic force etc.
- Forces that act between bodies separated by a distance without any actual contact.

Contact forces:

(i) **Tension:** When string, thread, wire or a spling is held tight, the ends of the string pull on whatever bodies are attached to them in the direction

of the string. This force is known as tension.



(ii) Normal:

- Normal force is perpendicular to surface.
- When two surface are in contact, then the surface exert forces on each other.

(iii) **Friction:**

- Force that acts between bodies in contact with each other.

Special points: The forces whose lines of action is lie on the same plane are known as coplanar force.

A force equal in magnitude, opposite in direction and collinear with the resultant is known as equilibrant force.

If lines of Action of forces in a system of force meet a point. Then these forces are called concurrent forces.

Concurrent coplanar forces – Lines of actions of all forces lie in the same plane and pass through a common point.

Collinear forces – Lines of actions of all forces lie along same line.

Newton's first Law

Each body continues to be in its rest state or of uniform motion in a Straight line unless compelled by some external force to act otherwise.

- The Newton's first law leads to the definition of force

Example:

(i) A bullet fired on a glass window makes a clean hole through it while a stone breaks the whole of it.

Bullet speed – high – large inertia of motion – cut clean hole.

(ii) Passenger sitting in a bus gets a jerk when the bus starts or stops suddenly.

Second Law of motion

- The rate of change of momentum of a body is directly proportional to the

applied force.

$\vec{F} = \frac{d\vec{p}}{dt}$ or $\vec{F} = m\vec{a}$

Where $\vec{P} = m\vec{v}$

important points about second law:

- Obviously consistent with the first law as F = 0 implies a = 0.
- It is a vector law.
- It is strictly applicable to a single point mass.

Third law of motion.

- Every Action has equal and opposite reaction.

Ex: Rowing a boat, Hitting a wall, Walking, Jet

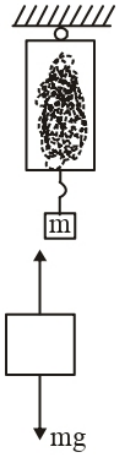
Weighing Machine

- A weighing machine does not measure the weight but the force exerted by object on its upper surface.

Spring balance

- It does not measure the weight.
- Measures the force exerted by the object at the hook.

  = mg – T = 0 $\Rightarrow$ T = mg.



Work, Power & Energy

5

Work: Following two conditions must be fulfilled:

(i) A force must be applied.

(ii) The applied force must produce a displacement in any direction except perpendicular to the force direction.

$W = F \cdot S$

dot product

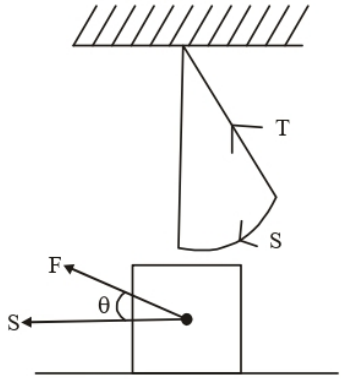
F →

- Scalar quantity

Note: The tension in the string of a simple pendulum is always perpendicular to displacement.

So, Work done = zero.

by tension



Case 1. If $\theta = 0$; $\cos\theta = 1$. So, work done is max.

$\theta < 90°$; $\cos\theta$ = +ve; So, work done positive.

$\theta = 90°$; $\cos\theta = 0$; So, work done is zero.

θ is obtuse, $\cos\theta$ = – ve, So W is negative.

Dimention and Unit:

Unit: erg [CGS], Joule or N-m.

1 erg = 1 dyne × 1 cm = 1g cm s^{-2} × cm = 1g cm^2 s^{-2}

Dimention: – [ML^2 T^{-2}]

Energy

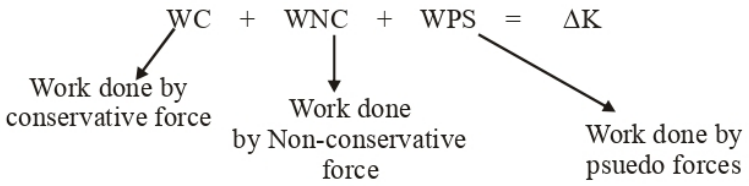
- Intinal capacity of doing work.

  Kinetic energy:
- Internal capacity of doing work of the object by virtue of its motion.
- $KE = \frac{1}{2}mv^2$
- $E_K = \frac{p^2}{2m}$; P = momentum

  E_K = Kinetic energy.

Work - Energy theorem

According to this theorem, the workdone by all the forces on a particle is equal to the change in its kinetic energy.



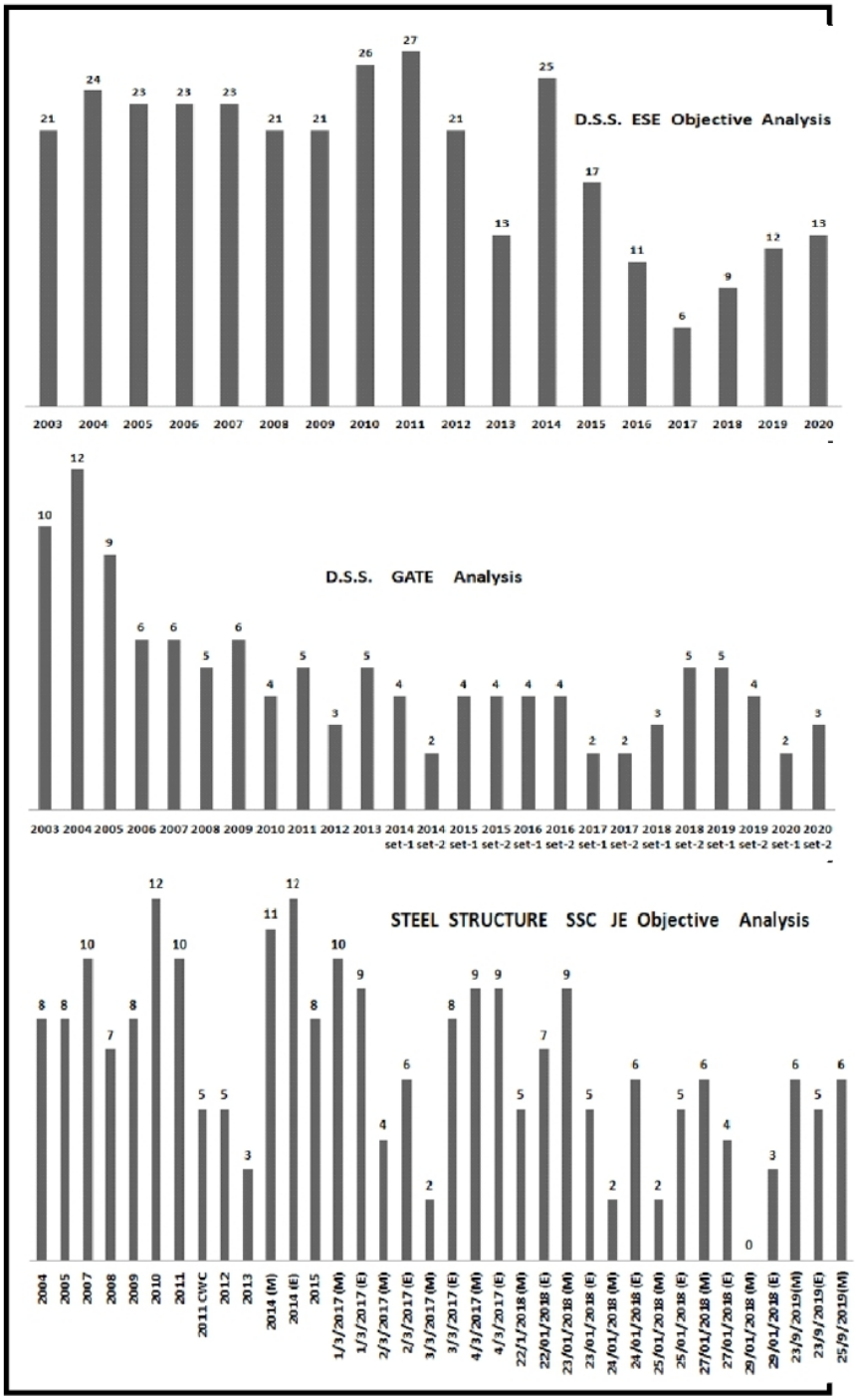
Potential energy:

- Internal capacity to do work by virtue of relative motion.

  Ex. Gravitation P.E = mgh.

Special Points:

- Centre of gravity of a body is the point through which the resultant gravitational force act
- Centre of gravity apply to the bodies with mass and weight
- Centroid is a point in a plane area such that the moment of area about any Axis through that point is zero. the term centroid applied to the plain areas
- When a rigid body is taken out in spacecraft its weight change


D.S.S. ESE Objective Analysis
21 24 23 23 23 21 21 26 27 21 13 25 17 11 6 9 12 13
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
D.S.S. GATE Analysis
10 12 9 6 6 5 6 4 5 3 5 4 2 4 4 4 4 2 2 3 5 5 4 2 3
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 set-1 2014 set-2 2015 set-1 2015 set-2 2016 set-1 2016 set-2 2017 set-1 2017 set-2 2018 set-1 2018 set-2 2019 set-1 2019 set-2 2020 set-1 2020 set-2
STEEL STRUCTURE SSC JE Objective Analysis
8 8 10 7 8 12 10 5 5 3 11 12 8 10 9 4 6 2 8 9 9 5 7 9 5 2 6 2 5 6 4 0 3 6 5 6
2004 2005 2007 2008 2009 2010 2011 2011 CWC 2012 2013 2014 (M) 2014 (E) 2015 1/3/2017 (M) 1/3/2017 (E) 2/3/2017 (M) 2/3/2017 (E) 3/3/2017 (M) 3/3/2017 (E) 4/3/2017 (M) 4/3/2017 (E) 22/1/2018 (M) 22/01/2018 (E) 23/01/2018 (M) 23/01/2018 (E) 24/01/2018 (M) 24/01/2018 (E) 25/01/2018 (M) 25/01/2018 (E) 27/01/2018 (M) 27/01/2018 (E) 29/01/2018 (M) 29/01/2018 (E) 23/9/2019(M) 23/9/2019(E) 25/9/2019(M)

Rivets

1

IS 432:1982 Mild steel and medium tensile steel.

Various physical properties of structural steel are given below.

Unit mass of steel, $\rho = 7850\ kg/m^3$

Modulus of elasticity, $E = 2 \times 10^5 N/mm^2$

modulus of rigidity, $G = 0.769 \times 10^5 N/mm^2$

Poisson ratio, $\mu = 0.3$

Coefficient of thermal expansion, $\alpha = 12 \times 10^{-6}/^oC$

Methods of design of steel frame work:

(a) Simple design

- Based on elastic theory & most uneconomical method
- No moment is transferred from the connected member to another connected member (for design purpose, structure is assumed to be pin jointed).
- All connection of beams, grider or trusses are virtually flexible.

(b) Semi-rigid design

- It ensure that partial flexibility is available at supports.
- It permits a reduction in maximum bending moments in beams suitable connected to supports due to partial transfer of mement to another connected member.
- It is economical than simple design.

(c) Fully rigid design method

- It involves the assumption of the end connections being fully rigid & capable of transmitting moments & shears.
- The end connection of the members of the frame should have sufficient rigidity to hold virtually unchanged original angles between such members & members they connect.
- It is used in convenient cases & given economy in the weight of steel & saves construction cost.

Wind pressure, $\boxed{P = KV^2}$

where, P = Wind pressure (in kg/cm^2),
V = Velocity of wind (in km/hr)
K = Constant of proportionality.

Note: As per IS 875 (Part III)

Design wind velocity (V_z)

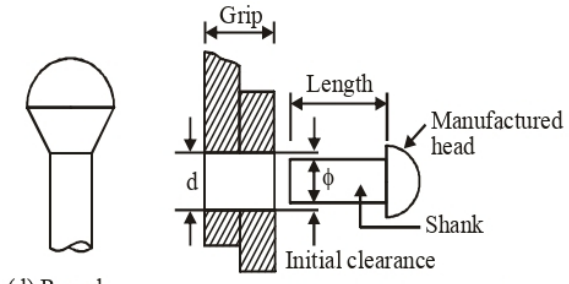
$$V_Z = V_b(K_1K_2K_3)$$

where, V_b = Basic wind speed (m/s)
K_1 = Probability factor or risk coefficient
K_2 = Terrain, height & structure size factor.
K_3 = Topography factor.

- Connections are made by either Riveting, Bolting or welding.

Riveting

Rivet is made up of a round ductile steel bar piece (mild or high tensile) called shank, with a head at one end.The size of a rivet is identified by diameter of shank.



(d) Round countersunk

(e) ϕ-Nominal diameter of rivet
d-Gross diameter of rivet

Rivet is classified as:

1. Hot driven field rivets.
2. Hot driven shop rivets.
3. Cold driven rivets.

Special Point: When the rivets are heated before driving, they are called hot driven field or hot driven shop rivets, depending upon if they are placed in the field or in the workshop.

When riveting is done at atmospheric temperature by large pressure to form the head & complete the driving. Such rivets are called cold driven rivets.

4. Hand driven rivets.
5. Power driven rivets

Cold driven rivets are used for rivet diameter ranging from 12 to 22 mm diameter.

Cold driven rivets are squeezed of driven to fill the holes & to form the heads by applicaion of large pressure.

Most important point is strength of cold driven rivets is more than hot driven rivets.

Strength calculation of rivet is done on the basis of gross diameter.

Nominal diameter (d): It is shank diameter in cold condition.Various diameters available are 8, 10, 12, 16, 18, 20, 22, 25, 30 mm.

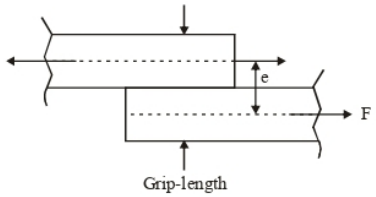
Gross diameter (d'): Diameter of the hole, considering that rivet fills the hole completely.

For $d \leq 25$ mm, $d' = d + 1.5$ mm, For $d > 25$ mm $d' = d + 2$ mm

As per Unwin's formula $\boxed{d_{mm} = 6.01\sqrt{t_{mm}}}$ Where t_{mm} = minimum thickness of the plates being connected.

Assumptions in riveted Connection

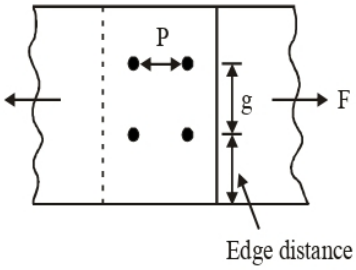
1. Friction between plates is neglected
2. Shear Stress is uniform over cross-section of rivet
3. Rivets in group subjected to direct load share the load equally (Infact Stress is equally Shared)
4. Bending Strees in rivet is neglected
5. Distribution of direct stress on the portion of plates between rivet hole is uniform.
6. Rivets fill the hole completely



Special Point: When the grip of the rivet is more than 6 times the diameter of hole, Number of rivets required by normal calculation should be increased by not less than 1% for each additional 1.5 mm of grip. Grip in any condition, should not exceed 8 times the diameter of holes.

Basic defination

Pitch: It is the distance between two consecutive rivetes in the direction of force.



Gauge:- It is the distance between two consecutive rivets Perpendicular to the direction of force.

Special Point:- Diagonal pitch is the distance between centres of two adjacent rivets in the diagonal direction.

Net area:- It is the area at the root of the thread.

Edge distance:- It is the distance between the edge of a member or Cover plate & the centre of the nearest rivet hole.

Slip factor:- It is coefficient of friction in friction type joint Rivet Value (R_v): It is the minimum strength of rivet in shearing or bearing

P_s = Strength of rivet in shear $P_s = n\frac{\pi}{4}d'^2\sigma_s$

n = 1, Single shear case, n= 2, Double shear case

σ_s = Allowable shear stress, d′ = Gross diameter

P_b = Strength of rivet in bearing

$$P_b = d't\sigma_{br}$$

σ_{br} = Allowable bearing resistance, d′ = Gross diameter

t = Minimum thickness of (sum of two cover plates, main plate)

Strength of Riveted joint : It is the minimum strength of plate in shearing & tearing . The shearing failure can be prevented by providing sufficient edge distance

Tearing strength: $P_t = (B - nd)t\sigma_{at}$

n = No. of holes

σ_{at} = Allowable tensile strength of plate.

Efficiency of joint

$$\eta = \frac{\text{minimum}\left(R_V, \text{Strength of plate}\right)}{\text{Strength of solid plate}}$$

Number of rivets (n) = Force/Rv

Maximum permissible stress in rivets & bolts (IS 800 : 1984)

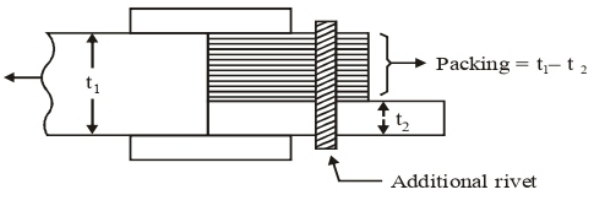
Type of faster	Axial tension σ_{at} (MPa)	Shear (MPa)	Bearing (MPa)
1. Power driven			
(a) Shop rivets	100	100	300
(b) Field rivets	90	90	270
2. Hand driven rivets	80	80	250
3. Close tolerance & turned bolts	120	100	300
4. Bolts in clearance holes	120	80	250

Permissible Stresses

Types of stresses	Notation	stress	FOS
Axial Tensile stress	σ_{at}	0.6fy	1.67
Max axial Comp Stress	σ_{ac}	0.6fy	1.67
Bending Tensile stress	σ_{bt}	0.66fy	1.515
Max Bending Comp. stress	σ_{bc}	0.66fy	1.515
Avg. shear stress	τ_{va}	0.4fy	2.5
Maximum shear stress	τ_{vm}	0.45fy	2.22
Bearing Stress	σ_{p}	0.75fy	1.33
Stress in slab base	σ_{bs}	185	–

Special Point: When wind & earthquake loads are considered, permissible stresses in steel structures are increased by 33.33% & in rivets & welds its increased by 25%.

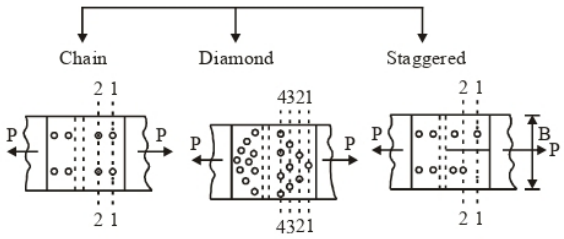
Packing:



If the difference between two plates to be joined ($t_1 - t_2 > 6$ mm), then additional rivet (over & above that required from normal calculations) shall be provided on Packing extension.

So, No. of additional rivets = 2.5% of actual no. of rivets obtained from normal calculation per 2 mm thickness of packing.

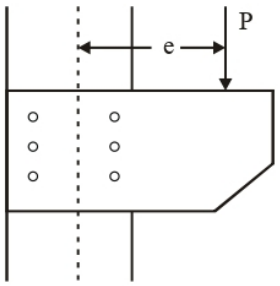
Patteren of riveted Joints:



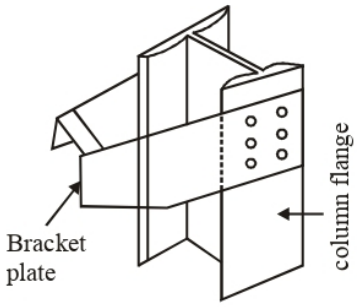
Eccentric Connection:

$$F_{Di} = \frac{PA_i}{\sum A_i}, \quad F_{Ti} = \frac{(Pe)r_iA_i}{\sum A_i r_i^2}$$

$$F_{ri} = \sqrt{(F_{Di})^2 + (F_{Ti})^2 + 2F_{D_i}F_{T_i}\cos\theta} \le R_v$$



Direct load + Twisting



F_{Di} = Direct force in i^{th} rivet & Acts in direction of applied load

F_{Ti} = Force in i^{th} rivet due to torsion & Acts perpendicular to the line joining C.G of rivet group & the rivet under consideration.

r_i = distance of ith rivet from C.G

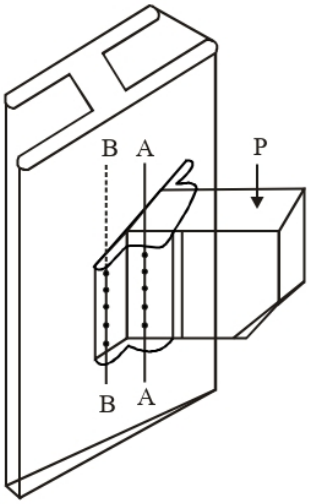
$$A_i = \frac{\pi}{4}(d_i)^2$$

Most critical rivet has maximum value of r & minimum value of θ

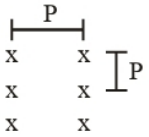
Rivets on Section A = Direct loading + Torsion

Rivets on Section B = Direct loading + Bending

Minimum No. of rivets in Direct load + Twisting case



$$n = \sqrt{\frac{6M}{mPR_v}}$$



M = Pe, R_v = Rivet Value
m = no. of lines of rivets = 2
n = no. of rivets in a line = 3
p = Pitch (Same in both direction)

Special Points :- For rivets subjected to combined shear & Tension

$$\frac{f_S(\text{calculated})}{\sigma_S} + \frac{f_t(\text{calculated})}{\sigma_t} \not> 1.4$$

f_t = Calculated tensile stress, f_s = Calculated shear stress

σ_S & σ_t = Permissible shear & tensile stress.

- IS 808:1989 Dimension for hot rolled steel beam, column, channel and angle section

Limit State Method of Design

2

Limitations of working stress method (WSM)

1. The main assumption of linear elastic behaviour (stresses can be kept within permissible limits) is not realistic.
2. In WSM there is no scientific basis for assumption of FOS. but in limit state method FOS is calculated from reliability analysis.

   The partial safety factory takes into account, possible overloads and possible understrength.
3. WSM fails to discriminate between various types of loads that act simultaneously , having different degree of uncertainty.

Partial safety factor load (γ_f)

$$\boxed{\text{Factored load} = \text{Characteristic laod} \times \gamma_f}$$

Combination	Limit State of Strength LL					Limit State of Serviceability			
	DL	Lead-ing	Combined (CL, SL, etc.)	WL/ EL	AL	DL	Lead-ing	Combined (CL etc.	WL/EL
DL+LL+CL	1.5	1.5	1.05	–	–	1.0	1.0	1.0	–
DL+LL+CL+ WL/EL	1.2 1.2	1.2 1.2	1.05 0.53	0.6 1.2	– –	1.0 –	0.8 –	0.8 –	0.8 –
DL+WL/EL	1.5 (0.9)*	–	–	1.5	–	1.0	–	–	1.0
DL+ER	1.2 (0.9)*	1.2	–	–	–	–	–	–	–
DL+LL+AL	1.0	0.35	0.35	–	1.0	–	–	–	–

*This value is to be considered when stability against overturning or stress reversal is critical

DL = Dead Load, SL = Snow Load, CL = Crane Load (Vertical/horizontal), AL = Accidental Load,

WL = Wind Load, EL = Earthquake Load., LL = Imposed Load (Live Loads), ER = Erection Load,

Partial safety factor for material strength (γ_m)

$$\text{Design strength} = \frac{\text{Characteristic Strength}}{\gamma_m}$$

S.No.	Definition	Partial Safety factor	
1.	Resistance, governed by yielding γ_m	1.10	
2.	Resistance of member to buckling γ_{m0}	1.10	
3.	Resistance, governed by ultimate stress	1.25	
4.	Resistance of connection :	Shop Fabrications	Field Fabrications
	(i) Bolts-Friction type, γ_{mf}	1.25	1.25
	(ii) Bolts-Bearing type, γ_{mb}	1.25	1.25
	(iii) Rivets, γ_{mr}	1.25	1.25
	(iv) Welds, γ_{mw}	1.25	1.50

*This value is to be considered when stability against overturning or stress reversal is critical

Various limit states in designing -

Limit states are the states beyond which the structure no longer satisfies the performance requirements specified. These are :

(a) **Limit state of strength** - which associated with failures, under the action of probable & most unfavourable combinations of loads on the structure. It includes strength, stability during sway, brittle failure, excessive deformation, stability against overturning & fracture due to fatigue.

(b) **Servicibility limit state -** It includes vibration, corrosion & durability, deflection & deformation and repairable damage due to fatigue cracking etc.

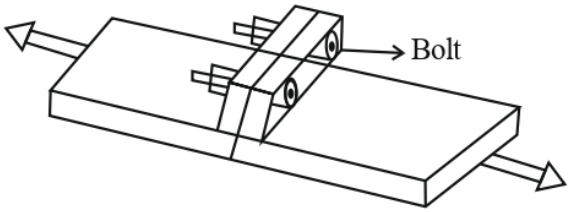
Bolts

3

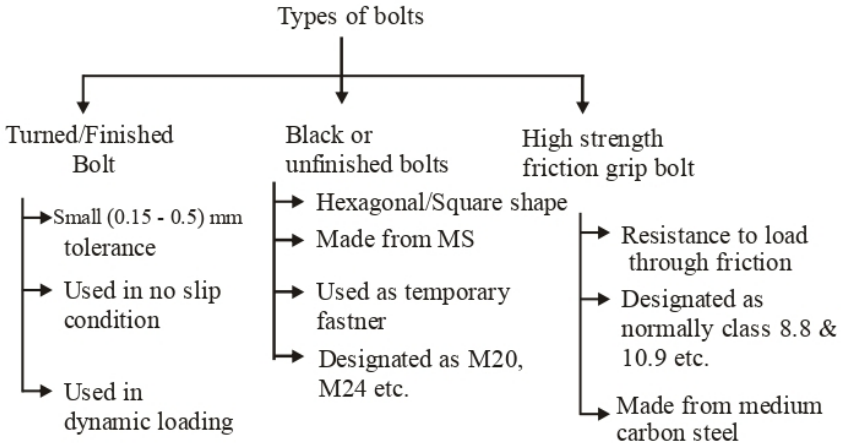
Bolts are used in place of rivets for structures not subjected to vibrations

- A bolt can be loaded in:

(i) Tension, (ii) Shear, (iii) Shear and tension both.



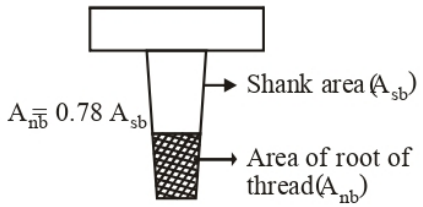
A bolt primarily designed to withstand tensile loading. Therefore, ideally the bolt should only be loaded in tension.

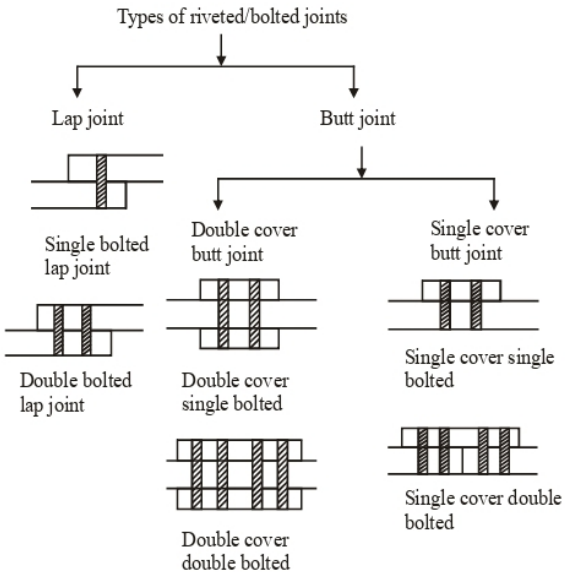


- For reversal of stresses, the most suitable bolt generally used in is HSFG bolt.

Diameter of bolt holes

Nominal diameter (mm)	12 14	16 20 24	30 36
Diameter of hole	13 15	18 22 26	33 39





S.No.	Lap joint	Butt joint
1.	Lap joint are less strength	A butt joint is very strong
2.	Number of Rivet required is less	Number of rivet required more
3.	In Lap joint cover plate are not required	In Butt joint cover plate are required
4.	Lap joint is less costly	Butt joint is high costly

Single and double cover butt joints both has eccentricity zero but, lap joint has an eccentricity. As compare to single cover butt joint, double cover butt joint is more efficient.

Advantages of welded joint over riveted joint:

(a) As no holes are required for welding, so the loss of member strength is smaller.

(b) The speed of fabrication is highter with the welding process.

(c) The welded connection look better than the usually bulky riveted joints.

(d) Welded joints are economical as less labour and material are required at joint.

(e) The welding process requires less working space than the riveting process.

(f) No noise is produced in the welding process as in the riveting process.

Specification in bolting

Minimum pitch = 2.5d

Maximum pitch

(a) Tension = min (16t, 200 mm)
(b) Compression = min (12t, 200 mm)
(c) When plates are used in tacking rivets:
(a) The tacking rivets are provided at a pitch in line should not more than 32 times the thickness of outside plate or 300 mm (whichever less)
(b) Where plates are exposed to weather, the pitch in line should not more than 16 times the thickness of the outside plate or 200 mm (whichever less)

Minimum edge & end distance

(a) Machine cut = 1.5 × hole dia
(b) Sheared or hand plane cut edges (Rough) = 1.7 × hole dia

Maximum edge distance = 12t ξ

Where, $\boxed{\xi = \sqrt{\frac{250}{f_y}}}$

t = thickness of thinner plate

Special Point: When members are exposed to corrosive environment, then maximum edge distance $\leq$ 40 mm + 4t (where t $\rightarrow$ thickness of thinner plate, mm)

The design strength of bearing bolts under shear is the least of the following
(a) Bearing strength
(b) Shearing strength

1. Nominal shear strength of bolt (V_{nsb})

$$V_{nsb} = \frac{f_{ub}}{\sqrt{3}}\left(n_n A_{nb} + n_s A_{sb}\right)\beta_{lj}\beta_{lg}\beta_{pk}$$

Factored shear strength

$$(V_{sb}) = \frac{V_{nsb}}{\gamma_{mb}}, \boxed{V_{sb} \le \frac{V_{nsb}}{1.25}}$$

Where,

f_{ub} = Ultimate tensile strength of bolt
n_s = No. of shear planes without threads intercepting the shear plane
A_{sb} = Nominal shank area
n_n = No. of shear planes with threads intercepting the shear plane
A_{nb} = Net tensile stress area

(a) β_{lj} → Reduction factor for long joints, applied when length of joint > 15 d

$$\beta_{lj} = 1.075 - \frac{0.005 l_j}{d}$$

Subjected to limits $0.75 \le \beta_{lj} \le 1.0$, l_j = length of joint

(b) β_{pk} — Reduction factor for packing plates, applied when thickness of packing plates > 6 mm

$$\beta_{pk} = 1 - 0.0125 t_{pk}$$

(c) β_{lg} - Reduction factor for large grip length, applied when grip length between 5d and 8d

$$\beta_{lg} = \frac{8d}{3d + l_g}$$

2. Nominal Bearing strength of bolt (V_{npb})

$$V_{npb} = 2.5 k_b d t_{min} f_u, \quad \left(V_{pb} \le \frac{V_{npb}}{\gamma_{mb}}\right)$$

t = aggregate thickness of connected plate experiencing bearing stress in same direction.
d = nominal diameter of the bolt
f_u = ultimate tensile stress of plate in Mpa

K_b = Smaller of $\left(\frac{e}{3d_0}, \frac{p}{3d_0} - 0.25, \frac{f_{ub}}{f_u}, 1\right)$, e = end distance

p = pitch, d_0 = hole diameter
f_{ub} & f_u = ultimate tensile stress of bolt & plate respectively

3. Nominal Tensile Strength of bolt (T_{nb})

$$T_{nb} = 0.9 f_{ub} A_{nb} < f_{yb} A_{sb} \left(\frac{\gamma_{mb}}{\gamma_{mo}}\right), \quad \left(T_{db} = \frac{T_{nb}}{\gamma_{mb}}\right)$$

A_{nb} = Net tensile area of bolt
A_{sb} = Shank area of bolt
f_{ub} = Ulimate tensile stress of bolt
f_{yb} = Yield stress of bolt
γ_{mb} = Partial safety factor for material of bolt = 1.25
γ_{mo} = Partial safety factor for material resistance governed by yielding = 1.10

Strength of plate (lesser of)

Shearing — Can be prevented by sufficient edge

Tearing — Rupture of plate

Block shear failure

1. Tensile strength of plate:-

$$T_{nd} = 0.9 A_n \frac{f_u}{\gamma_{m1}}$$

A_n = Net effective area in mm²
f_u = Ultimate strength of material
γ_{m1} = Partial safety factor = 1.25

Net effective area $A_n = (B - nd_h)t$ (For chain bolting)

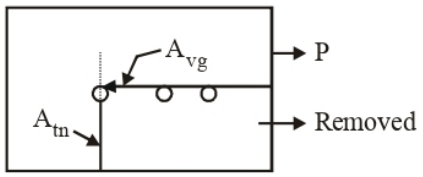
$$A_n = \left[B - nd_h + \sum_{t=1}^{m} \frac{p_{si}^2}{4g_1}\right] t$$

(For Staggered bolting)

2. Block Shear failure:- It is the minimum of strength due to

(a) Shear yield + Tension rupture

$$\frac{\frac{f_y}{\sqrt{3}} \times A_{vg}}{1.1} + \frac{0.9 f_u A_{tn}}{1.25}$$

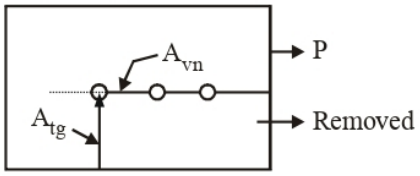


A_{tn} = Net section area in tension

A_{vg} = Gross section area in shearing,

(b) Shear Rupture + Tension yielding

$$\frac{0.9\frac{f_u}{\sqrt{3}} \times A_{vn}}{1.25} + \frac{f_y A_{tg}}{1.1}$$



A_{vn} = Net section area in shearing

A_{tg} = Gross section area in tension

Special Point:- Rupture always occurs on net area but yielding is considered to occur on gross area.

1.1 and 1.25 are FOS wrt yielding and rupture respectively.

Strength of plate in tearing without any deductions (P)

$$P = \min\left(\frac{f_y}{1.1} \times A_g, \frac{0.9 f_u A_{tn}}{1.25}\right)$$

Hence, $\boxed{P = \frac{f_y A_g}{1.1}}$ As gross-section yielding will always be Critical than net section rupture

Efficiency of joint

$$n = \frac{\text{minimum of (Strength of bolt, Strength of plate)}}{\text{Strength of plate in tearing without deductions}}$$

Welded Connections

4

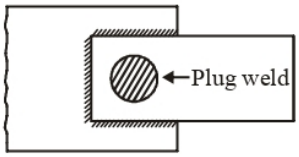
- Welding is the best method for achieving a rigid connection
- Classifications of welded joints based on various factors -

(a) **Position of weld** - Flat, overhead, vertical & horizontal welds.

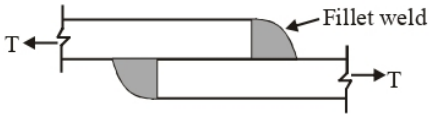
(b) **Types of weld** - Spot, plug , slot, fillet & groove (butt) welds.

(c) **Types of joint** - Butt, corner, Tee & lap welds.

- In Plug welds small holes are made in one plate and is kept over another plate to be connected & then entire hole is filled with filler material.



- Fillet welds are provided when two members to be jointed are in different place (lap joint)

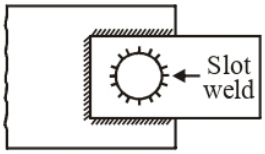


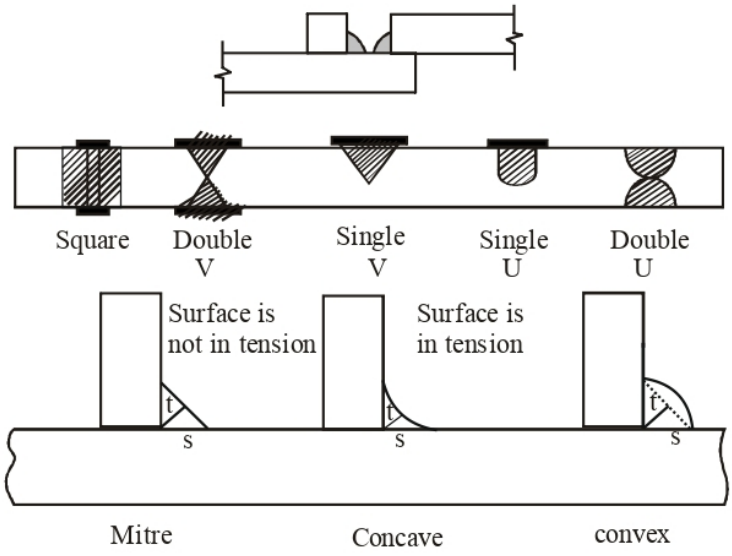
- Fillet weld is also called groove weld. It is provided when the members to be jointed are lined up (in one plane) (butt joint)



Single V_ Butt weld

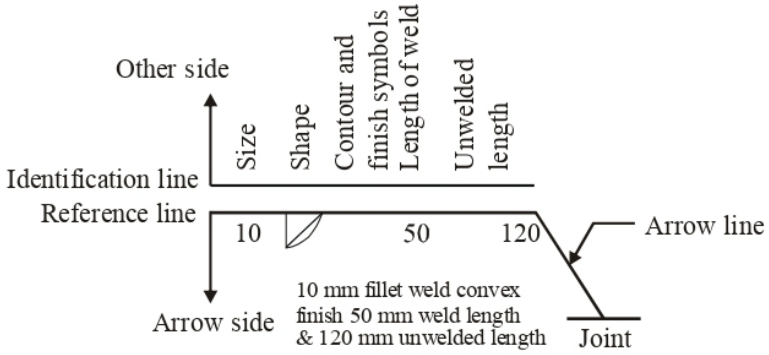
- In Slot weld fillet welding is made along the periphery of hole





Types of fillet welds

Method of Representation



Weld defects: Incomplete fusion, Slag inclusions, Porosity, Cracks and under cutting.

Specifications for Butt weld

Effective throat thickness:-

(a) **Incomplete penetration:-** It is the 5/8 times the minimum thickness of plates being joined.

(b) **Complete penetration:-** It is the thickness of thinner member joined.

Design Strength of butt weld (V_{dw})

$$V_{dw} = \frac{f_{yw1} L_w t_e}{\gamma_{mw}}$$

f_{yw1} = Smaller of Shear Stress of weld $\left(f_{yw}/\sqrt{3}\right)$ & the parent metal $\left(f_y/\sqrt{3}\right)$

γ_{mw} = Partial safety factor, Site welding = 1.5

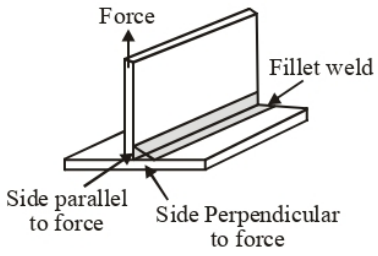
Shop welding = 1.25, f_{yw} = yield stress of weld

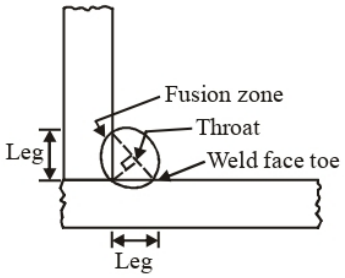
t_e = effective throat thickness in mm

Specifications for fillet weld

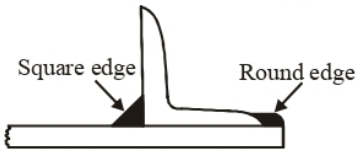
• Effective length is the length of the fillet weld for which the specified size & throat thickness of weld exist. It is considered equal to its overall length minus twice the weld size. The deduction is made to allow for craters to be formed at the ends of welded length. End returns are made equal to twice the size of the weld to relieve the latter from high stress concentrations at their ends.

- Throat of the fillet is the weakest section in a fillet weld:
- The theoretical throat of weld is the shortest distance from the root to the hypotenuse of the triangle.





Note: As per IS 800 – 2007 gives following provision for fillet welds:



1. If a fillet weld is applied to the square edge of a part, the specified

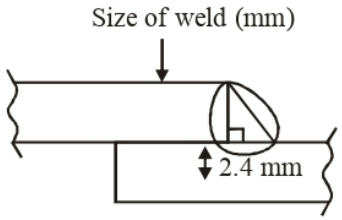
size of the weld should generally be atleast 1.5 mm less than edge thickness.

2. If the fillet weld is applied to the round toe of rolled section, the specified size of weld should not more than $\frac{3^{th}}{4}$ of thickness of section at toe.

Minimum size of weld:- depends on thickness of thicker member, but minimum size of fillet weld is 3 mm.

Thickness of thicker member	Minimum size
0 – 10	3
10 – 20	5
20 – 32	6
32 – 50	8 first run 10 second run

Size:- It is the minimum weld leg size in the largest right angled triangle that can be inscribed in the weld.



Special Point: In deep penetration weld where depth of penetration beyond the root run is minimum 2.4 mm, the size of weld is taken as 2.4 mm + minimum leg size.

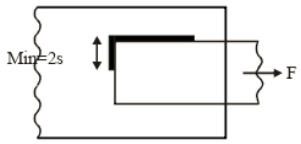
Effective throat thickness = K × size of weld

Angle b/w fusion faces	60° – 90°	91° – 100°	101° – 106°	107° – 113°	114° – 120
K	0.7	0.65	0.60	0.55	0.5

Special Point:- Fillet weld is not recommended if the angle of fusion faces is less than 60° or more than 120°.

Min. Overlap length → max (4 thickness of thinner plate), 40 mm)

Minimum end return = 2 × size of weld



Design strength of fillet weld:

$f_{wd} = \frac{f_{wn}}{\gamma_{mw}} = \frac{f_u}{\sqrt{3}\gamma_{mw}}$, throat area = $L_w \times KS$

so, design strength $= L_w(KS)\frac{f_u}{\sqrt{3}\gamma_{mw}}$

where L_w = effective length of the weld

If length of joint in the direction of load transfer is > $150t_t$, then length is decrease by a factor β

$$\beta = 1.2 - \left(\frac{l_j}{750t_t}\right) \leq 1.0$$

l_j = length of joint, t_t = KS = throat size of weld

Combination of stresses

(a) Fillet welds subjects to normal and shear stresses

$$f_e = \sqrt{f_h^2 + 3f_v^2} \leq \frac{f_u}{\sqrt{3}\gamma_{mw}}, \quad f_v = \text{Direct shear stress}$$

f_h = normal stress (compression or tension)

(b) Combined bearing, bending and shear

$$\boxed{f_e = \sqrt{f_b^2 + f^2{}_{br} + f_b f_{br} + 3q^2}}$$

f_b = calculated stress due to bending

f_{br} = calculated stress due to bearing, q = shear stress

Tension Member

5

1. Net area is effective in tension member
3. Permissible stress is fixed (0.6 f_y) and design is straight forward
2. There is no stability problem (as case of compression members) but slenderness ratio is limited to safeguard against buckling during transportation & erection.

Maximum slenderness ratio

Types of member	Max slenderness ratio
A tension member permanently in tension except pretessioned member	400
A member normally acting as a tie in a roof truss or bracing system. But subjected to possible reversal of stress resulting from the action of wind or earthquake forces	350
A tension member in which reversal of direcet stress due to loads other than wind or earthquake forces	180

Net sectional area (A_{net}):

$$A_{\text{net required}} = \frac{P}{\sigma_{at}}$$

σ_{at} = Permissible axial tensile stress

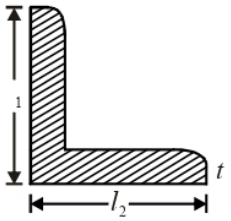
$A_{\text{net provided}} \geq A_{\text{net required}}$

(a) Net area for plate section

$$A_{net} = \left[b - nd_h + \Sigma \frac{p_i^2}{4g_i} \right] t$$

(b) Net area of angle section

· **Net Effective Area:**



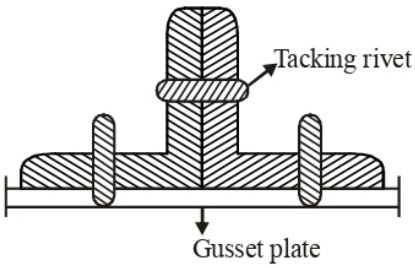
$$\boxed{A_{net} = A_1 + A_2 \times k_1}, \quad \boxed{k_1 = \frac{3 \times A_1}{3 \times A_1 + A_2}} \quad \boxed{A_1 = (l_1 - t/2)t}$$

$$\boxed{A_2 = (l_2 - t/2) \times t}$$

- For pair of Angle Placed back to back connected by only one lag of each angle.

$$\boxed{\bullet\ A_{net} = A_1 + A_2 \times k_2}, \quad \boxed{\bullet\ K_2 = \frac{5 \times A_1}{5 \times A_1 + A_2}}$$

The area of a web of Tee = Thickness of web × (depth - thickness of flange)



- The nonuniform straining of web due to tension is called shear lag.
- The shear lag reduces the effectiveness of the tension member (angle section) component that is not directly connected to gusset plate. For angle section, the unconnected leg is known as outstand leg.

Therefore, the contribution of outstanding leg in resisting tension is less than the connected leg by a factor which is known as k (reduction factor).

Permissible stress in design

The direct stress in axial tension on the effective net area should not exceed σ_{at}.

where $\sigma_{at} = 0.6\, f_y$, f_y = Minimum yield stress of steel in MPa

Allowable stress σ_{at} in Axial tension of steel

Form	Thickness / diameter	(mpa)
Plates, angles, tees & I–beams, channels and flats	upto & including 20mm	150
	20mm–40mm	140
	over 40mm	138
Bars (round, Squa–re & hexagonal	upto & including 20mm	150
	over 20 mm	144

Lug Angle: It is a short length of an anlge between section used at a joint to connect the outstanding leg of a member, by reducing the length of the joint.

- Lug Angle should be provided at the beginning of Joint, so-that It can be effictively sharing the given load
- Lug Angle are not very effective to transfer the given load due to eccen-tricity of C.G. of rivets.

Strength of tension member: It is the minimum of the following

1. **Net section rupture**

(a) For plates $\boxed{T_{dn} = \dfrac{0.9 A_n f_u}{\gamma_{m1}}}$

T_{dn} = Design rupture strength

A_n = Net effective area, f_u = Ultimate strength of material

γ_{m1} = Partial safety factor in rupture = 1.25

(b) For Angles

$$T_{dn} = \frac{0.9 A_{nc} f_u}{\gamma_{m1}} + \frac{\beta A_{go} f_y}{\gamma_{m0}}$$

Where, $\beta = 1.4 - 0.076 \left(\dfrac{W}{t}\right)\left(\dfrac{b_s}{L_c}\right)\left(\dfrac{f_y}{f_u}\right)$

$$\leq \left(\frac{f_u}{\gamma_{m1}}\right) \times \left(\frac{\gamma_{m0}}{f_y}\right)$$

$$\geq 0.7$$

A_{nc}=Net area of connected leg

t = Thickness of angle leg

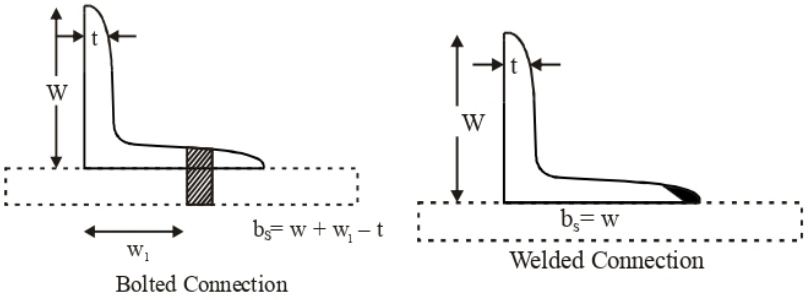
A_{go}= Gross area of outstanding

L_c = Length of end connection

W = Outstand leg width

b_s = Shear leg width

Special Point: The connected leg undergoes rupture (Net area is used) but outstanding leg undergoes yielding (gross area is used)



For prelilminary sizing of a tension member, the tearing strength of net section may be expressed as

$$\boxed{T_{dn} = \alpha \frac{A_n f_u}{\gamma_{m1}}}$$

where, α = 0.6 for number of bolts $\leq$ 1 or 2

= 0.7 for 3 bolts

= 0.8 for number of bolts $\geq$ 4

or equivalent weld length

2. Gross - Section yielding

$$\boxed{T_{dg} = \frac{A_g f_y}{\gamma_{mo}}}$$

γ_{mo} = 1.1, A_g = Gross-sectional area

3. Block Shear failure

(a) **For Angles:**- Appropriate areas in shear & tension should be considered for failure. But in welded angle tension members, it is the gross area only that is involved (No concept of net area).

(b) For plates

(1) Shear yielding + Tension rupture.

(2) Tension yielding + Shear rupture.

Compression-Members

6

- The principal compression member of a crane is called boom.

Effective length:- It's the distance between point of contra-flexures.

End condition	One end fixed one end free	Both end Hinged	Both end Fixed	One end fixed one end Hinged
L_{eff} (Theoretical)	2L 	L 	L/2 	$\frac{L}{\sqrt{2}}$ 
L_{eff} (As per IS code.)	2L	L	0.65L	0.8L

Effective length of struts

Slendemess ratio (λ): It's the ratio of effective length to appropriate radius of gyration.

$$\boxed{\lambda_{max} = \frac{l_{eff}}{r_{min}}}, \quad r_{min} = \sqrt{\frac{I_{min}}{A}}$$

Maximum Slenderness Ratio (λ_{max}) for compression Members

- Buckling of a member in compression always occurs about minor principle axis. For minor principle axis, area of moment of inertia is minimum. So, radius of gyration is minimum. (slenderness ratio is maximum).

Member	λ_{max}
A member carrying compressive load resulting from dead load and imposed load	180
A tension member in which reversal of direct stress due to load other than wind and seismic force	180
A member subjected to compressive forces resulting from wind EQ force provide deformation of such member does not affect stress	250
Compression flange of Beam against laterial torsional buckling.	300
Tension member other than Pre-tension	400

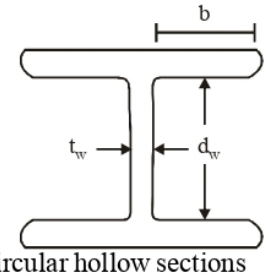
For prevention of local buckling of flange or web:

$$f_{cr} = \frac{K\pi^2 E}{12\left(1-\mu^2\right)\left(\frac{b}{t}\right)^2}$$

f_{cr} = critical stress, K = depends on support conditions

Special Point: The critical stress at which the plate buckles is inversely proportional to $(b/t)^2$

To prevent the buckling of flange plate and web plate



$\frac{b}{t_f} \not> 16$ $\frac{d_w}{t_w} \not> 50$

1. For circular hollow sections

   If $\frac{D}{t\varepsilon^2} > 88$, then it is a slender section and its $A_{eff} = A_g \sqrt{\frac{88}{D/\left(t\,\varepsilon^2\right)}}$

2. For slender cross-section other than circular hollow section

$$A_{eff} = \Sigma B_{eff}\, t$$

λ_t = limiting width to thickness ratio of semi-compact section

B_{eff} = Effective width of slender element, $B_{eff} = (\lambda_L t \times \varepsilon \le b)$

ε = modification factor for yield strength of material $\varepsilon = \sqrt{\frac{250}{f_y}}$

Rankine Merchant formula (for permissible compressive stress)

$$\sigma_{ac} = 0.6\frac{f_{cc}f_y}{\left[(f_{cc})^n + (f_y)^n\right]^{1/n}}$$

$f_{cc} = \frac{\pi^2 E}{\lambda^2}$ Elastic critical stress in compression

n = factor assumed as 1.4 (General range b/w 1-3)

Design recommendations for tack riveting

1. Slenderness ratio (λ) of each component between tack riveting should be such that

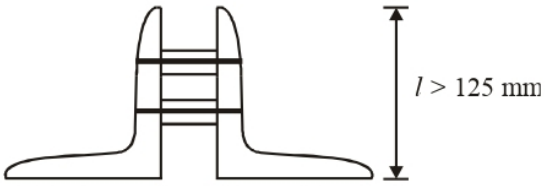
$$\lambda < 40,\ \lambda < 0.6\ (\lambda_{\text{whole section}})$$

2. The diameter of tack rivet should not be less than the minimum value given below

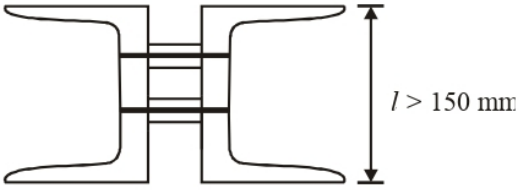
Thickness of member	Min.dia
Upto 10mm	16
10 - 16	20
> 16 mm	22mm

3. Two rows of tack rivets are provided if

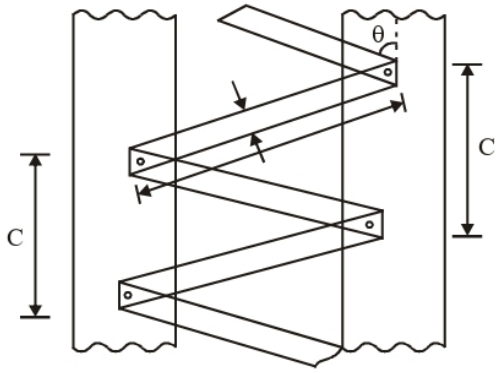
(a) Length of leg in angle > 125 mm



(b) Web of channel > 150 mm



Design recommendations for lacing



(1) The effective slenderness ratio of laced column shall be considered 1.05 times the actual maximum slenderness ratio due to the shear deformation effect.

(2) In lacing, length of column is increase by 5% of the effective length of column.

(3) The lacing shall be design to resist transverse shear V_t, at any point in the member, which is equal to atleast 2.5% of axial force in the member. If there are two transverse parallel system, then each system should resist $\frac{V_t}{2}$ of transverse shear.

(4) If column is subjected to bending also, then V_t= Bending shear + 2.5% of column force.

(5) As far as possible, the lacing system shall be uniform throughout.

(6) The effective length of single lacing in laced system is equal to the length between the inner end fasteners.

For double lacing system, it should be considered 0.7 times of this length.

In welded condition, the effective length shall be taken 0.7 times the distance between the inner ends of welds connecting the single lacing bar to the members.

(7) In single lacing system, the direction of lacing on opposite faces should be shadow of each other. It should not be mutually opposite.

(8) The slenderness ratio $\left(\frac{kL}{r}\right)$ for lacing bar shall not exceed 145.

(where $r = \frac{t}{\sqrt{12}}$) for flats where t = thickness of flat plate.

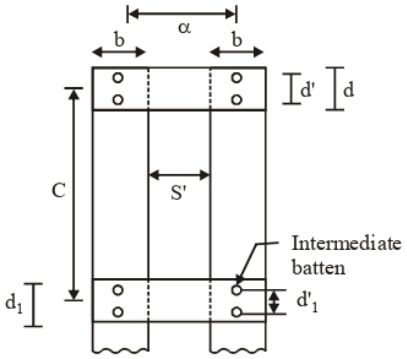
(9) The maximum spacing of lacing bar shall be such that the maximum slenderness of the main member between consecutive lacing connection is not larger than 50 or 0.7 times the most unfavourable slenderness ratio of the member as a whole.

(10). θ should be between 40° - 70°

(11).Minimum width of lacing bar (Generally 3 times of dia of rivet).

Diameter of rivet	Min width
16	50
18	55
20	60
22	65

Design recommendations for batten



1. Effective length of battened column is taken 10% more than the actual column but for lacing, it is 5% more.
2. $\frac{C}{(r_{min})} < 50, < 0.7(\lambda \text{Whole Section})$
3. Minimum number of battens required is 4 (2 end battens & 2 intermediate battens).
4. Thickness t of battens should not be less than 1/50 of the distance between the innermost connecting lines of rivets/bolts or welds perpendicular to main member.
5. **Depth:-**

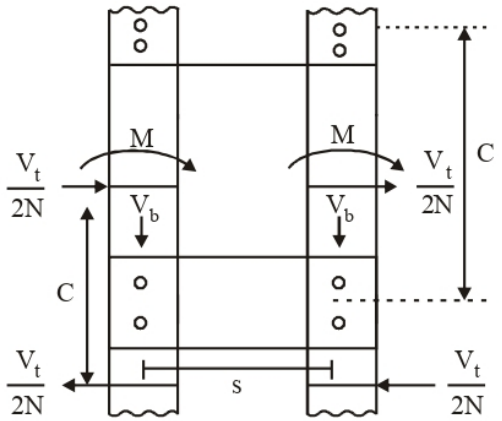
$d_1 < \frac{3}{4}\alpha$ $\quad$ $d < \alpha$

$< 2b$ $\quad$ $< 2b$

α = distance between C.G of component members.

b = width of member in plane of battens (flange width)

Special Point: Battens are designed only for axial loading as well as longitudinal shear & moment while but laced columns are designed for axial force & BM is zero in lacing to ensure zero BM in lacing provide one rivet at each and as far as possible.



Forces acting on batten

1. Designed to carry Bending moment & shear force arising from transverse shear force V_t which is 2.5% of total axial force on whole compression member.

2. $V_b = \frac{V_t C}{NS}$, $M = \frac{V_t C}{2N}$

   N = No. of parallel planes dividing the transverse shear force.

   V_b = longitudinal Shear force

3. $\frac{V_b}{A_t} < \frac{f_y}{\sqrt{3}\gamma_{mo}}$

   where, A_t = td, d = Overall depth of batten.

   t = thickness of batten

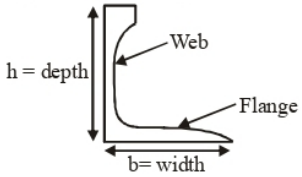
4. $\sigma_{bc,cal} = \frac{6M}{td^2} < \frac{f_y}{\gamma_{mo}}$

Bulb angle

Bulb angles are used in ship building because

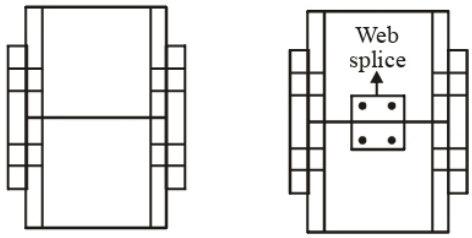
(a) When the structure is under extreme stress and starts to buckle, this shape is highly resistant & increases the longevity of the structure.

(b) They provide better plate stiffening.



Column Splice

- A joint provided in the length of the column is called splice.
- Theoretically, a splice plate should be located at the point of contraflexure of the column.
- A column splice is used to increase the length of the column.
- Column splices are located just above the floor beam connections, usually about 2 to 3 feet above the floor.



Column splice (Column flange having complete bearing)

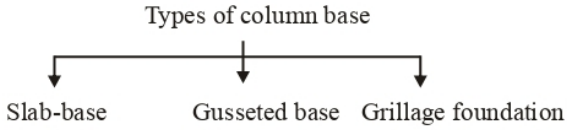
Web splice for shear

- Column section is spliced when the length of the column is more than the length of the column section available, a number of pieces are jointed to funish the full length of the column.
- Laced column are inclined member. Therefore, axial load in laced column is lesser than as compared to battened column.

Column Bases and Caps

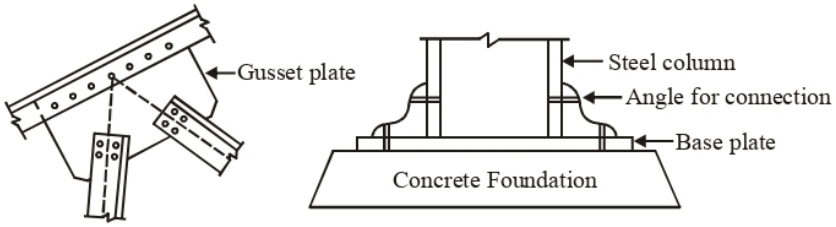
7

Sufficient fastening are provided to retain the column firmly on the base plate and resist all moments and forces (except direct compression in the column) arising during transit, unloading and erection.



(a) Gusset plate: It is a thick steel sheet used for joining two or more than two adjacent structural member when they are intersecting each other.

It may be fastened to a permanent member by bolts, welding or rivets or combination of these three.



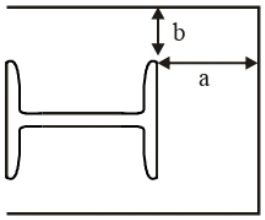
(b) Anchor plate: It is a steel plate attached to or embedded in a support & used as an anchor for supporting cables.

(c) Base plate: It is used to connect a column with a RCC foundation & they are installed below the steel column on RCC foundation.

When we provide a base plate under a column, the load gets dispersed to a larger area & after that it is transferred to concrete foundation. So system is safe.

1. When only axial load is acting

(a)



$$t = \sqrt{\frac{3w}{\sigma_{bs}}\left(a^2 - \frac{b^2}{4}\right)}\,(\text{WSM}),\quad t = \sqrt{\frac{2.5w\left(a^2 - 0.3b^2\right)}{f_y / \gamma_{m_0}}}\,(\text{LSM})$$

t = slab thickness in mm

$$w = \frac{P}{B^2\,(\text{assume B})}\ (\text{in WSM}),\quad w = \frac{1.5P}{\text{Area}}\ (\text{in LSM})$$

where, $B^2 > P/\sigma_c$ and $\left(\sigma_c = f_{ck}/4\right)$

a= Greater projection of plate beyond column

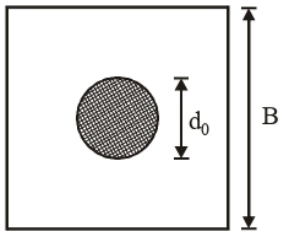
b =Lesser projection of plate beyond column

σ_{bs} = permissible bending stress in slab bases

= 165 Mpa for flanged beams.

= 185 Mpa for solid beams

(b) Square slab base under solid round column



$$t = 10\sqrt{\frac{90W}{16\sigma_{bs}}\left(\frac{B}{B - d_0}\right)}$$

$B \geq 1.5\left(d_0 + 75\right)$ mm

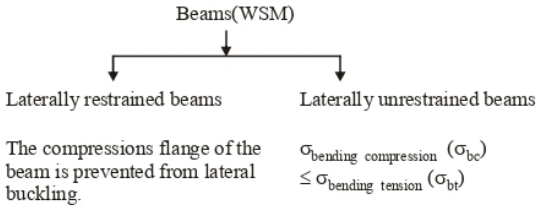
B = Length of the side of the cap or base.

W = Total axial load (KN)

d_0 = Diameter of the reduced end.

Beams (WSM)

8



Primary design criteria for design of beams

.Safety against bending

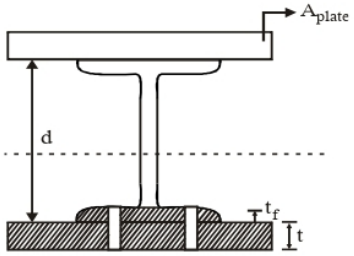
Maximum permissible compressive or tensile bending stress

$\sigma_{bc} = \sigma_{bt} = 0.66 f_y$

Permissible bending stress (IS 226 - 1975)

Nominal Thickness of plate	Yield Stress (f_y Mpa)	$\sigma_{bc} = \varepsilon_{bt}$
Angle, Tee, I, Channel & flat sections upto and including 20mm	250	165
From 20-40 mm	240	158.4
Over 40mm	230	151.8

For designing of rolled Sections for bending moment



Area due to holes = 2d (t + t_f)

$$A_{p\ required} = \frac{Z_{required} - Z_{rolled}}{d}$$

$$\frac{my_t}{I_{gross}} \times \left\{ \frac{\text{Gross area of tension flange}}{\text{Net area of tension flange}} \right\} \le \sigma_{bt}$$

Net area of tension flange = Gross area for tension – Area due to holes

Safety against Shear

Max. permissible average shear $\tau_{va} = 0.40\ f_y$

Max. permissible shear stress $\tau_{vm} = 0.45\ f_y$

Safety against deflection:-

The maximum allowable vertical deflection under live load for a cantilever member supporting brittle cladding in an industrial building is $\frac{Span}{150}$

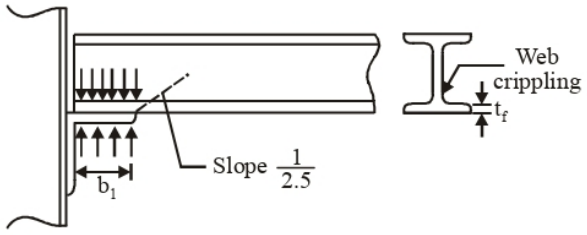
Maximum permissile deflection in simply supported steel beam = $\frac{\textbf{span}}{\textbf{325}}$

Some of the reasons for limiting deflections are:

(a) Excessive deflection may create problems for floor or roof drainage.
(b) Excessive deflection may lead to crack inthe plaster of ceilings & may damage the material attached to or supported by the beam.
(c) There may cause undersirable twisting and destortion of connections and connected materials.

Web crippling: It occurs due to a concentrated load on the beam, due to reaction at support, high compressive stresses are produced in the web near to the upper flange or lower flange.

- The crippling occurs at the root of the radius



- According to IS: 800-2007, accepted formulae to find crippling of web.

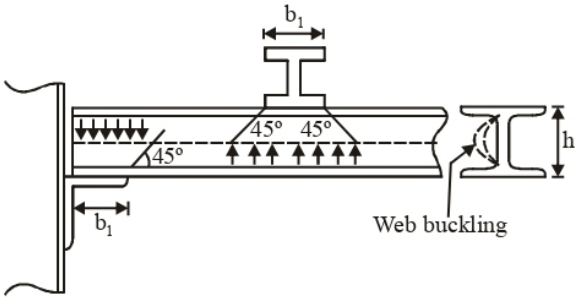
$$f_w = (b_1 + n_c)t_w \times \frac{f_{yw}}{\gamma_{mo}}$$

where, b_r = Stiff bearing length, f_{yw}=Yield stress of web

η_c = Length obtained by dispersion through the flange to web junction at a slope of 1 :2.5 the plane at flange.

$\eta_c = 2.5\ t_f$

Web buckling - It is the sudden sideways deflection of a structural member under the application of compressive load used.



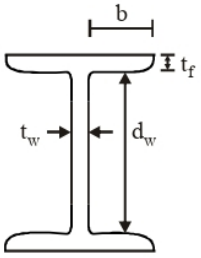
Generally, if the web is safe in crippling, it will be safe in buckling also.

(1) Local flange buckling is due to bending compression.

(2) Web buckling is due to diagonal compression.

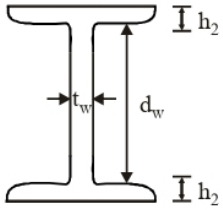
(3) Web crippling is due to bearing stress.

Safety against local buckling



$$\frac{b}{t_f} \not\geq 16 \qquad \frac{d_w}{t_w} \not\geq 50$$

Safety against web buckling

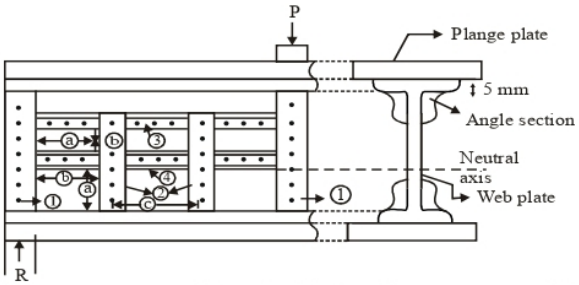


$$l_{eff} = \frac{d_w}{2} \quad r_{min} = \frac{t_w}{\sqrt{12}}$$

Plate-Girders

9

Generally it is used when bridge span > 20 m.



(a)- larger unsupported length, (b)-Smaller unsupported length
(c)- Spacing between vertical stiffners
(1)-Load bearing stiffner, (2)-Vertical stiffners, (3)-1st horizontal stiffner, (4)-2nd horizontal stiffner

- The girders having two or more than two webs are called box girder
- Usually a plate girder is called as economical if it corresponds to minimum weight. L/15 is the depth of plate girder in buildings.

Special Point:

$$a \not> 270\, t_w, \; b \not> 180\, t_w$$

For stiffned web avg. permissible shear depends upon d/t & c but for unstiffened web avg. permissible shear is $0.4f_y$.

Delection limits for gentry girders

Category	Maximum deflection
Vertical deflection	
(a) Manually operated cranes	Span/500
(b) Electrically operated cranes upto 500 kN	Span/750
(c) Electrically operated creanes over 500 kn	Sapn/1000
Relative displacement between Rails supporting crane	10 mm or span/400

Design of web: Average shear stress in the web $\tau_{va,cal} = \frac{V}{d_w \times t_w}$ permissible average shear stress, τ_{va}.

(i) $\frac{d_1}{t_w} \le$ lesser of $\left(\frac{816}{\sqrt{\tau_{va,cal}}}, \frac{1344}{\sqrt{f_y}}, 85\right)$ No stiffner will be required

(ii) $\frac{d_2}{t_w} \le$ lesser of $\left(\frac{3200}{\sqrt{f_y}}, 200\right)$. Vertical stiffners are provided.

(iii) $\frac{d_2}{t_w} \le$ lesser of $\left(\frac{4000}{\sqrt{fy}}, 250\right)$. Vertical stiffners alongwith one longitudinal stiffener @ 0.2D

(iii) $\frac{d_2}{t_w} \le$ lesser of $\left(\frac{6400}{\sqrt{fy}}, 400\right)$. Vertical stiffners alongwith two longitudinal stiffener @ 0.2D & 0.5D, respectively.

d_2 = 2 × clear distance from compression flange angles or plate to the neutral axis.

Special Point: Vertical stiffner & first horizontal stiffner are provided at a distance from the compression flange equal to (1/5) of the distance from the compression flange to the neutral axis

(a) Design of vertical stiffners:-

1. Spacing between vertical stiffners should be such that average shear is greater than $\frac{V_{max}}{d.t}$
2. Vertical stiffers can be provided at angles on 2 sides of web plate.
3. The maximum & minimum distance between vertical stiffners is 1.5d and 0.33d respectively.
4. If it is to be provided on one side only, it is to be staggered.
5. Vertical stiffner should have size such that $I_{\alpha\alpha} = \frac{1.5d^3 t_\omega^3}{c^2}$

For design of of connections for vertical stiffner.

$125\frac{t_\omega^2}{h} \times p \le R_v$

1. Consider diameter of rivet and get Rivet value R_v

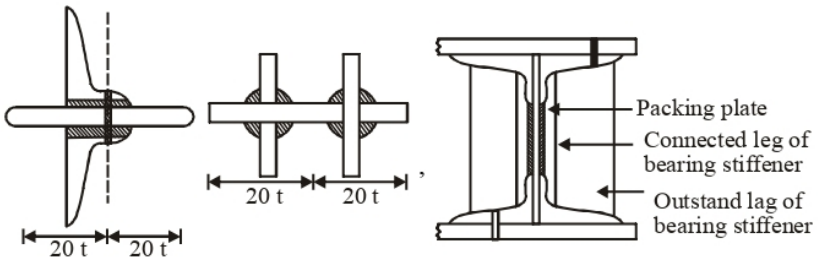
2. h = outstand of stiffner from the web, h $\leq$ 16t for angles, h $\leq$ 12t for flats.
3. Then Get pitch p.

(b) Design of horizontal stiffner:-

1. For first horizontal stiffner $I_{\alpha\alpha} \geq 4ct^3$
2. For second horizontal stiffner $I_{\alpha\alpha} \geq d_2 t_w^3$ Connection of horizontal stiffner with web is similar to that of vertical stiffner with web.

(c) Design of load bearing stiffner

- Bearing stiffeners are used to transfer concentrated loads on girder & heavy reactions at support to the full depth of the web. A bearing stiffener at the support is called an end bearing stiffener.
- The bearing stiffeners are designed as columns with the length of the web 20 times the thickness of web on both sides.



- Bearing stiffeners should be placed
  (a) Straight (it is not crimped) , (b) Tight with the web
  (c) In pair of two or four angles, symmetrically placed on both sides of the web.

1. $r_{min} = \sqrt{\dfrac{I_{\alpha\alpha}}{\text{Shaded Area } (A_e)}}$
2. $\lambda = \dfrac{l_{eff}}{r_{min}}$, where $l_{eff} = 0.7l$
3. $\sigma_{ac} . A_c \geq$ P or R as the case may be

(d) Web splices are designed for shear but flange splices are designed for moment.

Industrial Building

10

We adopt windows on north side in such a way that diffused light comes inside the building which creates no shadow and hence dark pockets are avoided.

$$\text{Slope of the truss} = \tan\theta = \frac{2H}{L}$$

$$\boxed{\text{Slope} = 2 \times \text{Pitch}}$$

$$\text{Pitch of the truss} = \frac{H}{L}$$

Special Point: For Galvanised Iron sheet pitch is 1/6 but for asbestos cement sheet, roof covering, flatter pitch of 1/12 is preferred.

Economy of the roof

$$\text{Cost of truss/unit area} = \frac{\text{Cost of purlin}}{\text{Plan area}} \times 2 + \frac{\text{Cost of roof covering}}{\text{Plan area}}$$

$$\text{Spacing of truss (d) - for spans upto 12 m } d = \frac{\text{span}}{4}$$

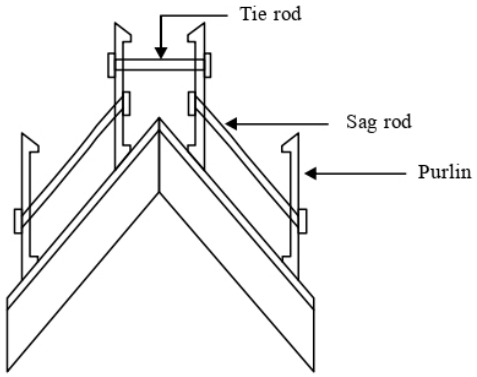
$$\text{for spans} > 15 \text{ m } d = \frac{\text{span}}{5}$$

Rafter: They supports the purlins. They are mainly compression member and may be subjected to shear and bending moment if the purlins are not placed at nodal points.

Struts: The member carrying compressive forces in a roof truss are called struts.

Sag tie: To reduce deflection and moment due to self weight. Sag rods are desgined as tension member.

At the crown, sag rod provided is termed as tie rod, it resists the tangential components from the two sides of the roof truss.



Spceial Point : According to IS specifications, for roofs of slope greater than 10° for every additional degree rise, the imposed load is reduced by 0.02kN/m²

Purlins: Member of truss which are supported on the principal rafter and which transverse loads to the truss.

(a) It is a biaxial bending member. It is located at the panel point of the truss.The span of purlin is centre to centre of truss.
(b) Maximum spacing between purlins < 1.4m
(c) Angle, Channel, I and Z Sections are used for purlins and girders to support the cladding
(d) If roof slope < 30° and minimum live load of 750 N/m². Then following reqirements are to be fulfilled (then uniaxial bending design)

1. Width of angle leg in the plane parallel to the roof covering $\geq \frac{L}{60}$
2. Width of angle leg in the plane perpendicular to the roof covering $\geq \frac{L}{45}$
3. Maximum bending moment in the prulin $M = \frac{wL^2}{10}$, L = Span of purlin, w = uniformly distributed load per unit length on purlin
4. Deflection of purlins $= \frac{span}{180}$ (For Brittle cladding)
5. Z_x required $= \frac{M}{\sigma_{bc}} = \frac{wL^2}{10 \times 165} mm^3$

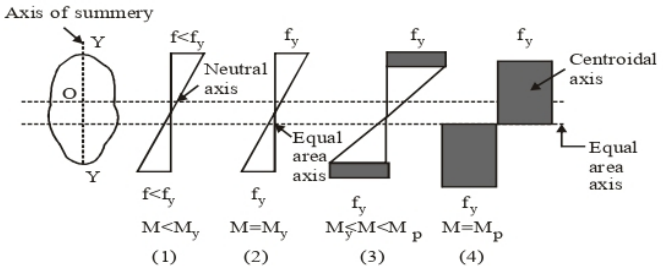
Plastic-Analysis

11

Assumptions in Plastic Analysis:

1. Stress-strain curve is elasto-plastic curve (strain hardening is neglected)
2. Relationship between tensile stress and tensile strain, compressive stress and compressive strain are same.
3. Steel possess ductility so that it could be deformed into plastic state
4. Strain variation is linear from Neutral axis.
5. Joint should be sufficiently strong to transfer the moments

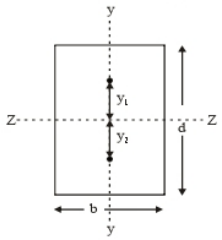
Plastic behaviour of beam



[Development (in stages) of full placticity of a beam section]

Plastic moment $M_p = \frac{f_y A}{2} (\bar{y}_1 + \bar{y}_2) = f_y Z_p$,

$\bar{y}_1$, $\bar{y}_2$ = distance of centre of gravity of the area above & below the neutral axis respectively



$Z_{p(\text{about major zz axis})} = \frac{d^2 b}{4}$, $Z_{p(\text{about major yy axis})} = \frac{db^2}{4}$

Plastic Hinge: It is a yielded zone in flexure in a structure in which infinite rotation can take place at a constant resisting moment M_p of the section.

1. For analysis plastic hinge is assumed at one section where stress at every point is f_y.
2. In a beam, if plastic hinge is formed at various locations then they will form alternatively due to sagging and hogging moment.
3. Moment will be maximum, if radius of curvature is minimum or curvature (1/R) is maximum.
4. Length of plastic hinge depends on loading and shape of crosssection.
5. Sufficient no of plastic hinges have to be developed to render the structure to a collapse or unstable state.
6. No of plastic hinges for complete collapse = $D_s + 1$
   D_s = degree of static indeterminacy.
7. Due to formation of plastic hinge one after another redistribution of moments takes place.
8. Plastic hinges are expected to form at
   (a) At fixed ends
   (b) At a section of sudden change in geometry.
   (c) At location of point loads
   (d) At a point of zero shear in the span loaded with variable loads like UDL, UVL etc.
9. When two section meet at a point, plastic hinge forms in a section having smaller M_p.

Shape factor $(\alpha) = \dfrac{M_p}{M_y} = \dfrac{\text{Plastic moment capacity}}{\text{Yield moment capacity}} = \dfrac{Z_p}{Z_y}$

It represents the reserve strength of a section beyond the point of first yield.

$$\text{Reserve strength } (\psi) = \frac{\text{Ultimate load } (W_u)}{\text{Load at first yield of structure } (W_y)}$$

$$\text{Load factor } (\lambda) = \frac{\text{Collapse load } (W_c)}{\text{Working load } (W_o)}$$

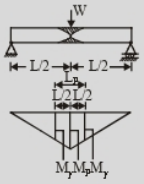
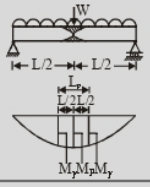
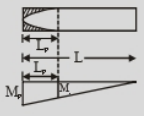
When all the hinges required for collapse are formed simultaneously, then

$$\boxed{\text{Load factor } (\lambda) = \text{Factor of safety} \times \text{shape factor } (\alpha)}$$

Shape factors for different shapes

	Section	Shape factor
1.	Rectangular Section	1.5
2.	Solid circular Section	1.7
3.	Triangular Section (vertex upward)	2.34
4.	Hollow circular Section	$1.7\times\left(\frac{1-k^3}{1-k^4}\right)$
5.	a. Diamand Section Rhombus	2.00
	b. Thin Hollow Rhombus	1.50
6.	Thin Circular ring Solid	1.27
7.	I section	
	a. About strong Axis	1.12
	b. About weak Axis	1.55
8.	T Section.	1.90 to 1.95

Length of plastic hinge (L_p):- Length of beam over which the moment is greater than yield moment. (M_y)

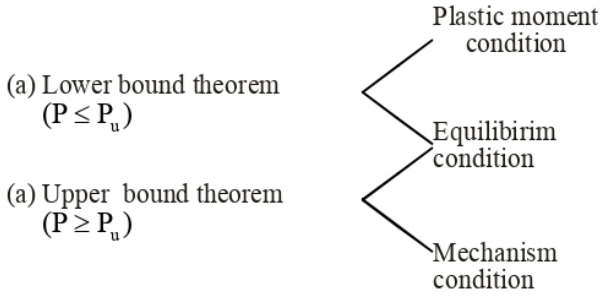
Support and loading condition	Elasto-plastic zone in beam (fig.)	Length of ealsto-plastic zone (L_p)
(a) Simply supported beam with concentrated load at mid span		Here S = shape factor = $\frac{M_P}{M_y}$
(b) Simply supported beam with UDL throughout the beam		$L_p = L\left(\sqrt{1-\frac{1}{S}}\right)$
(c) Cantilever beam subjected to point load at free end		$L_p = L\left(1-\frac{1}{S}\right)$

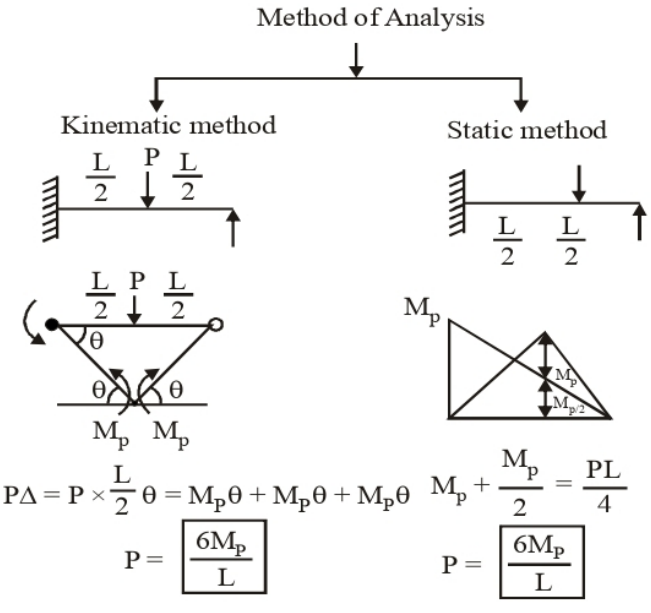
Conditions to be satisfied for complete collapse

1. **Equilibrium condition:-** $\sum F = 0$, $\sum M = 0$, both condition should be satisfied
2. **Yield condition:-** At collapse, bending moment at any section must not more than the fully plastic moment capacity of the section.
3. **Mechanism condition:-** At collapse sufficient no of plastic hinges must be developed so as to transform a part or whole of structure into mechanism leading to collapse.

Special Point: If all three conditions are satisfied we get a unique lowest value of collapse load.

Method of Analysis:

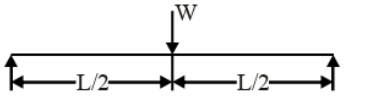




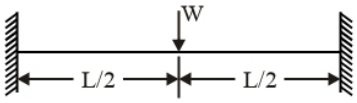
$$P\Delta = P \times \frac{L}{2}\theta = M_P\theta + M_P\theta + M_P\theta \qquad P = \boxed{\frac{6M_P}{L}}$$

$$M_p + \frac{M_p}{2} = \frac{PL}{4} \qquad P = \boxed{\frac{6M_P}{L}}$$

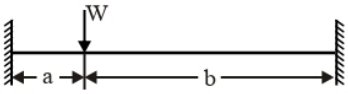
Collapse loads (W_c)



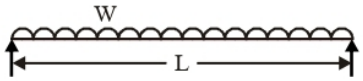
$$W_c = \frac{4M_P}{L}$$



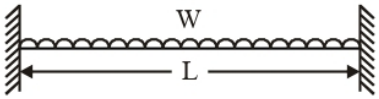
$$W_c = \frac{8M_P}{L}$$



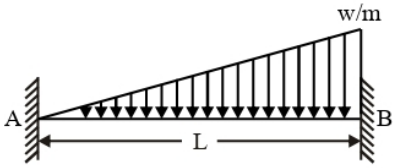
$$W_c = \frac{2M_P L}{ab}$$



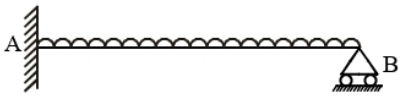
$$W_c = \frac{8M_P}{L^2}$$



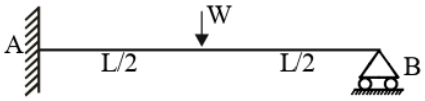
$$W_c = \frac{16M_P}{L^2}$$



$$W_c = \frac{18\sqrt{3}M_P}{L^2}$$



$$W_c = \frac{11.66M_P}{L^2}$$



$$W_c = \frac{6M_P}{L}$$

Auto-CAD

- Auto-Cad is a Commercial Computer -aided design (Cad) and drafting software application.
- Auto Cad - Automatic Computer Aided Design
- CADD - Computer Aided Design and Drafting
- CAD - Computer Aided Design
- Auto CAD was first developed by Autodesk in December 1982 and Latest Version Auto Cad - 2021 version 24.0 released on 25 March 2020
- Father of Auto Cad - **Mike Riddle**
- Founder of Autocad - **John Walker**
- Operating system - Windows, Macos, ios, Android

Type of Autocad

1. 2D CAD (Flat Drawing)
2. 2.5D CAD (Prismatic model)
3. 3D CAD (3D objects)
4. 3D Wireframe & surface modelling
5. Solid Modelling (Solid Geometry)

- Auto Cad file format - •*dwg*
- Auto Cad backup file format - •*BAK*
- Auto Cad Auto save file format - •*SV*$

Note:- The Character limit for file is 256 Character.

Type of unit in Auto CAD -

1. Architectural
2. Decimals
3. Engineering
4. Fractional
5. Scientific

Process of Designing - 6 Steps

1. Recognition of need
2. The definition of a problem
3. Synthesis
4. Analysis & optimization
5. Evaluation
6. Presentation

Functionality area of Auto Cad - 4 Categories

1. Geometric Modelling
2. Engineering Analysis
3. Design review & Evaluation
4. Automated Drafting

Work Space - 3 work spaces available

1. Drafting & annotation
2. 3D Basics
3. 3D Modelling

CRT - Cathode Ray Tube Technology used in Traditional Computer monitors & TV. The color your see on screen is produced by a blend of red, blue and green light.

Esc
F1
F2
F3
F4
F5
F6
F7
F8
F9
F10
F11
F12
PrtScn SysRq
ScrLK
Pause Break
Display Help
Toggle text screen
Toggle object snap mode
Toggle 3D Osnap
Toggle Isoplane
Toggle Dynamic UCS
Toggle grid mode
Toggle ortho mode
Toggle snap mode
Toggle polar mode
Toggle object snap tracking
Toggle dynamic input mode
Backspace
Home
End
Insert
Page Up
Delete
Page Down
Enter
Tab
Caps Lock
Shift
Ctrl
Start
Alt
Shift
Alt
Ctrl
QSAVE
WBLOCK
ERASE
REDRAW
MTEXT
GROUP
HATCH
JOIN
INSERT
OFFSET
PAN
LINE
MOVE
BLOCK
VIEW
CIRCLE
FILLET
DIMSTYLE
STRETCH
EXPLODE
ZOOM
ARC

Q **QSAVE** / Saves the current drawing.
A **ARC** / Creates an arc.
Z **ZOOM** / Increases or decreases the magnification of the view in the current view port.
W **WBLOCK** / Writes objects or a block to a new drawing file.
S **STRETCH** / Stretches objects crossed by a selection window or polygon.
X **EXPLODE** / Breaks a compound object into its component objects.
E **ERASE** / Removes objects from a drawing.
D **DIMSTYLE** / Creates and modifies dimension styles.
C **CIRCLE** / Creates a circle.
R **REDRAW** / Refreshes the display in the current viewport.
F **FILLET** / Rounds and fillets the edges of objects.
V **VIEW** / Saves and restores named views, camera views, layout views, and preset views.
T **MTEXT** / Creates a multiline text object.
G **GROUP** / Creates and manages saved sets of objects called groups.
B **BLOCK** / Creates a block definition from selected objects.
H **HATCH** / Fills an enclosed area or selected objects with a hatch pattern, solid fill, or gradient fill.
J **JOIN** / Joins similar objects to form a single, unbroken object.
M **MOVE** / Moves objects a specified distance in a specified direction.
I **INSERT** / Inserts a block or drawing into the current drawing.
O **OFFSET** / Creates concentric circles, parallel lines, and parallel curves.
L **LINE** / Creates straight line segments.
P **PAN** / Adds a parameter with grips to a dynamic block definition.

Toggle General Features

Ctrl + d	Toggle coordinate display
Ctrl + g	Toggle Grid
Ctrl + e	Cycle isometric planes
Ctrl + f	Toggle running object snaps
Ctrl + h	Toggle Pick Style
Ctrl + Shift + h	Toggle Hide paletts
Ctrl + I	Toggle coords
Ctrl + Shift + I	Toggle infer constraints

Manage Screen

Ctrl + 0 (zero)	Clean Screen

Ctrl + 1	Property Palette
Ctrl + 2	Design Centre Palette
Ctrl + 3	Tool Palette
Ctrl + 4	Sheet Set Palette
Ctrl + 6	DBConnect Manager
Ctrl + 7	Markup Set Manager Palette
Ctrl + 8	Quick Calc
Ctrl + 9	Command Line

Manage Drawings

Ctrl + n	New Drawing
Ctrl + s	Save drawing
Ctrl + o	Open drawing
Ctrl + p	Plot dialog box
Ctrl + Tab	Switch to next
Ctrl+Shift+Tab	Switch to previous drawing
Ctrl+PageUp	Switch to previous tab in current drawing
Ctrl+Page Down	Switch to next tab in current drawing
Ctrl + q	Exit
Ctrl + a	Select all objects

Toggle Drawing Modes

F1	Display Help
F2	Toggle text screen
F3	Toggle object snap mode
F4	Toggle 3DOsnap
F5	Toggle Isoplane
F6	Toggle Dynamic UCS
F7	Toggle grid mode
F8	Toggle ortho mode
F9	Toggle snap mode
F10	Toggle polar mode
F11	Toggle oject snap tracking
F12	Toggle dynamic input mode

Manage Workflow

Ctrl + c	Copy object
Ctrl + x	Cut object
Ctrl + v	Paste object

Ctrl + Shift + c	Copy to clipboard with base point
Ctrl + Shift + v	Paste data as a block
Ctrl + z	Undo last action
Ctrl + I	Cancel current command (or ctrl+\)
ESC	Cancel current command

A

A ARC/ Creates an arc.
AA AREA/Calculates the area and perimeter of objects or of defined areas.
ADC ADCENTER/ Manages and inserts content such as blocks, xrefs, and hatch patterns.
AL ALIGN/ Aligns objects with other objects in 2D and 3D.
AP APPLOAD/ Load Application.
AR ARRAY/Creates multiple copies of objects in a pattern
ARR ACTRECORD/ Starts the Action Recorder.
ARM ACTUSERMESSAGE/inserts a user message into an action macro.
ARU ACTUSERINPUT/Pauses for user input in an action macro.
ARSACTSTOP/Stops the Action Recorder and provides the option of saving the recorded actions to an action macro file.
ATI ATTIPEDIT/Changes the textual content of an attribute within a block.
ATT ATTDEF/Redefines a block and updates associated attributes.
ATE ATTEDIT/Changes attribute information in a block.

B

B BLOCk/Creates a block definition from selected objects.
BC BCLOSE/Closes the Block Editor.
BE BEDIT/Opens the block definition in the Block Editor.
BH HATCH/Fills an enclosed area or selected objects with a hatch pattern, solid fill, or gradent fill.
BO BOUNDARY/Creates a region or a polyline from an enclosed area.
BR BREAK/ Breaks the selected object between two points.
BS BSAVE/Saves the current block definition.
BVSBVSTATE/Creates, sets or deletes a visibility state in a dynamic block.

C

C CIRCLE/Creates a circle.
CAM CAMERA/Sets a camera and target location to create and save a 3D perspective view of objects.
CBAR CONSTRAINTBAR/A too bar-like UI element that displays the available geometric constraints on an object.
CH PROPERTIES/Controls properties of existing objects.
CHA CHAMFER/Bevels the edges of objects
CHK CHECKSTANDARDS/Checks the current drawing for standards violations.
CLI COMMANDLINE/Displays the Command Line window.
COL COLOR/Sets the color for new objects
CO COPY/Copies objects a specified distance in a specified direction.
CT CTABLESTYLE/SETS the name of the current table style
CUBE NAVVCUBE/Controls the visibility and display properties of the ViewCube tool.
CYL CYLINDER/Creates a 3D solid cylinder

D

D DIMSTYLE/Creates and modifies dimension styles.
DAN DIMANGULAR/Creates an angular dimension.
DAR DIMARC/Creates an arc length dimension.
DBA DIMBASELINE/Creates a linear, angular, of ordinate dimension from the baseline of the previous or selected dimension.
DBC DBCONNECT/Provides an interface to external database tables.
DCE DIMCENTER/Creates the center mark or the centerlines of circles and arcs.
DCO DIMCONTINUE/Creates a dimension that starts from an extension line of a previously created dimension.
DCON DIMCONSTRAINT/ Applies dimensional constraints to selected objects or points on objects.
DDA DIMDISASSOCIATE/Removes associativity from selected dimensions
DDI DIMDIAMETER/Creates a diameter dimenson for a circle or an arc.
DED DIMEDIT/Edits dimension text and extension lines.
DI DIST/Measures the distance and angle between two points.
DIV DIVIDE/Creates every spaced point object or blocks along the length or perimeter of an object.
DJL DIMJOGLINE/ Adds or remove a jog line on a linear or aligned

Dimension

DJO DIMJOGGED/Creates jogged dimensions for circles and arcs.

DL DATALINK/The Data Link dialog box is displayed

DLU DATALINKUPDATE/Updates data to or from an established external data link.

DO DONUT/Creates a filed circle or a wide ring.

DOR DIMORDINATE/Creates ordinate dimensions.

DOV DIMOVERRIDE/Control's overrides of system variables used in selected dimensions

DR DRAWORDER/Changes the draw order of images and other objects

DRA DIMRADIUS/Creates a radius dimension for a circle or an arc.

DRE DIMREASSOCIATE/Associates or reassociates selected dimensions to objects or points on objects.

DRM DRAWINGRECOVERY/Displays a list of drawing files that can be recovered after a program or system failure

DS DSETTINGS/Sets grid and snap, polar and object snap tracking, object snap modes, Dynamic input and Quick Properties.

DT TEXT/ Creates a single-line text object.

DV DVIEW/Defines parallel projection or perspective views by using a camera and target

DX DATAEXTRACTION/Extracts drawing data and merges data from an external source to a data extraction table or external file.

E-F

E ERASE/Removes objects from a drawing.

ED DDEDIT/Edits single-line text, dimension text, attribute definitions, and feature control frames.

EL ELLIPSE/Creates an ellipse or an elliptical arc.

EPDF EXPORTDF/Exports drawing to PDF.

ER EXTERNALREFERENCES/Opens the External References palette.

EX EXTEND/Extends objects to meet the edges of other objects.

EXIT QUIT/ Exits the program.

EXP EXPORT/Saves the objects in a drawing to a different file format.

EXT EXTRUDE/Extends the dimensions of a 2D object or 3D face into 3D face into 3D space.

F FILLET/ Rounds and fillets the edges of objects.

FI FILTER/ Creates a list of requirements that an object must meet to be included in a selection set.

FS FSMODE/Creates a selection set of all objects that touch the selected object.

FSHOT FLATSHOT/ Creates a 2D representation of all 3D objects based on the current veiw.

G GROUP/Creates and manages saved sets of objects called groups.

GCON GEOCONSTRAINT/ Applies or persists geometric relationships between objects or points on objects.

GD GRADIENT/Fills an enclosed area or selected objects with a gradient fill.

GEO GEOGRAPHICLOCATION/Specifies the geographic location information for a drawing file.

H HATCH/Fills an enclosed area or selected objects with a hatch pattern, solid fill, or gradient fill.

HE HATCHEDIT/Modifies an existing hatch or fill.

HI HIDE/Regenerates a 3D wireframe model with hidden lines suppressed.

I-K

I INSERT/Inserts a block or drawing into the current drawing

IAD IMAGEADJUST/Controls the image display of the brightness, contrast, and fade values of images.

IAT IMAGEATTACH/Inserts a reference to an image file.

ICL IMAGECLIP/Crops the display of a selected image to a specified boundary.

ID ID/Displays the UCS coordinate values of a specified location.

IM IMAGE/Displays the External References palette.

IMP IMPORT/Imports files of different formats into the current drawing .

IN INTERSECT/Creates a 3D solid, surface, or 2D region from overlapping solids, surfaces or regions.

INF INTERFERE/Creates a temporary 3D solid from the interferences between two sets of selected 3D solids.

IO INSERTOBJ/inserts a inked or embedded object.

J JOIN/Joins similar objects to form a single, unbroken object.

JOG DIMJOGGED/Creates jogged dimensions for circles and arcs.

L-M

L LINE/Creates straight line segments.
LA LAYER/Manages layers and layer properties.
LAS LAYERSTATE/Saves, restores, and manages named layer states.
LE QLEADER/Creates a leader and leader annotation.
LEN LENGTHEN/Changes the length of objects and the included angle of arcs.
LESS MESHSMOOTHLESS/Decreases the level of smoothness for mesh objects by one level.
LI LIST/ Displays property data for selected objects.
LO LAYOUT/Creates and modifies drawing layout tabs.
LT LINETYPE/Loads, sets, and modifies linetypes.
LTS LTSCALE/Changes the scale factor of linetypes for all objects in a drawing.
LW LWEIGHT/Sets the current lineweight, lineweight display options, and lineweight units.
M MOVE/Moves objects a specified distance in a specified direction.
MA MATCHPROP/Applies the properties of a selected object to other objects
MAT MATERIALS/Shows or hides the Materials window.
ME MEASURE/Creates point objects or blocks at measured intervals along the length or perimeter of an object.
MEA MEASUREGEOM/Measures the distance, radius, angle, area and volume of selected objects or sequence of points.
MI MIRROR/Creates a mirrored copy of selected objects.
ML MLINE/Creates multiple parallel lines.
MLA MLEADERALIGN/Aligns and spaces selected multileader objects.
MLC MLEADERCOLLECT/Organizes selected multileaders that contain blocks into rows or columns and displays the result with a single leader.
MLD MLEADER/Creates a multileader object
MLE MLEADEREDIT/Adds leader lines to, or removes leader lines from, a multileader object.
MLS MLEADERSTYLE/ Creates and modifies multileader styles.
MO PROPERTIES/Controls properties of existing objects.
MORE MESHSMOOTHMORE/Increases the level of smoothness for mesh objects by one level.
MS MSPACE/Switches from paper space to a model space viewport.

MSM MARKUP/Opens the Markup Set Manager.
MT MTEXT/Creates a multiline text object.
MV MVIEW/Creates and controls layout viewports.

N-O

NORTH GEOGRAPHICLOCATION/ Specifies the geographic location information for a drawing file.
NSHOT NEWSHOT/ Creates a named view with motion that is played back when viewed with ShowMotion.
NVIEW NEWVIEW/ Creates a named view with no motion.
O OFFSET/Creates concentric circles, parallel lines, and parallel curves.
OP OPTIONS/ Customizes the program setting.
ORBIT 3DORBIT/ Rotates the view in 3D space, but constrained to horizontal and vertical orbit only.
OS OSNAP/Sets running object snap modes.

P

P PAN/Adds a parameter with grips to a dynamic block defintion.
PA PASTESPEC/Pastes objects from the Clipboard into the current drawing and controls the format of the data.
PAR PARAMETERS/Controls the associative parameters used in the drawing.
PARAM BPARAMETER/Adds a parameter with grips to a dynamic block definition
PATCH SURFPATCH/Creates a new surface by fitting a cap over a surface edge that forms a closed loop.
PC POINTCLOUD/ Provides options to create and attach point cloud files.
PCATTACH POINTCLOUDATTACH/inserts an indexed point cloud file into the current drawing.
PCINDEX POINTCLOUDINDEX/Creates an indexed point cloud (PCG or ISD) file from a scan file.
PE PEDIT/Edits polylines and 3D polygon meshes.
PL PLINE/Creates a 2D polyline.
PO POINT/Creates a point object
POFF HIDEPALETTES/Hides currently displayed palettes (including the command line).
POL POLYGON/Creates an equilateral closed polyline.

PON SHOWPALETTES/Restores the display of hidden paletters.
PR PROPERTIES/Displays Properties palette.
PRE PREVIEW/Displays the drawing as it will be plotted.
PRINT PLOT/Plots a drawing to a plotter, printer, of file
PS PSPACE/Switches from a mode space viewport to paper space.
PSOLID POLYSOLID/Creates a 3D wall-like polysolid.
PTW PUBLISHTOWEB/Creates HTML pages that include images of selected drawings.
PU PURGE/Removes unused items, such as block definitions and layers, from the drawing.
PYR PYRAMID/Creates a 3D solid pyramid.

Q

QC QUICKCALC/Opens the QuickCalc calculator.
QCUI QUICKCUI/Displays the Customize User Interface Editor in a collapsed state.
QP QUICKPROPERTIES/Displays open drawings and layouts in a drawing in preview images.
QSAVE QSAVE/Saves the current drawing.
QVD QVDRAWING/Displays open drawings and layouts in a drawing using preview images.
QVDC QVDRAWINGCLOSE/Close preview images of open drawings and layouts in a drawing.
QVL QVLAYOUT/Displays preview images of model space and layouts in a drawing.
QVLC QVLAYOUTCLOSE/Closes preview images of model space and layouts in the current drawing.

R

R REDRAW / Refreshes the display in the current viewport.
RA REDRAWALL / Refreshes the display in all viewports.
RC RENDERCROP / Renders a specified rectangular area, called a crop window, within a viewport.
RE REGEN / Regenerates the entire drawing from the current viewport.
REA REGENALL / Regenerates the drawing and refreshes all viewports.
REC RECTANG / Creates a rectangular polyline.
REG REGION / Converts an object that encloses an area into a region object.

REN RENAME / Changes the names assigned to items such as layers and dimension styles.
REV REVOLVE / Creates a 3D solid or surface by sweeping a 2D object around an axis.
RO ROTATE / Rotates objects around a base point.
RP RENDERPRESETS / Specifies render presets, reusable rendering parameters,for rendering an image.
RPR RPREF / Displays or hides the Advanced Render Settings palette for access to advanced rendering settings.
RR RENDER / Creates a photorealistic or realistically shaded image of a 3D solid or surface model.
RW RENDERWIN / Displays the Render window without starting a rendering operation.

S

S STRETCH / Stretches objects crossed by a selection window or polygon.
SC SCALE / Enlarges or reduces selected objects, keeping the proportions of the object the same after scaling.
SCR SCRIPT / Executes a sequence of commands from a script file.
SEC SECTION / Uses the intersection of a plane and solids, surfaces, or mesh to create a region.
SET SETVAR / Lists or changes the values of system variables.
SHA SHADEMODE / Starts the VSCURRENT command.
SL SLICE / Creates new 3D solids and surfaces by slicing, or dividing, existing objects.
SN SNAP / Restricts cursor movement to specified intervals.
SO SOLID / Creates solid-filled triangles and quadrilaterals
SP SPELL / Checks spelling in a drawing.
SPE SPLINEDIT / Edits a spline or spline-fit polyline.
SPL SPLINE / Creates a smooth curve that passes through or near specified points.
SPLANE SECTIONPLANE / Creates a section object that acts as cutting plane through 3D objects.
SPLAY SEQUENCEPLAY / Plays named views in one category.
SPLIT MESHSPLIT / Splits a mesh face into two faces.
SPE SPLINEDIT / Edits a spline or spline-fit polyline.
SSM SHEETSET / Opens the Sheet Set Manager.
ST STYLE / Creates, modifies, or specifies text styles.

STA STANDARDS / Manages the association of standards files with drawings.
SU SUBTRACT / Combines selected 3D solids, surfaces, or 2D regions by subtraction.

T
T MTEXT / Creates a multiline text object.
TA TABLET / Calibrates, configures, and turns on and off an attached digitizing tablet.
TB TABLE / Creates an empty table object.
TEDIT TEXTEDIT / Edits a dimensional constraint, dimension, or text object.
TH THICKNESS / Sets the default 3D thickness property when creating 2D geometric objects.
TI TILEMODE / Controls whether paper space can be accessed.
TO TOOLBAR / Displays, hides, and customizes toolbars.
TOL TOLERANCE / Creates geometric tolerances contained in a feature control frame.
TOR TORUS / Creates a donut-shaped 3D solid.
TP TOOLPALETTES / Opens the Tool Palettes window.
TR TRIM / Trims objects to meet the edges of other objects.
TS TABLESTYLE / Creates, modifies, or specifies table styles.

U–W
UC UCSMAN / Manages defined user coordinate systems.
UN UNITS / Controls coordinate and angle display formats & precision.
UNHIDE / UNISOLATE UNISOLATEOBJECTS / Displays objects previously hidden with the ISOLATEOBJECTS or HIDEOBJECTS command.
UNI UNION / Unions two solid or two region objects.
V VIEW / Saves and restores named views, camera views, layout views, and preset views.
VGO VIEWGO / Restores a named view.
VP DDVPOINT / Sets the 3D viewing direction.
VPLAY VIEWPLAY / Plays the animation associated to a named view.
VS VSCURRENT / Sets the visual style in the current viewport.
VSM VISUALSTYLES / Creates and modifies visual styles and applies a visual style to a viewport.
W WBLOCK / Writes objects or a block to a new drawing file
WE WEDGE / Creates a 3D solid wedge.

WHEEL NAVSWHEEL / Displays a wheel that contains a collection of view navigation tools.

X–Z

X EXPLODE / Breaks a compound object into its component objects.

XA XATTACH / Inserts a DWG file as an external reference (xref).

XB XBIND / Binds one or more definitions of named objects in an xref to the current drawing.

XC XCLIP / Crops the display of a selected external reference or block reference to a specified boundary.

XL XLINE / Creates a line of infinite length.

XR XREF / Starts the EXTERNALREFERENCES command.

Z ZOOM / Increases or decreases the magnification of the view in the current viewport.

ZEBRA ANALYSISZEBRA / Projects stripes onto a 3D model to analyze surface continuity.

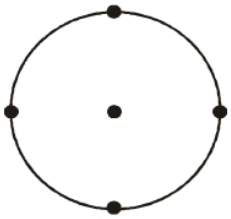
ZIP ETRANSMIT / Creates a Self-Extracting or Zipped Transmittal Package.

Q QSAVE
W WBLOCK
E ERASE
R REDRAW
T MTEXT
I INSERT
O OFFSET
P PAN
A ARC
S STRETCH
D DIMSTYLE
F FILLET
G GROUP
H HATCH
J JOIN
L LINE
Z ZOOM
X EXPLODE
C CIRCLE
V VIEW
B BLOCK
M MOVE
F12 Dynamic Input
F11 Object Snap Tracking
F10 Polar
F9 Snap
F8 Ortho
F7 Grid
F6 Dynamic UCS
F5 Isoplane
F4 3DOsnap
F3 Object Snap
F2 Text Screen
F1 Help

Important Points in Auto Cad-

- Origin of Drawing is at (0, 0)
- Modern CAD system are based on ICG (Interactive Computer Graphics)
- UCS - User Co-ordinate system
  WCS - World Co-ordinate system
  LTS - Line Type Scale Command
  CAM - Computer Aided Manufacturing

- Grip point



Circle has 5 Grip points



Rectangle has 8 Grip point

- We need 2 points to define Rectangle command.
- 1 Auto Cad objects in a Rectangle.
- Using Polygon Command in Auto Cad, we can drawn minimum 3 and maximum 1024 sides of polygon.
- Minimum Allowable layers in a drawing - 1
- Objects are rotate around the base point.
- One quick way to view the entire drawing area is use the zoom command by Type Z enter A enter
- Grid spacing in X & Y direction is 10.
- Ortho mode allows the user to draw 90° straight lines.
- Input Devices in Cad can be divided into 3 parts.
- Newman & Sproull formulated 6 ground rules to be considered in designing graphics software.
- Cad & Cam are tied by a common data base.
- To obtain parallel lines, concentric circles and parallel curves off set is used.

CIVIL ENGINEERING ROCKET CHART FOR QUICK REVISION

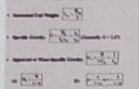
S.SOROUT, CIVIL Ki GOLI PUBLICATION, 9255624029





Soil Mechanics

- Water Content: $w = \frac{W_w}{W_s} \times 100\%$ (=volume)
- Void Ratio: $e = \frac{V_v}{V_s} = \frac{nV}{(1-n)V} = \frac{n}{1-n}$ (=%) e = 0
- Porosity: $n = \frac{V_v}{V} = \frac{e}{1+e}$ (e=water cap. Ratio)
- Degree of Saturation: $S = \frac{V_w}{V_v} \times 100\%$ (S = 0-1)
- Air Content: $A = \frac{V_a}{V} = \frac{V-V_w}{V} = n(1-S)$ (V = vol. (dimen) S = %)
- Bulk Unit Weight: $\gamma = \frac{W}{V} = \frac{W_s+W_w}{V_s+V_v} = \frac{G\gamma_w(1+w)}{1+e}$
- Dry Unit Weight: $\gamma_d = \frac{W_s}{V} = \frac{G\gamma_w}{1+e} = \frac{\gamma}{1+w}$
- Saturated Unit Weight: $\gamma_{sat} = \frac{W_s+V_v\gamma_w}{V} = \frac{(G+e)\gamma_w}{1+e}$
- Specific Gravity: $G = \frac{\gamma_s}{\gamma_w} = \frac{W_s}{V_s\gamma_w} = \frac{S_r e}{w}$ (Generally G = 2.65)
- Apparent or Mass Specific Gravity: $G_m = \frac{\gamma_m}{\gamma_w} = \frac{W_s+W_w}{V\gamma_w} = \frac{G(1+w)}{1+e}$
- $\gamma_d = \frac{\gamma}{1+w}$ $\gamma = \frac{G\gamma_w(1+w)}{1+e}$
- $\gamma_{sat} = \frac{(G+e)\gamma_w}{1+e}$ $\gamma' = \frac{(G-1)\gamma_w}{1+e}$
- $\gamma_d = \frac{G\gamma_w}{1+e}$ $\gamma_d = \frac{n\gamma_w}{1-n}$
- Method for Determination of water content
  - (i) Oven-drying Method: $w = \frac{W_w}{W_s} \times 100\%$ (Most accurate)
  - (ii) Pycnometer Method: $w = \frac{W_{bws}+W_s-W_{bw}}{W_{bw}-W_{bws}} \times 100\%$
  - Pycnometer: $G = \frac{W_s}{W_s+W_{bw}-W_{bws}}$
- Plasticity Index (I_p): $I_p = w_L - w_P$ (=Liquid limit, w_P = Plastic limit)
- Relative Consistency/Consistency Index: $I_c = \frac{w_L-w}{I_p} = \frac{w_L-w}{w_L-w_P}$
- Liquidity Index: $I_L = \frac{w-w_P}{I_p} = \frac{w-w_P}{w_L-w_P}$ (I_L = 1 - I_c)
- Flow Index: $I_f = \frac{w_1-w_2}{\log\frac{N_2}{N_1}}$ Toughness Index: $I_t = \frac{I_p}{I_f}$
- Flow Index = $\frac{\text{Slope}}{\log\frac{N_2}{N_1}}$ $C_c = C_c = e_1 - e_2$ (Relatively cons.)
- Liquidity: $I_L = \frac{w-w_P}{I_p} = \frac{w-w_P}{w_L-w_P}$
- Relative Density/Density Index: $I_D = \frac{e_{max}-e}{e_{max}-e_{min}} = \frac{\gamma_d-\gamma_{d(min)}}{\gamma_{d(max)}-\gamma_{d(min)}} \times \frac{\gamma_{d(max)}}{\gamma_d}$
- Activity of Clay: $A = \frac{\text{Plasticity Index}}{\text{Clay weight (finer than 2μ)}}$
- Uniformity Coefficient: $C_u = \frac{D_{60}}{D_{10}}$ (C_u = 1 uniform, > 4 well graded)
- Coefficient of Curvature: $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ (C_c = 1 well graded soil)
- IRC: 1: Dia for base of particle size



- Density/Loss: $L = \frac{W_1-W_2}{W_1} \times 100$
- Mechanical Stability
  - (i) Unsoaked Load Penetration Test: $P = \frac{\text{Load}}{\text{Area}}$
  - (ii) Soaked Load Penetration Test: $P = \frac{\text{Load}}{\text{Area}}$
  - (iii) Falling Head Permeameter Test: $k = \frac{aL}{At} \log_e \frac{h_1}{h_2}$
- (i) Constant Head Permeameter Test: $k = \frac{QL}{Ath}$
- (ii) Unconfined Flow Pumping Test: $k = \frac{2.3q}{\pi(h_2^2-h_1^2)} \log_{10} \frac{r_2}{r_1}$
- (iii) Unconfined Flow Pumping Test: $k = \frac{2.3q}{\pi(2H-s)s} \log_{10} \frac{R}{r}$
- (iv) Kenney-Crotton Equation: $\frac{D_{15}(\text{filter})}{D_{85}(\text{soil})} < 4 < \frac{D_{15}(\text{filter})}{D_{15}(\text{soil})}$
- (i) Allen Hazen's Equation: $k = cD_{10}^2$
- (ii) Coefficient of Consolidation Equation: $C_v = \frac{k}{m_v \gamma_w} = \frac{k(1+e)}{a_v \gamma_w}$
- Permeability of Stratified Soil: $k_{avg} = \frac{H}{\frac{H_1}{k_1}+\frac{H_2}{k_2}+\frac{H_3}{k_3}}$
- (i) Horizontal Flow: $k_H = \frac{k_1H_1+k_2H_2+k_3H_3}{H_1+H_2+H_3}$
- (ii) Vertical Flow: $k_V = \frac{H_1+H_2+H_3}{\frac{H_1}{k_1}+\frac{H_2}{k_2}+\frac{H_3}{k_3}}$
- Ratio k_H/k_V always
- Critical Hydraulic Gradient: $i_c = \frac{G-1}{1+e} = \frac{\gamma'}{\gamma_w}$
- Boussinesq's Equation: $\sigma_z = \frac{3Q}{2\pi} \frac{z^3}{(r^2+z^2)^{5/2}} = \frac{3Q}{2\pi z^2} \frac{1}{\left[1+\left(\frac{r}{z}\right)^2\right]^{5/2}}$
- Seepage Calculation: $q = \frac{N_f}{N_d} k H \frac{L}{B}$
- Westergaard's Solution: $\sigma_z = \frac{Q}{\pi z^2} \frac{1}{\sqrt{2\left(\frac{r}{z}\right)^2+1}}$
- Compressive Index: $C_c = \frac{e_1-e_2}{\log\frac{\sigma_2}{\sigma_1}} = \frac{e_1-e_2}{\log\frac{\sigma_1+\Delta\sigma}{\sigma_1}}$
- Coefficient of Volume Compressibility: $m_v = \frac{\Delta e}{\Delta\sigma(1+e_1)} = \frac{a_v}{1+e_1}$
- Coefficient of Consolidation: $C_v = \frac{k}{m_v \gamma_w}$ m²/s or cm²/day
- Time Factor: $T_v = \frac{C_v t}{H^2}$ $U = \frac{\text{Settlement at time } t}{\text{Total settlement}} \times 100\%$
  - $T_v = \pi/4 \cdot U^2$ U = 0-53% $T_v = 1.781 - 0.933 \log(100 - U)$ U = 53%
- Analysis of Doubly Reinforced Rectangular Section:
  - $f_{sc}' = f' + (m-1)f_{cc}'$ $f_{cc}' = 0.446 f_{ck}$
  - $p_t = \frac{100 A_{st}}{bd}$ $p_c = \frac{100 A_{sc}}{bd}$ $m = \frac{E_s}{E_c}$
  - For unreinforced soil
- Triaxial Test: $\sigma_1 = \tan^2\left(45° + \frac{\phi}{2}\right) + 2c\tan\left(45° + \frac{\phi}{2}\right)$
- Unconfined Compression Test: $\sigma_1 = \tan^2\left(45° + \frac{\phi}{2}\right)$ (ϕ for test is carried out each
- Vane Shear test: $C = \frac{T}{\pi D^2\left(\frac{H}{2}+\frac{D}{6}\right)}$
- Sat for any soil of the vane does not shear: $C = \frac{T}{\pi D^2\left(\frac{H}{2}+\frac{D}{6}\right)}$
- Pore Pressure Parameter (Given by Skempton): $\Delta U = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$
- $B = \frac{\Delta U_3}{\Delta\sigma_3}$ (For saturated soil, B = 1, for dry soil, B = 0)
- Stability of slope: $F = \frac{\text{Shear strength}}{\text{Shear stress}} = \frac{\tau_f}{\tau_d}$
- Stability Number: $N_s = \frac{\gamma H}{C}$ (Min. value = 0.261)
- Active Earth Pressure For Cohesive: $P_a = K_a \cdot \frac{\gamma H^2}{2}$
- $K_a = \tan^2\left(45° - \frac{\phi}{2}\right) = \frac{1-\sin\phi}{1+\sin\phi}$ $K_a = \frac{1}{K_p}$ (Coefficient of Earth pressure at rest, $K_o = \frac{\text{Horizontal stress}}{\text{Vertical stress}} = \frac{\sigma_h}{\sigma_v} = \frac{\mu}{1-\mu}$)
- Earth Pressure at Rest: $P_o = \frac{1}{2} K_o \gamma H^2$ (K_o = Coefficient of earth pressure at rest)
- Liquidity Index: $I_L = \frac{w-w_P}{I_p} = \frac{w-w_P}{w_L-w_P}$ $I_L = \frac{\text{Natural water content} - \text{Plastic limit}}{\text{Liquid limit} - \text{Plastic limit}}$
- Flow Index: $I_f = \frac{w_1-w_2}{\log\frac{N_2}{N_1}}$ Toughness Index: $I_t = \frac{I_p}{I_f}$
- Flow Index = $\frac{\text{Slope}}{\log\frac{N_2}{N_1}}$ $C_c = C_c = e_1 - e_2$ (Relatively cons.)
- Stability: $N_s = \frac{\gamma H}{C}$ (=cohesion)
- Relative Density/Density Index: $I_D = \frac{e_{max}-e}{e_{max}-e_{min}} = \frac{\gamma_d-\gamma_{d(min)}}{\gamma_{d(max)}-\gamma_{d(min)}} \times \frac{\gamma_{d(max)}}{\gamma_d}$
- Activity of Clay: $A = \frac{\text{Plasticity Index}}{\text{Clay weight (finer than 2μ)}}$
- Uniformity Coefficient: $C_u = \frac{D_{60}}{D_{10}}$ (C_u = 1 uniform, > 4 well graded)
- Coefficient of Curvature: $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ (C_c = 1 well graded soil)
- Net Safe Bearing Capacity: $q_{nf} = \frac{\text{Ultimate bearing capacity}}{\text{Factor of safety}}$
- Gross Intensity: $q_{gf} = q_{nf} + \gamma D$
- Elastic Settlement: $S = \frac{q_{nf} B(1-\mu^2)}{E} I_f$
- Bearing Capacity for Shallow foundation
- Safe Bearing: $q_{nf} = \frac{1}{3}(\gamma B N_\gamma + \gamma D N_q + 0.4 \gamma B N_\gamma)$
- Shallow Circular Footing: $q_{nf} = 1.3 CN_c + \gamma D(N_q + 0.2)$
- Shallow Square Footing: $q_{nf} = 1.3 CN_c + \gamma D(N_q + 0.4)$
- Settlement of Footing: $S_f = S_1 \left(\frac{2B}{B+0.3}\right)^2$ (For Sandy Soil)
- $S_f = S_1 \left(\frac{B}{0.3}\right)$ (In clay)
- Correction Applied to SPT Value:
  - Over Burden Correction: $N_1 = \frac{N_{obs} \times 10}{10 + \text{Effective overburden pressure in kg/cm}^2}$
  - Dilatancy Correction: $N = N_1 + \frac{15}{3}(N_2 - 15)$
  - Ultimate bearing Capacity of pile Load taken by base + load by skin friction: $Q_u = q_d \times A_b + f \times A_s$
- Safe Load: $Q_s = \frac{\text{Ultimate load}}{\text{Factor of safety}}$
- Engineering News Formula: Ultimate load on pile: $Q_u = \frac{WH}{S+C}$
- Safe Load: $Q_s = \frac{Q_u}{\text{Factor of safety}}$
- Hiley's Formula: $Q_u = \frac{W_H H \eta}{S + \frac{C}{2}}$
- Safe Load: $Q_s = \frac{Q_u}{\text{Factor of safety}}$
- Modified Hiley's Formula: $Q_u = \frac{W_H H \eta}{S + \frac{C}{2}} \times \frac{W_H + e^2 W_P}{W_H + W_P}$
- Safe Load: $Q_s = \frac{Q_u}{\text{Factor of safety}}$
- Dynamic Formula: $Q_u = \frac{W_H H}{S + C}$
- Safe Load: $Q_s = \frac{Q_u}{\text{Factor of safety}}$
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- Dynamic Formula: $Q_u = \frac{W_H H}{S + C}$
- Safe Load: $Q_s = \frac{Q_u}{\text{Factor of safety}}$

Reinforced Cement Concrete

- Iw Methods:
  - $f_{ck} = 0.66 f_{cu}$ Min. grade = M15 (fck 450-575%).
  - $f_{ck} = 0.80 f_{cu}$ Min. grade = M20 (fck 450-300%).
- Tensile Strength Of Concrete: Modulus of rupture $= 0.7\sqrt{f_{ck}}$

Steel	Grade of Concrete			
	M15	M20	M25	M30
Direct Tension	1.3	1.5	1.9	2.0
Bending Tension	1.7	2.0	2.5	2.7

RCC Structures	Min. Clear Covering (mm)
Slab	20
Beam	25
Column	40
Footing	50

Exposure Conditions	Min. Clear Cover (mm)
Moderate	20
Severe	30
Very Severe	40
Extreme	50

Fluid Mechanics

- Viscosity: $\tau = \mu \frac{du}{dy}$ μ = dynamic viscosity, $\nu = \frac{\mu}{\rho}$ = kinematic viscosity
- Kinematic Viscosity: $\nu = \frac{\mu}{\rho}$ m²/sec
- Newton's Law Of Viscosity: $\tau = \mu \frac{du}{dy}$ τ = τ_0, gradient, rotor
- Surface Tension: $\sigma = \frac{pd}{4}$ (for a soap bubble) $\sigma = \frac{pd}{2}$ (for a liquid jet) $\sigma = \frac{pd}{4}$ (for a soap bubble)
- Capillarity: $h = \frac{4\sigma\cos\theta}{\rho g d}$ σ = surface tension, θ = angle of contact, ρ = density, d = diameter of tube
- Pressure Inside The Liquid Drop: $p = \frac{2\sigma}{R}$
- Pressure Inside The Liquid Jet: $p = \frac{\sigma}{R}$
- Pressure Inside the Soap Bubble: $p = \frac{4\sigma}{R}$ or $p = \frac{8\sigma}{D}$
- Expression For Capillary Rise: $h = \frac{4\sigma\cos\theta}{\rho g d}$
- Resistance And Floatation:
  - Height of body = weight of floatation
- Continuity Equation: $A_1V_1 = A_2V_2$
- Hydrostatic Force:
  - Horizontal: $F_x = \bar{h} A \sin\theta = \bar{h} A_x$
  - Vertical: $F_y = \bar{h} A \cos\theta = \gamma \bar{h} A$
  - Inclined: $F_R = \sqrt{F_x^2 + F_y^2}$
- Accelerations Of A Fluid Particle: $a_x = \frac{du}{dt}$ $a_y = \frac{dv}{dt}$ $a_z = \frac{dw}{dt}$
- Rotational Component: $\omega_z = \frac{1}{2}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$ (Irrotational = Velocity = Zero)
- Velocity Potential Function: $\phi = -\int u\,dx + f(y)$ $u = -\frac{\partial\phi}{\partial x}$ $v = -\frac{\partial\phi}{\partial y}$
- Stream Function: $\psi = \int u\,dy + f(x)$ $u = \frac{\partial\psi}{\partial y}$ $v = -\frac{\partial\psi}{\partial x}$ ψ = Constant
- Euler's Equation: $\frac{dp}{\rho} + g\,dz + v\,dv = 0$ (Same as momentum equation)
- Bernoulli's Equation: $\frac{p}{\rho g} + \frac{v^2}{2g} + z = H$ (Same as energy conservation law)
- Theoretical Discharge: $Q = A_1 A_2 \sqrt{\frac{2g(h_1-h_2)}{A_1^2 - A_2^2}}$
- Percentage Error in Discharge: $\% = \frac{\text{Actual} - \text{Theoretical}}{\text{Theoretical}} \times 100$

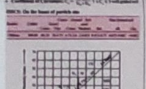
NOTE:
When Pressure Difference Measured by Manometer
When heavier fluid is manometer is lighter fluid is pipe.

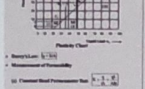
- $h = \frac{x}{s_2} - \frac{y}{s_1}$
- h = Specific gravity of heavier liquid
- s_1 = Specific gravity of lighter liquid
- x = Reading Manometer, y = Reading Pressures

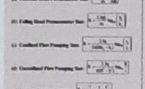
- Orifice Meter: $Q = \frac{C_d A_0 A_1 \sqrt{2gh}}{\sqrt{A_1^2 - A_0^2}}$
- Orifice meter: $Q = \frac{C_d A_0 A_1 \sqrt{2gh}}{\sqrt{A_1^2 - A_0^2}}$
- Where C_d = Coefficient of discharge, C_v = Coefficient of Velocity, C_c = Coefficient of Contraction
- Pitot Tube - Velocity Of Flow: $V = \sqrt{2gh}$
- Reynold's Number: $R_e = \frac{\rho v D}{\mu} = \frac{v D}{\nu}$
- Laminar Flow Through Circular Pipe: $Q = \frac{\pi p R^4}{8\mu l}$
- Velocity Distribution: $v = \frac{p}{4\mu l}(R^2 - r^2)$
- Discharge: $Q = \frac{\pi p R^4}{8\mu l}$
- Average Velocity: $v = \frac{Q}{\pi R^2} = \frac{p R^2}{8\mu l}$
- Friction Factor: $f = \frac{64}{R_e}$
- Weight Lower Based Loss: $h_f = \frac{f l v^2}{2gD}$

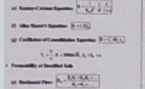
Number	Equation	Use
Reynolds No.	$R_e = \frac{\rho v D}{\mu} = \frac{v D}{\nu}$	Compliance, submersion, pipe flow
Euler No.	$E_u = \frac{p}{\rho v^2}$	Cavitation, some laminar problem
Mach No.	$M = \frac{v}{c}$	Incompressible wetting, rocket, missile
Froude No.	$F_r = \frac{v}{\sqrt{gL}}$	OCF, gydrology, wave
Weber No.	$W_e = \frac{\rho v^2 L}{\sigma}$	Wave, capillarity, strong bubble

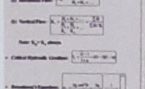
- Manning's Formula: $v = \frac{1}{n} R^{2/3} S^{1/2}$ $Q = \frac{1}{n} A R^{2/3} S^{1/2}$
- Chezy's Formula: $v = C\sqrt{mi}$ m = Hydraulic Mean depth, i = Hydraulic Slope.

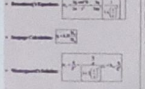


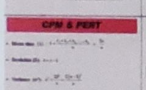


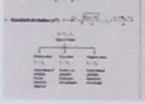


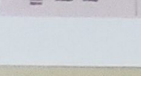




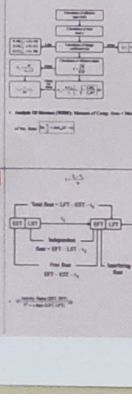


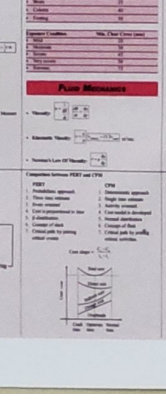


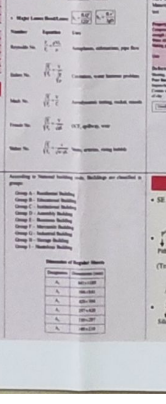


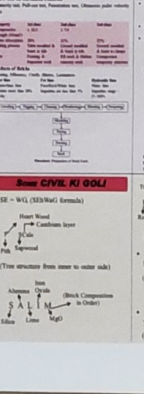


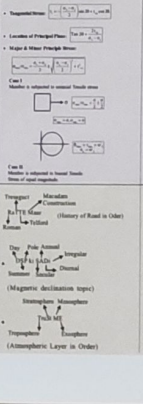
CPM & PERT

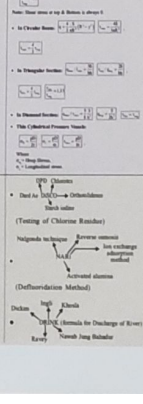


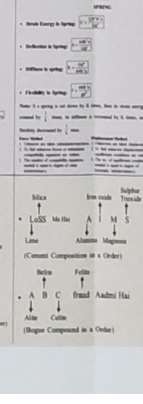


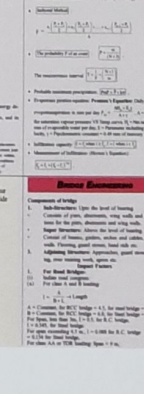


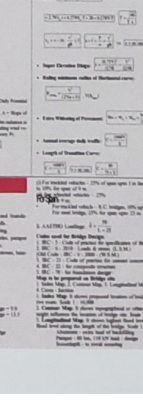


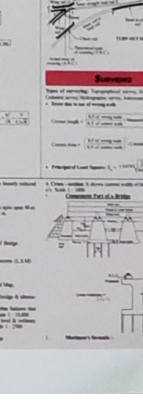


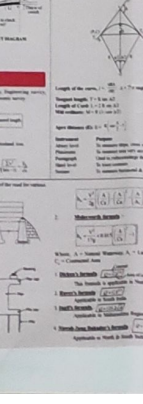


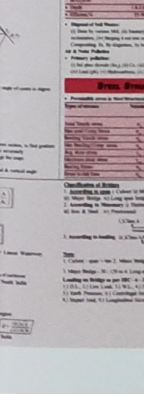


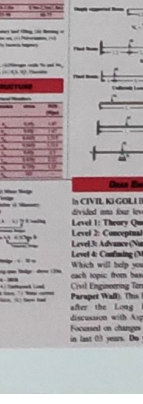


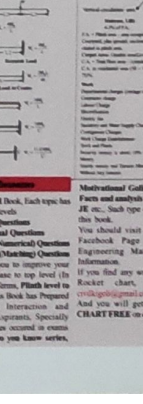


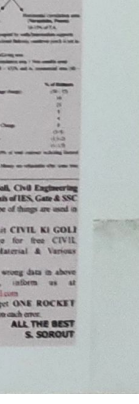












Some Civil Ki Goli

- SE = WG (SEt/WaG formula)

(Tree structure from inner to outer side)

(Block Composition in Order)

(Magnetic declination topic)

(Atmospheric Layer in Order)

(History of Road in Order)

(Testing of Chlorine Residue)

(Deflouridation Method)

(Bogue Compound in a Order)

(Cement Composition in a Order)

(Formula for Discharge of River)

(Nawab Jung Bahadur)

(Aadmi Hai)

(Aadmi Hai)

(Aadmi Hai

CIVIL ENGINEERING ROCKET CHART FOR QUICK REVISION

S.SOROUT, CIVIL Ki GOLI PUBLICATION, 9255624029





Soil Mechanics

Surveying

Reinforced Concrete Structures

Steel Structures

CPM & PERT

Irrigation Engineering

Hydraulics

Fluid Mechanics

Strength of Materials

Theory of Structures

Transportation Engineering

Environmental Engineering

Geotechnical Engineering

Building Materials

Estimating, Costing & Valuation

Construction Management

Miscellaneous

Some CIVIL Ki GOLI

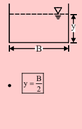
Some Solutions

Some Solutions

Some Solutions

- **Sudden expension:** $h_l = \frac{(v_1 - v_2)^2}{2g}$
- **Entry Loss:** $h_{entry} = 0.5\frac{v^2}{2g}$, **Exist of Pipe:** $h_{exit} = \frac{v^2}{2g}$
- **Sudden Contraction:** $h_{contraction} = \frac{(v_c - v_2)^2}{2g}$
- **Bending of the Pipe:** $h_{fitting} = k\frac{v^2}{2g}$, k = constant, T-Bend, k = 1.8, 90°-Bend, k = 1.2, 45°-Bend, k = 0.4

Chart for Most Economical Sections

Geometrical Parameters	Rectangular	Triangular	Trapezoidal
Diagram			
Condition for most Economical	$y = \frac{B}{2}$	m = 1, θ = 45°	$B = \frac{2y}{\sqrt{3}}$, $m = \frac{1}{\sqrt{3}}$, θ = 60° Hor. θ = 30° Vert.
Area	$A = B.y = 2y.y$	$A = my^2$	$A = (B + my) \times y$
	$A = 2y^2$	$A = y^2$	$A = \left(\frac{2y}{\sqrt{3}} + \frac{1}{\sqrt{3}}y\right)y = \left(\sqrt{3}\right)y^2$
Perimeter	$P = 4y$	$p = 2\sqrt{2}y$	$P = 2\sqrt{3}y$
Hydraulic Radius (R = A/P)	$R = y/2$	$R = \frac{y}{2\sqrt{2}}$	$R = \frac{y}{2}$
Top width (T)	$T = 2y$	$T = 2y$	$T = \frac{4y}{\sqrt{3}}$
Hydraulic Depth $\left(D = \frac{A}{T}\right)$	$D = y$	$D = y/2$	$D = \frac{3}{4}y$

Note: Circular section (a) For maximum discharge 2θ = 302°22′, d = 0.938 D, (b) For maximum velocity 2θ = 257°27′, d = 0.81 D

Type of flow	Depth of flow	Velocity of flow	Froude No	Comments
Subcritical	$y > y_c$	$v < v_c$	$F_r < 1$	As streaming or transquil flow
Critical	$y = y_c$	$v = v_c$	$F_r = 1$	
Super Critical	$y < y_c$	$v > v_c$	$F_r > 1$	Shooting flow, rapid flow, torrential flow

Dynamic eq. for G.V.F.: $\frac{dy}{dx} = \left(\frac{S_o - S_f}{1 - \frac{q^2}{gy^3}}\right)$

Hydraulic Jump Eq.

1. $\frac{2q^2}{g} = y_2y_2(y_1 + y_2)$, 2. Energy Loss $E_L = \frac{(y_2 - y_1)^3}{4y_1y_2}$

3. $\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8F_r^2} - 1\right)$, 4. $y_1' = \frac{y_1y_2(y_1 + y_2)}{2}$

Types of Jump	Fr	E_2/E_1	Water surface
Undular	1–1.7	≈ 0	Undulating
Weak	1.7–2.5	5–18%	Small rollers form
Oscillating	2.5–4.5	18–45%	Water oscillates in random manner
Steady strong	4.5–9 ≥ 9	45–70% ≥ 70%	Roller and jump action Very rough and choppy

$N_s = \frac{N\sqrt{P}}{(H)^{5/4}}$ (for Turbine), $N_s = \frac{N\sqrt{Q}}{(H_m)^{3/4}}$ (for Pump)

	Laminar	Transition	Turbulent
Flow in pipe	$R_e < 2000$	$2000 < R_e < 4000$	$R_e > 4000$
Flow between parallel plate	$R_e < 1000$	$1000 < R_e < 2000$	$R_e > 2000$
Flow in open channel	$R_e < 500$	$500 < R_e < 2000$	$R_e > 2000$
Flow through soil	$R_e < 1$	$1 < R_e < 2$	$R_e > 2$

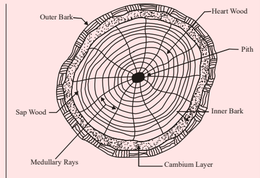
BMC

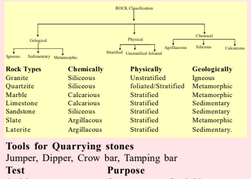
Test of Cement

- FINENESS TEST
  - Sieve Method
  - Air permeability Method
  - (Nurse and Blaine's method)
  - Sedimentation method
  - (Wanger Turbidimeter Method)
- CONSISTENCY TEST
  - Vicat's Apparatus.
- SETTING TIME
  - Vicat's Apparatus.
- SOUNDNESS TEST
  - Le-chatelier Method
  - Auto clave test
- TENSILE STRENGTH
  - Briquette test
- HEAT OF HYDRATION
  - Calorimeter test
- SPECIFIC GRAVITY TEST
  - Le-chatelier's Flask.

Test On Concrete

- WORKABILITY
  - Slump test
  - Compacting factor Test
  - Vee-bee consistometer method
- DIRECT TENSILE STRENGTH OF CONCRETE
  - Cylinder Splitting Test
- BOND B/W CONCRETE &STEEL
  - Pull out Test
- COMPRESSIVE STRENGTH
  - Rebound hammer Test
- DYNAMIC MODULUS





Rock Types	Chemically	Physically	Geologically
Granite	Siliceous	Unstratified	Igneous
Quartzite	Siliceous	foliated/Stratified	Metamorphic
Marble	Calcarious	Stratified	Metamorphic
Limestone	Calcarious	Stratified	Sedimentary
Sandstone	Siliceous	Stratified	Sedimentary
Slate	Argillaceous	Stratified	Metamorphic
Laterite	Argillaceous	Stratified	Sedimentary.

Tools for Quarrying stones
Jumper, Dipper, Crow bar, Tamping bar

Test	Purpose
Smith test	for presence of soluble matter
Brard's test	for frost resistance
Acid test	To check weather resistance
Hardness test	Mohr scale

Window Width = $\frac{1}{8}$[Width of room + Height of Room]

- The sill of a window should be located about (70 – 80) cm above floor level of the room.
- Generally Height of a Door should not be less than (1.8 – 2) m
- Commonly Width height relation used in India:
  (i) Width = (0.4 – 0.6) Height
  (ii) Height = (Width + 1.2) m
- Doors of residential Buildings:
  (a) External Door – (1 × 2) to (1.1 × 2) m
  (b) Internal Door – (0.9 × 2) to (1 × 2) m
  (c) Doors for bathrooms and Water closets:
  – (0.7 × 2) to (0.8 × 2) m
- Public Buildings (School, Hospital, library)
  (a) (1.2 × 2) m (b) (1.2 × 2.1) m (c) 1.2 × 2.25) m
  Designation of Door = Length × Type of Door × Height
  8 DS 20 – A door opening Having width (8 × 100 mm) × Height (20 × 100 mm) with S (Single SHutter) D (Door)

Types of Window

1. fixed 2. Pivoted 3. Sliding 4. Bay 5. Corner 6. Cable (7) Dormer (8) Skylights (9) Louvered (10) Lantern (11) Gable

Stairs

- No of steps are not more than 12 and not less than 3 in a flight.
- Angle of Inclination (Pitch) – (25° – 40).
- Head room must not be less than 2.05 m.
- Minimum width of stairs in residential building – 85 cm and in commercial building is 1 m.

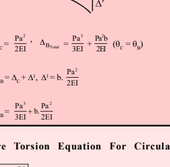
Type of Structure	Degree of Indeterminacy D_s
2D (plane) frames	(3m+r)-3j
3D frames	(6m + r)-6j
2D (plane) pin-jointed truss	(m+r)-2j
3D truss	(m+r)-3j

Slope Deflection Equations

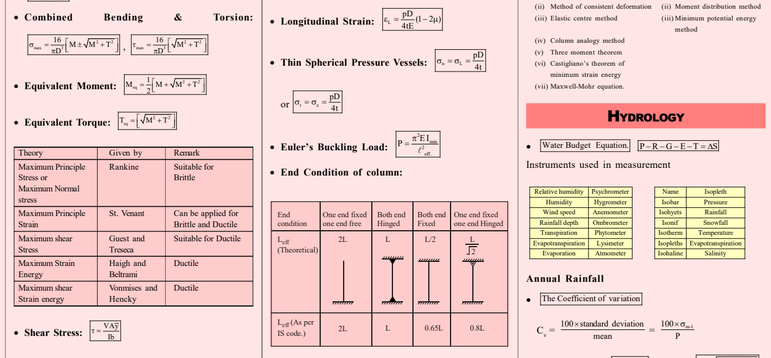
$M_{AB} = M_{FAB} + \frac{2EI}{l}\left(2\theta_A + \theta_B - \frac{3\delta}{l}\right)$ (Continuous Beam)

$M_{BA} = \frac{3EI}{L}\theta_B - \frac{3EI}{L^2}\delta = \frac{d\,\phi}{1.4}$ (one end is pin supported)

Important Points



Slope & Deflection



- **Pure Torsion Equation For Circular Shaft:** $\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{L}$
- **Combined Bending & Torsion:** $\sigma_{max} = \frac{16}{\pi D^3}\left[M \pm \sqrt{M^2 + T^2}\right]$, $\tau_{max} = \frac{16}{\pi D^3}\left[\sqrt{M^2 + T^2}\right]$
- **Equivalent Moment:** $M_{eq} = \frac{1}{2}\left[M + \sqrt{M^2 + T^2}\right]$
- **Equivalent Torque:** $T_{eq} = \left[\sqrt{M^2 + T^2}\right]$

Theory	Given by	Remark
Maximum Principle Stress or Maximum Normal stress	Rankine	Suitable for Brittle
Maximum Principle Strain	St. Venant	Can be applied for Brittle and Ductile
Maximum shear Stress	Guest and Treseca	Suitable for Ductile
Maximum Strain Energy	Haigh and Beltrami	Ductile
Maximum shear Strain energy	Vonmises and Hencky	Ductile

- **Shear Stress:** $\tau = \frac{VAy}{Ib}$
- **Shear Stress In Rectangular Section:** $q = \frac{6q}{bd^3}\left(\frac{d^2}{4} - y^2\right)$ (q = τ).
- **Hoop Strain:** $\varepsilon_h = \frac{pD}{4tE}(2 - \mu)$
- **Longitudinal Strain:** $\varepsilon_L = \frac{pD}{4tE}(1 - 2\mu)$
- **Thin Spherical Pressure Vessels:** $\sigma_x = \sigma_1 = \frac{pD}{4t}$ or $\sigma_1 = \sigma_2 = \frac{pD}{4t}$
- **Euler's Buckling Load:** $P = \frac{\pi^2 EI_{min}}{l'^2_{eff}}$
- **End Condition of column:**

End condition	One end fixed one end free	Both end Hinged	Both end Fixed	One end fixed one end Hinged
L_{eff} (Theoretical)	2L	L	L/2	$\frac{L}{\sqrt{2}}$
L_{eff} (As per IS code.)	2L	L	0.65L	0.8L

4. $D_s < D_d$
Force Method/Flexibility Method/ Compatibility Method
5. (i) Virtual work/Unit load method
(ii) Method of consistent deformation
(iii) Elastic centre method
(iv) Column analogy method
(v) Three moment theorem
(vi) Castigliano's theorem of minimum strain energy
(vii) Maxwell-Mohr equation.

4. $D_s < D_d$
Displacement Method/Stiffness Method/Equilibrium Method
(i) Slope deflection method
(ii) Moment distribution method
(iii) Minimum potential energy method

4. No eq. for bed slope
5. Recommended Kutter eq. to find velocity
6. Trial & error procedure

4. Gave eq. to calculate bed slope
5. Gave his own velocity equation
6. Direct procedure

- **Shaft In series:**

Note: On principle plane shear stress will always 0.

- **Radius of Mohr's Circle (τ_{max}):** $R = \frac{\sigma_{max} - \sigma_{min}}{2} = \tau_{max}$
- **Normal stress at Location of (τ_{max}) (τ_{max}-max shear stress):** $\sigma_n = \frac{\sigma_1 + \sigma_2}{2}$
- **Volumetric Strain of Rectangular:** $\frac{\Delta V}{V} = \varepsilon_v = \left[\frac{(\sigma_x + \sigma_y + \sigma_z)}{E}\right](1 - 2\mu)$
- **Volumetric Strain of Cylindrical:** $\varepsilon_v = \varepsilon_L + 2\varepsilon_0$
- **Volumetric Strain of Spherical:** $\varepsilon_v = 3\varepsilon_0$
- **Relationship Between Elastic Constant:**
  $G = \frac{E}{2(1+\mu)}$, $K = \frac{E}{3(1-2\mu)}$, $\mu = \frac{3k - 2G}{6k + 2G}$, $E = \frac{9kG}{3k + G}$
  Number of independent Elastic Constant: Homogenous & Isotropic = 2, Anisotropic = 21, Orthotropic = 9
- **Axial Elongation of the Prismatic Bar:**
  $\Delta L = \frac{PL}{AE}$, $\Delta L = \frac{2PL}{AE}$ (for Instantaneous loading)
- **Deflection In Non-Prismtic Bars:**
  1. **Stepped Bar:** $\Delta l = \frac{PL_1}{A_1E_1} + \frac{PL_2}{A_2E_2} + \cdots$
  2. **Circular Tapering Bar:** $\Delta L = \frac{4PL}{\pi E D_1 D_2}$
  - **Defection of Composit Bar:** $\Delta L_1 = \Delta L_2 \Delta = \frac{PL}{A_1E_1 + A_2E_2}$
  - **Deflection due to Self Weight of Bar:**
  1. **Prismatic Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{2E}$,
  2. **Conical Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{6E}$
- **Thermal Expansion:** σ = EαΔT, Δ = LαΔT
  Coefficient of Thermal expansion (Aluminium > Brass > Copper > Steel)
  $P_{cr} = \frac{\pi^2 EA}{\lambda^2}$ (Euler's Theory) $P_R = \frac{\sigma_c A}{1 + \alpha\lambda^2}$ (Rankine's Formula)
- **In case of Pure Bending:** $Z = \frac{\pi}{32}D^3$
- **In case of pure Torsion:** $\tau_{max} = \frac{T}{Z_p} = \frac{16T}{\pi D^3}$, $Z_p = \frac{\pi}{16}D^3$
- **Bending Equation:** $\frac{\sigma_b}{y} = \frac{M}{I} = \frac{E}{R}$

HYDROLOGY

- Water Budget Equation. $P - R - G - E - T = \Delta S$

Instruments used in measurement

Relative humidity	Psychrometer
Humidity	Hygrometer
Wind speed	Anemometer
Rainfall depth	Ombrometer
Transpiration	Phytometer
Evapotranspiration	Lysimeter
Evaporation	Atmometer

Name	Isopleth
Isobar	Pressure
Isohyets	Rainfall
Isonif	Snowfall
Isotherm	Temperature
Isopleths	Evapotranspiration
Isohaline	Salinity

Annual Rainfall

- The Coefficient of variation $C_v = \frac{100 \times \text{standard deviation}}{\text{mean}} = \frac{100 \times \sigma_{n-1}}{P}$
- Number of Stations $N = \left(\frac{C_v}{E}\right)^2$, $\varepsilon < 10\%$, $\sigma_{n-1} = \sqrt{\frac{\sum^n (P - \bar{P})^2}{m - 1}}$,

$f_c = f_c + (f_o - f_c)e^{-kt}$,
f_c = Infiltration capacity at any time t,
f_o = initial infiltration,
f_c = Final steady state infiltration.

IRRIGATION

Methods of Irrigation
Free flooding, Border flooding, Check flooding, Basin flooding, Furrow Irrigation, sprinkler Irrigation, Drip Irrigation.

- **Sodium Absorption Ratio:** $SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$
- **Depth of water stored in root zone:** $d_{rz} = \frac{d_1\gamma_d}{\gamma_w}(F_C - M_d)$
- **Relation b/w duty and Delta:** $\Delta = \frac{8.64B}{D}$(meter),
  B = Base period in days, D = Duty in hectare/cumec
- **Irrigation Efficiency**
  (a) **Water conveyance Efficiency:** $\eta_c = \frac{W_f}{W_r} \times 100$,
  W_f = water delivered to the farm, W_r = water supplied
  (b) **Water appliacation Efficiency (η_a):** $\eta_a = \frac{W_s}{W_f} \times 100$
  Below the farm root-zone $W_d = W_s + R_p + D_p$,
  W_s = Water stored in the root zone,
  W_f = Water delivered to the farm,
  R_p = Surface run off, D_p = deep percolation
  (c) **Water use efficiency (η_u):** $\eta_u = \frac{w_n}{w_d} \times 100$,
  w_n = water used beneficialy,
  w_d = water delivered.
  (d) **Water Storage Efficiency (η_s):** $\eta_s = \frac{W_s}{W_n} \times 100$,
  W_n = water needed in the root zone prior to Irrigation,
  W_s = (field capacity–Available moisture)
  (e) **Water Distribution Efficiency (η_d):**
  $\eta_d = 100\left(1 - \frac{Y}{d}\right)$, Y = average numerical deviation in depth of water average depth stored during Irrigation (d).
- **Consumption Irrigation Requirements (CIR):** $CIR = C_u - R_e$
  Field Irrigation Requirement (FIR): $FIR = \frac{NIR}{\eta_a}$
  Gross Irrigation Requirement: $GIR = \frac{FIR}{\eta_c}$
  $NIR = CIR + LR + PSR + NWR$, (GIR > FIR > NIR > CIR)
- **Kennedy's theory:** $V_o = 0.55 m y^{0.64}$
- **Kutter's/ chezy's Formula:** $V = \frac{23 + \frac{0.00155}{S} + \frac{1}{n}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{n}{\sqrt{R}}}\sqrt{RS}$
- **Lacey's Theory:** $V = \left(\frac{Qf^2}{140}\right)^{1/6}$, $f = 1.76\sqrt{d_{mm}}$
- $R = \frac{5}{2}\left(\frac{V^2}{f}\right)$, $S = \frac{f^{5/3}}{3340\,Q^{1/6}}$, $A = \frac{Q}{v}$
  wetted perimeter $P = 4.75\sqrt{Q}$ scour depth = $1.35\left(\frac{q^2}{f}\right)^{1/3}$

Difference B/W Lacey & Kennedy Theory

Kennedy	Lacey
1. Trapezoidal channel	1. Semi elliptical channel
2. Applicable for alluvial channels	2. Applicable for alluvial channels as well as for rivers.
3. Silt is kept in suspension due to eddies generated from bottom.	3. Silt is kept in suspension due to eddies generated both from side slope and the bottom i.e. through out the parameter.

- **By Rate of introduction of super elevation:** $L_s = e.N.(w + w_e)$ (Rotation about inner edge), $L_s = \frac{e.N.(w + w_e)}{2}$ (Rotation wrt centre line)
- **Empirial Formula:** $L_s = \frac{2.7v^2}{R} - C$(Plain & Rolling), $L_s = \frac{v^2}{R} - C$(Hilly area)
- **Length of Summit Curve:** $L = 2S - \frac{4.4}{N}$ **(L<SSD)**
  $L = \frac{NS^2}{4.4}$ **(L>SSD)**
- **Length of Valley Curve:** $L_s = 2\left(\frac{Nv^{1.3}}{C}\right)$ (Comfort criteria)
- **L > SSD:** $L = \frac{NS^2}{(2h_1 + 2S\sin\alpha)} = \frac{NS^2}{(1.5 + 0.035S)}$ ($h_1 = 0.75$, $\alpha = 1°$)
- **L< SSD:** $L = 2S - \frac{(2h_1 + 2S\sin\alpha)}{N}$
- **Basic Capacity of Single lane, Vehicle Per hours:** v = speed kmph, T(Sec/km) = $\frac{3600}{v}$, $q_{max} = \frac{v.k_j}{4}$,
  Where,
  v_f= Free mean speed, (Maximum speed at zero density.),
  k_j = jam density, (Maximum density at zero speed), Maximum flow q_{max} occurs when the speed is $\frac{v_f}{2}$ and density is $k_j/2$.
  Number of potential conflicts: Both roads are two way = 24, Both road one way = 6, One road is two way, other one way = 11
- $Q = \frac{280w\left(1 + \frac{v}{5}\right)\left(1 - \frac{p}{2}\right)}{\left(1 + \frac{w}{l}\right)}$, $W_{weaving} = \frac{e_1 + e_2}{2} + 3.5$ (Types of interchange: Trumpet, Diamond, Full Cloverleaf, Partial Cloverleaf

Floating Car Method: For Speed and delay study.

- **Aggregate crushing value:** $\frac{w_2}{w_1} \times 100$
- **Coefficient of Hardness:** $= 20 - \frac{\text{Loss of wt. in gm}}{3}$
- **Rigidity factor:** $R.F = \frac{\text{Contact Pressure}}{\text{Tyre Pressure}}$
- **California Resistance Value:** $t = \frac{k.(T.1)(90 - R)}{C^{2.5}}$
- **Elastic Modulus:** Δ is maximum vertical deflection of the flexible plate, $\Delta = \frac{1.18pa}{F_s}$, Rigid circular plate is used instead of flexible $\Delta = \frac{1.5Pa}{F_s}$, a = radius of plate, p = pressure at deflection, E_s = young's modulus of pavement material.
- **California Bearing Ratio M/D:** $t = \left(\frac{1.75P}{CBR} - \frac{A}{\pi}\right)^{1/2}$, t = Pavement thickness in Cm, P = wheel load in kg, CBR = California Bearing Ratio (%), A = Contact Area in cm^2
- **CBR TEST:** $CBR = \frac{\text{Load or pressure Substained at 2.5 or 5.0 mm Penetration}}{\text{Load or pressure Substained by standard aggregate at corresponding pressure level.}}$
- **Tri Axial Method:** $T_v = \left(\sqrt{\frac{2p_1 \times y}{2\pi E_s h}} - d\right)\left(\frac{E_s}{E_p}\right)$, $\frac{L_1}{L_2} = \left(\frac{E_s}{E_1}\right)^{1/3}$
- **Design of Rigid Pavement:** $k = \frac{p}{\Delta} = \frac{P}{0.125}$
- **Radius of Relative Stifness:** $l = \left[\frac{Eh^3}{12K(1 - \mu^2)}\right]^{1/4}$,
  $b = \sqrt{1.6a^2 + h^2} - 0.675h$ when (a < 1.724 h)
  $S_l = \frac{3P}{h^2}$ (Glodbeck's formula)
  $N = \frac{365A[(1+r)^n - 1]}{r} \times FD$

Bankelman Beam Deflection Method

Overlay Thickness: $h_0 = 550\log_{10}\frac{D_o}{D_a}$

Test	Purpose
CBR test	For classifying & evaluating soil subgrade & base course materials for flexible pavements
Crushing test	Strength of Aggregate
Abrasion test	Hardness of Aggregate
Impact test	Toughness of Aggregate
Soundness test	Durability of Aggregate
Shape test	Gives idea of workability & stability of mix
Bitumen Adhesion test	Gives stripping value of Aggregates
Softening point test	It is done by Ring & ball apparatus to ensure safety of Bitumen
Float test	for viscosity of Bitumen.

S.SOROUT, 9255624029
FOLLOWING BOOKS AVAILABLE BY
CIVIL Ki GOLI PUBLICATION:
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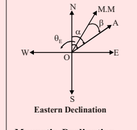
HIGHWAY ENGINEERING

Roman Roads → Tresaguet Construction → Metcalf Construction → Telford Construction → Macadam Construction
Nov. 1927 → Jayakar Committee formed
Feb. 1928 → Recommendations by Jayakar Committee

RAILWAY ENGINEERING

Surveying Chain: Revenue chain (33 ft), Gunter's chain (66 ft), Engineer's chain (100 ft), Metric chain
Equipments for Measurement Right Angles: Cross staff, optical square, Prism square.

- **Tap Corrections:**
- **Correction for Slope:** $C_s = L - \sqrt{L^2 - h^2}$
- **Correction for alignment or bad ranging:** $C_a = \frac{h^2}{2L}$
- **Correction for Temperature:** $C_t = \alpha\,(T_m - T_o)L$
- **Correction for pull or Tension:** $C_p = \frac{(P - P_o)L}{AE}$
- **Correction for Sag:** $C_s = -\frac{L(wL)^2}{24P^2}$
- **Important Terms**
- **Bearing:** Direction of a line with respect to fixed meridian is called bearing.
- **True Meridian/Bearing**
  → True meridian is a line joining True North pole, True South Pole end and point of reference. **It never changes with time.**
  → Angle measured for any line w.r.t True Meridian is called Ture bearing.
- Bearing Taken W.r.t magnetic meridian is called magnetic Bearing.



Magnetic Declination

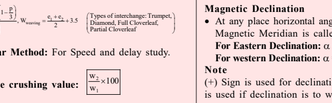
- At any place horizontal angle b/w True Meridian and Magnetic Meridian is called magnetic Declination.
  For Eastern Declination: α = B + θ_o or T.B = M.B +θ_o
  For western Declination: α = B – θ_o or T.B = M.B – θ_o

Note
(+) Sign is used for declination is to the east, sign (–) is used if declination is to west

Fore bearing and Back Bearing: B.B = F.B ± 180°
Local Attraction: F.B – B.B ≠ 180°
Latitude and Departure
→Projection of a line on N-S direction is called latitude: $L = l\cos\theta$
→Projectione of a line on E-W direction is called deparature: $D = l\sin\theta$

Adjustment of closing Error.

- Sum of all internal Angles of a closed Traverse: (2n–4)×90° where n = No. of sides.
- Sum of all deflection Angle = 360°
- Sum of latitude: $\Sigma L = 0$
- Sum of departure: $\Sigma D = 0$
- **Closing error In the Traverse:** $e = \sqrt{(\Sigma L)^2 + (\Sigma D)^2}$
- **Bowditch's Method (Compass Rule)**
  Permissible error in linear Measurment $e\alpha\sqrt{l}$
  Permissible error in angular measurement $e\alpha\frac{1}{\sqrt{l}}$
- **Correction to latitude:** $C_L = \Sigma L \times \frac{l}{\Sigma l}$
- **Correction due to departure:** $C_D = \Sigma D \times \frac{l}{\Sigma l}$
- **Transit Method:** $C_L = \Sigma L \times \frac{L}{L_r}$, $C_D = \Sigma D \times \frac{D}{D_r}$
- **Axis Method.**
  Correction of any length: That length × $\frac{\frac{1}{2}\text{closing error}}{\text{Length of Axis}}$



- **Sensitivity:** Angle b/w the line of sights in radius $\alpha = \frac{S}{D} = n \times \frac{l}{R} = \left(\frac{l}{R} = \frac{S}{nD}\right) \times 206265$
  D = Distance of the instrument from the staff
  n = Number of divisions
  l = length of one division (2mm)
  R = Radius of curvature
  S = Staff intercept.
- **Check in Height of Instrument Method**
  Σ BS– Σ FS = Σ Rise – Σ Fall = Last RL–First RL
- **Curvature:** $C_c = -\frac{d^2}{2R} = -0.0785d^2$. **•Refraction:** $C_r = \frac{1}{7}\left(\frac{d^2}{2R}\right)$
- **Final Combination Correction:**
  $C = C_c - C_r = -\frac{6}{7}\left(\frac{d^2}{2R}\right) = -0.06735d^2$
- **Distance of Visible Horizon**
  $d = 3.85\sqrt{h}$, d = in km and h = in meter.
- **Reciprocal Levelling:** The true difference Elevation: $H = \frac{1}{2}[(h_1 - h_2) + (h_1' - h_2')]$
- **Determining Areas:** Mid ordinate rule Δ (Area) = Average ordinate × Length of base, $\Delta = \frac{O_1 + O_2 + \ldots + O_n}{n} \times L$
- **Average ordinate Rule:** Area D = Average ordinate of the base= $\left(\frac{O_1 + O_1 + \ldots + O_n}{n+1}\right) \times L$, $D = \frac{L}{(n+1)} \times \Sigma D$,

ENVIRONMENTAL ENGINEERING

- **Variation of Demand**
  Max. daily Consump. = 1.8 × Annual avg. daily consump.
  Maximum Weekly Consumption = 1.48 ×Avg. weekly
  Maximum Monthly Consumption = 1.28 × Avg. monthly.
- **Population Forecasting Mehtod**
  Arithmetic Increase Method: $P_n = P_o + n\bar{x}$ (For old cities)
  Geometric Increases Method: $P_n = P_o\left(1 + \frac{x}{100}\right)^n$ (For new cities)
  Incremental Increase Method: $P_n = P_o + n\bar{x} + \frac{n(n+1)}{2}\bar{y}$

- **Physical characteristics**
  Turbidity: (limit 1-5 NTU) Baylis, Jackson, Nephelometer
  Colour: Tintometer (limit 5-15 TCU), **Taste & odour:** T.O.N = 1 (↓3)
  Temperature: 10°C desirable (↑25°C)
  Total solid = Dissolved solids + Suspended solids (Gravimetric Method)
- **Chemical Characteristics**
  Total solids & suspended solids: Limit 500-2000 ppm
  PH = – log H^+ (6.6 to 8.5) Methyl Orange & Phenolphthalein
  Total Hardness: $[Ca^{++}] \times \frac{50}{20} + [Mg^{++}] \times \left(\frac{50}{12}\right)$ (EDTA using EBT)
  Carbonate Hardness: min of total hardness or alkalinity
  Chloride: limit – 120mg/L (Water), 250 mg/L (Sewage)
  Nitrogen Content: Limits: Free ammonia ↓0.15mg/L, Organic Nitrogen ↓ 0.3 mg/l, nitrite should be zero, nitrate ↓ 45 mg/l
  Measurement (i) Free Ammonia-by simple boiling of water. (ii) Organic Ammonia – By adding $Kmno_4$, (i+ii) are known as **kjeldahl Nitrogen** Nitrite and Nitrate by - colour Matching Method.
  Chemical: (Mn = 0.05 mg/L) (Iron – 0.3 mg/L), (Fluride : 1.0 –1.5 mg/L) (Sulphate : 250 mg/L) (Cyanides = 0.2mg/L) (Arsenic : 0.01 ppm)
  Screening: Velocity ↑0.8 to 1m/sec
  Based on stokes law. Setting velocity: $V_s = \frac{Q}{BL}$
- **Design Criteria:** Over flow rate = $\frac{Q}{BH}$, 500–750 lit/hr/m2 for plain sedimentation, Depth = 03 to 4.5m Width B ≈ 10 m
- **Coagulants**
  1. Use of Alum
  2. Use of copperas: $(FeSo_4.7H_2O)$
  3. Use of chlorinated copperas $(Fe.(So_4)_3 + FeCl_3)$.
  4. Use sodium Aluminate $(Na_2Al_2O_4)$

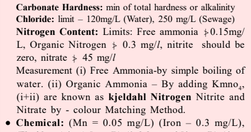
Comparision of slow sand and Rapid Gravity Filters.

Slow sand filter	Rapid sand filter
$C_u = 3–5$	$C_u = 1.2–1.6$
$D_{10} = (0.2–0.3)$ mm	$D_{10} = (0.35–0.55)$ mm
Frequency of cleaning = (1–3) months	Cleaned through Back washing
Design period = 10 year	$n = 1.22\sqrt{Q}$
Use for smaller plants in village	Rate of filtration (3000-6000)
Design on max. daily demand.	$l/m^2/hr$
Rate of filtration (100-200) $l/m^2/hr$ is very low as compared to R.S.F., but efficiency is High	Operational Troubles– (a) Air Binding (b) Mud ball formations (c) Cracking of filter

1. Minor Methods.
(i) Boiling, (ii) Treatment with excess lime, (iii) Treatment with ozone $(KMNO_4)$, (iv) Treatment with silver Process.
2. Major Method Chlorination (Disinfection with Cl_2)

- $Cl_2 + H_2O \xrightarrow{pH<3} HOCl + HCl$, • $HOCl \xrightarrow{pH>3} H^+ + OCl^-$
- $HOCl + \xrightarrow{pH<3} H^+ + OCl^-$, • $NH_2 + HOCl \rightarrow NH_2Cl + H_2O$

NH_2 + HOCl is called combined chlorine.
Chlorine forms: Free chlorine, Hypochlorites (Swimming Pool), Chloramines, Chlorine dioxide



Treatment With Water
1. Treatment with Copper Sulphate $(CuSO_4.H_2O)$

- Added to open reservoir and lakes to kill algae or to check the growth.

2. Treatment with $KMNO_4$

- Acts as oxidizing agent to remove to taste, odour and colour and to kill bacteria.

3. Aerations

- For increasing Di-oxygen to remove CO_2, upto some extent removal of Fe and Mn.

4. Fluoridation

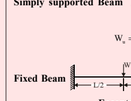
- Necessary if F < 1mg/L. Add Naf or Na_2SiF_6 or H_2SiF_6 to keep fluorine content between 1 to 1.5 mg/L

(1) De-Fluoridation. (if F > 1.5 mg/L) In India, Treatment is done by Nalgonda Technique (Use Alum for reducing flurides)
5. Removal of Radioactive Substances By coagulation & filtration.
6. Desalination (i) By evaporation and distillation (ii) Electrodialysis (iii) Reverse Osmosis.

- **Hydraulic design of sewers:** $V = \frac{1}{n}R^{2/3}S^{1/2}$
- **Oxygen Demand:** $\frac{dL}{dt} = -KL, L_t = L_0 - 10^{-k_1}D^1$,
  $BOD_t = L_o - L_t = L_o\left[1 - 10^{-k_1 t}\right]$, $[BOD_5 = 0.684L_0]$,
  $K_{(T^o)} = KD_{20}\,[1.047]^{T-20}$

Member	λmax
A member carrying compressive load resulting from dead load and imposed load	180
A tension member in which reversal of direct stress due to load other than wind and seismic force	180
A member subjected to compressive forces resulting from wind EQ force provide deformation of such member does not affect stress	250
Compression flange of Beam against lateral torsional buckling.	300
A member normally act as a tie in Roof Truss	350
Tension member other than Pre-tension	400

- Strength of plate between rivet holes in Tension = $\sigma_{at} \times (p\text{-}d) \times t$
- Bearing strength of rivet = $\sigma_{at} \times d \times t$ or = $\sigma_{pr} \times d \times t$.
- Shear Strength of rivet = $T_{sr} \times \frac{\pi}{4} \times d^2$ (in single shear), $2 \times T_{sr} \times \frac{\pi}{4} \times d^2$ in double shear), d = gross diameter of rivet, $d = 6.01\sqrt{t}$ (unwins formula)
- **Diameter:** Grosss diameter = nominal diameter + 1.5 mm (if ≤ 25mm), Nominal diameter + 2mm (if > 25mm)
- **Pitch:** Should not exceed 16t or 200mm, which ever is less in tension member, and 12t or 200mm, which ever is less in Compression Members. Tacking rivets should not exceed 32 t or 300 mm which ever is less. Minimum pitch = 2.5d
- **Force due to axial load on each rivet:** $F_a = \frac{W}{n}$
- **Force due to moment M on any rivet:** $F_m = \frac{M \times r}{\Sigma h^2}$
- **Area along Section:** $A_{ns} = t\left[b - n \times d + \left(\frac{S^2}{4 \times g_1} + \frac{S^2}{4 \times g_2}\right)\right]$
- **Net Effective Area:**

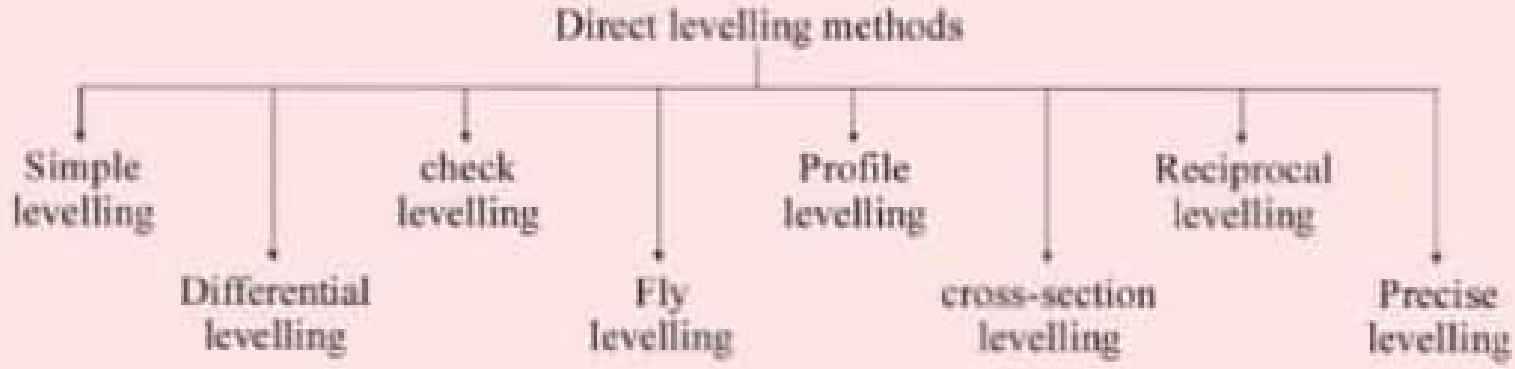


$A_{ns} = A_s + A_1 \times k_1$, $k_1 = \frac{3 \times A_1}{3 \times A_1 + A_2}$,
$A_s = (l_1 - t/2 - d)t$, $A_1 = (l_1 - t/2) \times t$,
$A_{ns} = (l_1 + l_2 - t)t$

- For pair of Angle Placed back to back connected by only one lag of each angle.

$A_{ns} = A_1 + A_2 \times k_2$, • $K_2 = \frac{5 \times A_1}{5 \times A_1 + A_2}$

The area of a web of Tee = Thickness of web × (depth - thickness of flange)



- **Sensitivity:** Angle b/w the line of sights in radius

$$\alpha = \frac{S}{D} = n \times \frac{\ell}{R} \qquad \frac{l}{R} = \left(\frac{S}{nD}\right) \times 206265$$

D = Distance of the instrument from the staff
n = Number of divisions
l = length of one divison (2mm)
R = Radius of curvature
S = Staff intercept.

- **Check in Height of Instrument Method**

$$\sum BS - \sum FS = \sum Rise - \sum Fall = Last\ RL - First\ RL$$

- **Curvature:** $C_c = \frac{d^2}{2R} = 0.0785d^2$. •**Refraction:** $C_r = \frac{1}{7}\left(\frac{d^2}{2R}\right)$

- **Final Combination Correction:** $C = C_c - C_r = \frac{6}{7}\left(\frac{d^2}{2R}\right)$,

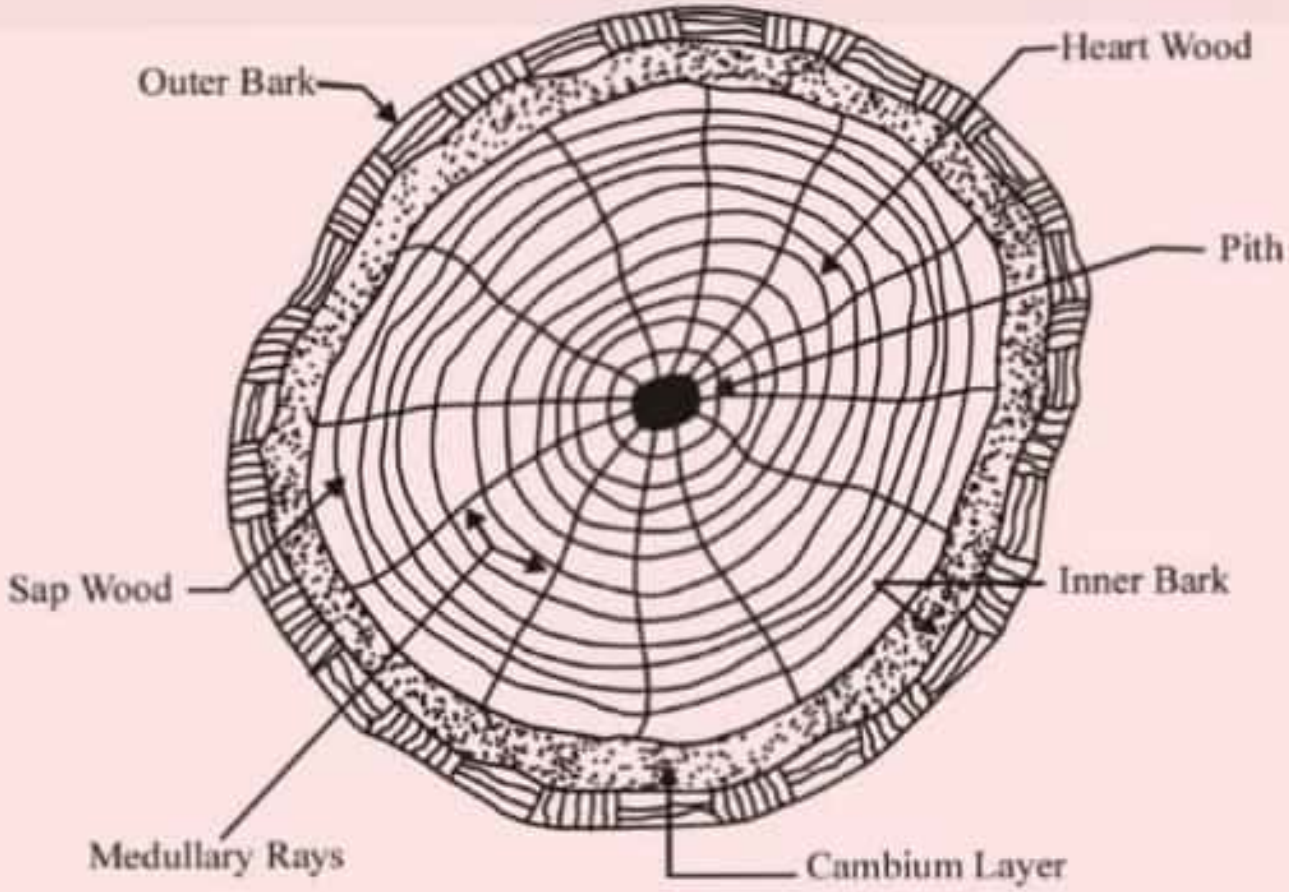
$C = 0.06735d^2$,

- **Distance of Visible Horizon**

$d = 3.85\sqrt{h}$, d = in km and h = in meter.

- **Reciprocal Levelling:** The true difference Elevation:

$$H = \frac{1}{2}(h_a - h_b) + (h_a' - h_b')]$$





Rock Types	Chemically	Physically	Geologically
Granite	Siliceous	Unstratified	Igneous
Quartzite	Siliceous	foliated	Metamorphic
Marble	Calcarious	Foliated	Metamorphic
Limestone	Calcarious	Stratified	Sedimentary
Sandstone	Siliceous	Stratified	Sedimentary
Slate	Argillacous	Foliated	Metamorphic
Laterite	Argillacous	Stratified	Sedimentary.

Tools for Quarrying stones

Jumper, Dipper, Crow bar, Tamping bar

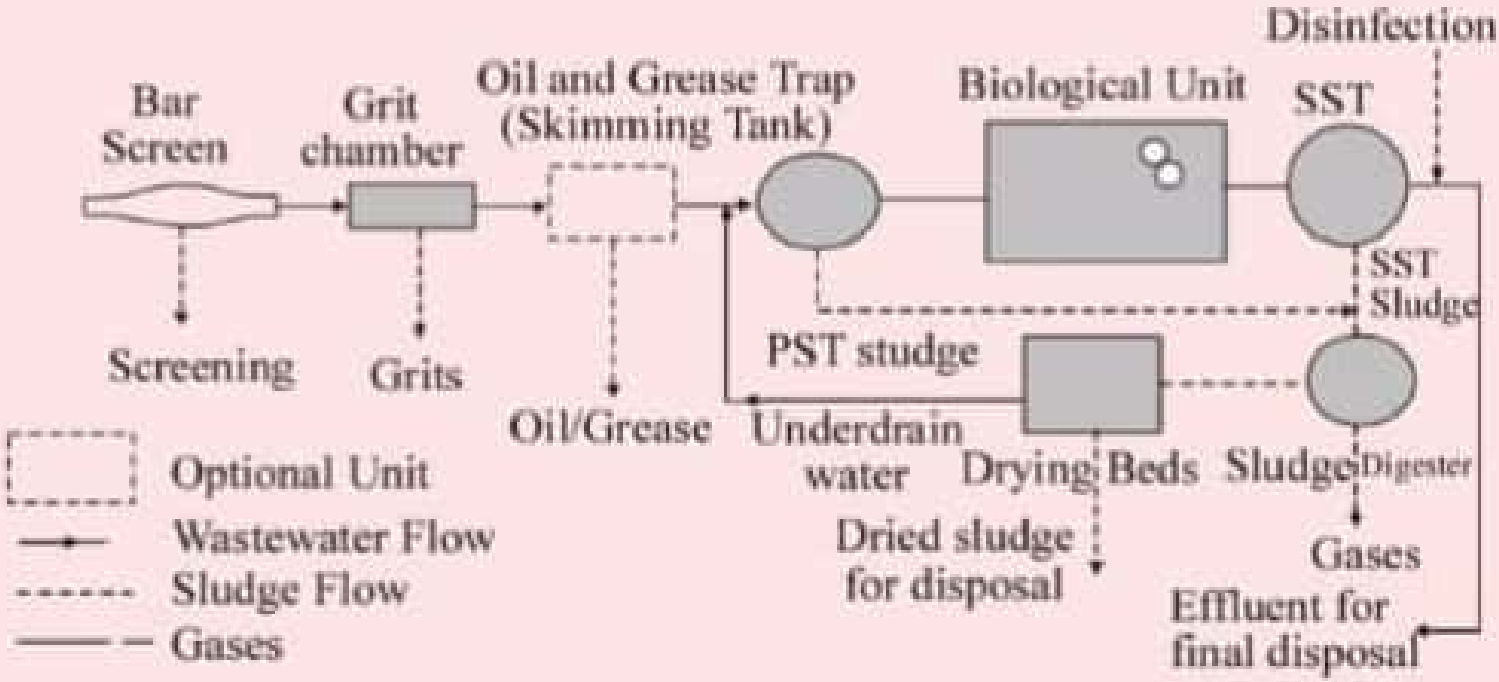
Test	Purpose
Smith test	for Durability of stones
Brard's test	for frost resistance
Acid test	To check weather resistance
Hardness test	Mohn scale

- **Hydraulic design of sewers:** $V = \frac{1}{n} r^{2/3} S^{1/2}$ (manning, formula)
- **Oxgen Demand:** $\frac{dL_t}{dt} = -KL, L_t = L_0 - 10^{-k_1 t}$,

$Y_t = L_0 - L_t = L_0\left[1 - 10^{-k_1 t}\right]$, $y_5 = [BOD_5 = 0.684 L_0]$,

$K\ K_{DT} = KD_{20}\,[1.047]^{T-20}$

Note: Minimum velocity about 0.45m/sec.



- **Design Criteria for Grit Chamber:** Setting velocity $V_S =$

$\frac{g}{18}(G_S - 1)\frac{d^2}{V}$ (Min. $V_{Self} = 0.45$ m/s.)

- **Detention Time:** 30-60S, Horizontal velocity of flow–15-30 cm/sec. Length to breath ratio of chamber varies from 6 to 15 and length to depth ratio varies form 40 to 30, cleaning interval = 1 or 2 weeks, **Channel length = detention time × velocity of flow**

FOLLOWING BOOKS
AVAILABLE BY

CIVIL Ki GOLI PUBLICATION:

1. CIVIL Ki GOLI
2. REASONING Ki GOLI
3. CIVIL BOOSTER
4. HARYANA Ki GOLI
5. SOLUTION OF CIVIL Ki GOLI

HIGHWAY ENGINEERING

Roman Roads → Tresaguct Construction → Metcalf Construction → Telford Construction → Macadam Construction

Nov. 1927 → Jayakar Committee formed

Feb. 1928 → Recommendations by Jayakar Committee

1929 → Central Road Fund

1934 → Indian Road Congress

1939 → Motor Vehicle act

1952 → Central Road Research Institute

1956 → National Highway act

Nagpur Plan	Bombay Plan	Lucknow Plan
→ 1943–1963	1961–1981	1981–2001
→ Road density 16 km/100 km²	Road density 32 km/100 km²	Road density 82 km/100 km²
→ Recommended star & grid pattern	→ Construction of 1600 km of Expressway	

- **SSD:** $v.t + \frac{v^2}{2g(f \pm 0.01n)}$ $= 0.278v.t + \frac{V^2}{254(f \pm 0.01n)}$

CIVIL Ki GOLI
12.09.19 at 2:46 PM

- **OSD:** $= V.t + (V.T + 2S) + V.T$

- Strength of plate between rivet holes in Tension = $\sigma_{at} \times (p-d) \times t$
- Bearing strength of rivet = $\sigma_{at} \times d \times t$ or $= \sigma_{Pb} \times d \times t$.
- Shear Strength of rivet $= T_{vf} \times \frac{\pi}{4} \times d^2$ (in single shear),

  $2 \times T_{vf} \times \frac{\pi}{4} \times d^2$ in double shear), d = gross diameter of rivet,

  $\boxed{d = 6.01\sqrt{t}}$ (unwins formula)
- **Diameter:** Grosss diameter = nominal diameter + 1.5 mm (if < 25mm), Nominal diameter + 2mm (if > 25mm)
- **Pitch:** Should not exceed 16t or 200mm, which ever is less in tension member, and 12t or 200mm, which ever is less in Compression Members. Tacking rivets should not exceed 32 t or 300 mm which ever is less. Minimum pitch = 2.5d

Tacking rivets.

Thickness of member	Minimum diameter of rivets
Up to 10 mm	16mm
Over 10mm to 16 mm	20 mm
Over10 mm	22mm

- **Force due to axial load on each rivet:** $F_a = \frac{W}{n}$
- **Force due to moment M on any rivet:** $F_m = \frac{M \times r}{\sum h^2}$

Column: Longitudinal reinforcement-Minimum (0.8%), Maximum (6%) (4% – overlapping). Minimum Number of Bars (Rectangular - 4, circular - 6). Minimum diameter of longitudinal bar = 12 mm. Maximum centre to centre spacing of reinforcement = 300 mm

- **Short & Long Column:** Short if salenderness. ratio of both axes are

less than, $12.\left(\frac{l_{ex}}{h}\right)$ or $\left(\frac{l_{ey}}{b}\right) \geq 12$

Lateral ties: Tie diameter $\phi_t \geq \begin{cases} \frac{\phi \text{ longitudinal max}}{4} \\ 6 \text{ mm} \end{cases}$

Tie spacing $S_v \leq \begin{cases} D \\ 16\phi \text{ longitudinal min} \\ 300 \text{ mm} \end{cases}$

Minimum Eccentricity:

$$e_{y,min} = \max\left\{\begin{matrix} \frac{l_{ey}}{500} + \frac{D_y}{30} \\ 20 \text{ mm} \end{matrix}\right. \quad \text{For non – rectangular / circular section}$$

$$e_{x,min} = \max\left\{\begin{matrix} \frac{l_{ex}}{500} + \frac{D_x}{30} \\ 20 \text{ mm} \end{matrix}\right. \qquad e_{min} = \max\left\{\begin{matrix} \frac{l_z}{300} \\ 20 \text{ mm} \end{matrix}\right.$$

Slenderness Limits to Ensure Lateral Stability

Slenderness limits to ensure lateral stability

- Cantilever beam
- Simply supported beam or continuous beam

Clear span < min. $\begin{cases} 25b \\ \frac{100b^2}{d} \end{cases}$ Clear span < min. $\begin{cases} 60b \\ \frac{250b^2}{d} \end{cases}$

Control of Deflection:

Cantilever beam	7
Simply supported beam	20
Continuous beam	26

Type of slab	Type of reinforcement	
	Mild steel	Fe 415
Simply supported	35	28
Continuous	40	32

- **Concentrically Loaded Column:** (e = 0)

$$\boxed{P = 0.45f_{ck}A_c + 0.75f_y A_{st}}$$

- **Axially Loaded Column:** (e < 0.05h)

$$\boxed{P_{uz} = 0.9P = 0.4f_{ck}A_c + 0.67f_y A_{st}}$$

Prestressed Concrete

- **Loss due to length effect :** $P_0 kx$
- **Curvature effec:** $P_0 \mu\alpha$
- **Loss of pre-stress at the Anchoring stage:** $= \frac{\Delta L}{L} \times E_s$
- **Loss of stress due to shrinkage of concrete:** $= \varepsilon_{sh} \times E_s$
- **Loss of stress due to creep of concrete:** $= \phi m f_c$
- Losss of stress = strain lost in steel × E_s $\boxed{\frac{f_c}{E_c} \times E_s = \frac{P_0}{A} + \frac{N}{Z}}$

Pre tensioned losses>Post tensioned losses

Post tensioning system: Freyssinet, Magnel-Blaton, Lee-mc-call, Gifford

REINFORCE CEMENT CONCRETE

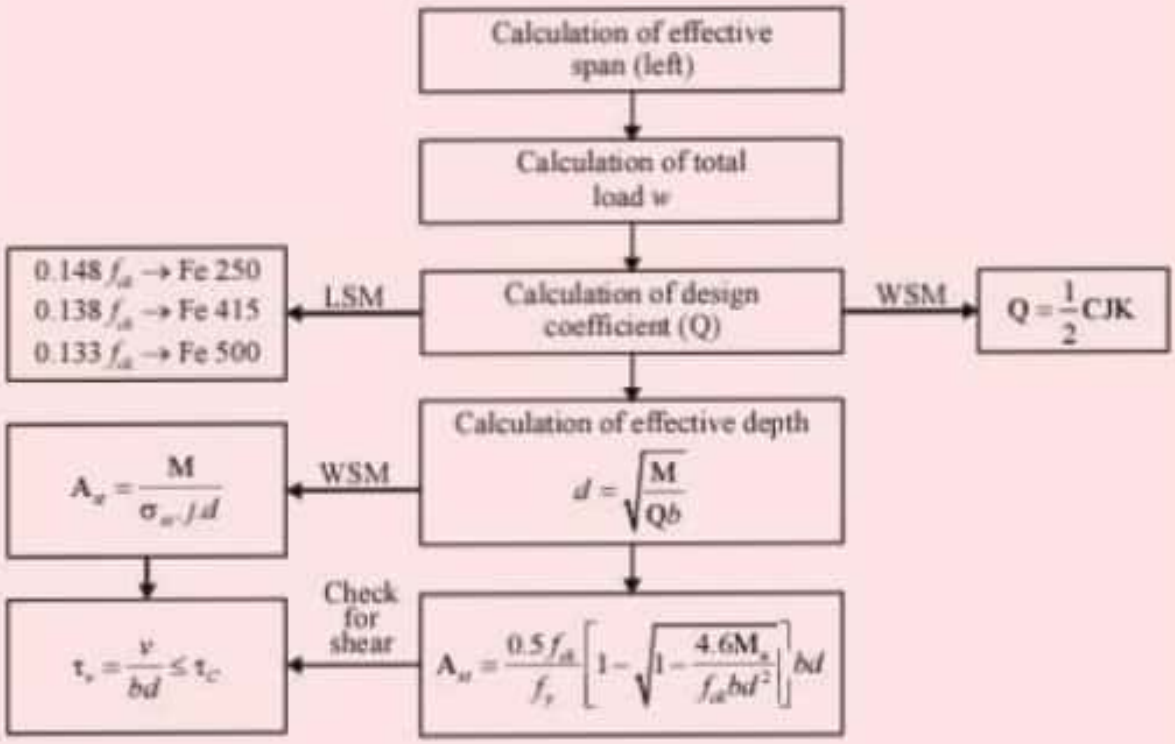
$E_c = 5700\sqrt{f_{ck}}\ N/mm^2$. Min. grade = M15 (IS 456:1978).

$E_c = 5000\sqrt{f_{ck}}\ N/mm^2$. Min. grade = M20 (IS 456:2000)

$m = \frac{280}{3\sigma_{cbc}}$

$f_{cr} = 0.7\sqrt{f_{ck}}$, $f_{ct} = 0.66 f_{cr} = \frac{2p}{\pi DL}$

f_{cr} (flexure > Splitting > Direct Tensile strength)



- **Analysis Of Stresses (WSM):** Moment of Comp. Area = Moment of ten. Area $bx.\frac{x}{2} = mA_{st}(d-x)$

$p = \frac{A_s}{bd}$, $j = \frac{Z}{d}$ = lever arm coefficient $= \left(1 - \frac{k}{3}\right)$

- **Optimum Section:** $\frac{x}{d-x} = \frac{\sigma_{cb}}{\sigma_{st}/m}$,

$$\text{Window Width} = \frac{1}{8}[\text{Width of room} + \text{Height of Room}]$$

- The sill of a window should be located about (70 – 80) cm above floor level of the room.
- Generally Height of a Door should not be less than (1.8 – 2) m
- Commonly Width height relation used in India:
  (i) Width = (0.4 – 0.6) Height
  (ii) Height = (Width + 1.2) m
- Doors of residential Buildings:
  (a) External Door – (1 × 2) to (1.1 × 2) m
  (b) Internal Door – (0.9 × 2) to (1 × 2) m
  (c) Doors for bathrooms and Water closets: – (0.7 × 2) to (0.8 × 2) m
- Public Buildings (School, Hospital, library)
  (a) (1.2 × 2) m (b) (1.2 × 2.1) m (c) 1.2 × 2.25) m
  Designation of Door = Length × Type of Door × Height 8 DS 20 – A door opening Having width (8 × 100 mm) × Height (20 × 100 mm) with S (Single SHutter) D (Door)

Types of Window

1. fixed 2. Pivoted 3. Sliding 4. Bay 5. Corner 6. Cable (7) Dormer (8) Skylights (9) Louvered (10) Lantern (11) Gable

Stairs

- No of steps are not more than 12 and not less than 3 in a flight.
- Angle of Inclination (Pitch) – (25° – 40).
- Head room must not be less than 2.05 m.
- Minimum width of stairs in residential building – 85 cm and in commercial building is 1 m.
- Some Thumb rule:
  (a) (2R + T) = 60
  (b) (R + T) = (40 – 45)
  (c) R × T = (400 – 450)
  where R – Rise in cm, T – Tread in cm
- For residential building, common size of steps is (16 × 26) cm, IN Hospital etc. –(10 × 30) cm.
- In case of straight staircase, No. of Trade = (No. of Riser – 1)

$$\text{No. of riser} = \frac{\text{Total Height between floor and Roof}}{\text{Height of One Riser}}$$

- **Consumption Irrigation Requirements (CIR):** $CIR = C_u - R_e$

Field Irrigation Requirement (FIR): $FIR = \frac{NIR}{n_a}$

Gross Irrigation Requirement: $GIR = \frac{FIR}{n_c}$

$NIR = CIR + LR + PSR + NWR$, $(GIR > FIR > NIR > CIR)$

- **Kennedy's theory:** $V_o = 0.55 my^{0.64}$

- **Kutter's/ chezy's Formula:** $$V = \left[\frac{23 + \frac{0.00155}{S} + \frac{1}{n}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{n}{\sqrt{R}}}\right]\sqrt{RS}$$

- **Lacey's Theory:** $V = \left[\frac{Qf^2}{140}\right]^{1/6}$, Q = Discharge $f = 1.75\sqrt{d_{mm}}$

- **Hydraullic Mean depth:** $R = \frac{5}{2}\left(\frac{V^2}{f}\right)$ $S = \frac{f^{5/3}}{3340\,Q^{1/6}}$ $A = \frac{Q}{v}$

wetted perimeter $P = 4.75\sqrt{Q}$

Difference B/W Lacey & Kennedy Theory

Kennedy	Lacey
1. Trapezoidal channel	1. Semi elliptical channel
2. Applicable for alluvial channels	2. Applicable for alluvial channels as well as for rivers.
3. Silt is kept in suspension due to eddies generated from bottom.	3. Silt is kept in suspension due to eddies generated both from side slope and the bottom i.e. through out the parameter.
4. No eq. for bed slope	4. Gave eq. to calculate bed slope
5. Recommended Kutter eq. to find velocity	5. Gave his own velocity
6. Trial & error procedure	6. Diret procedure

FLUID MECHANICS

- **Viscosity:** $\boxed{\mu = \frac{\tau}{\frac{d\theta}{dt}}}$ $\boxed{\frac{d\theta}{dt} = \frac{du}{dy}}$ $\boxed{\nu = \frac{\mu}{\rho}}$ $\boxed{\nu_{mercury} = 15.2\nu_{water}}$ $m^2/sec.$

$\boxed{\tau = \mu \frac{du}{dy}}$ 1 mm of Hg = 10^{-3} m of Hg = $10^{-3} \times 13.6$ m of water

$= 10^{-3} \times 13.6 \times 9810\ N/m^2$, $1\ N/mm^2 = 10^6\ N/m$

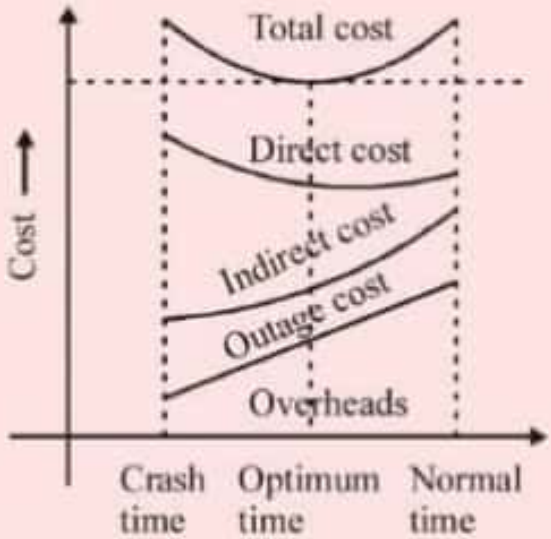
$1\ Kgf/cm^2 = \frac{9.81\ N}{10^{-4} m^2} = 98.1 \times 10^3\ N/m^2$, $1\ mm = 10^{-3} \times 10^5\ N/m^2$

Compressibility $= \frac{1}{K} = \frac{d\delta}{\delta dp}$, $1 \frac{NS}{m^2}(SI) = 10$ poise, $1\ m^2/s\ (SI) = 10^4$ stoke

Comparison between PERT and CPM

PERT	CPM
1. Probabilistic approach	1. Deterministic approach
2. Three time estimate	2. Single time estimate
3. Event oriented	3. Activity oriented.
4. Cost is proportional to time	4. Cost model is developed
5. β-distribution	5. Normal distribution
6. Concept of slack	6. Concept of float
7. Critical path by joining critical events	7. Critical path by joining critical activities.

$$\text{Cost slope} = \frac{C_c - C_n}{t_n - t_c}$$



2. **Circular Tapering Bar:** $\Delta L = \frac{4PL}{\pi E D_1 D_2}$

- **Defection of Composit Bar:** $\Delta L_1 = \Delta L_2 \Delta = \frac{PL}{A_1E_1 + A_2E_2}$
- **Deflection due to Self Weight of Bar:**

1. **Prismatic Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{2E}$,

2. **Conical Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{6E}$

- **Thermal Expansion:** $\sigma = E\alpha\Delta T$, $\Delta = L\alpha\Delta T$

Coefficient of Thermal expansion (Aluminium > Brass > Copper > Steel)

$P_{cr} = \frac{\pi^2 E}{\lambda^2}$ (Euler's Theory) $P_R = \frac{\sigma_c A}{1 + a\lambda^2}$ (Rankine's Formula)

- **In case of Pure Bending:** $Z = \frac{\pi}{32} D^3$
- **In case of pure Torsion:** $\tau_{max} = \frac{T}{Z_p} = \frac{16T}{\pi D^3}$ $Z_p = \frac{\pi}{16} D^3$
- **Bending Equation:** $\frac{\sigma_b}{y} = \frac{M}{I} = \frac{E}{R}$

HYDROLOGY

- Water Budget Equation. $P - R - G - E - T = \Delta S$

Instruments used in measurement

Relative humidity	Psychrometer
Humidity	Hygrometer
Wind speed	Anemometer
Rainfall depth	Ombrometer
Transpiration	Phytometer
Evaptoranspiration	Lysimeter
Evaporation	Atmometer

Name	Isopleth
Isobar	Pressure
Isohyets	Rainfall
Isonif	Snowfall
Isotherm	Temperature
Isopleths	Evapotranspiration
Isohaline	Salinity

Annual Rainfall

- The Coefficient of variation

$$C_v = \frac{100 \times \text{standard deviation}}{\text{mean}} = \frac{100 \times \sigma_{m-1}}{P}$$

- Number of Stations $N = \left(\frac{C_v}{E}\right)^2$, $\varepsilon \leq 10\%$, $\sigma_{m-1}\sqrt{\frac{\sum_i^m (P_i - \bar{P})^2}{m-1}}$,

P_1 = Precipitation magnitude in the ith station, $\bar{P} = \frac{1}{m}\left(\sum_i^m (P_i)\right)$ =

mean precipitation

Normal ppt. = 30 years data, avg. annual ppt. = 35 years data

Method for Calculation of Average Depth: Arithmetic Mean, Thiessen Polygon, Isohyetal Method

Hyetograph (Time Vs Intensity), Mass curve (Time Vs Accumulated ppt)

- **Estimate of Missing Data:**

$$\bar{P} = \frac{P_1 + P_2 + ... + P_i + ... + P_n}{N} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

- Thiessen Mean Method : $\bar{P} = \frac{P_1A_1 + P_2A_2 + ... + P_6A_6}{(A_1 + A_2 + ... + A_6)}$

- Isohyetal Method :

$$\bar{P} = \frac{a_1\left(\frac{P_1 + P_2}{2}\right) + a_2\left(\frac{P_2 + P_3}{2}\right) + ... + a_{n-1}\left(\frac{P_{n-1} + P_n}{2}\right)}{A}$$

(g) **Coefficient of Consolidation**

$$V_s = \frac{V}{n}, R = 3000d\sqrt{K}, S_1 + S_2 = n$$

- **Permeability of Stratified Soils**

(a) **Horizontal Flow:** $$K_H = \frac{K_1H_1 + K_2H_2 + \ldots}{H_1 + H_2 + \ldots}$$

(b) **Vertical Flow:** $$K_v = \frac{H_1 + H_2 + \ldots}{\frac{H_1}{K_1} + \frac{H_2}{K_2} + \ldots} = \frac{\Sigma H}{\Sigma H/K}$$

Note: $K_H > K_V$ always.

- **Critical Hydraulic Gradient:** $$I_c = \frac{G-1}{1+e} = (G-1)(1-n)$$

- **Boussinesq's Equations:** $$\sigma_z = \frac{3q}{2\pi z^2}\left[\frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{5/2}$$

- **Seepage Calculation:** $$q = kH\frac{N_f}{N_d}$$

- **Westergaard's Solution:** $$\sigma_z = \frac{1}{\pi}\frac{q}{Z^2} \times \frac{1}{\left[1+2\left(\frac{r}{z}\right)^2\right]^{3/2}} = k_w \cdot \frac{q}{Z^2}$$

- **Compoiession Index:** $$C_c = \frac{e_1 - e_2}{\log\bar{\sigma}_2 - \log\bar{\sigma}_1}$$

HYDROLOGY

- Water Budget Equation. $P - R - G - E - T = \Delta S$

Instruments used in measurement

Relative humidity	Psychrometer
Humidity	Hygrometer
Wind speed	Anemometer
Rainfall depth	Ombrometer
Transpiration	Phytometer
Evaptoranspiration	Lysimeter
Evaporation	Atmometer

Name	Isopleth
Isobar	Pressure
Isohyets	Rainfall
Isonif	Snowfall
Isotherm	Temperature
Isopleths	Evapotranspiration
Isohaline	Salinity

Annual Rainfall

- The Coefficient of variation

$$C_v = \frac{100 \times \text{standard deviation}}{\text{mean}} = \frac{100 \times \sigma_{m-1}}{P}$$

- Number of Stations $N = \left(\frac{C_v}{E}\right)^2$, $\varepsilon \leq 10\%$, $\sigma_{m-1}\sqrt{\frac{\sum_i^m (P_i - \bar{P})^2}{m-1}}$,

P_i = Precipitation magnitude in the ith station, $\bar{P} = \frac{1}{m}\left(\sum_i^m (P_i)\right)$ =

mean precipitation

Normal ppt. = 30 years data, avg. annual ppt. = 35 years data

Method for Calculation of Average Depth: Arithmetic Mean, Thiessen Polygon, Isohyetal Method

Hyetograph (Time Vs Intensity), Mass curve (Time Vs Accumulated ppt)

- **Estimate of Missing Data:**

$$\bar{P} = \frac{P_1 + P_2 + ... + P_i + ... + P_n}{N} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

- Thiessen Mean Method : $\bar{P} = \frac{P_1A_1 + P_2A_2 + ... + P_6A_6}{(A_1 + A_2 + ... + A_6)}$

- Isohyetal Method :

$$\bar{P} = \frac{a_1\left(\frac{P_1 + P_2}{2}\right) + a_2\left(\frac{P_2 + P_3}{2}\right) + ... + a_{n-1}\left(\frac{P_{n-1} + P_n}{2}\right)}{A}$$

- **End Condition of column:**

End condition	One end fixed one end free	Both end Hinged	Both end Fixed	One end fixed one end Hinged
L_{eff} (Theoretical)	2L 	L 	L/2 	$\frac{L}{\sqrt{2}}$ 
L_{eff} (As per IS code.)	2L	L	0.65L	0.8L

- **Shaft In series:**

$$\theta_{AD} = \theta_{AB} + \theta_{BC} + \theta_{CD} \quad , \quad \theta_{AD} = \frac{T_{AB}L_{AB}}{G_{AB}J_{AB}} + \frac{T_{BC}L_{BC}}{G_{BC}J_{BC}} + \frac{T_{CD}L_{CD}}{G_{CD}J_{CD}}$$

- **Shaft In parallel:** $\theta_1 = \theta_2$ $\quad \frac{T_1L}{G_1J_1} = \frac{T_2L}{G_2J_2}$

- **Strain Energy in Spring:** $U = \frac{32P^2R^3n}{Gd^4}$ **Deflection :** $\delta = \frac{64PR^3n}{Gd^4}$

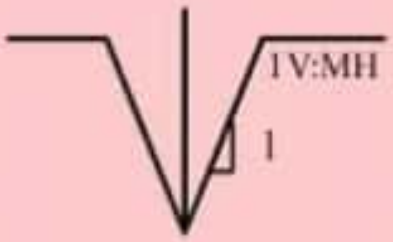
- **Stiffness in spring:** $K = \frac{Gd^4}{64R^3n}$ **Flexibility in Spring:** $f = \frac{64R^3n}{gd^4}$

$\frac{1}{K_{eq}} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + ... + \frac{1}{K_n}$, $K_{eqs} = K_1 + K_2 + K_3 + ...K_n$ (In Spring)

Note: It a spring is cut down by K times, then its strain energy decreased by $\frac{1}{k}$ times, its stiftness is increased by K times, and its flexibity decreased by $\frac{1}{k}$ time.

Most Economical Sections

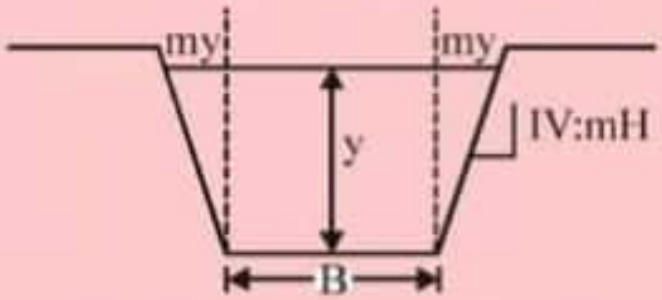
- **TRIANGULAR**



$m = 1, \theta = 45^\circ$

- $A = my^2$
- $A = y^2$
- $p = 2\sqrt{2}y$
- $R = \frac{y}{2\sqrt{2}}$
- $T = 2y$
- $D = y/2$

- **TRAPEZOIDAL**



- $B = \frac{2y}{\sqrt{3}}$ $m = \frac{1}{\sqrt{3}}$ $\theta = 60^\circ$ Hor. $\theta = 30^\circ$ Vert.
- $A = (B + my) \times y$
- $A = \left(\frac{2y}{\sqrt{3}} + \frac{1}{\sqrt{3}}y\right)y = \left(\sqrt{3}\right)y^2$
- $P = 2\sqrt{3}y$
- $R = \frac{y}{2}$
- $T = \frac{4y}{\sqrt{3}}$
- $D = \frac{3}{4}y$

Type of flow	Depth of flow	Velocity of flow	Froude No	Comments
Subcritical	$y > y_c$	$v < v_c$	$F_r < 1$	As streaming or transquil flow
Critical	$y = y_c$	$v = v_c$	$F_r = 1$	
Super Critical	$y < y_c$	$v > v_c$	$F_r > 1$	Shooting flow, rapid flow, torrential flow

Dynamic eq. for G.V.F.: $\frac{dy}{dx} = \left(\frac{S_o - S_f}{1 - \frac{q^2}{gy^3}} \right)$

Hydraulic Jump Eq.

1. $\frac{2q^2}{g} = y_1 y_2 (y_1 + y_2)$, 2. Energy Loss $E_L = \frac{(y_2 - y_1)^3}{4 y_1 y_2}$

3. $\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8F_1^2} - 1\right)$, 4. $y_c^3 = \frac{y_1 y_2 (y_1 + y_2)}{2}$

Types of Jump	Fr	E_L/E_1	Water surface
Undular	1-1.7	≈ 0	Undulating
Weak	1.7-2.5	5–18%	Small rollers form
Oscillating	2.5-4.5	18–45%	Water oscillates in random manner
Steady	4.5-9	45–70%	Roller and jump action
strong	≥ 9	$\geq 70\%$	Very rough and choppy

$$N_S = \frac{N\sqrt{P}}{(H)^{5/4}} \text{ (for Turbine),}$$

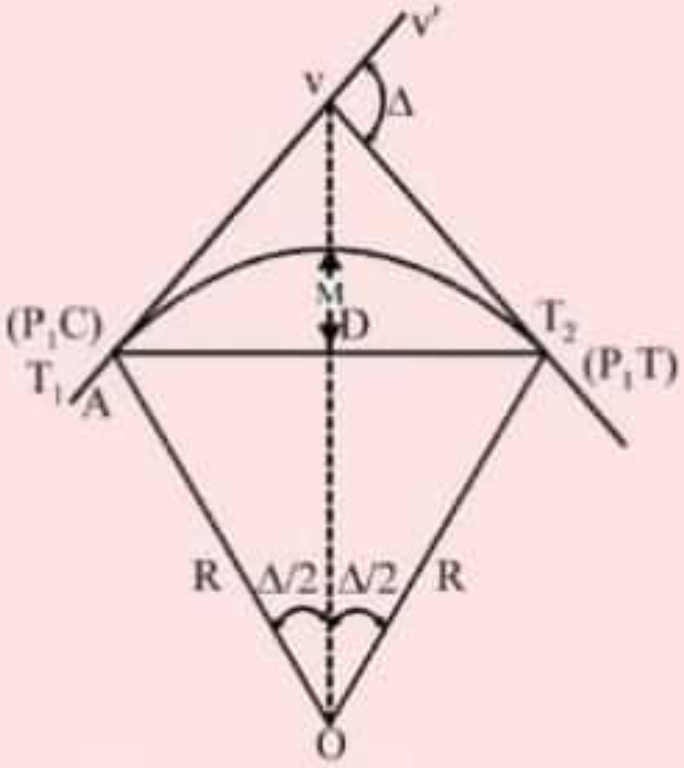
$$N_S = \frac{N\sqrt{Q}}{(H_m)^{3/4}} \text{ (for Pump)}$$

	Laminar	Transition	Turbulent
Flow in pipe	$R_e < 2000$	$2000 < R_e < 4000$	$R_e > 4000$
Flow between parallel plate	$R_e < 1000$	$1000 < R_e < 2000$	$R_e > 2000$
Flow in open channel	$R_e < 500$	$500 < R_e < 2000$	$R_e > 2000$
Flow through soil	$R_e < 1$	$1 < R_e < 2$	$R_e > 2$

- **Trapezoidal Formula (Area mean area Method):**

$$V = d\left(\frac{A_1 + A_n}{2} + A_2 + A_3 + \ldots A_{n-1}\right)$$

- **Fixed Hair Method:** $D = k \times S + C$, $K = \frac{f}{i} = 100$ (Multiplying Constant), Addition Constent $C = (f + d)$, S = Staff intercept, i = Stadia interval, f = focal length of object



$$l = \frac{\pi R \Delta}{180}$$

$$T = R \tan \Delta/2$$

$$L = 2R \sin \Delta/2$$

$$M = R(1 - \cos \Delta/2)$$

$$E = R\left(\sec \frac{\Delta}{2} - 1\right)$$

Method of orientation: trough compass, back sighting, resection,
Method of plane table surveying: Radiation, Traversing, Intersection, Resection
Plane Table Accessories: Tripod, Alidade, Spirit level, Plumbing fork, clinometer, Drawing sheet, Plane Table Board, Trough compass.

Instrument	Purpose
Abney level	To measure slope, cross section, to find gradient
Planimeter	To measure area very accurately
Pantagraph	Used to reduce/enlarge the maps
Hand level	To trace contours
Sextant	To measure horizontal & vertical angle
Substense	To measure horizontal distance

- **Basic Capacity of Single lane, Vehicle Per hours:** v = speed kmph,

$$T(\text{Sec/km}) = \frac{3600}{v}, \quad \boxed{q_{max} = \frac{v_f k_j}{4}},$$

Where,

v_f = Free mean speed, (Maximum speed at zero density.),

k_j = jam density, (Maximum density at zero speed), Maximum flow q_{max} occurs when the speed is $\frac{V_f}{2}$ and density is $k_j/2$.

Number of potential conflicts: Both roads are two way = 24, Both road one way = 6, One road is two way, other one way = 11

$$Q = \frac{280w\left(1+\frac{e}{w}\right)\left(1-\frac{p}{3}\right)}{\left(1+\frac{w}{l}\right)}, \quad W_{weaving} = \frac{e_1+e_2}{2}+3.5$$

(Types of interchange: Trumpet, Diamond, Full Cloverleaf, Partial Cloverleaf)

Floating Car Method: For Speed and delay study.

- **Aggregate crushing value:** $\boxed{\frac{w_2}{w_1}\times 100}$
- **Coefficient of Hardness:** $\boxed{= 20 - \frac{\text{Loss of wt. in gm}}{3}}$
- **Rigidity factor:** $\boxed{R.F = \frac{\text{Contact Pressure}}{\text{Tyre Pressure}}}$
- **California Resistance Value:** $\boxed{t = \frac{k.(T.I)(90-R)}{C^{1/5}}}$
- **Elastic Modulus:** Δ is maximum vertical deflection of the flexible plate, $\boxed{\Delta = \frac{1.18pa}{E_s}}$, Rigid circular plate is used instead of flexible $\boxed{\Delta = \frac{1.5Pa}{E_s}}$, a = radius of plate, p = pressure at deflection, E_s = young's modulus of pavement material.
- **California Bearing Ratio M/D:** $\boxed{t = \left(\frac{1.75P}{CBR} - \frac{A}{\pi}\right)^{1/2}}$,

RAILWAY ENGINEERING

$$CSI = \frac{S + 10H}{20}, \text{ Sleeper density} = M + x, D_{min} = \frac{S - W}{2}, e = \frac{GV^2}{127R}$$

Length of transition curve

I approach

II approach

Maximum of the following

$$L = \max \begin{cases} 7.2e \\ 0.073eV_{max} \\ 0.073D\,V_{max} \end{cases}$$

(*i*) Railway board formula

e = S.E in cm

D = cant deficiency in cm

$$L = 4.4\sqrt{R}$$

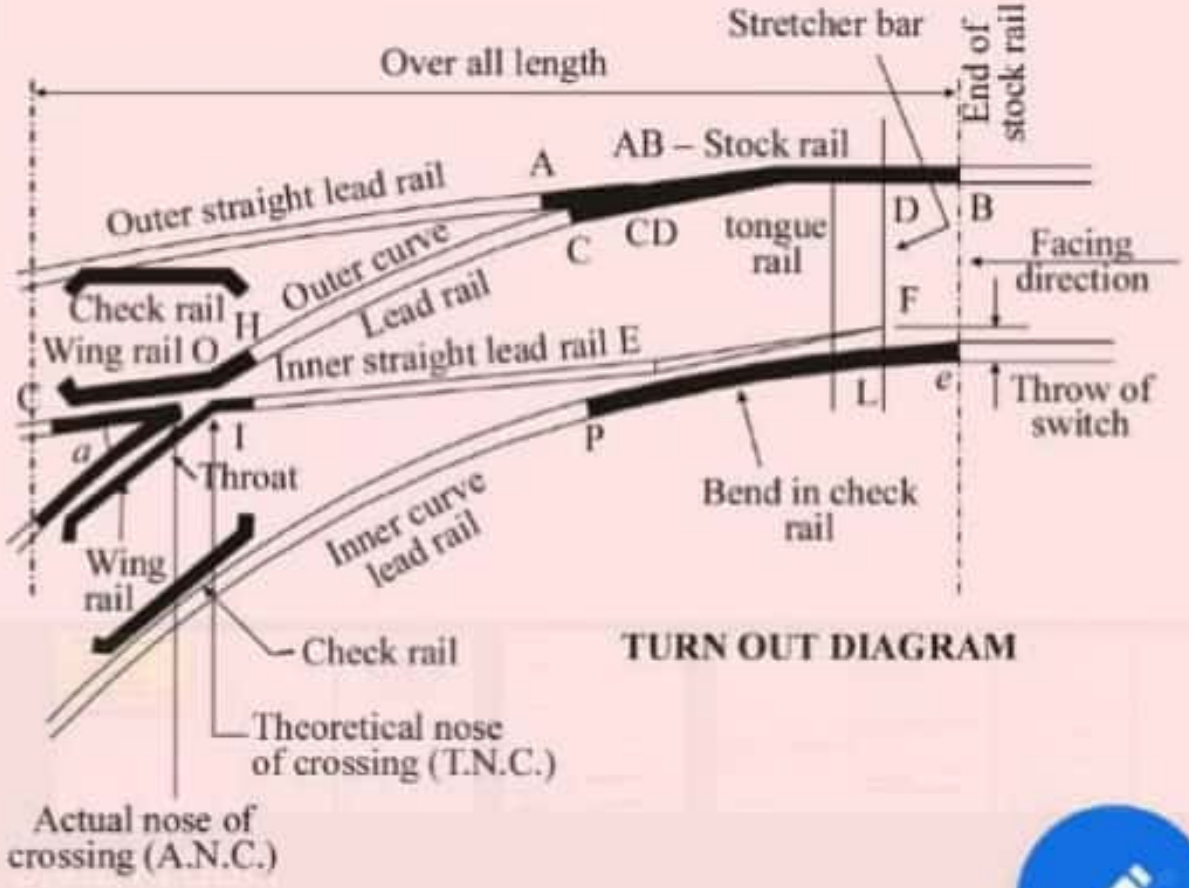
L, R → m

(*ii*) Change of radial acceleration

$$L = \frac{3.28V^3}{R}$$

(*iii*) Rate of change of super elevation

L = 3.6e



TURN OUT DIAGRAM



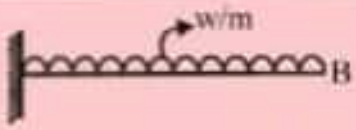
$\theta_A = 0 \quad \theta_B = \frac{ML}{EI}$

$\Delta_A = 0 \quad \Delta_B = \frac{ML^2}{2EI}$



$\theta_B = \frac{PL^2}{2EI}$

$\Delta_A = \frac{PL^3}{3EI}$



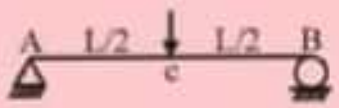
$\theta_B = \frac{WL^3}{6EI}$

$\Delta_B = \frac{WL^4}{8EI}$



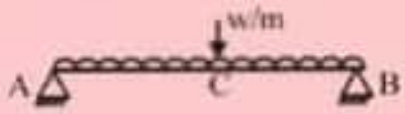
$\theta_A = \theta_B = \frac{ML}{2EI}$

$\Delta_{max\ @\ C} = \frac{ML^2}{8EI}$



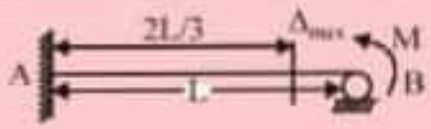
$\theta_A = \theta_B = \frac{PL^2}{16EI}$

$\Delta_C = \frac{PL^3}{48EI}$



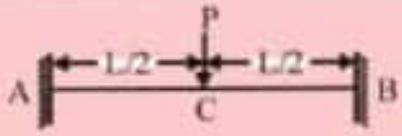
$\theta_A = \theta_B = \frac{WL^3}{24EI}$

$\Delta_C = \left[\frac{5}{384} \times \frac{WL^4}{EI}\right]$



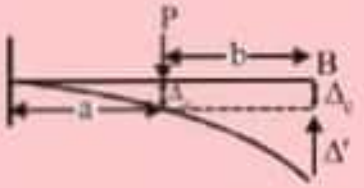
$\theta_B = \frac{ML}{4EI}$

$\Delta_{max} @ \frac{2L}{3}$ from A. $\frac{ML^2}{27EI}$



$\theta_A = \theta_B = \theta_C = 0$

$\Delta_C = \frac{PL^3}{192EI}$



$\theta_C = \frac{Pa^2}{2EI}$, $\Delta_C = \frac{Pa^3}{3EI} + \frac{Pa^2b}{2EI}$ $(\theta_C = \theta_B)$

$\Delta_B = \Delta_C + \Delta'$, $\Delta' = b.\frac{Pa^2}{2EI}$

$\Delta_B = \frac{Pa^3}{3EI} + b.\frac{Pa^2}{2EI}$



$\theta_B = \frac{ML}{3EI}$

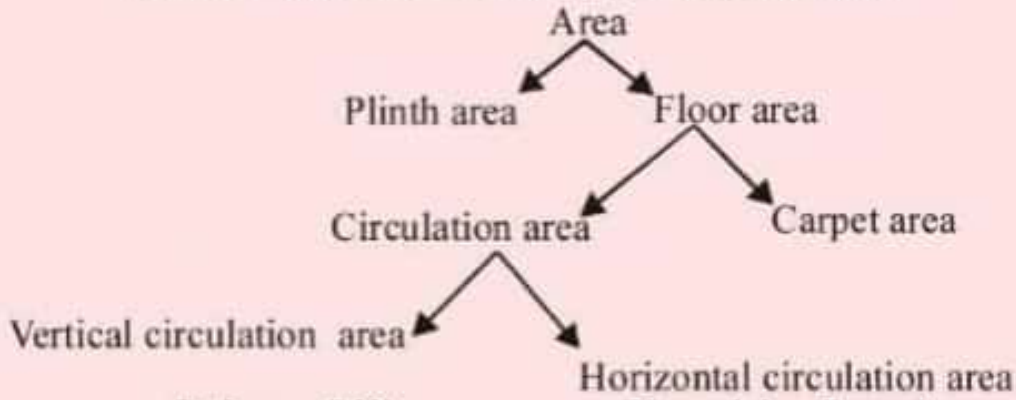
$\theta_A = \frac{ML}{6EI} = \theta_B/2$

$\Delta_{max} @ \frac{L}{\sqrt{3}}$ from

Description	Quantity
Work in foundation with Mud Mortar	1.5 m^3
Work in foundation with Lime/Cement Mortar	1.25 m^2
Work in Superstructure with Mortar	1 m^3
Work in Superstructure mud Mortar	1.25 m^3
Distemper (1 coat)	35 m^2
White Washing/Colour Washing (3 Coat)	70 m^2
White Washing/Colour Washing (1 Coat)	200 m^2
RCC Work	3m^3
Half Brick wall/Partition Wall	5 m^2
Lime concrete in Roof	6 m^2
Lime Concrete in foundation/Floring	8.9 m^2
12 mm Plastering with cement/Lime Mortar	8 m^2

Degree of Accuracy (descreasing order)

Detailed > Cube rate > Plinth area > Rough estimate



F.A. = Plinth area – area occupied by walls/Intermediate supports

Courtyard, play ground, unclosed Balcony, cantilever porch is not included in plinth area.

Carpet Area: Useable area/Living area

C.A. = Total floor area – (circulation area + Non-useable area)

C.A. in residential area (50 – 65)% and in commercial area (60 – 75)%.

Work	% of Estimate
Departmental charges (centage charge)	(10 – 15)
Contractor charge	10
Labour Charge	25
Electrification	8
Electric fan	4
Saniatory and Water Supply Charge	8
Contigences Charges	(3–5)
Work Charge Establishment	(1.5–2)
Tools and Plants	(1–1.5)

Security money is about 10% of total contract including Earnest Money. Security money and Earnest Money are refundable after some time Without Any Interest.

Types of Contract: Lum sum, unit price, cost plus contract.

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- **California Bearing Ratio M/D:** $\boxed{t = \left(\frac{1.75P}{CBR} - \frac{A}{\pi}\right)^{1/2}}$,

- **Lacey's Theory:** $V = \left[\frac{Qf^2}{140}\right]^{1/6}$, Q = Discharge $f = 1.75\sqrt{d_{mm}}$

- **Hydraullic Mean depth:** $R = \frac{5}{2}\left(\frac{V^2}{f}\right)$ $S = \frac{f^{5/3}}{3340\,Q^{1/6}}$ $A = \frac{Q}{v}$

wetted perimeter $P = 4.75\sqrt{Q}$

Difference B/W Lacey & Kennedy Theory

Kennedy	Lacey
1. Trapezoidal channel	1. Semi elliptical channel
2. Applicable for alluvial channels	2. Applicable for alluvial channels as well as for rivers.
3. Silt is kept in suspension due to eddies generated from bottom.	3. Silt is kept in suspension due to eddies generated both from side slope and the bottom i.e. through out the parameter.
4. No eq. for bed slope	4. Gave eq. to calculate bed slope
5. Recommended Kutter eq. to find velocity	5. Gave his own velocity equation
6. Trial & error procedure	6. Diret procedure

S.SOROUT, 9255624029

FOLLOWING BOOKS

AVAILABLE BY

CIVIL Ki GOLI PUBLICATION:

1. CIVIL Ki GOLI

2. REASONING Ki GOLI

3. CIVIL BOOSTER

4. HARYANA Ki GOLI

5. SOLUTION OF CIVIL Ki GOL

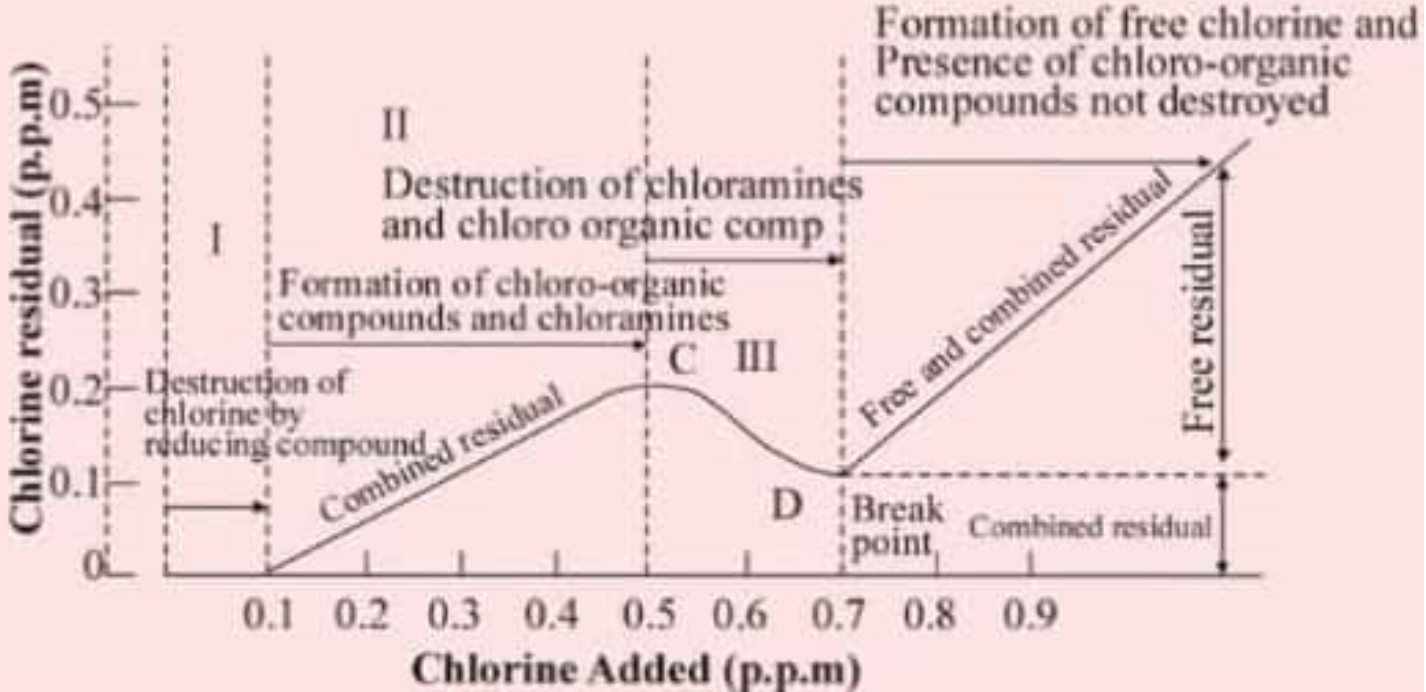
Comparision of slow sand and Rapid Gravity Filters.

Slow sand filter	Rapid sand filter
$C_u = 5$	$C_u = 1.3–1.7$
$D_{10} = (0.2–0.3)$ mm	$D_{10} = (0.45–0.7)$ mm
Frequency of cleaning = (1–3) months	Cleaned through Back washing
Design period = 10 year	$n = 1.22\sqrt{Q}$
Rate of filtration is very low as compared to R.S.F., but efficiency is High	Operational Troubles– (*a*) Air Binding (*b*) Mud ball formations (*c*) Cracking of filter

1. **Minor Methods.**
   (i) Boiling, (ii) Treatment with excess lime, (iii) Treatment with ozone ($KMNO_4$), (iv) Treatment with silver Process.
2. **Major Method Chlorination (Disintection with Cl_2)**

- $Cl_2 + H_2O \xrightarrow{pH>5} HOCl + HCl$
- $HOCl \xrightarrow{pH>8} H^+ + OCT^-$
- $HOCl \xleftrightarrow{pH<7} H^+ + OCl^-$

  NH_3 + HOCl is called combined chlorine.
- $NH_3 + HOCl \rightarrow NH_2Cl + H_2O$



Theory	Given by	Remark
Maximum Principle Stress or Maximum Normal stress	Rankine	Suitable for Brittle
Maximum Principle Strain	St. Venant	Neither accurate for Brittle nor Ductile
Maximum shear Stress	Guest and Treseca	Suitable for Ductile
Maximum Strain Energy	Haigh and Beltrami	Ductile
Maximum shear Strain energy	Vonmises and Hencky	Ductile

- **Shear Stress:** $\boxed{\tau = \frac{VA\bar{y}}{Ib}}$

- **Shear Stress In Rectangular Section:** $\boxed{q = \frac{6s}{bd^2}\left(\frac{d^2}{4} - y^2\right)}$ $(q = \tau)$,

  Where S = shear -force, $\boxed{q_{max} = \tau_{max} = \frac{3}{2}\frac{S}{bd}}$ $\boxed{q_{avg} = \tau_{avg} = \frac{S}{bd}}$,

  $\boxed{\frac{\tau_{max}}{\tau_{avg}} = 1.5}$

Note: Shear stress at top & Bottom is always 0.

- **In Circular Beam:** $\boxed{q = \frac{4}{3}\frac{S}{\pi R^4}\left(R^2 - y^2\right)}$ $\boxed{\tau_{max} = \frac{4S}{3\pi R^2}}$,

  $\boxed{\tau_{max} = \frac{4}{3}\tau_{avg}}$

- **In Triangular Section:** $\boxed{q_{max}/I_{max} = \frac{3S}{bh}}$ $\boxed{\tau_{avg}/q_{avg} = \frac{2S}{bh}}$,

  $\tau_{NA} = 1.33\tau_{avg}$, $\tau_{CG} = 1.5\tau_{avg}$

ESTIMATE COSTING

Description	Unit
Earthwork, Stone/Brick Work, Wood Work/Sunshade	m^3
Surface/Shallow Excavation, batten, panel, plywood	m^2
Pointing, Soling, DPC, Plastering	m^2
Steel/Iron Work	kg/Quintel
Dressing of stone/Half Brick wall/partition wall	m^2
Painting Work/Distemper/Colour Washing/Jali Work	m^2

Degree of Accuracy: Wood Work: 2mm, Weight – 1 kg, length – 1 cm, Area – 0.01 m^2, Volume – 0.01 m^3

- Purpose of Valuation:(a) Taxation– (10–14%), (b) Rent fixation – (6 –10% of total value)

Outgoing: (a) Repairness – (10 – 15)% of total Income, (b) Management and collection Charge – (5 – 10)% of total Income.

Scrap Value: It is about 10% of total value. It is the value of Dismental Material.

Salvage Value: It is value at the end of Utility period without being this dismental.

Book value = Initial cost – Depreciation cost

Sinking Fund: Annual Installment (I) = $\frac{S.i.}{(1+i)^n - 1} = I_C.S$

(a) Straight line Method: Assume depreciation by same amount

$$D = \frac{C-S}{n}$$

(b) **Constant percentage Method:** Also called Balancing Decline Method. It assume depreciation by same percentage. $D = 1-\left(\frac{S}{C}\right)^{1/n}$

General Overhead Cost	Job Overhead Cost
Telephone Bill	Salary Delay
Travelling charges	Establishment of a New Office
Printing, Post office	Compensation

Description	Quantity
Work in foundation with Mud Mortar	1.5 m^3
Work in foundation with Lime/Cement Mortar	1.25 m^2
Work in Superstructure with Mortar	1 m^3
Work in Superstructure mud Mortar	1.25 m^3

REINFORCE CEMENT CONCRETE

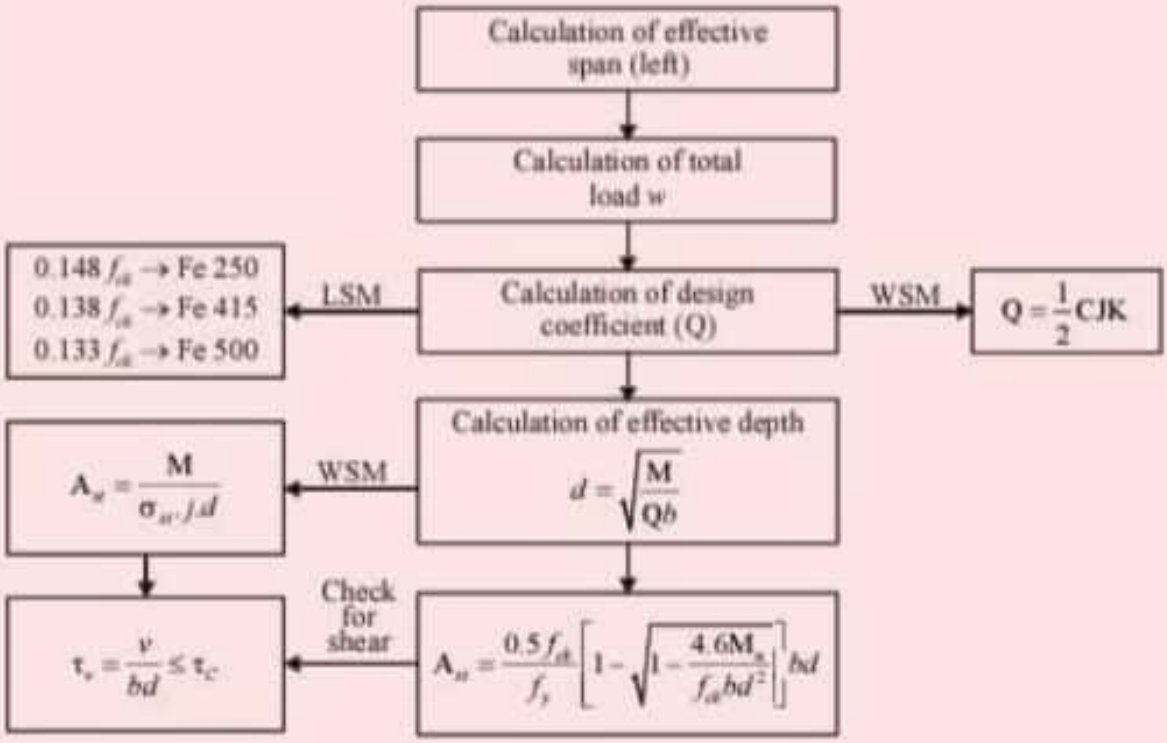
$E_c = 5700\sqrt{f_{ck}}\ N/mm^2$. Min. grade = M15 (IS 456:1978),

$E_c = 5000\sqrt{f_{ck}}\ N/mm^2$. Min. grade = M20 (IS 456:2000)

$m = \dfrac{280}{3\sigma_{cbc}}$

$f_{cr} = 0.7\sqrt{f_{ck}}$, $f_{ct} = 0.66 f_{cr} = \dfrac{2p}{\pi DL}$

f_{cr} (flexure > Splitting > Direct Tensile strength)



- **Analysis Of Stresses (WSM):** Moment of Comp. Area = Moment of ten. Area $bx.\dfrac{x}{2} = mA_{st}(d-x)$

$p = \dfrac{A_s}{bd}$, $j = \dfrac{Z}{d}$ = lever arm coefficient $= \left(1 - \dfrac{k}{3}\right)$

- **Optimum Section:** $\dfrac{x}{d-x} = \dfrac{\sigma_{cb}}{\sigma_{st}/m}$,

CIVIL KI GOLI

- **Variation of Demand**

  Maximum daily Consumption = 1.8 avg. daily consumption.
  Maximum Weekly Consumption = 1.48 ×Avg. weekly
  Maximum Monthly Consumption = 1.28 × Avg. monthly.

- **Population Forecasting Mehtod**

  Arithmetic Increase Method: $P_n = P_o + n\bar{x}$ (For old cities)

  Geometric Increases Method: $P_n = P_o\left(1+\frac{r}{100}\right)^n$ (For new cities)

  Incremental Increase Method: $P_n = P_o + n\bar{x} + \frac{n(n+1)}{2}\bar{y}$

- **Physical characteristics**

  Turbidity: Turbidity limit = 5 to 10 NTU
  Colour: Tintometer Limit = 20PPm
  Taste and odour: T.O.N = 1 ($\not>$3)
  Temperature: 10°C desirable ($\not>$25°C)

- **Chemical Characteristics**

  Total solids and suspended soils: Limited to 550 ppm PH = $-\log H^+$ (6.6 to 8.5)

  Total Hardness: $[Ca^{2+}]\times\frac{50}{20} + [Mg^{2+}]\times\left(\frac{50}{12}\right)$

  Carbonate Hardness: min of total hardness or alkalinity
  Chloride Content: Prescribed limit – 120mg/L
  Nitrogen Content: Limits: Free ammonia $\not>$0.15mg/L, Organic Nitrogen $\not>$ 0.3 mg/*l*, nitrite should be zero, nitrate $\not>$ 45 mg/*l*
  Measurement (i) Free Ammonia-by simple boiling of water. (ii) Organic Ammonia – By adding $Kmno_4$, (i+ii) are known as **kjeldahl Nitrogen** Nitrate and Nitrate by - colour Matching M/d.

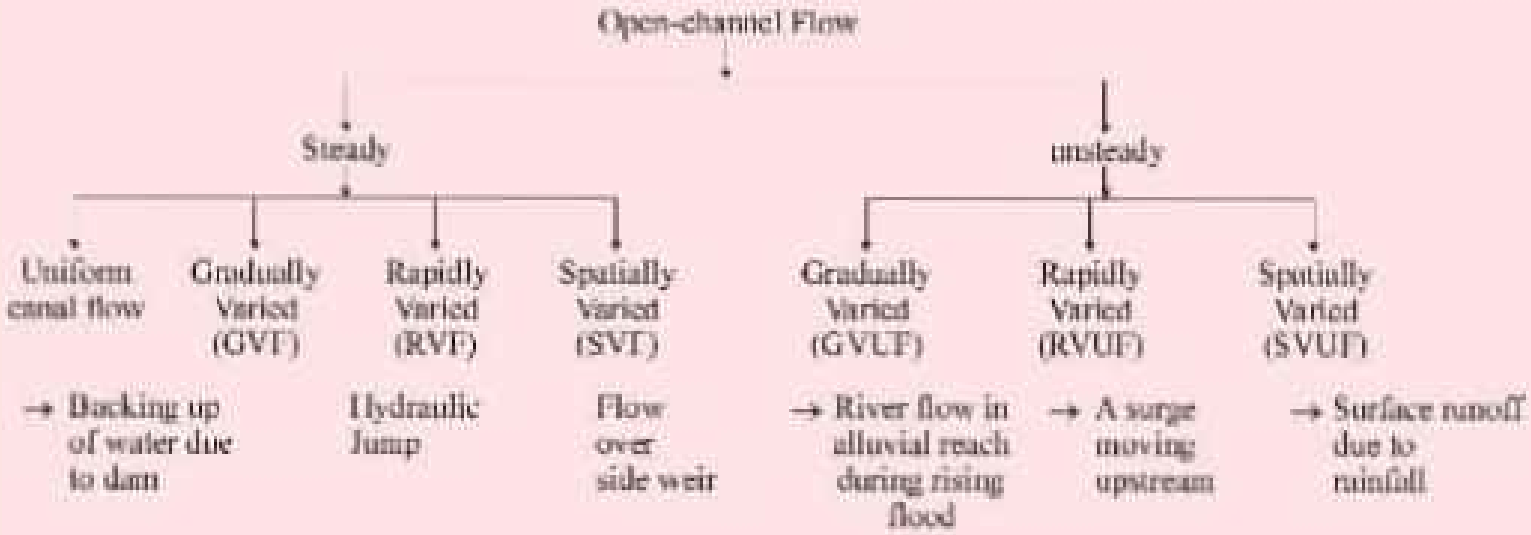
- **Chemical:** (Mn = 0.05 mg/L) (Iron – 0.3 mg/L), (Fluride –1.0 –1.2 mg/L) (Sulphate : 250 mg/L) (Cyanides = 0.2mg/L)

- **Screening:** Velocity $\not>$0.8 to 1m/sec

  Principle is based on stokes law.

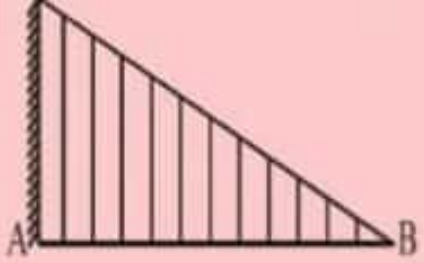
  Setting velocity: $V_s = \frac{Q}{B.L}$





- **Chezy's Formula:** $\boxed{V = C\sqrt{RS}}$, Manning equation $\boxed{V = \frac{1}{n} R^{2/3} S_0^{1/2}}$

Dimension of $C = L^{1/2} T^{-1}$, $n = L^{-1/3} T^{1}$, f = Dimensionless



$$\theta_B = \frac{WL^3}{24EI}$$

$$\Delta_B = \frac{WL^3}{30EI}$$

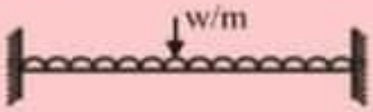


$$\theta_A = \theta_B = \frac{ML}{24EI}$$

$$\theta_c = \frac{ML}{12EI}$$

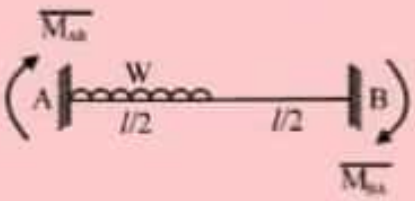


$$\theta_A = \theta_B = \frac{5}{192} \times \frac{WL^3}{EI}$$



$$\theta_A = \theta_B = \theta_C = 0$$

$$\Delta_C @ l/2 \quad \frac{WL^4}{384EI}$$



$$M_{ab} = \frac{-11}{192} wl^2$$

$$M_{ba} = \frac{5}{192} wl^2$$

S.SOROUT, 9255624029

FOLLOWING BOOKS

AVAILABLE BY

CIVIL Ki GOLI PUBLICATION:

1. CIVIL Ki GOLI

2. REASONING Ki GOLI

3. CIVIL BOOSTER

4. HARYANA Ki GOLI

5. SOLUTION OF CIVIL Ki GOLI

HIGHWAY ENGINEERING

Roman Roads → Tresaguct Construction → Metcalf Construction → Telford Construction → Macadam Construction

Nov. 1927 → Jayakar Committee formed

Feb. 1928 → Recommendations by Jayakar Committee

1929 → Central Road Fund

1934 → Indian Road Congress

1939 → Motor Vehicle act

1952 → Central Road Research Institute

1956 → National Highway act

Nagpur Plan	**Bombay Plan**	**Lucknow Plan**
→ 1943–1963	1961–1981	1981–2001
→ Road density 16 km/100 km²	Road density 32 km/100 km²	Road density 82 km/100 km²
→ Recommended star & grid pattern	→ Construction of 1600 km of Expressway	

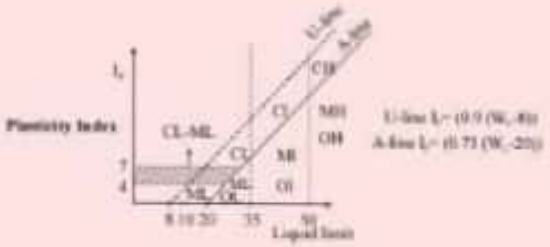
- **SSD:** $\boxed{v.t+\frac{v^2}{2g(f\pm 0.01n)}}$ $\boxed{=0.278v.t+\frac{V^2}{254(f\pm 0.01n)}}$

- **OSD:** $\boxed{=V_b.t+(V_b.T+2S)+V.T}$

ISSCS: On the bases of particle size

Boulder	Cobble	Gravel		Coarse Grained Soil			Fine Grained soil	
		Coarse	Fine	Coarse sand	Medium sand	fine sand	silt	clay
>300mm	300-80	80-20	20-4.75	4.75-2.0	2.0-.425	0.425-0.75	0.075-0.002	<0.002

Caliche - Gravel, Sand, silt mixture Loam - Sand, silt, clay mixture



Plasticity Chart

- **Darcy's Law:** $q = kiA$
- **Measurement of Permeability**

(a) **Constant Head Permeameter Test:** $K = \frac{q}{iA} = \frac{qL}{Aht}$

(b) **Falling Head Permeameter Test:** $K = \frac{2.3aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$

(c) **Confined Flow Pumping Test:** $K = \frac{2.3q}{2\pi D(h_2 - h_1)}\log_{10}\left(\frac{r_2}{r_1}\right)$

(d) **Unconfined Flow Pumping Test:** $K = \frac{2.3q}{\pi(H^2 - h^2)}\log_{10}\frac{R}{r}$

(e) **Kozeny-Carman Equation:** $K = \frac{1}{K_0 S^2}\frac{\gamma}{\mu}\frac{e^3}{1+e}$

(f) **Allen Hazen's Equation:** $K = CD_{10}^2$

(g) **Coefficient of Consolidation Equation:** $K = C_v M_v \gamma_w$

$$V_s = \frac{V}{n}, R = 300d\sqrt{K}, S_o + S_s = n$$

- **Permeability of Stratified Soils**

(a) **Horizontal Flow:** $K_H = \frac{K_1H_1 + K_2H_2 + \dots}{H_1 + H_2 + \dots}$

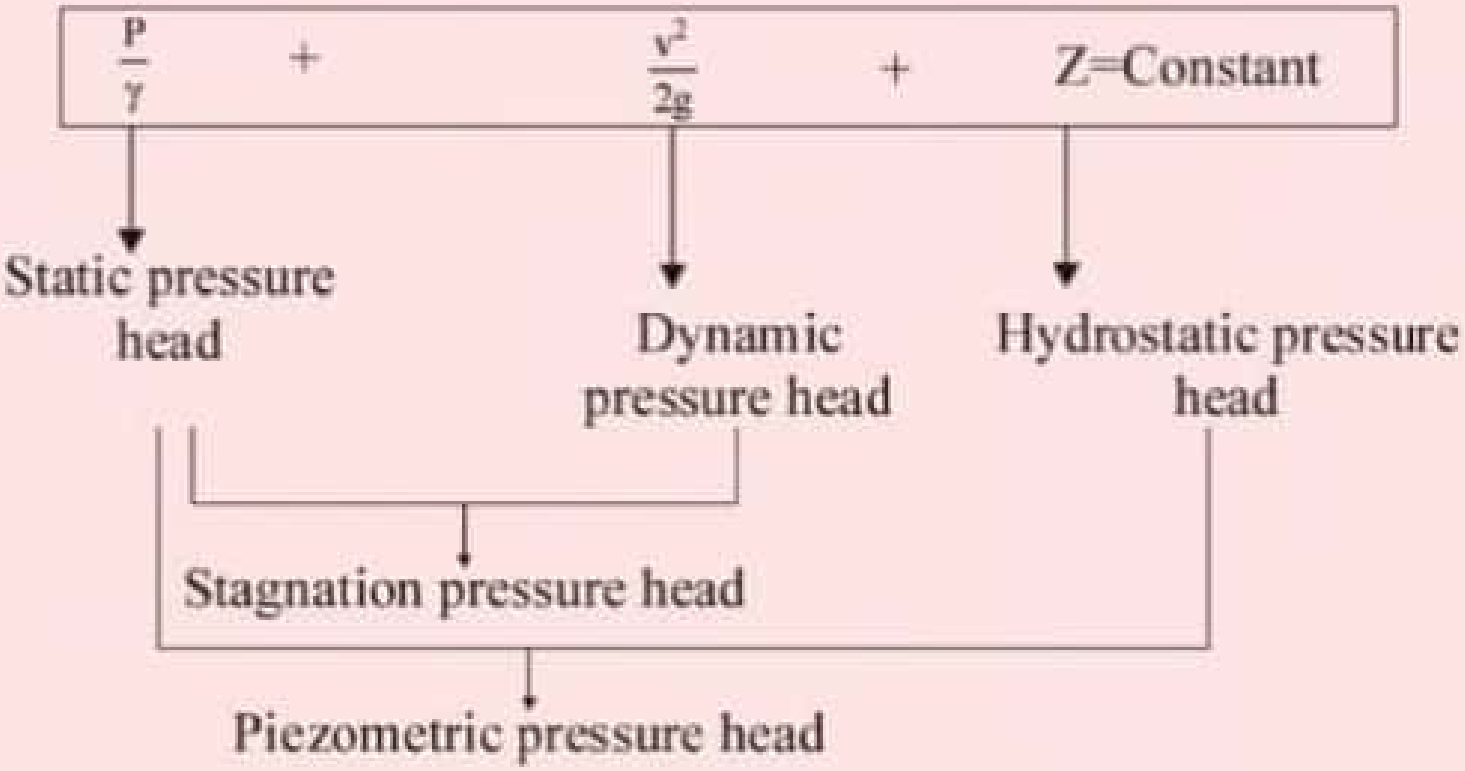
(b) **Vertical Flow:** $K_v = \frac{H_1 + H_2 + \dots}{\frac{H_1}{K_1} + \frac{H_2}{K_2} + \dots} = \frac{\sum H}{\sum H/K}$

Note: $K_H > K_v$ always.

- **Critical Hydraulic Gradient:** $i_c = \frac{G-1}{1+e} = (G-1)(1-n)$
- **Boussinesq's Equations:** $\sigma_z = \frac{3q}{2\pi z^2}\left[\frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{\frac{5}{2}}$
- **Seepage Calculation:** $q = kH\frac{N_f}{N_d}$
- **Westergaard's Solution:** $\sigma_z = \frac{1}{\pi}\frac{q}{Z^2} = \frac{1}{\left[1+2\left(\frac{r}{z}\right)^2\right]^{\frac{3}{2}}} = k_w\frac{q}{Z^2}$
- **Compression Index:** $C_c = \frac{e_1 - e_2}{\log\bar{\sigma}_2 - \log\bar{\sigma}_1}$

- **Velocity Potential Function (ϕ):** $\boxed{-\frac{\partial \phi}{\partial x} = u}$ $\boxed{-\frac{\partial \phi}{\partial y} = v}$

- **Stream Function (v):** $\boxed{u = -\frac{\partial \psi}{\partial y}}$ $\boxed{v = \frac{\partial \psi}{\partial x}}$



- **Euler's Equation:** $\boxed{\frac{dp}{p} + gd_z + vdv = 0}$

(Base on momentum conservation)

- **Bernoullies Equation:** $\frac{P}{w} + z + \frac{v^2}{2g} = C$

(Base on energy conservation)

2. **Circular Tapering Bar:** $\Delta L = \frac{4PL}{\pi E D_1 D_2}$

- **Defection of Composit Bar:** $\Delta L_1 = \Delta L_2 \Delta = \frac{PL}{A_1E_1 + A_2E_2}$
- **Deflection due to Self Weight of Bar:**

1. **Prismatic Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{2E}$,

2. **Conical Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{6E}$

- **Thermal Expansion:** $\sigma = E\alpha\Delta T$, $\Delta = L\alpha\Delta T$

Coefficient of Thermal expansion (Aluminium > Brass > Copper > Steel)

$P_{cr} = \frac{\pi^2 E}{\lambda^2}$ (Euler's Theory) $P_R = \frac{\sigma_c A}{1 + a\lambda_e^2}$ (Rankine's Formula)

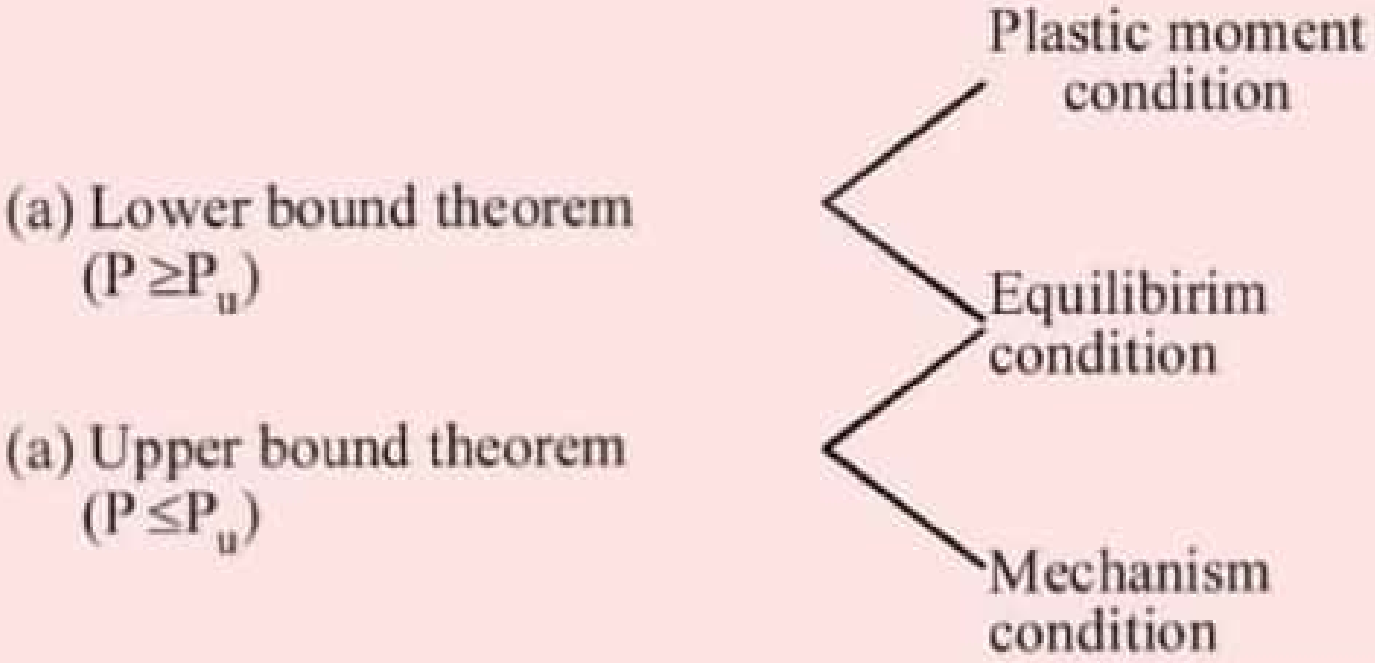
- **In case of Pure Bending:** $Z = \frac{\pi}{32} D^3$
- **In case of pure Torsion:** $\tau_{max} = \frac{T}{Z_p} = \frac{16T}{\pi D^3}$ $Z_p = \frac{\pi}{16} D^3$
- **Bending Equation:** $\frac{\sigma_b}{y} = \frac{M}{I} = \frac{E}{R}$

- **Shape Factor:** $S = \frac{M_p}{M_y} = \frac{a_y Z_p}{a_{ye}} = \frac{Z_p}{Z}$ (Load factor = FOS × S)

Shape factor For different Shapes

Section	Shape factor
1. Rectangular Section	1.5
2. Solid circular Section	1.7
3. Triangular Section (vertex upward)	2.34
4. Hallow circular Section	$1.7\times\left(\frac{1-k^3}{1-k^4}\right)$
5. a. Diamand Section Rhombus	2.00
b. Thin Hollow Rhombus	1.50
6. Thin Circular ring Solid	1.27
7. I section	
a. About strong Axis	1.12
b. About weak Axis	1.55
8. T Section.	1.90 to 1.95

- **Method of Analysis:**



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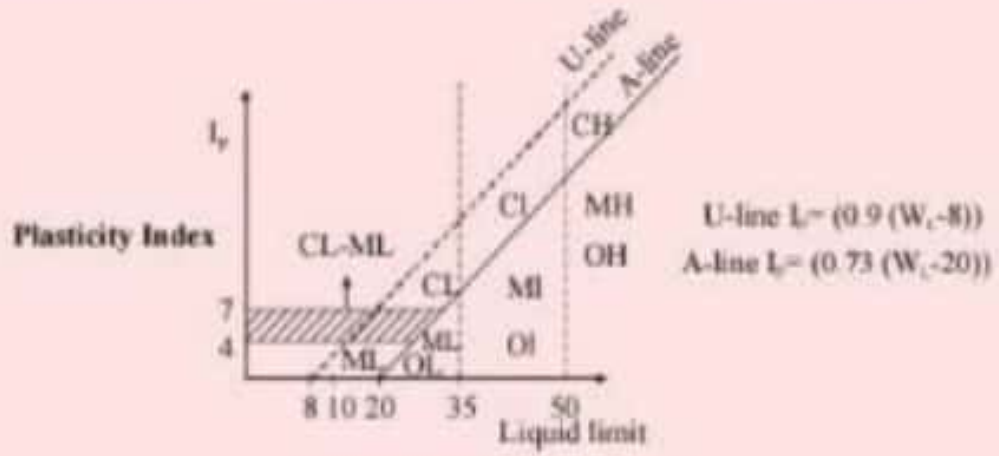
Caliche - Gravel, Sand, silt mixture					Loam - Sand, silt, clay mixture			



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$$V_s = \frac{V}{n}, R = 3000d\sqrt{K}, S_y + S_R = n$$

CIVIL KI GOLI

- **Permeability of Stratified Soils**

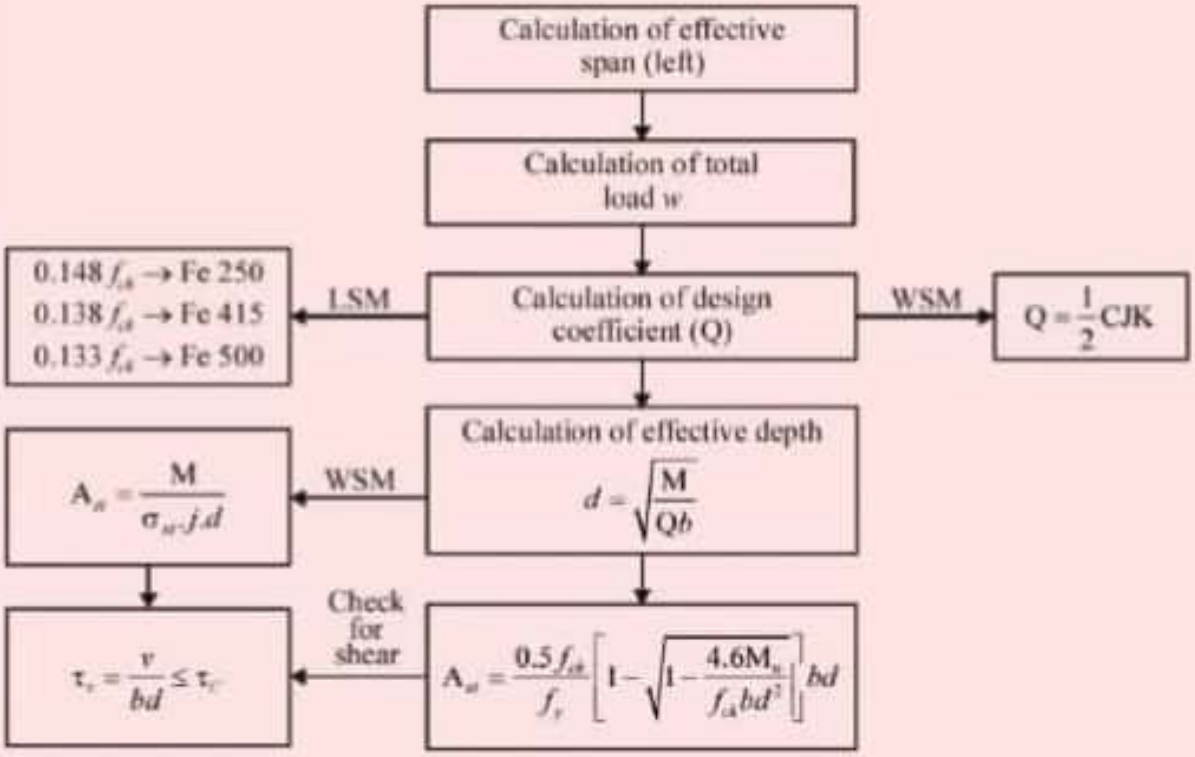
REINFORCE CEMENT CONCRETE

$E_c = 5700\sqrt{f_{ck}}\ N/mm^2$. Min. grade = M15 (IS 456:1978),

$E_c = 5000\sqrt{f_{ck}}\ N/mm^2$. Min. grade = M20 (IS 456:2000)

$m = \frac{280}{3\sigma_{cbc}}$ $\qquad f_{cr} = 0.7\sqrt{f_{ck}}$, $f_{ct} = 0.66 f_{cr} = \frac{2p}{\pi DL}$

f_{cr} (flexure > Splitting > Direct Tensile strength)



- **Analysis Of Stresses (WSM):** Moment of Comp. Area = Moment of ten. Area $\boxed{bx.\frac{x}{2} = mA_{st}(d-x)}$

$\boxed{p = \frac{A_{st}}{bd}}$, $\boxed{j = \frac{Z}{d} = \text{lever arm coefficient}} = \left(1 - \frac{k}{3}\right)$

- **Optimum Section:** $\boxed{\frac{x}{d-x} = \frac{\sigma_{cb}}{\sigma_{st}/m}}$,

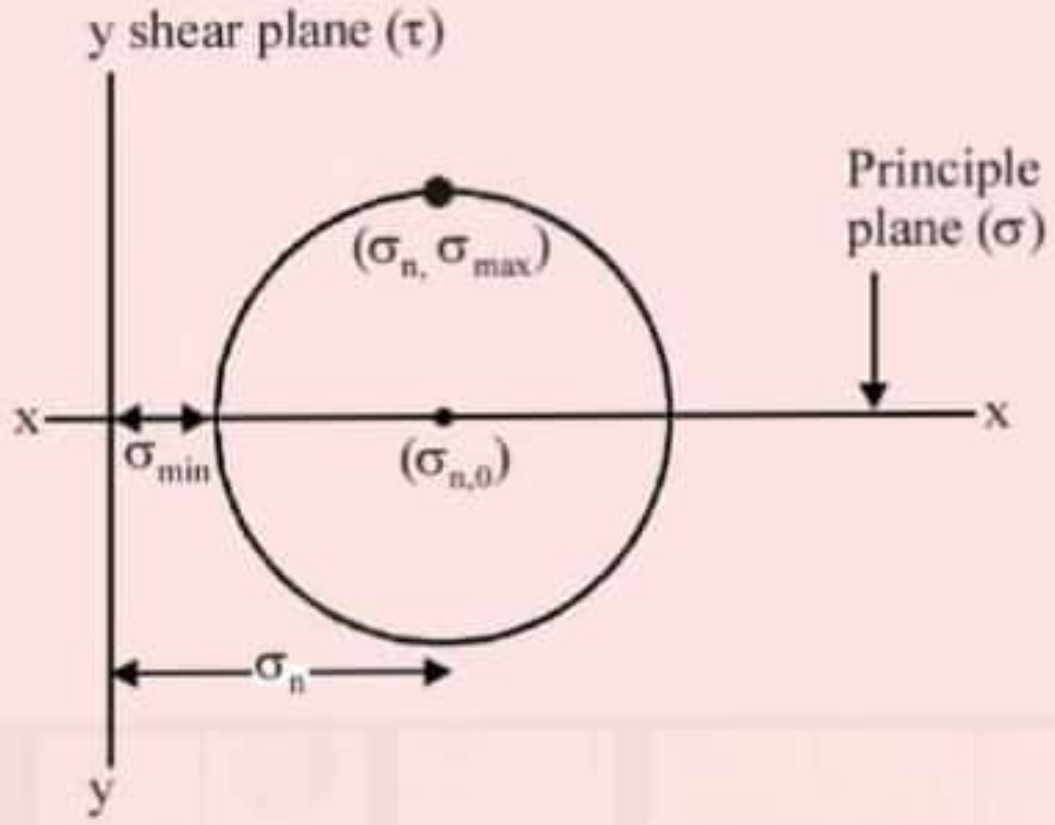
Type of Structure	Degree of Indeterminacy D_s
2D (plane) frames	(3m+r)-3j
3D frames	(6m + r)-6j
2D (plane) pin-jointed truss	(m+r)-2j
3D truss	(m+r)-3j

Slope Deflection Equations

$$M_{AB} = M_{FAB} + \frac{2EI}{l}\left(2\theta_A + \theta_B - \frac{3\delta}{l}\right)$$ (Continuous Beam)

$$M_{AB} = M_{FAB} + \frac{3EI}{L}\left(\theta_A - \frac{\delta}{L}\right)$$ (one end is pin supported)

Important Points





- **Net Safe Bearing Capacity:** $q_{net} = \dfrac{\text{Net ultimate bearing capacity}}{\text{Factor of safety}}$

$$q_{net} = \frac{q_{nu}}{F} = \frac{q_u - \gamma D_f}{F} \qquad \text{(Generally F = 2-3)}$$

- **Elastic Settlement:** $S = k.q.\sqrt{A}\dfrac{(1-\mu^2)}{E}$ $\qquad$ $\text{Depth} = \dfrac{q}{\gamma}\left(\dfrac{1-\sin\phi}{1+\sin\phi}\right)^2$
- **Bearing Capacity for shallow foundation**
- **Strip footing:** $q_{ult} = CN_c + \gamma D_f N_q + \dfrac{1}{2}\gamma b N_\gamma$
- **Circular Footing:** $q_{ult} = 1.3CN_c + \gamma D_f N_q + 0.3\,\gamma b N\gamma$
- **Square Footing:** $q_{ult} = 1.3\,CN_c + \gamma D_f N_q + 0.4\gamma b N\gamma$
- **Settlement of Footing:** $\dfrac{S_f}{S_p} = \left(\dfrac{B_f(B_p + 0.3)}{B_p(B_f + 0.3)}\right)^2$ (For Sandy Soil),

$\dfrac{q_{uf}}{q_{up}} = \dfrac{B_f}{B_p}$ (for sand). $\qquad$ (PLT test: IS 1888-1992, $B_f = 5 \times B_p$)

(SPT test : height 75 cm, weight 63.5 kg)

- **Coorection Applied to SPT Value:**

Over burden Correction: $N_1 = N_{obs} \times \left(\dfrac{350}{\bar{\sigma} + 70}\right)$

- **Dilatancy Correction:** $N = 15 + \dfrac{1}{2}(N_1 - 15)$
- **Ultimate bearing Capacity of pile Load taken by base + load by skin friction:** $Q_{up} = q_{eb} + Qs_p$, $Q_{up} = q_b \times A_b + F_s A_s$.
- **Engineering News Formula:** Ultimate load on pile, $Q_{up} = \dfrac{WH}{6(S+C)}$
- **Inside Clearance:** $C_i = \dfrac{D_3 - D_1}{D_1} \times 100\%$ Generally (1 - 3)%
- **Out Side Clearance:** $C_0 = \dfrac{D_2 - D_4}{D_4} \times 100$ $(C_0 > C_i$ always)
- **Area ratio:** $A_r = \left(\dfrac{D_2^2 - D_1^2}{D_1} \times 100\right)\begin{pmatrix} A_r < 20 \text{ For stiff clay} \\ A_r < 10 \text{ For sensitive clay} \end{pmatrix}$

Prestressed Concrete

- **Loss due to length effect :** $P_o k.x$
- **Curvature effec:** $P_o \mu\alpha$
- **Loss of pre-stress at the Anchoring stage:** $= \frac{\Delta L}{L} \times E_s$
- **Loss of stress due to shrinkage of concrete:** $= e_{sh} \times E_s$
- **Loss of stress due to creep of concrete:** $= \phi m f_c$
- Losss of stress = strain lost in steel × E_S $\boxed{\frac{f_c}{E_c} \times E_s = \frac{P_0}{A} + \frac{N}{Z}}$

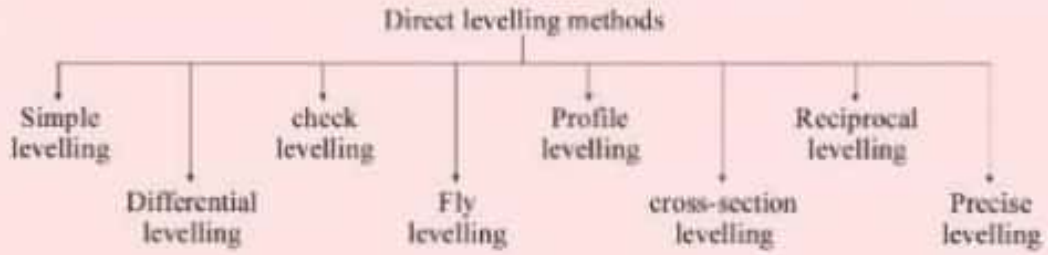
Pre tensioned losses>Post tensioned losses

Post tensioning system: Freyssinet, Magnel-Blaton, Lee-mc-call, Gifford

Stress	**Grade of Concrete**			
	M_{20}	M_{25}	M_{30}	M_{35}
• Direct Tension	1.2	1.3	1.5	1.6
• Bending Tension	1.7	1.8	2.0	2.2

RCC. Structure	**Min. Clear Cover(mm)**
• Slab	20
• Beam	25
• Column	40
• Footing	50

Exposure Condition	**Min. Clear Cover (mm)**
• Mild	20
• Moderate	30
• Severe	45
• Very severe	50
• Extreme.	75



- **Sensitivity:** Angle b/w the line of sights in radius

$$\alpha = \frac{S}{D} = n \times \frac{\ell}{R} \qquad \frac{l}{R} = \left(\frac{S}{nD}\right) \times 206265$$

D = Distance of the instrument from the staff
n = Number of divisions
l = length of one divison (2mm)
R = Radius of curvature
S = Staff intercept.

- **Check in Height of Instrument Method**

$$\Sigma \text{ BS} - \Sigma \text{ FS} = \Sigma \text{ Rise} - \Sigma \text{ Fall} = \text{Last RL} - \text{First RL}$$

- **Curvature:** $C_c = \frac{d^2}{2R} = 0.0785d^2$. •**Refraction:** $C_r = \frac{1}{7}\left(\frac{d^2}{2R}\right)$

- **Final Combination Correction:** $C = C_c - C_r = \frac{6}{7}\left(\frac{d^2}{2R}\right)$,

$C = 0.06735d^2$,

- **Distance of Visible Horizon**

$d = 3.85\sqrt{h}$, d = in km and h = in meter.

- **Reciprocal Levelling:** The true difference Elevation:

$$H = \frac{1}{2}(h_a - h_b) + (h_a' - h_b')]$$

- **Determining Areas:** Mid ordinate rule Δ = Area = Average ordinate

× Length of base, $\Delta = \frac{O_1 + O_2 + ... + O_n}{n} \times L$

- **Average ordinate Rule:** Area D = Average ordinate of the base

$$= \left(\frac{O_0 + O_1 + ... + O_n}{n+1}\right) \times L, \quad D = \frac{L}{(n+1)} \times \Sigma D \text{ , } \Sigma D = D_0 + ... + O_n.$$

- **Simpson's One-Third Rule:**

$$\Delta = \frac{d}{3}[(O_0 + O_n) + 2(O_1 + O_3 + ... + O_{n-1}) + 4(O_2 + O_4 + ...O_{n-2})]$$

- **Trapezoidal Formula (Area mean area Method):**

$$V = d\left(\frac{A_1 + A_n}{2} + A_2 + A_3 + ... A_{n-1}\right)$$

(i) For trackled vehicles – 25% of span upto 5 m linearly reduced to 10% for span of 9 m.
(ii) For wheeled vehicles – 25%
For Span ≥ 9 m;

- For trackled vehicle – R.C. bridges, 10% upto span 40 m.
  For steel bridge, 25% for span upto 23 m.

2. AASTHO Loadings: $\bar{d} = \frac{50}{L+25}$

Codes used for Bridge Design:
1. IRC - 5 - Code of practice for specification of Bridge.
2. IRC - 6 - 2010 - Loads & stress. (L.S.M.)
(Old Code - IRC - 6 - 2000 - (W.S.M.)
3. IRC - 21 - Code of practice for cement concrete (L.S.M)
4. IRC - 22 - for composite structure
5. IRC - 78 - for foundation design

Map to be prepared on Bridge site
1. **Index Map**: It shows proposed location of bridge & alternative route. Scale 1 : 50,000
2. **Contour Map**: It shows topographical or other features that might influence the location of bridge site. Scale 1 : 10,000
3. **Longitudinal Map**: It shows highest flood level & ordinary flood level along the length of the bridge. Scale 1 : 2500

Abutment - extra load of backfilling
Parapet - 80 km, 110 kN load - design
Scourdepth - to avoid scouring

4. **Cross - section**: It shows current width of the road for various c/s. Scale 1 : 1000

$$\text{Window Width} = \frac{1}{8}[\text{Width of room} + \text{Height of Room}]$$

- The sill of a window should be located about (70 – 80) cm above floor level of the room.
- Generally Height of a Door should not be less than (1.8 – 2) m
- Commonly Width height relation used in India:
  (i) Width = (0.4 – 0.6) Height
  (ii) Height = (Width + 1.2) m
- Doors of residential Buildings:
  (a) External Door – (1 × 2) to (1.1 × 2) m
  (b) Internal Door – (0.9 × 2) to (1 × 2) m
  (c) Doors for bathrooms and Water closets: – (0.7 × 2) to (0.8 × 2) m
- Public Buildings (School, Hospital, library)
  (a) (1.2 × 2) m (b) (1.2 × 2.1) m (c) 1.2 × 2.25) m
  Designation of Door = Length × Type of Door × Height 8 DS 20 – A door opening Having width (8 × 100 mm) × Height (20 × 100 mm) with S (Single SHutter) D (Door)

Types of Window

1. fixed 2. Pivoted 3. Sliding 4. Bay 5. Corner 6. Cable (7) Dormer (8) Skylights (9) Louvered (10) Lantern (11) Gable

Stairs

- No of steps are not more than 12 and not less than 3 in a flight.
- Angle of Inclination (Pitch) – (25° – 40).
- Head room must not be less than 2.05 m.
- Minimum width of stairs in residential building – 85 cm and in commercial building is 1 m.
- Some Thumb rule:
  (a) (2R + T) = 60
  (b) (R + T) = (40 – 45)
  (c) R × T = (400 – 450)
  where R – Rise in cm, T – Tread in cm
- For residential building, common size of steps is (16 × 26) cm, IN Hospital etc. –(10 × 30) cm.
- In case of straight staircase, No. of Trade = (No. of Riser – 1)

$$\text{No. of riser} = \frac{\text{Total Height between floor and Roof}}{\text{Height of One Riser}}$$

BRIDGE ENGINEERING

Components of bridge

1. **Sub-Structure:** Upto the level of bearing.
- Consists of piers, abutments, wing walls and foundations for the piers, abutments and wing walls.
- **Super Structure:** Above the level of bearing.
- Consist of beams, girders, arches and cables, parapet walls. Flooring, guard stones, hand rails etc.

3. **Adjoining Structure:** Approaches, guard stones, bearing, river training work, apron etc.

Impact Factors

1. **For Road Bridges:**

(i) Indian road congress:

(a) For class A and B loading:

$$I = \frac{A}{B+L} \rightarrow \text{Length}$$

A = Constant, for RCC bridge = 4.5, for steel bridge = 9.0
B = Constant, for RCC bridge = 6.0, for Steel bridge = 13.5
For Span, less than 3m, I = 0.5, for R.C. bridge,
I = 0.545, for Steel bridge.
For span exceeding 4.5 m., I = 0.088 for R.C. bridge
= 0.154 for Steel bridge,
For class AA or TOR loading: Span < 9 m,

ESTIMATE COSTING

Description	Unit
Earthwork, Stone/Brick Work, Wood Work/Sunshade	m^3
Surface/Shallow Excavation, batten, panel, plywood	m^2
Pointing, Soling, DPC, Plastering	m^2
Steel/Iron Work	kg/Quintel
Dressing of stone/Half Brick wall/partition wall	m^2
Painting Work/Distemper/Colour Washing/Jali Work	m^2

Cornice (unit running meter),

Order of Booking the Dimension in MB = L, B, H

If depth of excavation < 30 cm, surface excavation (unit m^2)

Number of Bricks using flat soling & edge soling (using conventional brick) 38 & 56 respectively.

For doors & window, we use 6 & 4 hold fast respectively.

Truck: No. of bricks = 4000, volume of sand = 3-5 m^3 (generally)

Formula for weight of steel bar per meter length = $(d^2/162)$ kg.

Degree of Accuracy: Wood Work: 2mm, Weight – 1 kg, length – 1 cm, Area – 0.01 m^2, Volume – 0.01 m^3

- Purpose of Valuation:(a) Taxation– (10–14%), (b) Rent fixation – (6 –10% of total value)

Outgoing: (a) Repairness – (10 – 15)% of total Income, (b) Management and collection Charge – (5 – 10)% of total Income.

Scrap Value: It is about 10% of total value. It is the value of Dismental Material.

Salvage Value: It is value at the end of Utility period without being this dismental.

Book value = Initial cost – Depreciation cost

Sinking Fund: Annual Installment (I) = $\frac{S.i.}{(1+i)^n - 1} = I_c S$

(a) Straight line Method: Assume depreciation by same amount

$$D = \frac{C - S}{n}$$

(b) **Constant percentage Method:** Also called Balancing Decline Method. It assume depreciation by same percentage. $D = 1 - \left(\frac{S}{C}\right)^{1/n}$

Capitalised Value = Net income × Years purchases

Classification of Work on the Basis of amount: Petty < 50000, minor 50000 - 200000, major > 200000.

If distance between source of material and construction site is more than 8 km, then transportation charge will be given.

General Overhead Cost	Job Overhead Cost
Telephone Bill	Salary Delay
Travelling charges	Establishment of a New Office
Printing, Post office	Compensation

Description	Quantity
Work in foundation with Mud Mortar	1.5 m^3

- **Design Criteria:** Over flow rate = $\frac{Q}{BH}$, 500–750 lit/hr/m² for plain sedimentation, Depth = 03 to 4.5m Width B ≈ 10 m
- **Coagulants**
  1. Use of Alum
  2. Use of copperas: ($FeSo_4, 7H_2O$)
  3. Use of chlorinated copperas ($Fe_2(So_4)_3 + FeCl_3$),
  4. Use sodium Aluminate ($Na_2Al_2O_4$)

Comparision of slow sand and Rapid Gravity Filters.

Slow sand filter	**Rapid sand filter**
$C_u = 5$	$C_u = 1.3–1.7$
$D_{10} = (0.2–0.3)$ mm	$D_{10} = (0.45–0.7)$ mm
Frequency of cleaning = (1–3) months	Cleaned through Back washing
Design period = 10 year	$n = 1.22\sqrt{Q}$
Rate of filtration is very low as compared to R.S.F., but efficiency is High	Operational Troubles– (*a*) Air Binding (*b*) Mud ball formations (*c*) Cracking of filter

1. Minor Methods.

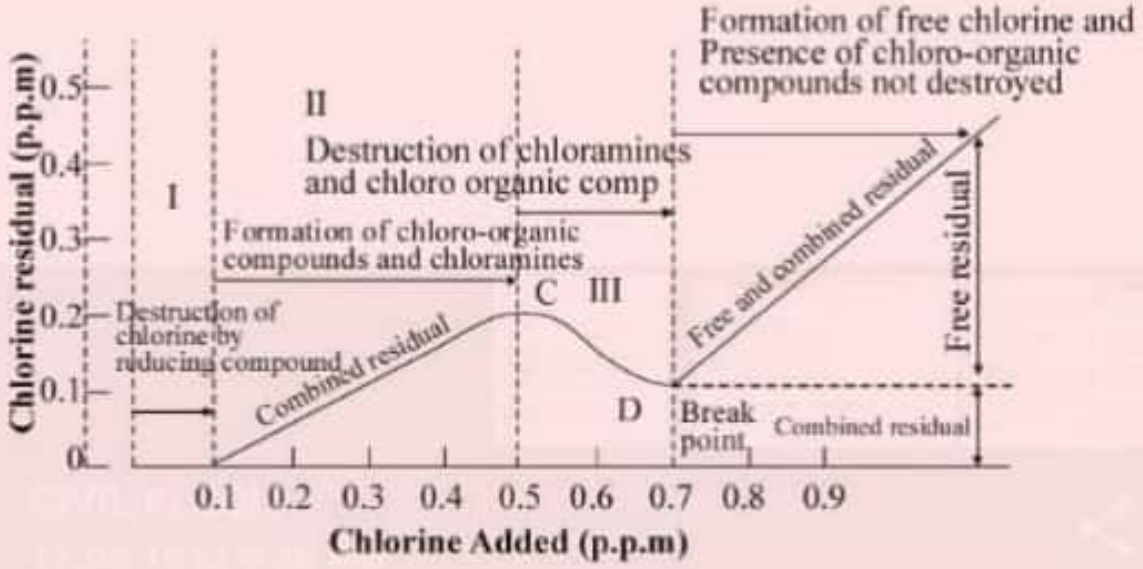
(i) Boiling, (ii) Treatment with excess lime, (iii) Treatment with ozone ($KMNO_4$), (iv) Treatment with silver Process.

2. Major Method Chlorination (Disintection with Cl_2)

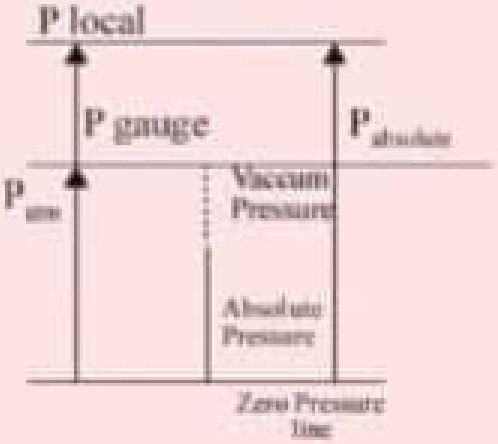
- $Cl_2 + H_2O \xrightarrow{pH>5} HOCl + HCl$, • $HOCl \xrightarrow{pH>8} H^+ + OCT^-$
- $HOCl \xleftrightarrow{pH<7} H^+ + OCl^-$, • $NH_3 + HOCl \rightarrow NH_2Cl + H_2O$

NH_3 + HOCl is called combined chlorine.

Chlorine forms: Free chlorine, Hypochlorites (Swimming Pool), Chloramines, Chlorine dioxide



Number	Equation	Uses
Reynolds No.	$\frac{F_i}{F_v} = \frac{\rho V L}{\mu}$	Aeroplanes, submarines, pipe flow
Eulers No.	$\sqrt{\frac{F_i}{F_p}} = \frac{V}{\sqrt{\frac{p}{\rho}}}$	Cavitation problem
Mach No.	$\sqrt{\frac{F_i}{F_e}} = \frac{V}{C}$	Aerodynamic testing, rocket, missile
Froude No.	$\sqrt{\frac{F_i}{F_g}} = \frac{V}{\sqrt{gL}}$	OCF, spillway, weir
Weber No.	$\sqrt{\frac{F_i}{F_\sigma}} = \frac{V}{\sqrt{\sigma/\rho L}}$	Veins, arteries, rising bubble



Type of flow	Convective Acceleration	Temporal Acceleration
Steady & uniform	0	0
Steady & non-uniform	Exists	0
Unsteady & uniform	0	Exists
Unsteady & non-uniform	Exists	Exists

$P_{absolute} = P_{atm} + P_{gauge}$

Total Acceleration = Convective acceleration with respect to space + local acceleration with respect to time.

FLUID MECHANICS

- **Viscosity:** $\boxed{\mu = \frac{\tau}{\frac{d\theta}{dt}}}$ $\boxed{\frac{d\theta}{dt} = \frac{du}{dy}}$ $\boxed{\nu = \frac{\mu}{\rho}}$

$\boxed{\tau = \mu \frac{du}{dy}}$ 1 mm of Hg = 10^{-3} m of Hg = $10^{-3} \times 13.6$ m of water

$= 10^{-3} \times 13.6 \times 9810$ N/m², 1 N/mm² = 10^6 N/m

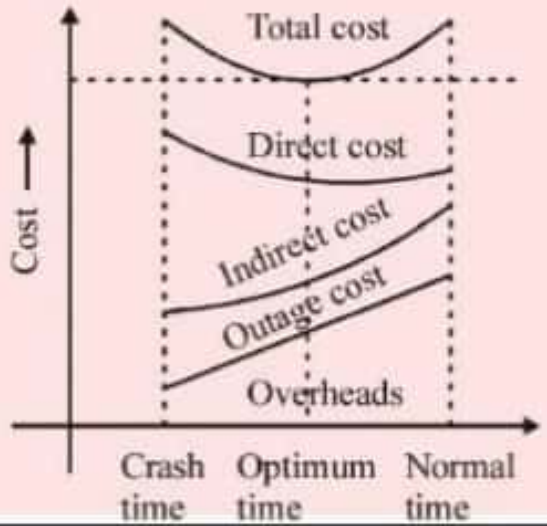
1 Kgf/cm² = $\frac{9.81\,N}{10^{-4}\,m^2} = 98.1 \times 10^3$ N/m², 1 mm = $10^{-3} \times 10^5$ N/m²

Compressibility = $\frac{1}{K} = \frac{d\delta}{\delta dp}$, $1\frac{NS}{m^2}$ (SI) = 10 poise, 1 m²/s (SI) = 10^4 stoke

Comparison between PERT and CPM

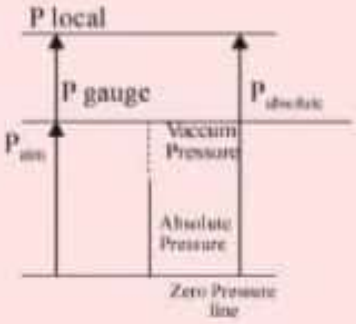
PERT	CPM
1. Probabilistic approach	1. Deterministic approach
2. Three time estimate	2. Single time estimate
3. Event oriented	3. Activity oriented.
4. Cost is proportional to time	4. Cost model is developed
5. β-distribution	5. Normal distribution
6. Concept of slack	6. Concept of float
7. Critical path by joining critical events	7. Critical path by joining critical activities.

$$\text{Cost slope} = \frac{C_c - C_n}{t_n - t_c}$$



Froude No. $\sqrt{\frac{F_i}{F_g}} = \frac{V}{\sqrt{gL}}$ OCF, spillway, weir

Weber No. $\sqrt{\frac{F_i}{F_\sigma}} = \frac{v}{\sqrt{\sigma/\rho L}}$ Veins, arteries, rising bubble



Type of flow	Convective Acceleration	Temporal Acceleration
Steady & uniform	0	0
Steady & non-uniform	Exists	0
Unsteady & uniform	0	Exists
Unsteady & non-uniform	Exists	Exists

$P_{absolute} = P_{atm} + P_{gauge}$

Total Acceleration = Convective acceleration with respect to space + local acceleration with respect to time.

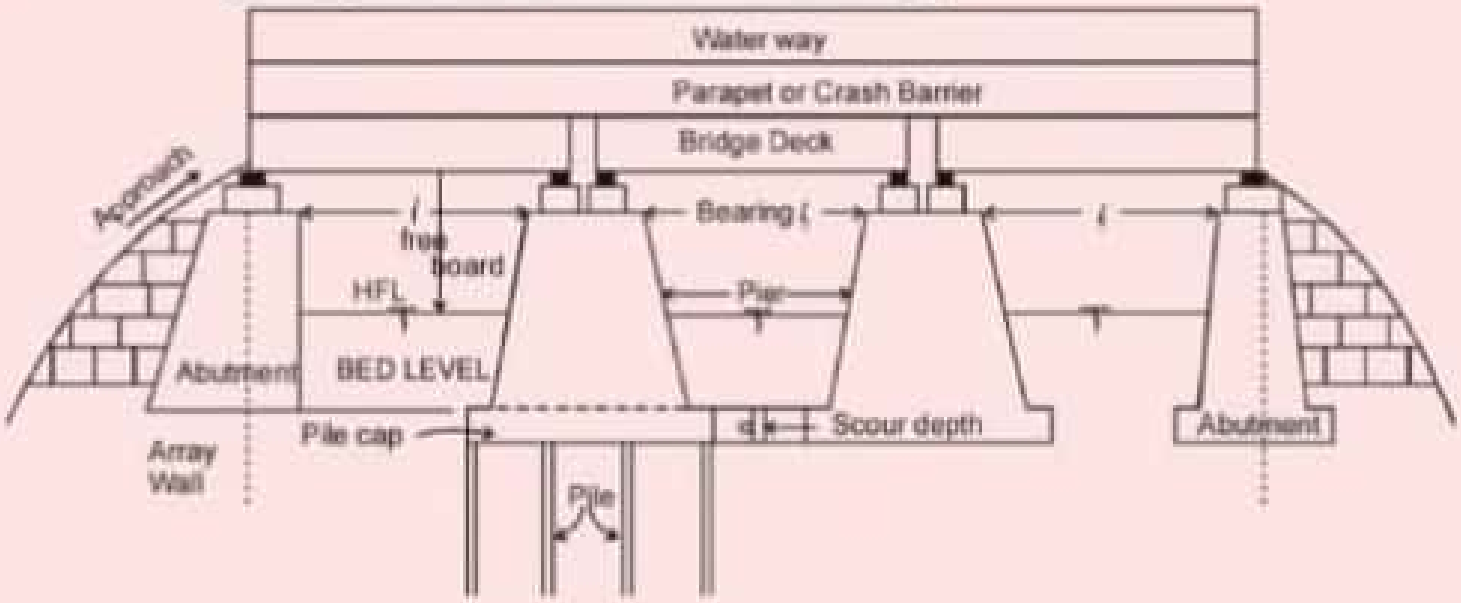
According to National building code, Buildings are classified in groups:

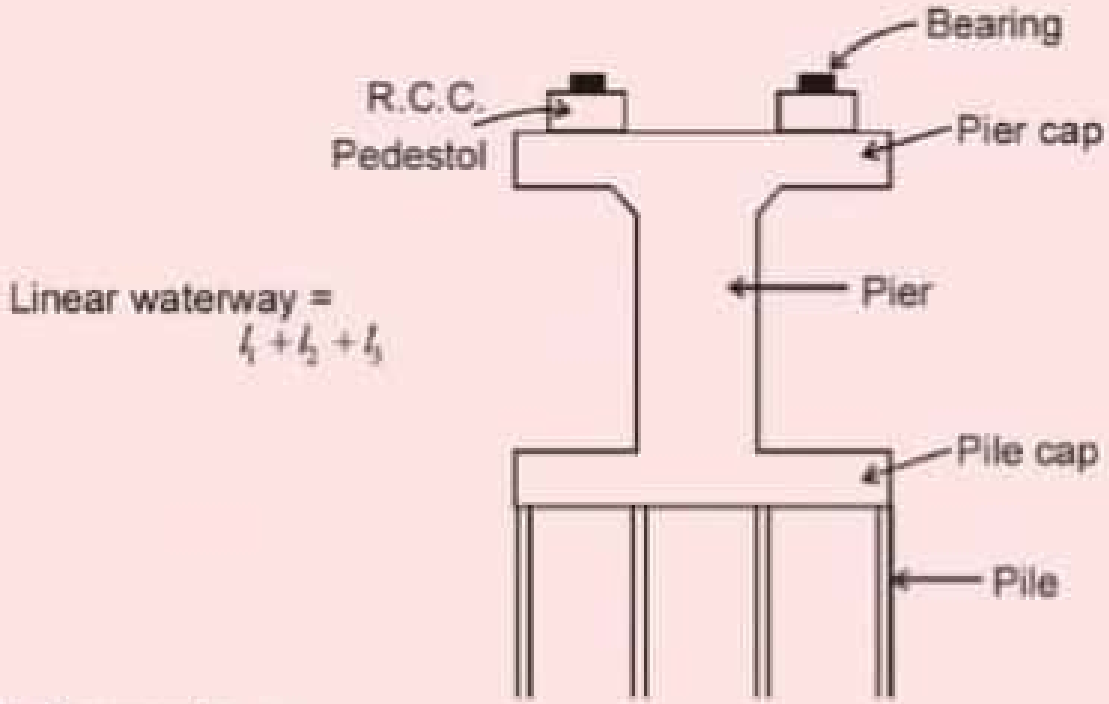
Group A – Residential Building
Group B – Educational Building
Group C – Institutional Building
Group D – Assembly Building
Group E – Business Building
Group F – Mercantile Building
Group G – Industrial Building
Group H – Storage Building
Group I – Hazardous Building

Dimension of Regular Sheets

Designation	Dimensions (mm)
A_0	841×1189
A_1	594×841
A_2	420×594
A_3	297×420
A_4	210×297
A_5	149×210

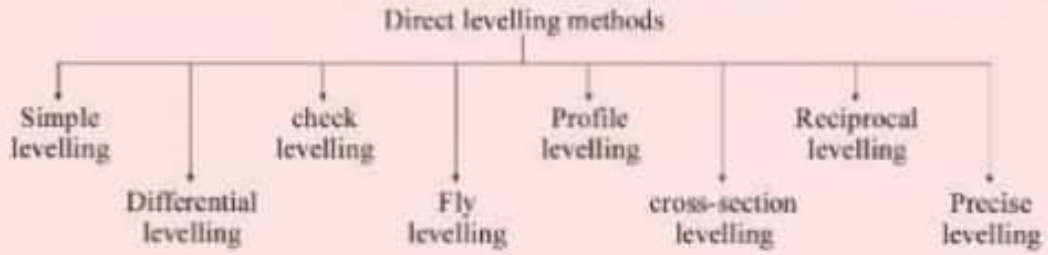
- **Component Part of a Bridge**





1. Marriman's formula :-

$$h_a = \frac{V^2}{2g}\left[\left(\frac{A}{Ca}\right)^2 - \left(\frac{A}{A_1}\right)\right]$$



- **Sensitivity:** Angle b/w the line of sights in radius

$$\alpha = \frac{S}{D} = n \times \frac{\ell}{R} \qquad \frac{l}{R} = \left(\frac{S}{nD}\right) \times 206265$$

D = Distance of the instrument from the staff
n = Number of divisions
l = length of one divison (2mm)
R = Radius of curvature
S = Staff intercept.

- **Check in Height of Instrument Method**

$$\Sigma \text{ BS} - \Sigma \text{ FS} = \Sigma \text{ Rise} - \Sigma \text{ Fall} = \text{Last RL} - \text{First RL}$$

- **Curvature:** $C_c = \frac{d^2}{2R} = 0.0785d^2$. •**Refraction:** $C_r = \frac{1}{7}\left(\frac{d^2}{2R}\right)$

- **Final Combination Correction:** $C = C_c - C_r = \frac{6}{7}\left(\frac{d^2}{2R}\right)$,

$C = 0.06735d^2$,

- **Distance of Visible Horizon**

$d = 3.85\sqrt{h}$, d = in km and h = in meter.

- **Reciprocal Levelling:** The true difference Elevation:

$$H = \frac{1}{2}(h_a - h_b) + (h_a' - h_b')]$$

- **Determining Areas:** Mid ordinate rule Δ = Area = Average ordinate

× Length of base, $\Delta = \frac{O_1 + O_2 + ... + O_n}{n} \times L$

- **Average ordinate Rule:** Area D = Average ordinate of the base

$$= \left(\frac{O_0 + O_1 + ... + O_n}{n+1}\right) \times L, \quad D = \frac{L}{(n+1)} \times \Sigma D \text{ , } \Sigma D = D_0 + ... + O_n.$$

- **Simpson's One-Third Rule:**

$$\Delta = \frac{d}{3}[(O_0 + O_n) + 2(O_1 + O_3 + ... + O_{n-1}) + 4(O_2 + O_4 + ...O_{n-2})]$$

- **Trapezoidal Formula (Area mean area Method):**

$$V = d\left(\frac{A_1 + A_n}{2} + A_2 + A_3 + ... A_{n-1}\right)$$

2. **Molesworth formula** :-

$$h_a = \frac{V^2}{17g} + 0.015\left[\left(\frac{A}{Ca}\right)^2 - 1\right]$$

Where, A = Natural Waterway, A_1 = Linear Waterway
C_a = Contracted Area

1. **Dicken's formula** : $Q = CA^{3/4}$ (C: Constant, A: Area of catchment)

This formula is applicable in North India

2. **Ravey's formula** : $Q = CA^{2/3}$

Applicable in South India

3. **Ingli's formula** : $Q = 123.2\sqrt{A}$

Applicable in Maharashtra Region

4. **Nawab Jung Bahadur's formula** : $Q = \frac{123.2\sqrt{A}}{\sqrt{A} + 10.36}$

Applicable in North & South India

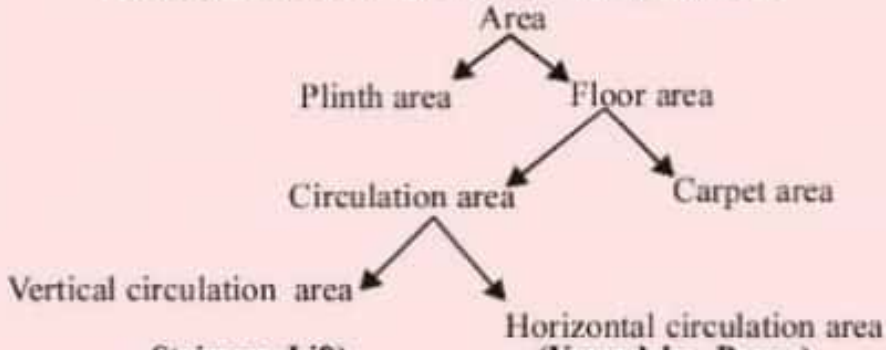
Classification of Bridges

1. **According to span** i. Culvert ii) Minor Bridge iii) Major Bridge iv) Long span bridge
2. **According to Masonary** i) Timber ii) Masonary iii) Iron & Steel iv) Prestressed

Description	Quantity
Work in foundation with Mud Mortar	1.5 m^3
Work in foundation with Lime/Cement Mortar	1.25 m^2
Work in Superstructure with Lime/Cement Mortar	1 m^3
Work in Superstructure mud Mortar	1.25 m^3
Distemper (1 coat)	35 m^2
White Washing/Colour Washing (3 Coat)	70 m^2
White Washing/Colour Washing (1 Coat)	200 m^2
RCC Work	3m^3
Half Brick wall/Partition Wall	5 m^2
Lime concrete in Roof	6 m^2
Lime Concrete in foundation/Floring	8.9 m^2
12 mm Plastering with cement/Lime Mortar	8 m^2

Degree of Accuracy (descreasing order)

Detailed > Cube rate > Plinth area > Rough estimate



Plinth area = Built up covered area

Courtyard, play ground, unclosed Balcony, cantilever porch is not included in plinth area.

F.A. = Plinth area – area occupied by walls/Intermediate supports

Area of balcony is included upto 50% in the floor area.

$$FAR = \frac{\text{Total floor area of all floors}}{\text{Area of plot}}$$

(Also known as Site ratio, plot ratio, floor space index)

Carpet Area: Useable area/Living area

C.A. = Total floor area – (circulation area + Non-useable area)

C.A. in residential area (50 – 65)% and in commercial area (60 – 75)%.

Work	% of Estimate
Departmental charges (centage charge)	(10 – 15)
Contractor charge	10
Labour Charge	25
Electrification	8
Electric fan	4
Saniatory and Water Supply Charge	8
Contigences Charges	(3–5)
Work Charge Establishment	(1.5–2)
Tools and Plants	(1–1.5)

Security money is about 10% of total contract including Earnest Money. Security money and Earnest Money are refundable after some time Without Any Interest.

Types of Contract: Lum sum, unit price, cost plus contract.

Types of Trap: P, Q, S (Shape), Intercepting, Gully, Floor (Purpose)

I.)Class A ii.) 70 R loading

Permanent Bridges

3. **According to loading** iii.)Class AA iv.)Class B

Temporary Bridge

Note:

1. Culvert - span < 6m 2. Minor Bridge - 6 - 30 m

3. Major Bridge - 30 - 120 m 4. Long span Bridge - above 120m

Loading on Bridge as per IRC - 6 - 2010

1.) D.L., 2.) Live Load, 3.) W.L., 4.) Earthquack Load,
5.) Earth Pressure, 6.) Centrifugal force, 7.) Water current
8.) Impact load, 9.) Longitudinal force, 10.) Snow load

Correction for Elevation, Temperature and Gradient (Airport)

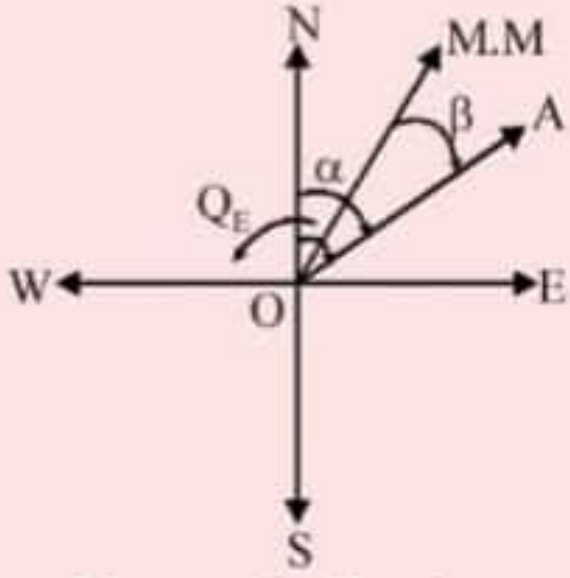
Elevation: Basic Runway length is increase at the rate of 7% per 300 m rise in elevation above MSL.

Temperature: Airport reference temperature = $T_a + \frac{T_m - T_a}{3}$

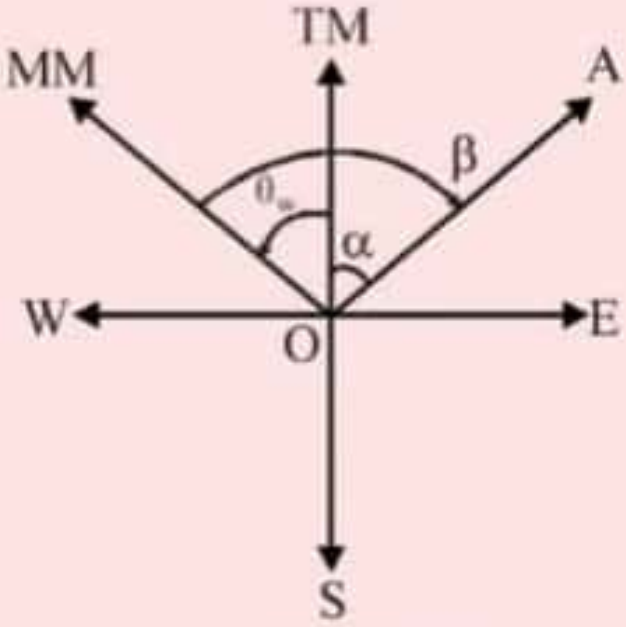
Gradient: After elevation and temperature correction, should be further increase at the rate of 20% for every 1% of effective gradient.

$$\text{Radius of taxiway (in m)} = \frac{0.388\,W^2}{T/2 - S}$$

- **True Meridian/Bearing**
  - → True meridian is a line joining True North pole, True South Pole end and point of reference. **It never changes with time.**
  - → Angle measured for any line w.r.t True Meridian is called Ture bearing.
- Bearing Taken W.r.t magnetic meridian is called magnetic Bearing.



Eastern Declination



Western Declination

Magnetic Declination

- At any place horizontal angle b/w True Meridian and Magnetic Meridian is called magnetic Declination.

  For Eastern Declination: $\alpha = B + \theta_E$ or $T.B = M.B + \theta_E$

  For western Declination: $\alpha = B - \theta_w$ or $T.B = M.B - \theta_w$

Note

(+) Sign is used for declination is to the east, sign (–) is used if declination is to west

Fore bearing and Back Bearing: $B.B = F.B \pm 180^\circ$

Local Attraction: $F.B - B.B \neq 180^\circ$

Latitude and Departure

→ Projection of a line on N-S direction is called latitude: $\boxed{L = +l\cos\theta}$

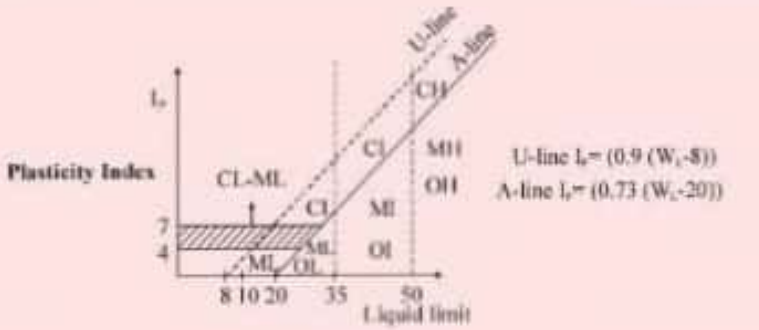
→ Projectione of a line on E-W direction is called deparature:

$\boxed{D = l\sin\theta}$

ISSCS: On the bases of particle size

Boulder	Cobble	Gravel		Coarse sand		Fine	Grained soil	
		Coarse	Fine	Coarse	Medium	fine	silt	clay
>300mm	300-80	80-20	20-4.75	4.75-2.0	2-0.425	0.425-0.75	0.075-0.002	<0.002

Caliche - Gravel, Sand, silt mixture Loam - Sand, silt, clay mixture



Plasticity Chart

- **Darcy's Law:** $\boxed{q = kiA}$
- **Measurement of Permeability**

(a) **Constant Head Permeameter Test:** $\boxed{K = \frac{q}{iA} = \frac{qL}{Aht}}$

(b) **Falling Head Permeameter Test:** $\boxed{K = \frac{2.3aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)}$

(c) **Confined Flow Pumping Test:** $\boxed{K = \frac{2.3q}{2\pi D(h_2 - h_1)}\log_{10}\left(\frac{r_2}{r_1}\right)}$

(d) **Unconfined Flow Pumping Test:** $\boxed{K = \frac{2.3q}{\pi(H^2 - h^2)}\log_{10}\frac{R}{r}}$

(e) **Kozeny-Carman Equation:** $\boxed{K = \frac{1}{K_0 S^2}\cdot\frac{\gamma}{\mu}\cdot\frac{e^3}{1+e}}$

(f) **Allen Hazen's Equation:** $\boxed{K = CD_{10}^2}$

(g) **Coefficient of Consolidation Equation:** $\boxed{K = C_v \cdot M_v \cdot \gamma_w}$

$$V_s = \frac{V}{n},\ R = 3000d\sqrt{K},\ S_s + S_n = n$$

- **Permeability of Stratified Soils**

(a) **Horizontal Flow:** $\boxed{K_H = \frac{K_1H_1 + K_2H_2 + ...}{H_1 + H_2 + ...}}$

(b) **Vertical Flow:** $\boxed{K_v = \frac{H_1 + H_2 + ...}{\frac{H_1}{K_1} + \frac{H_2}{K_2} + ...} = \frac{\Sigma H}{\Sigma H/K}}$

Note: $K_H > K_v$ always.

- **Critical Hydraulic Gradient:** $\boxed{I_c = \frac{G-1}{1+e} = (G-1)(1-n)}$

2. **Circular Tapering Bar:** $\Delta L = \frac{4PL}{\pi E D_1 D_2}$

- **Defection of Composit Bar:** $\Delta L_1 = \Delta L_2 \Delta = \frac{PL}{A_1E_1 + A_2E_2}$

- **Deflection due to Self Weight of Bar:**

1. **Prismatic Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{2E}$,

2. **Conical Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{6E}$

- **Thermal Expansion:** $\sigma = E\alpha\Delta T$, $\Delta = L\alpha\Delta T$

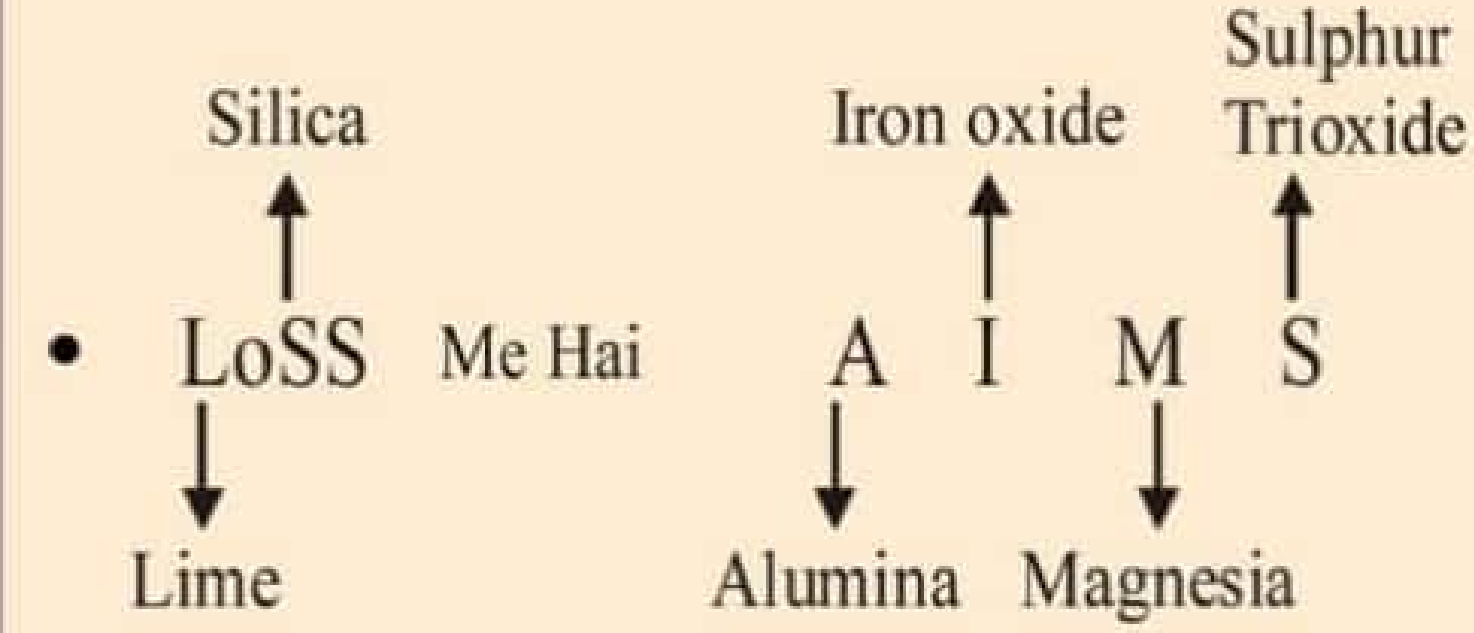
Coefficient of Thermal expansion (Aluminium > Brass > Copper > Steel)

$P_{cr} = \frac{\pi^2 E}{\lambda^2}$ (Euler's Theory) $P_R = \frac{\sigma_c A}{1 + a\lambda_e^2}$ (Rankine's Formula)

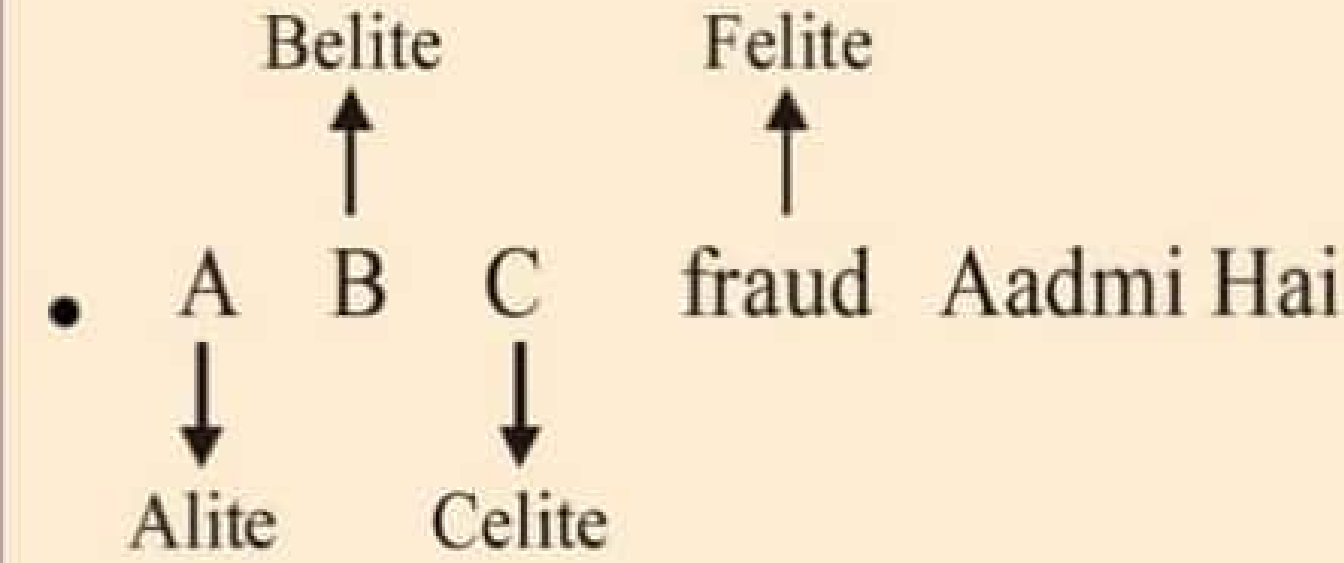
- **In case of Pure Bending:** $Z = \frac{\pi}{32} D^3$

- **In case of pure Torsion:** $\tau_{max} = \frac{T}{Z_p} = \frac{16T}{\pi D^3}$ $Z_p = \frac{\pi}{16} D^3$

- **Bending Equation:** $\frac{\sigma_b}{y} = \frac{M}{I} = \frac{E}{R}$



(Cement Composition in a Order)



(Bogue Compound in a Order)

Column: Longitudinal reinforcement-Minimum (0.8%), Maximum (6%) (4% – overlapping). Minimum Number of Bars (Rectangular - 4, circular - 6). Minimum diameter of longitudinal bar = 12 mm. Maximum centre to centre spacing of reinforcement = 300 mm

- **Short & Long Column:** Short if salenderness. ratio of both axes are

less than, $12.\left(\frac{l_{ex}}{h}\right) \text{or} \left(\frac{l_{y}}{b}\right) \geq 12$

Lateral ties: Tie diameter $\phi, \geq \begin{cases} \frac{\phi \text{ longitudinal max}}{4} \\ 6 \text{ mm} \end{cases}$

Tie spacing $S_v \leq \begin{cases} D \\ 16\phi \text{ longitudinal min} \\ 300 \text{ mm} \end{cases}$

Minimum Eccentricity:

$$e_{y,min} = \max\left\{\begin{matrix} \frac{l_{ey}}{500} + \frac{D_y}{30} \\ 20 \text{ mm} \end{matrix}\right.$$

$$e_{x,min} = \max\left\{\begin{matrix} \frac{l_{ex}}{500} + \frac{D_x}{30} \\ 20 \text{ mm} \end{matrix}\right.$$

For non – rectangular / circular section

$$e_{min} = \max\left\{\begin{matrix} \frac{l_e}{300} \\ 20 \text{ mm} \end{matrix}\right.$$

Slenderness Limits to Ensure Lateral Stability

Slenderness limits to ensure lateral stability

- Cantilever beam
- Simply supported beam or continuous beam

Clear span < min. $\begin{cases} 25b \\ \frac{100b^2}{d} \end{cases}$

Clear span < min. $\begin{cases} 60b \\ \frac{250b^2}{d} \end{cases}$

Control of Deflection:

Cantilever beam	7
Simply supported beam	20
Continuous beam	26

Type of slab	Type of reinforcement	
	Mild steel	Fe 415
Simply supported	35	28
Continuous	40	32

- **Concentrically Loaded Column:** (e = 0)

$$\boxed{P = 0.45f_{ck} A_c + 0.75f_y A_{st}}$$

Basic Capacity of Single lane, Vehicle Per hours: v = speed kmph,

$T(\text{Sec/km}) = \frac{3600}{v}$, $\boxed{q_{max} = \frac{v_f k_j}{4}}$,

Where,

v_f = Free mean speed, (Maximum speed at zero density.),

k_j = jam density, (Maximum density at zero speed), Maximum flow

q_{max} occurs when the speed is $\frac{V_f}{2}$ and density is $k_j/2$.

lumber of potential conflicts: Both roads are two way = 24, Both road one way = 6, One road is two way, other one way = 11

$)=\frac{280w\left(1+\frac{e}{w}\right)\left(1-\frac{p}{3}\right)}{\left(1+\frac{w}{l}\right)}$, $W_{weaving} = \frac{e_1+e_2}{2}+3.5$ (Types of interchange: Trumpet, Diamond, Full Cloverleaf, Partial Cloverleaf)

loating Car Method: For Speed and delay study.

Aggregate crushing value: $\boxed{\frac{w_2}{w_1}\times 100}$

Coefficient of Hardness: $\boxed{= 20 - \frac{\text{Loss of wt. in gm}}{3}}$

Rigidity factor: $\boxed{R.F = \frac{\text{Contact Pressure}}{\text{Tyre Pressure}}}$

California Resistance Value: $\boxed{t = \frac{k.(T.I)(90-R)}{C^{1/5}}}$

Elastic Modulus: Δ is maximum vertical deflection of the flexible plate, $\boxed{\Delta = \frac{1.18pa}{E_s}}$, Rigid circular plate is used instead of flexible

$\boxed{\Delta = \frac{1.5Pa}{E_s}}$, a = radius of plate, p = pressure at deflection, E_s = young's modulus of pavement material.

California Bearing Ratio M/D: $\boxed{t = \left(\frac{1.75P}{CBR} - \frac{A}{\pi}\right)^{1/2}}$,

t = Pavement thickness in Cm, P = wheel load in kg, CBR = California Bearing Ratio (%), A = Contact Area in cm^2

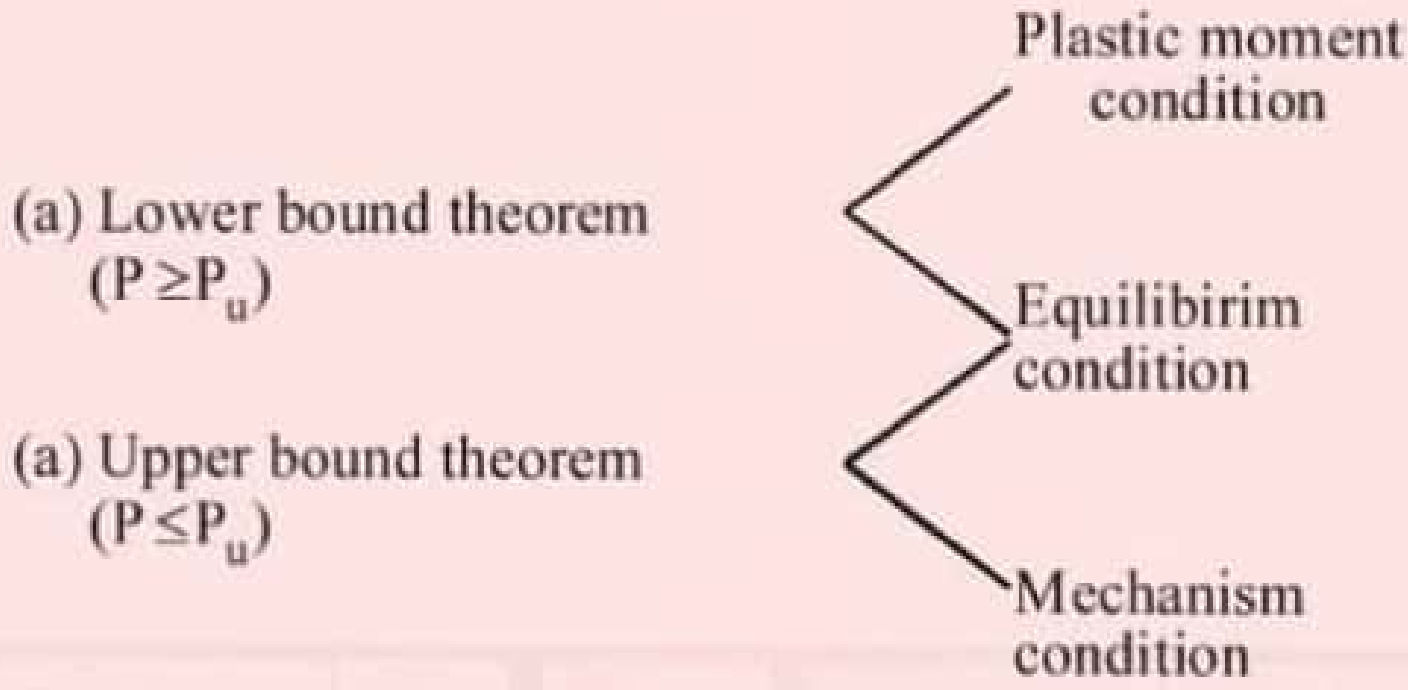
CBR TEST: $\boxed{CBR = \frac{\text{Load or pressure Substained at2.5 or 5.0 mm Penetration}}{\text{Load or pressure Substained by standard aggregate at}}}$

- **Shape Factor:** $S = \frac{M_p}{M_y} = \frac{a_2 Z_p}{a_{y2}} = \frac{Z_p}{Z}$ (Load factor = FOS × S)

Shape factor For different Shapes

Section	Shape factor
1. Rectangular Section	1.5
2. Solid circular Section	1.7
3. Triangular Section (vertex upward)	2.34
4. Hallow circular Section	$1.7\times\left(\frac{1-k^3}{1-k^4}\right)$
5. a. Diamand Section Rhombus	2.00
b. Thin Hollow Rhombus	1.50
6. Thin Circular ring Solid	1.27
7. I section	
a. About strong Axis	1.12
b. About weak Axis	1.55
8. T Section.	1.90 to 1.95

- **Method of Analysis:**



- DPD Chlorotex
  Dard Ae DiSCO → Orthotolidence
  Starch iodine

(Testing of Chlorine Residue)

- Nalgonda technique
  Reverse osmosis
  Ion exchange adsorption method
  NARi
  Activated alumina

(Defluoridation Method)

- Inglis Khosla
  Dicken
  DRINK (formula for Discharge of River)
  Ryne
  Nawab Jung Bahadur

- **Radius of Mohr's Circle (τ_{max}):** $R = \frac{\sigma_{max} - \sigma_{min}}{2} = \tau_{max.}$

- **Normal stress at Location of (τ_{max}) (τ_{max}-max shear stress):**

$$\sigma_n = \frac{\sigma_1 + \sigma_2}{2}$$

- **Volumetric Strain of Rectangular:**

$$\frac{\Delta V}{V} = \varepsilon_v = \left[\frac{(\sigma_x + \sigma_y + \sigma_z)}{E}\right](1 - 2\mu)$$

- **Volumetric Strain of Cylindrical:** $\varepsilon_v = \varepsilon_e + 2\varepsilon_D$

- **Volumetric Strain of Spherical:** $\varepsilon_v = 3\varepsilon_D$

- **Relationship Between Elastic Constant:**

$$G = \frac{E}{2(1+\mu)}, \quad K = \frac{E}{2(1-2\mu)}, \quad \mu = \frac{3k - 2G}{6k + 2G}, \quad E = \frac{9kG}{3k + G}$$

Number of independent Elastic Constant: Homogenous & Isotropic = 2, Anisotropic = 21, Orthotropic = 9

- **Axial Elongation of the Prismatic Bar:** $\Delta L = \frac{PL}{AE}$, $\Delta L = \frac{2PL}{AE}$

(for Instantaneous loading)

- **Deflection In Non-Prismtic Bars:**

1. **Stepped Bar:** $\Delta L = \frac{P_1 L_1}{A_1 E_1} + \frac{P_2 L_2}{A_2 E_2} + ---$

$$CSI = \frac{S + 10H}{20}, \text{ Sleeper density} = M + x, D_{min} = \frac{S - W}{2}, e = \frac{GV^2}{127R}$$

Length of transition curve

I approach

II approach

Maximum of the following

$$L = \max \begin{cases} 7.2e \\ 0.073eV_{max} \\ 0.073D\,V_{max} \end{cases}$$

(*i*) Railway board formula

e = S.E in cm

$L = 4.4\sqrt{R}$

L, R → m

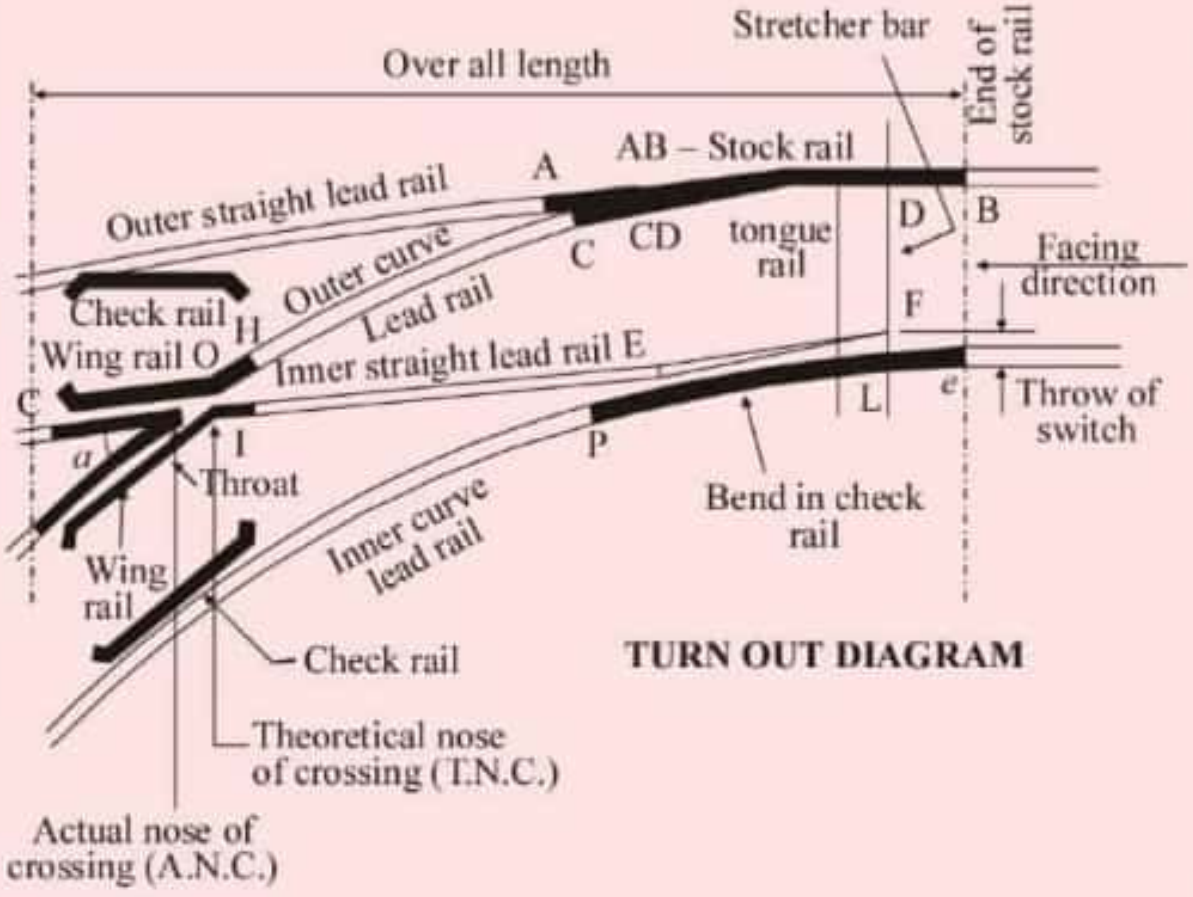
D = cant deficiency in cm

(*ii*) Change of radial acceleration

$$L = \frac{3.28V^3}{R}$$

(*iii*) Rate of change of super elevation

L = 3.6e



TURN OUT DIAGRAM

Member	λmax
A member carrying compressive load resulting from dead load and imposed load	180
A tension member in which reversal of direct stress due to load other than wind and seismic force	180
A member subjected to compressive forces resulting from wind EQ force provide deformation of such member does not affect stress	250
Compression flange of Beam	300
A member normally act as a tie in Roof Truss	350
Tension member other than Pre-tension	400

- Strength of plate between rivet holes in Tension = $\sigma_{at} \times (p-d) \times t$
- Bearing strength of rivet = $\sigma_{at} \times d \times t$ or $= \sigma_{Pb} \times d \times t$.
- Shear Strength of rivet = $T_{vf} \times \frac{\pi}{4} \times d^2$ (in single shear),

  $2 \times T_{vf} \times \frac{\pi}{4} \times d^2$ in double shear), d = gross diameter of rivet,

  $\boxed{d = 6.01\sqrt{t}}$ (unwins formula)
- **Diameter:** Grosss diameter = nominal diameter + 1.5 mm (if < 25mm), Nominal diameter + 2mm (if > 25mm)
- **Pitch:** Should not exceed 16t or 200mm, which ever is less in tension member, and 12t or 200mm, which ever is less in Compression Members. Tacking rivets should not exceed 32 t or 300 mm which ever is less. Minimum pitch = 2.5d

Tacking rivets.

Thickness of member	Minimum diameter of rivets
Up to 10 mm	16mm
Over 10mm to 16 mm	20 mm
Over10 mm	22mm

- **Equivalent Torque:** $T_{eq} = \left[\sqrt{M^2 + T^2}\right]$

Theory	Given by	Remark
Maximum Principle Stress or Maximum Normal stress	Rankine	Suitable for Brittle
Maximum Principle Strain	St. Venant	Neither accurate for Brittle nor Ductile
Maximum shear Stress	Guest and Treseca	Suitable for Ductile
Maximum Strain Energy	Haigh and Beltrami	Ductile
Maximum shear Strain energy	Vonmises and Hencky	Ductile

- **Shear Stress:** $\tau = \frac{VA\bar{y}}{Ib}$

- **Shear Stress In Rectangular Section:** $q = \frac{6s}{bd^2}\left(\frac{d^2}{4} - y^2\right)$ $(q = \tau)$,

  Where S = shear -force, $q_{max} = \tau_{max} = \frac{3}{2}\frac{S}{bd}$ $q_{avg} = \tau_{avg} = \frac{S}{bd}$,

  $\frac{\tau_{max}}{\tau_{avg}} = 1.5$

Note: Shear stress at top & Bottom is always 0.

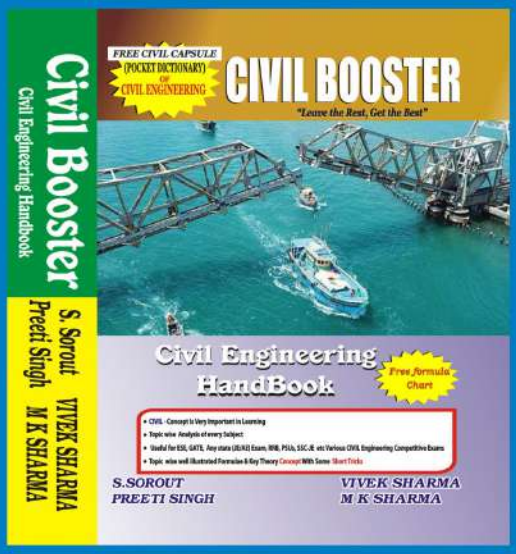
- **In Circular Beam:** $q = \frac{4}{3}\frac{S}{\pi R^4}\left(R^2 - y^2\right)$ $\tau_{max} = \frac{4S}{3\pi R^2}$,

  $\tau_{max} = \frac{4}{3}\tau_{avg.}$

- **In Triangular Section:** $q_{max}/I_{max} = \frac{3S}{bh}$ $\tau_{avg}/q_{avg} = \frac{2S}{bh}$,

  $\tau_{NA} = 1.33\tau_{avg}$, $\tau_{CG} = 1.5\tau_{avg}$

CIVIL CAPSULE



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of Civil Engineering

By

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PREFACE

It is an immense pleasure to present the **CIVIL Capsule (Pocket Dictionary) of Civil Engineering** in the hand of young Engineers. It will help you in the quick revision of CIVIL Engineering Subjects.

I have true desire of serving to society and Nation by way of making easy path of the education for People of India. You should visit the **CIVIL Ki GOLI** You-Tube channel for better use of this pocket dictionary.

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Date: Dec. 2020 **S. Sorout**

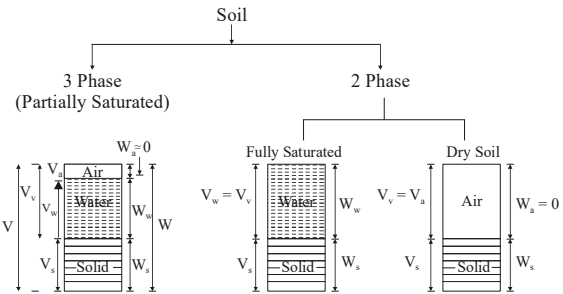
CONTENTS

1. Soil Mechanics 1–15
2. Reinforce Cement Concrete 16–24
3. Fluid Mechanics 25–44
4. Building Material & Construction .. 45–77
5. Strength of Material 78–88
6. Hydrology Engineering 89–92
7. Irrigation Engineering 93–99
8. Highway Engineering 100–110
9. Railway Engineering 111–113
10. Surveying 114–130
11. Environmental Engineering 131–140
12. Steel Structure 141–149
13. Estimation Costing 150–153
14. CPM & PERT 154–158
15. BRIDGE Engineering 159–169
16. TUNNEL Engineering 170–172
17. STRUCTURAL ANALYSIS 173–188

1 SOIL MECHANICS

Soil	Deposited by
Alluvial Soil	River
Marine Soil	Sea water
Lacustrine Soil	Still water like as lakes
Aeolian Soil	Wind
Glacial Soil	Ice

Note: Loess is an aeolian soil.



- **Water Content:** $$W = \frac{W_W}{W_S} \times 100$$
- **Void Ratio:** $$e = \frac{V_V}{V_S}$$

- **Porosity:** $n = \frac{V_V}{V} \times 100$
- **Degree of Saturation:** $S = \frac{V_W}{V_v} \times 100$
- **Air Content:** $a_c = \frac{V_a}{V_v} = 1 - S$

  % Air Voids $\eta = \frac{V_a}{V}$, $\eta = n\, a_c$
- **Bulk Unit Weight:** $\gamma = \frac{W}{V} = \frac{W_S + W_W}{V_a + V_W + V_S}$
- **Dry Unit Weight:** $\Upsilon_d = \frac{W_S}{V}$
- **Saturated Unit Weight:** $\Upsilon_{sat} = \frac{W_{sat}}{V}$
- **Specific Gravity:** $G = \frac{W_S}{V_S \cdot \gamma_W} = \frac{\gamma_S}{\gamma_W}$
- **Appearent or Mass Specific Gravity:**

  $G_m = \frac{W}{V\Upsilon_W} = \frac{\Upsilon}{\Upsilon_W}$
- $W_S = \frac{W}{1+w}$
- $n = \frac{e}{1+e}$ or $e = \frac{n}{1-n}$

- $Se = WG$
- $\Upsilon = \frac{G\gamma_W(1+W)}{(1+e)}$
- $\Upsilon_{sat} = \left[\frac{G+e}{1+e}\right].\Upsilon_w$
- $\Upsilon_d = \frac{G\Upsilon_w}{1+e}$
- $\Upsilon' = \left[\frac{G-1}{1+e}\right]\Upsilon_w$
- $\Upsilon_d = \frac{\Upsilon}{1+w}$

Method for Determination of water content

- **Oven drying Method:** $W = \frac{W_2 - W_1}{W_3 - W_1} \times 100$
- **Pycnometer Method:** $W = \left[\frac{(W_2 - W_1)}{(W_3 - W_4)}\left(\frac{G-1}{G}\right) - 1\right] \times 100$

Determination of Unit Weight:

1. **Core Cutter method**
   - Field method suitable for, fine grained and clayey soil.
   - Not suitable for stoney, gravelly soil and dry soil.
2. **Water displacement method**
   - Suitable for ohesive soils only
3. **Sand replacement method**
   - Field method & used for gravelly, sandy and dry soil

4. Water ballon method

- Volume of the pit is measured by covering the pit with plastic sheet and then filling it with water.
- Wt. of water thus calculated is equal to volume of soil excavated.

- **Plasticity Index [I_P]:** $I_P = W_L - W_P$

$$I_C = \frac{W_L - W_N}{I_P}, \quad I_L = \frac{W_N - W_P}{I_P} \quad (I_C + I_L = 1)$$

- **Flow Index:** $I_f = \dfrac{W_1 - W_2}{\log_{10}\left(\dfrac{N_2}{N_1}\right)}$, $I_t = \dfrac{I_P}{I_f}$

- **Sensitivity:** $S_t = \dfrac{(q_u)\ \text{undisturbed}}{(q_u)\ \text{Remoulded}}$

- **Relative Density/Density Index:** $I_D = \dfrac{e_{max} - e}{e_{max} - e_{min}} \times 100$

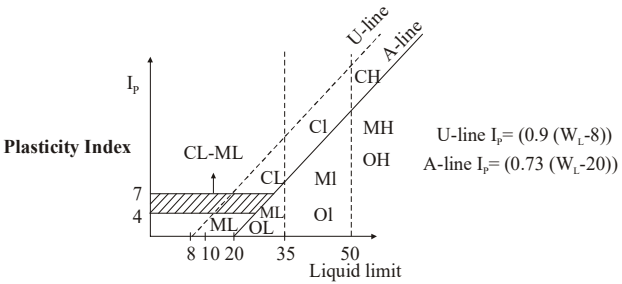
- **Activity of Clay:** $A_C = \dfrac{\text{Plasticity Index}}{\%\ \text{by weight fine than } 2\mu}$

$$C_u = \frac{D_{60}}{D_{10}}, (C_u > 4 \text{ Gravel}, C_u > 6 \text{ Sand})$$

$$C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}, 1 \le C_C \le 3 \text{ for well Graded soil}$$

Coarse grained soil classification based on grain size (mm)

Boulder	Cobble	Coarse grained soil					Fine Grained soil	
		Gravel			Sand			
		coarse	fine	coarse	medium	fine	silt	clay
>300	300-80	80-20	20-4.75	4.75-2.0	2-0.425	0.425-0.075	0.075-0.002	<0.002



Hydrometer correction: $C_T = C_M - C_d \pm C_t$

Compaction	Consolidation
Reduction in volume of air voids at a given water content	Volume reduction due to expultion of pore water from voids
Partially saturated soil	Completely saturated soil
Instantaneous phenomenon	Time dependent phenomenon
Specific compaction Technique (use dynamic load)	By static load placed on soil

Quick sand condition: In case of upward seepage flow, if the upward seepage force becomes equal to the buoyant weight of soil, the effective stress in soil becomes zero.

Critical hydraulic gradient:

$$i_{cr} = \frac{\gamma_{sub}}{\gamma_w} = \frac{G-1}{1+e} = (G-1)(1-n), \quad FOS = \frac{i_{cr}}{i_e}$$

Quick sand condition occurs in sand but not in clay becuase in clay cohesion exists.

Darcy's Law: $\boxed{q = kiA}$

Measrement of Permeability:

- **Constant Head Permeameter Test:** $\boxed{K = \frac{q}{iA} = \frac{qL}{Aht}}$
- **Falling Head Permeameter Test:** $\boxed{K = \frac{2.3aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)}$
- **Confined Flow Pumping Test:** $\boxed{K = \frac{2.3q}{2\pi D}\log_{10}\frac{\left(\frac{r_2}{r_1}\right)}{h_2 - h_1}}$
- **Unconfined Flow Pumping Test:** $\boxed{K = \frac{2.3q}{\pi(H^2 - h^2)}\log_{10}\frac{R}{r}}$
- **Kozeny-Carman Equation:** $\boxed{K = \frac{1}{K_0 . S^2}.\frac{\gamma}{\mu}.\frac{e^3}{1+e}}$
- **Allen Hazen's Equation:** $\boxed{K = C.D_{10}^2}$

- **Coefficient of Consolidation Equation:** $K = C_V.M_V.\gamma_w$

$$V_s = \frac{V}{n}, R = 3000d\sqrt{K}, S_y + S_R = n$$

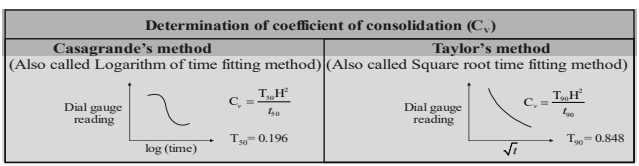
Permeability of Stratified Soils

- **Horizontal Flow:** $$K_H = \frac{K_1H_1 + K_2H_2 + ...}{H_1 + H_2 + ...}$$

- **Vertical Flow:** $$K_V = \frac{H_1 + H_2 + ...}{\frac{H_1}{K_1} + \frac{H_2}{K_2} + ...} = \frac{\sum H}{\sum H/K}$$

Note: $K_H > K_V$ always.

Determination of coefficient of consolidation (C_V)



C_V is inversely proportional to liquid limit (w_L) where as C_c is directly proportional to liquid limit.

Value of C_V decreases with increases in plasticity.

- **Boussinesq's Equations:** $$\sigma_Z = \frac{3q}{2\pi z^2}\left[\frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{5/2}$$
- **Seepage Calculation:** $$q = k.H\frac{N_F}{N_d}$$
- **Westergaard's Solution:**

$$\sigma_z = \frac{1}{\pi}\frac{q}{z^2}\times\frac{1}{\left[1+2\left(\frac{r}{z}\right)^2\right]^{3/2}} = k_w\cdot\frac{q}{Z^2}$$

$$C_c = \frac{e_1 - e_2}{\log\bar{\sigma}_2 - \log\bar{\sigma}_1}, \quad a_v = \frac{\Delta e}{\Delta\bar{\sigma}}, \quad M_v = -\frac{\frac{\Delta V}{V}}{\Delta\bar{\sigma}}$$

$$M_V = -\frac{\Delta e}{(1+e_0)\Delta\bar{\sigma}} = \frac{a_v}{1+e_0}$$

- **Terzaghi Equation for one- dimension consolidation:**

$$\frac{du}{\partial t} = C_{v.}\frac{\partial^2 u}{\partial_Z{}^2}$$

- **Time Factor:** $$T_v = \frac{C_v.t}{H^2}$$

$$T_v = \frac{\pi}{4}(u)^2, u \le 60\%$$

$$T_v = 1.781 - 0.933 \log (100 - u); u > 60\%$$

- **Degree Of Consolidation:** $\boxed{V_z = \frac{u_1 - u_z}{u_1} =}, \boxed{\frac{\Delta H}{H} = \frac{\Delta e}{1 + e_o}}$
- **Calculation of Settlement:**

$$\boxed{\Delta H = C_C \times \frac{H_0}{1 + e_0} \log \left(\frac{\bar{\sigma}_0 + \Delta\bar{\sigma}}{\bar{\sigma}_0} \right)}$$

$$\boxed{\Delta H = m_v . H_0 . \Delta\bar{\sigma},} \quad \boxed{C_C = 0.009(w_L - 10)}$$

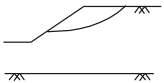
- **Triaxial Test:** $\boxed{\sigma_1 = \sigma_3 \tan^2 \left(45^o + \frac{\phi}{2} \right) + 2c \tan \left(45^o + \frac{\phi}{2} \right)}$
- **Vane Shear test:**

$$\boxed{S = \frac{T}{\pi d^2 \left(\frac{h}{2} + \frac{d}{6} \right)}}$$ [when both top & bottom end shear the soil]

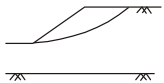
- **Pore Pressure Parameter (Given by Skempton):** $\Delta U = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$

  $B = \frac{\Delta U}{\Delta\sigma_3}$ (For saturated soil, B = 1, for dry soil, B = 0)

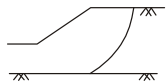
- **Stability of slope:** $F = \frac{\tan\phi}{\tan\beta}, \tau = \gamma z \cos\beta \sin\beta$
- **Swedish Circle Method:** Surface of sliding is assumed as "arc of circle"



Face/slope failure soil close to the toe is quite strong depth factor < 1



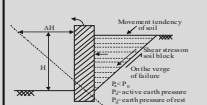
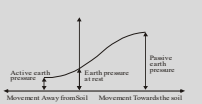
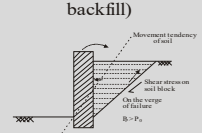
Toe failure most common mode of failure depth factor = 1



Base failure soil below the toe is soft and slope is flat depth factor > 1

$$\text{Stability Number} = S_N = \frac{C_m}{\gamma H.} = \frac{c}{F_c.\gamma H} \quad (\text{Max. value} = 0.261)$$

Classification of lateral earth pressure

Active earth pressure (wall moves away from backfill)	Earth pressure at rest (wall does not moves at all)	Passive earth pressure (wall moves towards the backfill)
		

Active earth pressure	**Passive earth pressure**
Failure plane is inclined at $(45 + \phi/2)$ with the horizontal	Failure plane is inclined at $(45 - \phi/2)$ with the horizontal
Very little movement is required to mobilise the active pressure	Much higher movement is required to mobilise the pressure
$\Delta H = 0.2\%$ of H Dense sands	$\Delta H = 2\%$ of H Dense sands
$\Delta H = 0.5\%$ of H loose sands	$\Delta H = (5\text{-}10)\%$ of H loose sands
$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45-\frac{\phi}{2}\right)$	$k_P = \frac{1+\sin\phi}{1-\sin\phi} = \tan^2\left(45+\frac{\phi}{2}\right)$

- **Active Earth Pressure For Cohesive:**

$$P_a = K_a \gamma z - 2C\sqrt{k_a}$$

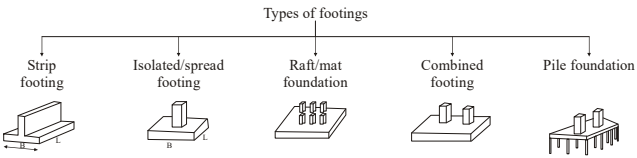
$$Z = 0 \text{ when } P_a = -2C\sqrt{K_a}$$

$$Z_C = \frac{2C}{\gamma\sqrt{K_a}}, H_c = 2Z_c$$

- **Earth Pressure at Rest:**

$$\frac{\sigma_h}{\sigma_v} = \frac{\mu}{1-\mu} = K_0 \text{ , Coefficient of earth pressure at rest.}$$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45^o - \frac{\phi}{2}\right) = \frac{1}{K_p}$$



- **Net Safe Bearing Capacity:**

$$q_{ns} = \frac{\text{Net ultimate bearing capacity}}{\text{Factor of safety.}}$$

$$q_{ns} = \frac{q_{nu}}{F} = \frac{q_u - \gamma D_f}{F}$$

- **Safe Bearing Capacity:** $q_{saf} = \frac{q_u - \gamma D_f}{F} + \gamma D_f$

- **Elastic Settlement:** $S = k.q.\sqrt{A}\,\dfrac{(1-\mu^2)}{E}$
- **Bearing Capacity for Strip footing**

$$q_{ult} = CN_c + \gamma D_f N_q + \frac{1}{2}\gamma b N_\gamma$$

- **Bearing Capacity of Shallow Circular Footing**

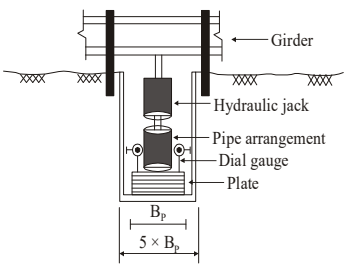
$$q_{ult} = 1.3CN_C + \gamma D_f N_q + 0.3\,\gamma b N\gamma$$

- **Bearing Capacity of Shallow Square Footing**

$$q_{ult} = 1.3\,CN_C + \gamma D_f N_q + 0.4\gamma b N\gamma$$

Note: Load carrying capacity in order - Strip < Circular < Square Footing

- **Plate Load test:** (IS 1888–1982)



$$\frac{S_f}{S_p} = \left(\frac{B_f(B_p+0.3)}{B_p(B_f+0.3)}\right)^2$$ For sandy soil

$$\frac{S_f}{S_p} = \frac{B_f}{B_p}$$ (For clay, $q_{uf} = q_{up}$)

It is used to calculate

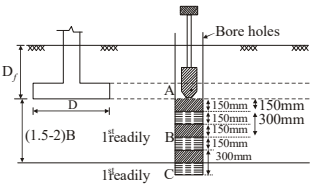
(*a*) Ultimate bearing capacity

(*b*) Allowable bearing capacity

(*c*) Safe settlement of foundation

Significant only for cohesionless soil

Standard Penetration Test:



Reading Taken

Over burden Correction: $N_1 = N_{obs} \times \left(\frac{350}{\bar{\sigma} + 70}\right)$

Dilatancy Correction: $N_2 = 15 + \frac{1}{2}(N_1 - 15)$

- For Granular soils only
- For Granular soils only & split spoon sampler is allowed to penetrate into the soil by applying impact load of 65 kg. having a free fall of 75 cm.
- N-value is determined at selected number of bore hoes and avg. value of corrected N is calculated for the depth from D_f + (1.5–2) B.
- STP-N value recorded in clayey deposit dose not require corrections for overburden pressure & dilatancy

Classification of Piles based on various factors -

(a) Function/Action - Fender, sheet, batter, tension (uplift), load bearing etc.

(b) Installation method - Driven, jack, screw & Bored (cast in-situ) piles.

(c) Material - Steel, timber, concrete & composite piles.

(d) Displace-ment of soil - Displacement and non-displacement piles.

(e) Mode of load transfer - End bearing, friction and combined piles.

- **Ultimate bearing Capacity of pile Load taken by base + load by skin friction.**

$$Q_u = Qp_u + Q_f,\ Q_u = q_{pu} \times A_b + F_S A_S.$$

- **Engineering News Formula:** Ultimate load on pile

$$Q_{allowable} = \frac{WH}{6(S+C)}$$

C = 2.5 cm for drop hammer
C = 0.25 cm for single acting steam hammer

- **Boring and its its methods:** Making and advancing of bore holes is called boring

Boring and its methods

It is the making & advancing of bore holes is called boring

Various methods of boring -

(a) Auger boring - It is use in partially saturated sands, silts and medium to stiff clays. But it gives highly disturbed sample. It is suitable for small depth of exploration (hand operated auger upto 6m depth) like as highway & borrow pit etc.

(b) Wash boring - It gives disturbed sample. It is not use in hard soils, rock and soil containing boulder.

(c) Percussion boring - In it, heavy drilling bit is dropped and raised. It can be used only in boulder & gravel strata.

(d) Rotary boring - It gives least disturbed samples.

Soil samples

- **Disturbed sample** are those in which natural soil structure gets modified or destroyed during the sampling operation.
- **Undisturbed samples** are those in which original soil

structure is preserved as well as mineral properties have not undergone any change. These samples are use in size distribution, Atterberg's limits, coefficient of permeability, consolidation parameters, shear strength parameters.

- **Inside Clearance:** $C_i = \frac{D_3 - D_1}{D_1} \times 100\%$
- **Out Side Clearance:** $C_0 = \frac{D_2 - D_4}{D_4} \times 100$

  Note: $C_0 > C_i$ always.
- **Area ratio:** $A_r = \frac{D_2^2 - D_1^2}{D_1^2} \times 100$
- **Recovery Ratio:** $L_r = \frac{\text{Recovery length of the Sample.}}{\text{Penetration length of the Sample}}$

Field Compaction Control.

Type	Soil Types	Uses
• Rammers	• All Types	• Confined construction area
• Smooth wheeled Roller	• Sand, Gravels	• Road Embankment
• Sheep footed Roller	• Clay-Soil	• Earthen dam Construction
• Pneumatic Tyred Roller	• Silty Sand	• Base, Sub base formation
• Vibrators	• Sand, all type Soil Most prefer	• Soil Embankment

2 REINFORCE CEMENT CONCRETE

- **Sec Modulus**

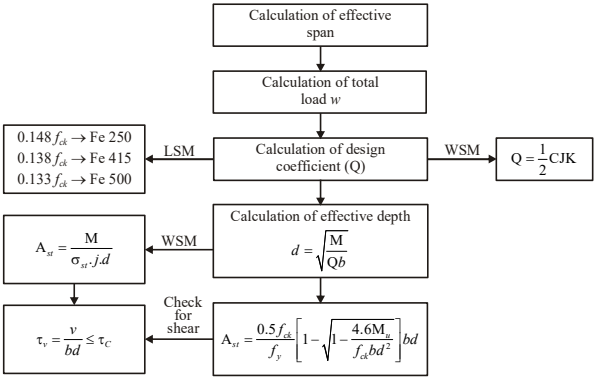
$E_c = 5700\sqrt{f_{ck}}\ N/mm^2.$, Min. grade = M15 (IS 456:1978)

$E_c = 5000\sqrt{f_{ck}}\ N/mm^2.$, Min. grade = M20 (IS 456:2000)

S. No.	Discription	Collapse	Servicability
1.	D.L + L.L	1.5	1
2.	D.L + (W.L) or (E.L) combination		
	(i) for normal case D.L + W.L (or E.L) D.L + W.L (or E.L)	1.5	1
	(ii) for checking stability against over turning/stress reversal D.L + W.L (or E.L)	0.9	1
3.	D.L + (L.L) + W.L (or E.L) combination	1.2	1
	D.L	1.2	0.8
	W.L (or E.L)	1.2	0.8

$m = \dfrac{280}{3\sigma_{cbc}}$ $\qquad f_{cr} = 0.7\sqrt{f_{ck}},\ f_{ct} = 0.66 f_{cr} = \dfrac{2p}{\pi DL}$

f_{cr} (flexure > Splitting > Direct Tensile strength)



For Singly Reinforced Rectangular beam

Unbalanced Section	Balanced Section
$k = \frac{1}{1 + \frac{\sigma_{st}}{mf_c}} = \frac{mf_c}{\sigma_{st} + mf_c}$	$k_c = \frac{m\sigma_{cbc}}{\sigma_{st} + m\sigma_{cbc}} (if\ m\ is\ given)$
$R = \frac{1}{2} f_c k \left(1 - \frac{k}{3}\right)$	$R_c = \frac{1}{2}\sigma_{cbc} k_c \left(1 - \frac{k_c}{3}\right)$
$M = Rbd^2 = A_{st} f_{st} \left(d - \frac{n}{3}\right)$ $= A_{st} f_{st}\, d \left(1 - \frac{k}{3}\right)$	$M_c = R_c bd^2 = A_{st}\sigma_{st} \left(d - \frac{n_c}{3}\right)$ $= A_{st}\sigma_{st}\, d \left(1 - \frac{k_c}{3}\right)$
$P = \frac{A_{st}}{bd} \times 100 = \frac{50kf_c}{f_{st}}$	$P_c = \frac{A_{st}}{bd} \times 100 = \frac{50k_c\sigma_{cbc}}{\sigma_{st}}$

- **Doubly Reinforce Rectangular Setction**

$$\frac{bx^2}{2} + (m^1 - 1)A_{st}\left(x - d^{'}\right) = m\ As\left(d - x\right)^{'}$$

- **FLexure (LSM)- Balanced Section**

$$\left(\frac{x}{d}\right)_{max} = \frac{700}{0.87f_y + 1100}$$

- **Design of S.R Rectangular Section**

$$d = \sqrt{\frac{\gamma_f M}{R_u b}} \qquad A_s = \frac{y_f M}{0.87f_y\ jd}$$

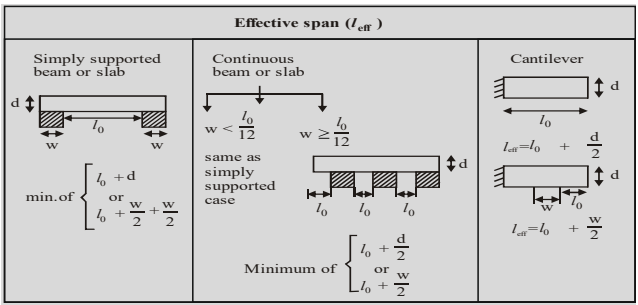
- **Analysis of Doubly Reinforced □ Section**

$$C_1 + C_2 = T = 0.36f_{ck}\ x_u b + A_{sc}(F_{sc} - 0.45f_{ck.})$$

$$T = 0.87\ f_y\ A_{st}, \qquad x_u = \frac{0.87f_y A_{st} - A_{sc}(f_{sc} - 0.45f_{ck})}{0.36f_{ck}\ b.}$$

- **Nominal Shear Stress**

$$\tau_v = \frac{V}{b.d}, \qquad \tau_{c\,max} = 0.631\sqrt{f_{ck.}}, \qquad \%pt = \frac{A_{st}}{bd} \times 100.$$



- **Inclined Bars**

$$V_s = V_V - \tau_{cbd} = 0.87 f_y A_{S_V} \frac{d}{s_v}(\sin\alpha + \cos\alpha)$$

$$S_v = 0.87 f_y \, As_v d(\cos\alpha + \sin\alpha),$$

$$S_v = \frac{0.87 f_y \, As_v d}{v - v_c} \qquad V_c = \tau_c bd.$$

- **Maximm Spacing:** 0.75d or 450mm
- **Development Length:** $L_d = \frac{\sigma_{st}}{4\tau_{bd}}\phi$
- **Longitudinal Reinforcement:**

$$M_1 = M_1 + M_2 \qquad M_k = \frac{T_u(1 + d/b)}{1.7}, \qquad \frac{A_{st}}{bd} = \frac{0.85}{f_y}$$

- **Slabs**

$\left(\frac{l_y}{l_x}\right) \le 2$, two way slab , $\left(\frac{l_y}{l_x}\right) > 2$ one way slab

Member	Max. reinfocement	Min. reinforcement
Column	6% of gross cross sectional area	0.8% of gross cross sectional area
Slab		0.15% for mild steel & 0.125 for HYSD bars
Beam	4% of gross sectional area for each compr-ession and tension	$\frac{A_{st_{min}}}{bd} = \frac{0.85}{f_y}$
Hanger bars in beams	0.2% of gross cross sectional area of beam	–
Side face reinforcement in beam	–	0.1% of the web area
Shear reincorcement	–	$0.87 f_y A S_v \frac{d}{s_v} \ge 0.4bd$

- **Short Column:** Short if salenderness. ratio of both axes are less than 12.

Lateral ties: Diameter of lateral ties is given by criteria of stiffness not by strength. Hence, it is independent of grade of steel.

$$\text{Tie diameter } \phi_t \geq \begin{cases} \dfrac{\phi_{\text{longitudinal, max}}}{4} \\ 6 \text{ mm} \end{cases}, \quad S_t \leq \begin{cases} D \\ 16\,\phi_{\text{longitudinal, min}} \\ 300 \text{ mm} \end{cases}$$

Minimum Eccentricity

$$e_{y,min} = \max\left\{\begin{matrix} \dfrac{l_{ey}}{500} + \dfrac{D_y}{30} \\ 20 \text{ mm} \end{matrix}\right. \quad \text{For non – rectangular / circular section}$$

$$e_{x,min} = \max\left\{\begin{matrix} \dfrac{l_{ex}}{500} + \dfrac{D_x}{30} \\ 20 \text{ mm} \end{matrix}\right.$$

$$e_{min} = \max\left\{\begin{matrix} \dfrac{l_e}{300} \\ 20 \text{ mm} \end{matrix}\right.$$

Slenderness Limits to Ensure Lateral Stability

Slenderness limits to ensure lateral stability

- Cantilever beam: Clear span < min. $\begin{cases} 25b \\ \dfrac{100b^2}{d} \end{cases}$
- Simply supported beam or continuous beam: Clear span < min. $\begin{cases} 60b \\ \dfrac{250b^2}{d} \end{cases}$

Control of Deflection:

Cantilever beam	7
Simply supported beam	20
Continuous beam	26

Type of slab	Mild steel	Type of reinforcement Fe 415
Simply supported	35	28
Continuous	40	32

- **Concentrically Loaded Column (e=0)**

$$P = 0.45f_{ck}\ A_y + 0.75f_y\ A_{st}$$

- **Axially Loaded Column.** ($e < 0.05h$)

$$P_w = 0.9P = 0.4f_{ck}A_c + 0.67f_yA_{st}$$

Prestressed Concrete:

- Loss due to length effect = $P_o k.x$
- Loss due to curvature effect = $P_o.\mu.\alpha$
- Loss of pre-stress at the

  Anchoring stage = $\frac{\Delta L}{L} \times E_s$

  E_S = Young's Modulus for tension wires, L = length of tendon
- Loss of stress due to shrinkage of concrete = $e_{sh} x\ E_s$
- Loss of stress due to creep of concrete = $\phi.m.f_c$.
- Losss of stress = strain lost in steel x E_S

$$\frac{f_c}{E_c} \times E_s = \frac{P_0}{A} + \frac{N}{Z}$$

Types of prestressing on various basis-

Source of force - Hydraulic, electrical, mechanical, chemical.

Time of force application - pretensioning & post-tensioning.

Place of force application - External like as in bridges, internal like as in sleepers.

System (Country)	Type of tendon	Range of force	Arrangement of tendons in duct	Type of Anchorage
Freyssinet (France)	Wires & stands	Medium Large	Annular, spaced by helical wire core.	Concrete wedge
Lee-mc-call (Great Britain)	Bar threaded at ends	Small medium large	Single bars	High strength nut
Gifford-Udall (Great Britain)	Wires	Small & medium	Evenly spaced by perforated spacers	Split Conical wedge
Magnel-Blaton (Belgium)	wires	Small medium large	Horizontal rows of 4 wires spaced by metal griller	Flat steel wedge in sandwich plates

Stress	Grade of Concrete			
	M_{20}	M_{25}	M_{30}	M_{35}
• Direct Tension	1.2	1.3	1.5	1.6
• Bending Tension	1.7	1.8	2.0	2.2

Total of Loss	Pretensioned	Post tensioned
(1) Elastic shorting of concrete	3%	1%
(2) Creep in concrete	6%	5%
(3) Shrinkage of concrete	7%	6%
(4) Relaxation of steel	2%	3%
	18%	15%

S.No	Type of Construction	Min. Grade
1.	Lean Concrete bases	M5, M 7.5
2.	Plain Concrete Cement	M 15
3.	RCC (general construction)	M 20
4.	Water tanks, dome	M 30
5.	In sea water	M30(RCC) M20 (PCC)
6.	Post-tensioned PSC	M 30
7.	Pre - tensioned PSC	M40

	Pre – tensioning	Post – tensioning
Stages	Anchoring of tendons, placing jacks, applying tension, casting concrete & finally cutting of tendons.	Casting of concrete, placing tendons, placement of anchorage block & jack, applying tension to tendons & finally seating wedges
Devices	Prestressing bed, Jack, Anchoring device, End Abutments, Shuttering/mould, Harping device	Casting bed, Ducts, mould/Shuttering, Anchoring devices, Jacks.
Advantages	• Suitable for Large scale production • Do not required Large anchorage device	• Heavy casting place members can be easily post-tensioned • Transfer of prestress is independent of length • Less waiting period in casting bed
Disadvan – tages	• Good bond is neccessary between transmission length. • Pre-stressing bed required	• Requirement of anchorage device & grouting equipment.

3 FLUID MECHANICS

Some specific fluid properties

1. Density = $\frac{\text{mass}}{\text{volume}}$ (measured in kg/m^3).

2. Density of liquid & gas is directly proportional to pressure and inversely to temperature

3. Specific gravity/relative density

$$= \frac{\text{Density of liquid}}{\text{Density of water at 4°C}}$$

4. If R.D < 1, then fluid is lighter than water.

5. Specific weight = $\frac{\text{Weight of substance}}{\text{Volume of substance}}$, ($\gamma = \rho g$ in N/m^3)

6. Some Important Relation

1 milibar = 10^{-3} bar = 100 N/m^2

1 mm of Hg = 10^{-3} m of Hg = $10^{-3} \times 13.6$ m of water = $10^{-3} \times 13.6 \times 9810$ N/m^2 = 133.42 N/m^2

1 N/mm^2 = 10^6 N/m^2

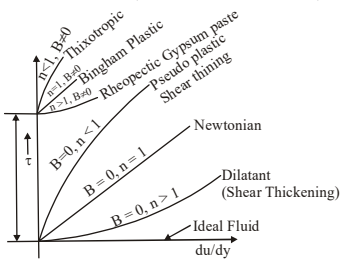
$$1 \text{ Kgf/cm}^2 = \frac{9.81 \text{ N}}{10^{-4} \text{ m}^2} = 98.1 \times 10^3 \text{ N/m}^2$$

7. $\gamma_{water} = 9810 \frac{N}{m^3} = 9.81 \frac{KN}{m^3}$

8. $\gamma_{mercury} = 13.6\ \gamma_w$

9. Specific volume $= \dfrac{1}{\text{Density}}$

- **Viscosity:** $\boxed{\mu = \dfrac{\tau}{\dfrac{d\theta}{dt}}}$ $\boxed{\dfrac{d\theta}{dt} = \dfrac{du}{dy}}$
- **Kinematic Visocity:** $\boxed{V = \dfrac{\mu}{\rho}}$ $m^2/sec.$
- **Newton's Law Of Viscosity:** $\boxed{\tau = \mu \dfrac{du}{dy}}$
- **Non- Newtonian Fluid:** $\boxed{\tau = A\left(\dfrac{du}{dy}\right)^n + B}$



- Ex.
  - (a) Thixotropic — Ink, Ketchup, Enamels etc.
  - (b) Bingham plastic — Sewage, Sludge, Drilling mud, Gel,

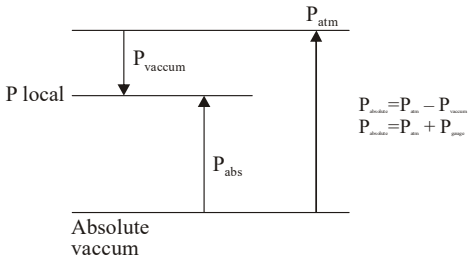
		Toothpaste, Cream
(c)	Rheopectic	Gypsum in water & Bentonite slurry.
(d)	Pseudo Plastic	Paint, Paper, Pulp, Blood, Syrup, Polymer, Lipstick, Nailpaint
(e)	Dilatant	Quick sand, Sugar in water, Butter

Special Points:

1. Wetting property is due to surface tension.
2. Higher temperature, more chances of cavitation.
3. At 100ºC, vapour pressure of water = Atmospheric pressure.
4. Air cavitation is less damaging than vapour cavitation.
5. Ideal fluids → No-viscosity → no "No slip" condition
6. No slip condition is due to fluid viscosity.

- **Pressure Inside The Liquid Drop:** $P_{ld} = \frac{4\sigma}{d}$
- **Pressure Inside The Liquid Jet:** $P_{lj} = \frac{2\sigma}{d}$
- **Pressure Inside the Soap Bubble:** $P_{sb} = \frac{8\sigma}{d}$
- **Expression For Capillary Rise:** $h = \frac{4\sigma\cos\theta}{wd}$

$\phi < 90^\circ$	Cohesion < Adhesion	Wetting of surface	Concave top surface	Rise in capillary tube
$\phi > 90^\circ$	Adhesion < cohesion	Does not wets the	Convex top surface	Drop in capillary tube



Special Points:

- Buoyant force is independent of distance of body from free surface of liquid and also the density of solid body.
- Mechanical gauges are used for measuring high pressure values which does not requires high precision.
- Air cavitation is less damaging than vapour cavitation.

Measurement of fluid pressure

Manometer	**Mechanical gauges**
Based on principle of balancing a column of fluid by the same or other column	Mechanical pressure measuring instruments with a deflecting needle (used in filling air in tyres)

Simple manometer	**Differential manometer**
To measure pressure at a point	To measure the pressure difference
U-Tube manometer	Inverted differential manometer
Single column manometer	Micro manometer
Piezometer	

No.	Type of Manometer	Fluid Types	Pressure measurement
1.	Piezometer	Liquid	Positive (Gauge pressure)
2.	U-tube Manometer	Both liquid & gases	Both positive & Negative Pressure
3.	Inclined Tube Manometer	Gases (for very low pressure)	Both (+ve & -ve) (mostly +ve)
4.	Differential & Inverted Differential	Both liquid & gases	Pressure difference Between 2 points
5.	Bourdon Pressure gauge	Both liquid & gases	It measures pressure at a point

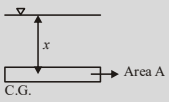
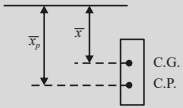
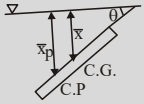
Facts about pressure

1. Longer runway's needed at higher altitude due to reduced drag and lift.
2. Nose bleeding starts at higher altitude due to difference in body's blood pressure & atmosphere pressure.
3. Motor capacity reduces at higher altitude.
4. Cooking takes longer time at higher altitudes.

- **Buoyancy And Floatation**

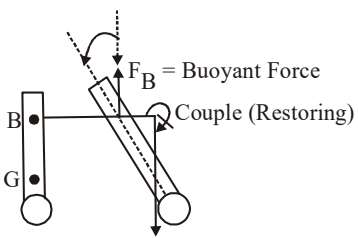
Buoyant force = Net upward force = weight of liquid displaced

- Point of application of buoyant force is the C.G. of the displaced liquid & it is called centre of buoyancy.
- Buoyant force is independent of distance of body from free surface of liquid and also the density of solid body.

Horizontal Plane Surface	Vertical Plane Surface	Inclined Plane Surface
		
$F = \gamma A\bar{x}$	$F = \gamma A\bar{x}$	$F = \gamma A\bar{x}$
	$x_p = \bar{x} + \frac{I_g}{A\bar{x}}$	$x_p = \bar{x} + \frac{I_g \sin^2\theta}{A\bar{x}}$

$\bar{x}$ & $\bar{x}_p$ for same horizontal plane surface from liquid surface

Rotational Stability: When a small angular displacement sets up a restoring couple, then stability is known as rotational stability.



Submerged body		Floating body
Stable equilibrium	G below B	M above G BM > BG GM = MB – BG = +Ve

Unstable equilibrium	G above B	M below G BM < MG GM = MB – BG = –Ve
Neutral equilibrium	G and B coincide	M and G GM = 0

Metacentre (M) is the point of intersection of lines of action of buoyant force before and after rotation.

- **Continuity Equation:** $\boxed{A_1V_1 = A_2V_2}$
- **Hydrostatic Force**

Horizontal $\boxed{F = WA\bar{x}}$ $\boxed{h = \bar{x}}$

Vertical $\boxed{F = WA\bar{x}}$ $\boxed{h = \bar{x} + \frac{I_g}{A\bar{x}}}$

Inclined $\boxed{F = WA\bar{x}}$ $\boxed{h = \bar{x} + \frac{Ig}{Ax}\sin^2\theta}$

Note: We generally follow Eulerian concept, as its difficult to keep the track of a single fluid particle.

Types of fluid show:

1. **Steady and Unsteady Flow:** At any given location, the flow and fluid properties do not change with time, then its steady flow otherwise unsteady.

$$\frac{\partial v}{\partial t} = 0, \frac{\partial p}{\partial t} = 0, \frac{\partial f}{\partial t} = 0 \Rightarrow \text{Steady flow}$$

2. **Uniform and Non-Uniform Flow:** A flow is said to be uniform flow in which velocity & flow both in magnitude and direction do not change along the direction of flow

for given instant of time.

3. **One, two or three Dimensional Flow:** If flow parameters varies in one dimension wrt space only then its one dimensional otherwise its 2 or 3 dimension respectively.
   $V = V(x, t) \rightarrow$ one dimensional
   $V = V(x, y, t) \rightarrow$ two dimensional
   $V = V(x, y, z, t) \rightarrow$ three dimensional
4. **Laminar and Turbulent Flow:** In Laminar flow, the particles moves in layers sliding smoothly over the adjacent layers while in turbulent flow particles have the random and erratic movement, intermixing in the adjacent layers. Which causes continuous momentum transfer.
   Flow of blood in veins and arteries occurs as a viscous flow. Hence, Laminar flow.
   A water supply pipe carries water at high speed leading to rapid mixing which causes highly turbulent conditions.
5. **Rotational and Irrotational Flow:** When fluid particles rotate about their mass centre during movement. Flow is said to be rotational otherwise irrotational.
   Rotational Flow $\rightarrow$ Forced Vortex, Flow inside boundary layer.
   Irrotational Flow $\rightarrow$ Free Vortex, Flow outside boundary layer.
   In a straight tube of uniform diameter and uniform roughness, the flow properties does not vary across the length of the pipe. Hence, Uniform flow.
   Flow above the drain having a wash basin is a free vortex motion (Irrotational flow).

6. **Compressible and Incompressible Flow:** In compressible flow density of fluid changes from time to time while in Incompressible flow it remains constant.

- **Stream Line:** There are a set of concentric circle with origin at centre.
- Stream lines neither touch nor cross each other. Line tangent to it give direction of Instantaneous velocity.
- Tracing of motion of different fluid particle.

$$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w}$$ Equation of stream line

- **Streak Line:** It is line traced by series of fluid particles passing through a fixed point. It is formed by continous introduction of dye or smoke from a point in the flow.
- **Path Lines:** It is actual path traced by a fluid particle over a period of time. It is based on lagrangian concept. Two path lines can intersect each other.

Continuity Equation: It is based on principle of conservation of mass. Fluid mass can neither be created nor can be destroyed hence mass of fluid entering a fixed region should be equal to mass of fluid leaving that fixed region in a particular time.

(*a*) Steady Flow in 1-D, $\rho AV = \text{Constant}$

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

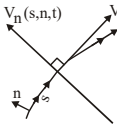
(*b*) Steady Incompressible in 1-D, $A_1 V_1 = A_2 V_2$

Total Acceleration = Convective acceleration with respect to space + local acceleration with respect to time.

Type of flow	Convective Acceleration	Temporal Acceleration
Steady & uniform	0	0
Steady & non-uniform	Exists	0
Unsteady & uniform	0	Exists
Unsteady & non-uniform	Exists	Exists

Acceleration on a stream line

Trangential Acceleration
It is due to change in magnitude of velocity. If spacing b/w stream line changes tangensial acceleration exists



Normal Acceleration
It is due to the change in the direction of fluid moving on a curved path

- **Acceleration Of A Fluid Particle**

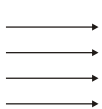
$$a_x = \underbrace{\frac{u\partial u}{\partial x} + \frac{v\partial u}{\partial y} + \frac{w\partial u}{\partial z}}_{\text{Convective acceleration}} + \underbrace{\frac{\partial u}{\partial t}}_{\text{Temporal acceleration}}$$

$$a_s = V_s \frac{\partial v_s}{\partial s} + \frac{\partial v_s}{\partial t}$$

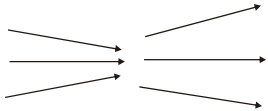
convective tangential acceleration — local tangential acceleration

$$a_n = V_s \frac{\partial v_n}{\partial s} + \frac{\partial v_s}{\partial t}$$

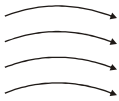
convective normal acceleration — local normal



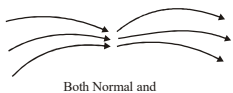
No Acceleration



Tangential Convective Acceleration



Normal Convective Acceleration



Both Normal and Tangential Convective Accelation

- **Rotational Component**

$$w_x = \frac{1}{2}\left(\frac{\partial w}{dy} - \frac{\partial v}{dz}\right), \quad w_z = \frac{1}{2}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right), \quad w_y = \frac{1}{2}\left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right)$$

Special points:

1. Velocity potential exists only for ideal and irrotational flow.
2. Velocity of flow is in direction of decreasing potential function.
3. Equipotential line is the line joining points having same potential function.

- **Velocity Potential Function (ϕ):** $-\frac{\partial \phi}{\partial x} = u$ $-\frac{\partial \phi}{\partial y} = v$
- **Stream Function (v):** $u = -\frac{\partial \psi}{\partial y}$ $v = \frac{\partial \psi}{\partial x}$

It is the study of motion of fluid along with the forces causing the motion.

(*i*) Newton's equation of motion

$$\vec{F_g} + \vec{F_P} + \vec{F_V} + \vec{F_t} + \vec{F_c} + \vec{F_\sigma} = m\vec{a}$$

(*ii*) Reynold's equation of motion

$$\vec{F_g} + \vec{F_P} + \vec{F_V} + \vec{F_t} = m\vec{a}$$

(*iii*) Navier-stock equation of motion

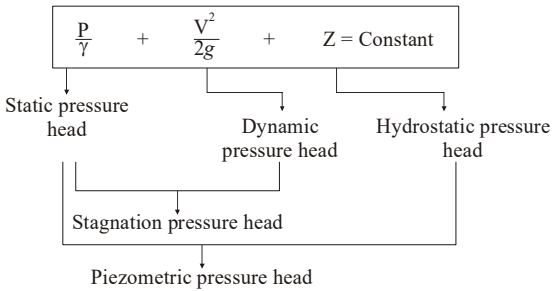
$$\vec{F_g} + \vec{F_P} + \vec{F_V} = m\vec{a}$$

(*iv*) Euler's equation of motion

$$\vec{F_g} + \vec{F_P} = m\vec{a}$$

Special points:

- Energy equation can be used to find the pressure at a point in a pipeline using Bernoulli's eq.
- Continuity eq. is used to find out the flow at two sections of tapering pipes.
- Euler equation based on momentum conservation while Bernoulli is based on energy conservation.
- Impulse momentum principle is used to find out the force on a moving vane.
- Concept of moment of momentum (Angular momentum principle is used in lawn sprinkler problems)



- **Euler's Equation:** $\frac{dp}{p} + gd_z + vdv = 0$
- **Bernoullies Equation:** $\frac{P}{w} + z + \frac{v^2}{2g} = \text{constant.}$
- **Rotameter** is used to measure discharge while current meter is used to measure velocity in open channel.
- **Hot Wire Anemometer:** Used for measurement of Instantaneous velocity and temperature at a point in flow.
- **Theoretical Discharge:**

$$Q_{th} = \frac{A_1 A_2 \sqrt{2gh}}{\sqrt{A_1^2 - A_2^2}} \qquad C_d = \frac{qA_{ct}}{q_{th}} = \sqrt{\frac{h - h_L}{h}}$$

- **Percentage Error In Discharge:**

$$\% \text{ error} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100 \qquad \% \text{ error} = (1 - C_d) \times 100$$

NOTE.

When Pressure Difference Measured by Manometer

When heavier fluid in manometer & lighter fluid in pipe.

$$h = x\left(\frac{g_h}{g_l} - 1\right)$$

$g_h \rightarrow$ Specific gravity of heavier liquid

$g_l \rightarrow$ Specific gravity of lighter liquid

$x \rightarrow$ Reading Manometer

$h \rightarrow$ Reading Piezometer.

- **Orificemeter:**

$$\theta = \frac{Cd_0\ A_1A_0\sqrt{2gh}}{\sqrt{A_1^2 - A_2^2}} \qquad C_C = \frac{A_C}{A_0} \qquad C_d = C_c \times C_v$$

Where

$C_c \rightarrow$ Coefficient of Contraction.

$C_d \rightarrow$ Coefficient of Discharge

$C_V \rightarrow$ Coefficient of Velocity.

- **Pitot Tube –Velocity Of Flow:** $\frac{P_1}{w} + \frac{V_1^2}{2g} = \text{Constant}$

- **Reynold's Number:** $R_e = \frac{\rho vd}{\mu}$

Nature of flow according to Reynold's number (R_e)

	Laminar	Transition	Turbulent
Flow in pipe	$R_e < 2000$	$2000 < R_e < 4000$	$R_e > 4000$
Flow between parallel plate	$R_e < 1000$	$1000 < R_e < 2000$	$R_e > 2000$
Flow in open channel	$R_e < 500$	$500 < R_e < 2000$	$R_e > 2000$
Flow through soil	$R_e < 1$	$1 < R_e < 2$	$R_e > 2$

- **Laminar Flow Through Circular Pipe:** $\tau = -\frac{r}{2}\left(\frac{dp}{dx}\right)$

- **Velocity Distribution:**

$$U_{max} = -\frac{1}{4\mu}\left(\frac{\partial p}{\partial x}\right)R^2 \qquad U = U_{max}\left(1 - \frac{r^2}{R^2}\right)$$

- **Discharge:** $Q = \frac{\pi U_{max} R^2}{2}$ $\quad Q = \frac{\pi}{128\mu}\left(-\frac{\partial P}{\partial x}\right)D^4$

- **Friction Factor:** $F = 4f$ $\quad f = \frac{16}{R_e}$ $\quad f = \frac{8\tau_0}{\rho u^2}$

- **Trapezoidal Notch:**

$$Q = \frac{2}{3}C_{d_1}\sqrt{2g}LH^{3/2} + \frac{8}{15}C_{d_2}\sqrt{2g}\tan\frac{\theta}{2}H^{5/2}$$

Cipolletti-Weir: It is a trapezoidal weir whose slopes are adjusted in such a way that:

- Reduction in discharge due to end contraction in rectangular weir = Increase in discharge due to triangular portion.

- **Entrance length** in a pipe is the length where boundary layer increases and flow is fully developed.
  For Laminar Flow $L = 0.07 R_e D$
  For Turbulent Flow $L_e = 50 D$

Note:

- **Hele Show flow:** Laminar flow between parallel plates
- **Stoke's Law:** Settling of fine particles.
- **Hagen Poiseuille flow:** Laminar flow in Tubes/pipes.
- **Major Losses Head/Loses**

$$h_L = \frac{fLQ^2}{12D^5} \qquad h_f = \frac{fLv^2}{2gD}$$

Number	Equation	Uses
Reynolds No.	$\frac{F_i}{F_v} = \frac{\rho VL}{\mu}$	Aeroplanes, submarines, pipe flow
Eulers No.	$\sqrt{\frac{F_i}{F_p}} = \frac{V}{\sqrt{\frac{p}{\rho}}}$	Cavitation problem
Mach No.	$\sqrt{\frac{F_i}{F_e}} = \frac{V}{C}$	Aerodynamic testing, rocket, missile
Froude No.	$\sqrt{\frac{F_i}{F_g}} = \frac{V}{\sqrt{gL}}$	OCF, spillway, weir
Weber No.	$\sqrt{\frac{F_i}{F_\sigma}} = \frac{v}{\sqrt{\sigma/\rho L}}$	Veins, arteries, rising bubble

Water hammer Pressure: Rapid/Sudden closure of valve in a pipe carying flowing liquid destroys the momentum of

flowing liquid and sets up a high pressure wave. This pressure wave travels with the speed of sound and causes hammering action in pipe called Knocking water hammer.

- Surge tanks are used to absorb the Increase in the pressure due to water hammer phenomenon.

Chezy's Formula: $\boxed{V = C\sqrt{RS}}$,

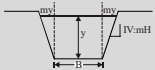
Manning equation $\boxed{V = \frac{1}{n} R^{2/3} S_0^{1/2}}$

Dimension of $C = L^{1/2} T^{-1}$, $n = L^{-1/3} T^{1}$, f = Dimensionless

Open-channel Flow						
Steady				unsteady		
Uniform Canal Flow	Gradually Varied (GVF)	Rapidly Varied (RVF)	Spatially Varied (SVF)	Gradually Varied (GVUF)	Rapidly Varied (RVUF)	Spatially Varied (SVUF)
Flow in river U/S of a weir during winter		Flow D/S of an overflow spillway.	Flow over side weir	River Flow in alluvial reach during rising flood	A surge moving upstream	Surface runoff due to rainfall

Type of flow	Depth of	Velocity of flow	Froude flow	Comments No
Subcritical	$y > y_c$	$v < v_c$	$F_r < 1$	Also called as streaming or transquil flow
Critical	$y = y_c$	$v = v_c$	$F_r = 1$	
Super Critical	$y < y_c$	$v > v_c$	$F_r > 1$	Shooting flow, rapid flow, torrential flow

Chart for Most Economical Sections

• Gedmetrical Parameters	• Rectangular	• Triangular	• Trapezoidal
• Diagram			
• Condition for most Economical	• $y = \frac{B}{2}$	m = 1, q = 45°→From Horizontal θ = 45° → From vertical	• $B = \frac{2y}{\sqrt{3}}$ $m = \frac{1}{\sqrt{3}}$ θ = 60° Hor. θ = 30° vert.
• Area	A = B.y = 2y.y	• $A = my^2$	• $A = (B + my) \times y$
	• $A = 2y^2$	• $A = y^2$	• $A = \left(\frac{2y}{\sqrt{3}} + \frac{1}{\sqrt{3}}y\right)y = \left(\sqrt{3}\right)y^2$
	(in most economical) θ = 2y	(in most economical) m = 1	
• Perimeter	$P = 4y$	$p = 2\sqrt{2}y$	• $P = 2\sqrt{3}y$
• Hydraullic Radius (R = A/P)	• $R = y/2$	• $R = \frac{y^2}{2\sqrt{2}y}$	• $R = \frac{y}{2}$
• Top width (T)	• $T = 2y$	• $T = 2y$	• $T = \frac{4y}{\sqrt{3}}$
• Hydraullic Depth $\left(D = \frac{A}{T}\right)$	• $D = y$	• $D = y/2$	• $D = \frac{3}{4}y$

Note: Circular section (a) For maximum discharge $2\theta = 302°22'$, $d \simeq 0.95\,D$, (b) For maximum velocity $2\theta = 257°27'$, $d = 0.81\,D$

Dynamic eq. for G.V.F.: $\dfrac{dy}{dx} = \left(\dfrac{S_o - S_f}{1 - \dfrac{q^2}{gy^3}} \right)$

Hydraulic Jump Eq.

1. $\dfrac{2q^2}{g} = y_1 y_2 (y_1 + y_2)$ 2. Energy Loss $E_L = \dfrac{(y_2 - y_1)^3}{4 y_1 y_2}$

3. $\dfrac{y_2}{y_1} = \dfrac{1}{2}\left(\sqrt{1 + 8F_1^2} - 1\right)$ 4. $y_c^3 = \dfrac{y_1 y_2 (y_1 + y_2)}{2}$

Types of Jump	Fr	E_L/E_1	Water surface
Undular	1-1.7	≈ 0	Undulating
Weak	1.7-2.5	5–18%	Small rollers form
Oscillating	2.5-4.5	18–45%	Water oscillates in random manner
Steady	4.5-9	45–70%	Roller and jump action
strong	≥ 9	≥ 70%	Very rough and choppy

$$N_S = \frac{N\sqrt{P}}{(H)^{5/4}} \text{ (for Turbine)}, \quad N_S = \frac{N\sqrt{Q}}{(H_m)^{3/4}} \text{ (for Pump)}$$

Classificationaccording to energy available at input

	Impulse turbine	Reaction Turbine
1.	Input energy is only kinetic energy	1. Input energy is kinetic energy + pressure energy
2.	Pressure remains constant throughout the working & which is equal to atmospheric.	2. Pressure drop takes place.
3.	Useful for high head & low discharge	3. Useful for low head & high discharge
4.	Degree of reaction is zero.	4. Degree of reaction not zero.
5.	No draft tabe	5. Draft tube is present.
6.	Example Pelton wheel	6. Example (i) Francis Turbine (ii) kaplan & propeller Turbine.

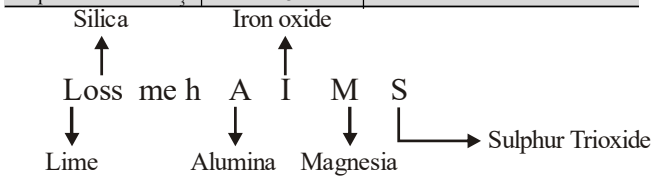
Turbine						
Name	Type	Type of Energy	N_s (MKS)	Head	Discharge	Direction of flow
Pelton wheel turbine (Single jet)	Impulse	Kinetic	10-35	High (250 to 1000m)	Low(Q<1000 LPM)	Tangential
Peloton wheel turbine (multiple jet)	Impulse	Kinetic	35-60	High (250 to 1000 m)	Low	Tangential flow runner
Francis Turbine	Reaction	Kinetic + Pressure	60-300	Medium (60 to 150 m)	Medium (1000-10000) LPM	Inward Radial Mixed flow (Modern Francis)
Kaplan & Propeller turbine	Reaction	Kinetic + Pressure	300-1000	Low (< 30 m)	High(Q>10000LPM)	Axial flow

CIVIL ENGINEERING ROCKET CHART
FOR QUICK REVISION
BY
S.SOROUT: 9255624029

4 BUILDING MATERIAL CONSTRUCTION

Chemical Composition of Raw materials

Oxide	Composition (%)	Function
Lime, CaO	60–65	It control strength and soundness.
Silica, SiO_2	17–25	Excess of it causes slow setting
Alumina, Al_2O_3	3–8	Responsible for quick setting, excess of it lowers strength
Iron oxide Fe_2O_3	0.5–6	Gives colour and helps in fusion of different ingredients
Magnesia, MgO	0.1 –4	Give colour and hardness
Soda and Potash Na_2O and K_2O	0.5–1.3	If in excess causes efflore-scence & cracking
Sulphur trioxide SO_3	1–3	Makes cement sound



456	Plain and reinforced concrete
269	Specification of OPC 33 grade
8112	Specification of OPC 43 grade
12269	Specification of OPC 53 grade
8041	Rapid hardening Portland cement
8042	White Portland cement
8043	Hydrophobic Portland cement

IS:6452 High alumina cement
IS:1489 Part-I Portland Pozzolana cement (fly ash based)
IS:1489 Part-II Portland Pozzolana cement (Calcined clay)
383 Coarse & fine aggregates from natural sources
516 Strength of concrete tests
650 Specification for standard sand for testing
2386 Test for Aggregate (1–8 Parts)
2430 Sampling of aggregate for concrete
5816 Splitting tensile strength of concrete
6461 Glossary of terms related to cement concrete (Part 1–12)
7320 Specification of concrete slum test apparatus
10262 Guidelines for concrete mixed design
13311 Part –1 Ultrasonic pulse velocity test
Part – 2 Rebound hammer
] Non-Destructive testing of concrete
875 Design loads (other than earthquakes) for building & structures
Part I : Dead load. Part II: Live load
Part III : Wind load, Part IV : Snow load
Part V : Special loads & load combinations
1893 Earthquake resistant design for structures

Note: The new code for all OPC 33, 43 & 53 grade is IS 269:2015

Bogue's Compound

Principal Mineral Compound	Formula	Symbol	Function
Tri calcium Silicate (Alite)	$3CaO.SiO_2$	C_3S	7-day strength and Hardness
Dicalcium silicate (Belite)	$2CaO.SiO_2$	C_2S	Ultimate strength
Tricalcium Aluminate (Celite)	$3CaO.Al_2O_3$	C_3A	Flash–set
Tetra calcium Alumina Oxide (Felite)	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	Poorest cementing value

Water Requirement for hydration

Bound water = 23% by weight of cement.
Gel water = 15% by weight of cement
Total minimum = 38%

Property	Dry Process	Wet Process
Temperature range	1400-1500°C	1500-1600°C
Gypsum amount	2-3%	3%
Economically (in fuel)	Less	More

Material	Unit weight (kN/m^3)
Brick Masonry	19 – 20
Plain cement concrete	22–24
Reinforced cement concrete	24–25
Cement mortar	20–21
Steel	78–80
Cement	14.4

$\boxed{E_c = 5700\sqrt{f_{ck}}\ N/mm^2.}$, Min. grade = M15 (IS 456:1978)

$\boxed{E_c = 5000\sqrt{f_{ck}}\ N/mm^2.}$, Min. grade = M20 (IS 456:2000)

Types of Cement

1. **Portland cement:** Classified on the basis of manufacturing as 33 grade, 43 grade and 53 grade.
   OPC
   (i) OPC-33 (IS : 269-2015)
   (ii) OPC-43 (IS : 8112-1989)
   (iii) OPC-53 (IS : 12269-1987)
   Initial Setting Time (IST) – 30 minute & final Setting Time (FST) – 600 minute
2. **Rapid hardening cement (IS:8041):** More C_3S and less C_2S as compared to OPC
   - Not-used in mass concrete & it produce Large Shrinkage
   - RHC attains same strength in 1 day which an OPC attains in 3 days with same w/c.
   - It is suitable for repair of roads, bridges etc.
3. **Extra Rapid hardening cement:** Rapid hardening cement + 2% $CaCl_2$ (also called calcium chloride cement)
   - Especially used in cold weather but also give Excessive Shrinkages
4. **High alumina cement (IS:6452):**
   IST – Min. 3 hour 30 minute & FST – Max. 5 hour.
   It is used for refractory conerete, industries & used widely in Pre-casting.
   - Particularly suitable to sea and under-water work
   - Widely used in Pre-Casting, Expansion $\leq$ 5 mm

5. **Portland Slag cement:** The mixture of portland cement, granulated blast furnace slag & Gypsum
   - High Sulphate resistance & it is Used in mass concreting work.
6. **Super Sulphated Portland cement :** 80–85% Granulated slag + 10– 15% calcium sulphate + 5% Portland cement clinker.
   - It is resistant to chemical attacks particularly to sulphate & highly resistant to sea water
   - It should not be used with any admixture
7. **Low heat Portland cement:** Low C_3S and C_3A and more contents of C_2S

   It is use in mass concrete work
   - Rate of development of strength is low but ultimate strength is same
8. **Portland Pozzolana cement (IS:1489 Part-I) :** OPC + 10– 30% of fly ash by mass of PPC it is use in marine work.
   - Free lime is removed, hence, resistant to chemical attack increases

Note: Puzzolana has no cementing property in itself but when it combines with lime, it produces a stable lime pozzolana compound which has cementious property.

The addition of pozzolanas to conncrete results in.

(a) Improvement in durability by reducing permeability

(b) Reduction in shrinkage.

(c) Increase in workability of concrete.
(d) Deduction in the rate of hardening of concrete.
(e) Reduction in segregation and bleeding of concrete.
(f) Increased resistance against sulphate attack (reduction in chemical action with sulphates).

9. **Quick setting cement:** Fine grounded OPC with reduced Gypsum content & small amount of aluminium sulphate.
   - IST = 5 minutes & FST = 30 minutes
   - Used in under water concreting.
10. **White and Coloured Portland cement (IS: 8042) :** From Pure white chalk, china clay & Iron Oxide should not be more than 1%.
    - These are used for making Terrazzo flooring, ornamental works & casting stones.
    - Hunter scale is use for checking the whiteness of cements
    - 5–10% Colouring pigment before grinding
11. **Air Entraining cement:** OPC + Vinsol resin or vegetable fats of oils or fatty acids.
    - Small amount of (0.1%) by weight of an air entraining agent.
12. **Water Repellent or Hydrophobic cement:** OPC + fractions of olic acid, Stearic acid or pentachlorophenol.
    - Suitable for basement and making water tight structures.

Minimum Specified Strength in N/mm²				
Type/days	1 day	3days	7 days	28 days
OPC (33 grade)	–	16.0	22.0	33.0
Portland Pozzolana	–	16.0	22.0	33.0
Low heat Portland	–	10.0	16.0	35.0

Test of Cement

• FINENESS TEST	• Sieve Method
	• Air permeability Method
	• Sedimentation mehtod
• CONSISTENCY TEST	• Vicat's Apparatus.
• SETTING TIME	• Vicat's Apparatus.
• SOUNDNESS TEST	• Le-chatelier Method • Auto clave test
• TENSILE STRENGTH	• Briquette test
• HEAT OF HYDRATION	• Calorimeter test
• SPECIFIC GRAVITY TEST	• Le-chatelier's Flask.

Consistency Test: It is the Amount of water used to make paste of normal consistency. It is about 30% generally. It is the percentage of water required for the cement paste, the viscosity of which will be such that Vicat's plunger penetrates upto 5 to 7 mm from bottom (33 to 35 mm from top) of the Vicat's mould.

Attahment	Use
1. Plunger, 10 mm dia, 50 mm long	Consistency test
2. 1 mm × 1 mm square needle	Initial setting time
3. 5 mm dia Annular collar	Final setting time

Initial and Final Setting time:

Initial Setting Time	Final Setting Time
• It is possible to remix cement paste during this period • 300 gm cement + 0.85 P of water • 1 mm² square needle penetrates by 33–35 mm from top. • IST for OPC, RHC is 30 minute, for low Heat Cement - 1 hour, for High Alumina Cement – (3.5) hour	• Annular collar replaces square needle • It is the time elapsed between moments water is added and paste completely loose its plasticity. • Needle makes an impression but collar fails to do so. • FST for OPC, RHC, LHC – 10 Hour for High Alumina Cement – (5) Hour

S. No.	Types of test	Diameter or size	Shape
1.	Initial setting time	1mm of square needle	
2.	Final setting time	5mm annualar ring	
3.	Consistency	10mm solid circular	

Soundness Test: To detect change in volume after setting

Le – Chatelier method	Auto clave test
Measure unsoundness (free lime only)	Sensitive to both lime & magnesia
100 gm of cement + 0.78 P water	Internal mould dimension (25 × 25 × 282) mm
Result is given in "mm"	Result is given in %

Strength determination

Compressive strength	Tensile strength
• Cube test (size 7.06cm)	• Briquette test (6.45 cm^2), 6 no.
• Cement (185 gm) + Ennore sand (555 gm), ratio of 1 : 3	• T.S = (10 – 15)% of compressive strength
• Water = $\left(\frac{P}{4}+3\right)$%	• Generally used for RHC
• Temperature 27 ± 2ºC	• Cement : sand = 1 : 3
• Atleast 3 cube for testing	• Water = $\left(\frac{P}{5}+2.5\right)$%
• Rate of loading:- 140 Kg/cm^2 /min	• Rate of loading:- (1.2 - 2.4)N/mm^2/min

Type of formwork	Minimum period before stricking formwork
(a) Vertical formwork to columns, walls, beams	16-24 h
(b) Soffit formwork to slabs (props to be refixed jut after removal of formwork)	3 days
(c) Soffit formwork to beams (Props to be refixed just after removal of formwork)	7days
(d) Props to slabs	
(i) Spanning up to 4.5m	7 days
(ii) Spanning over 4.5m	14 days
(e) Props to beams and arches	
(i) Spanning up to 6 m	14 days
(ii) Spaning over 6 m	21 days

Concrete classification (Based upon)				
Cementing material	**Bulk density**	**Grade of cement**	**Perspective specification**	**Place of casting**
Lime concrete Gypsum concrete Cement concrete	Extra light <500 kg/m^3 Light 500-1800 kg/m^3 Dense weight 1800-2500 kg/m^3 Super heavy weight > 2500 kg/m^3	Low strength <20 N/mm^2 Medium strength 20-40 N/mm^2 High strength > 40 N/mm^2	1 : 4 : 8 → M7.5 1 : 3 : 6 → M10 1 : 2 : 4 → M15 1 : 1.5 : 3 → M20 1 : 1 : 2 → M25	In Situ concrete Precast concrete
			Use CIVIL Ki GOLI for Remembering	

Test on Concrete

• WORKABILITY	• Slump test
	• Compacting factor Test
	• Vee-bee consistometer method
• DIRECT TENSILE STRENGTH OF CONCRETE	• Cylinder Splitting Test
• BOND B/W CONCRETE & STEEL	• Pull out Test
• COMPRESSIVE STRENGTH	• Rebound hammer Test
• DYNAMIC MODULUS OF ELASTICITY	• Resonant Frequency Test

Manufacturing of Concrete: Batching → Mixing → Transporting → Placing → Compacting → Finishing → Curing

Methods of Curing:

(*a*) Shading
(*b*) Covering surface with wet hessian cloth or gunny bags
(*c*) Sprinkling
(*d*) Ponding
(*e*) Steam curing (For precast members)
(*f*) Applying curing compounds

Maturity of Concrete = Time × Temperature = ºC Hours or ºC days

Compressive strength test:

- Size of coarse aggregate upto 38 mm
- Size of cube – 150 × 150 ×150 mm
- Size of cylinder – 150 mm dia, 300 mm height
- Cube mould filled in 3 layers, tempered 35 times per layer with tampering rod of 16 mm dia & 600 mm length.
- Stored at temp of 27 ± 3ºC at 90% humidity for 24 ± 1/2 hour.
- Then immersed in water for 7 days or 28 days.
- Rate of loading in compression testing machine = 14 N/ mm^2/ minute.

Cube strength = 1.25 × Cylinder strength

Workability Test: Slump test, compacting factor test, flow test, Vee-Bee consistometer

Defects in Concrete: Cracks, Crazing, Efflorescence, Segregation, Bleeding

Admixtures: Plasticizers, Superplasticizers, Air entrainers, Acceleraters, Retarders

NDT Test on Hardened Concrete: Maturity test, Pull-out test, Penetration test, Ultrasonic pulse velocity test

Fineness Modulus: It is an index number which is roughly proportional to the average size of the particles in the aggregate.

It is the sum of cumulative percentage retained on the sieves of the standare sieves: 150 μm, 300 μm, 600 μm, 1.18 mm, 2.36 mm, 4.75 mm, 10 mm, 12.5 mm, 63 m and 80 mm.

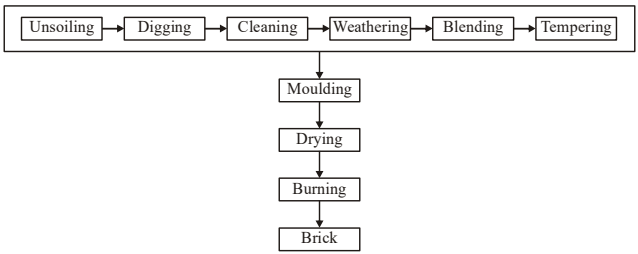
Higher Fineness modulus aggregate results in harsh concrete mixes and lower Fineness modulus results in uneconomical concrete mixes.

Order of Aggregates: **Strength**– Cubical > Crushed> Rounded > flaky, **Workability** – Rounded > Cubical > Crushed > flaky

Property	1st class	2nd class	3rd class
Compressive strength (N/mm^2)	≥ 10.5	≥ 7.0	3.5
Water Absorption	20%	22%	25%
Making process	Table moulded & burnt in kiln	Ground moulded & burnt in kiln	Ground moulded & burnt in clamps
Uses	Pointing & Important work	RB work & Hidden masonry work	Unimportant temporary structure

Defects of Bricks: Bloating, Efflorence, Chuffs, Blisters, Laminations

Poor lime	Fat lime	Hydraulic lime
Impure/lean lime Contain more than 30% of clay	Pure/Rich/White lime Impurties are less than 5%	Water lime Impurties range – (5–30)%



Flowchart: Preparation of Brick Earth

- Moulds are made (8–12)% larger in size.
- To prevent the moulded bricks from sticking to the side of the mould, sand is sprinkled on the inner sides of the mould.

Drying: If green bricks burnt, it can get cracked & distorted.

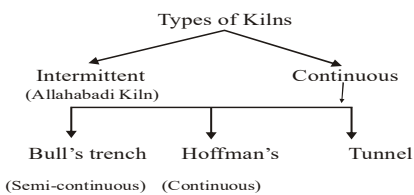
Types of Drying - (a) Natural drying

(b) Artificial drying - (i) Hot floor drier, (ii) Tunnel drier.

· In clamp burning process, at 15^0 angle bricks are to be laid.

· The percentage of moisture in wet bricks is 7 to 30%

· The wet bricks should be dried in an open atmosphere 4-5 days



Stages of burning are	ⓐ Dehydration (400-650ºC)	ⓑ Oxidation (650-900ºC)	ⓒ Virtification (900-1250ºC)

Comparison between clamp Burning and Kiln Burning

S. No.	Item	Clamp burning	Kiln burning
1.	Capacity	About 20000 to 100000 bricks can be prepared at time	Average 25000 bricks can be prepared per day.
2.	Structure	Temporary structure.	Permanent structure
3.	Initial cost	Very low as no structures are to be built	More as permanent structures are to be constructed.
4.	Suitability	Suitable when bricks are to be manufactured on a small scale and when the demand of brick is not continuous	Suitable when bricks are to be manufactured on a large when there is continuous scale and demand of brick
5.	Regulation of fire	It is not possible to control or regulate fire during the process of burning	The fire is under control throughout the process of burning
6.	Skilled supervision	Not necessary through-out the process of bruning	The continuous skilled supervion is necessary
7.	Cost	Law, as grass, cow dung litter, etc. may be used.	Generally high as coal dust is to be used.
8.	Quality of bricks	The percentage of good quality bricks is small.	The percentage of good quality is more.
9.	Time of bruning and cooling	It requires about 2 to 6 months for burning and cooling of bricks	Actual time for burning is about 24 hours and only about 12 days are required for cooling of bricks.
10.	Wastage of heat	There is considerable wastage of heat from top and sides and hot fuel gas is not properly utilized.	The hot fuel gas is used to dry and pre heat raw bricks. Hence the wastage of heat is the least.

- Water Absorption test: (IS 3495 –Part II)
- Warpage Test (IS : 3495 –Part IV):
- Efflorescence test (IS 3495 – Part III):

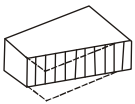
Comparison between Bull's trench Kiln and Hoffman's Kiln

S. No.	Item	Bull Trench Killn	Hoffman's Klin
1.	Burning capacity	About 3 lakhs in 12 days.	About 40 kakhs in one season.
2.	Popularity	More popular because of less initial cost.	Less popular because of high initial cost.
3.	Drying space	It requires more space for drying of bricks	It requires less space for drying of bricks.
4.	Initial cost	Low	High
5.	Nature	It is semicontinuous in loose sense.	It is perfectly Continuous.
6.	Cost of fuel	High as consumption of fuel is more	Low as consumption of fuel is less.
7.	Quality of bricks	Percentage of good quality bricks is small	Percentage of good quality bricks is more.
8.	Suitability	Suitable when demand of bricks in monsoon is not continuous	Suitable when demand of bricks is throughout the year.

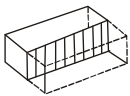
Defects of bricks

1. **Over burning:** Bricks loose their shape.
2. **Blisters:** Formed due to air imprisioned during their moulding.
3. **Bloating:** Spongy swollen mass over bricks surface due to excess of carbonaceous and sulphur matter.
4. **Efflorescence:** Due to alkalies.
5. **Chuffs:** Deformation of shape of the bricks caused by the rain water falling on hot bricks.
6. **Under burning:**Higher water absorption and less compressive strength.

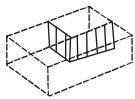
7. **Laminations:** It is due to entrapped air in the Voids of day.



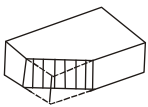
(a) Bevelled closer



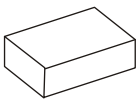
(b) Queen-closer (half)



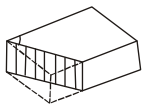
(c) Queen-closer (quarter)



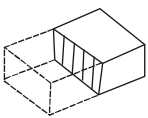
(d) King closer



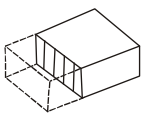
(e) Full brick



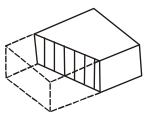
(f) Mitred closer



(g) Half bat



(h) Three quarter bat



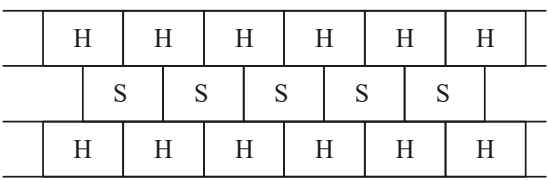
(i) Bevelled bat

Rules of Bonding

1. Lap should be minimum (1/4) bricks along the length of wall & (1/2) bricks across the thickness of the wall.
2. Vertical Joints in the alternate courses should be along the same perpend.
3. It is preferable to provide every 6th course as a header course.

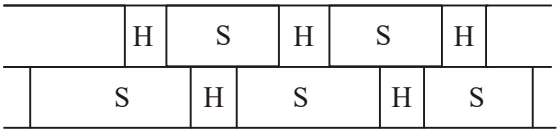
Types of bonds

1. **Stretcher bond:** All the bricks are laid as Stretchers on the faces of the wall.Used for constructing 10 cm thick brick partition wall.
2. **Header bond:** All the bricks are laid as headers on the faces of the wall. Commonly used for constructing staining of wells, corbels, footing etc.
   - It is using three-quarter brick bats in each alternate courses as quoins.
3. **English bond:** Alternate courses of headers & stretchers.
   - English Bond is stronger & costly than flemish Bond.
   - Mostly English bond is used in government work
   - Adopted for work where strength is of prime importance.



4. **Facing bond :** Bricks of different thickness are to be used in the facing or backing of the wall.
5. **Flemish bond:** Each course has alternate header & stretcher.
   - Flemish Bond give better appearance than English Bond.
   - Construction with flemish Bond requirs greater skill in comparison to English Bond & bat bricks are use in it.

- Minimum width of wall for single flemish bond is 1½ brick wall.

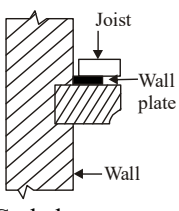


Slenderness ratio of brick masonry: It is the effective height of the wall divided by effective thickness or effective length divided by effective thickness, whichever is less.

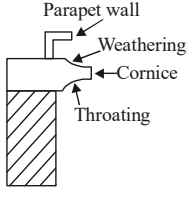
Maximum slenderness ratio for load bearing walls

No. of storeys	Using Portland cement or pozzolana cement	Using lime mortar
Not exceeding 2	27	30
exceeding 2	27	12

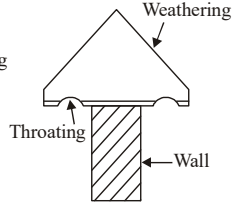
Note: Permissible tensile stress of brick masonry is 0.1 N/mm^2 where as. Permissible shear stress of brick masonary is 0.15 N/mm^2.



Corbel



Cornice



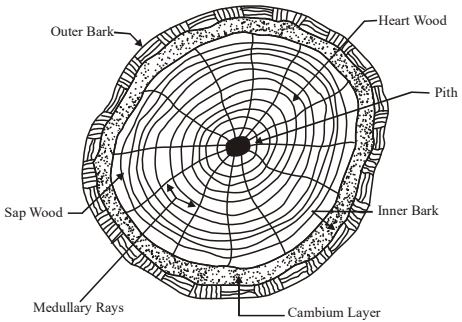
Coping

Classification of Walls									
Load bearing wall					Non load bearing wall				
Solid wall with piers (Pilasters)	Veneered wall	Cavity wall	Solid wall	Faced wall	Partion wall	Panel wall	Free standing wall	Curtain wall	Faced wall

Types of trees		
Endogenous tree	**Exogeneous tree**	
These grow inward Bamboo, Cane, Palm	These grow outward Deodar, Sal, Teak	
	Conifers (soft wood)	Deciduous (hard wood)
	Needle shape leaves Evergreen tree Pine, Chir, Deodar	Broad shape leaves Open tree Oak, Teak, Shishum

Comparison of softwood and Hardwood

Property	Sotwood	Hard-wood
Colour	Lighter	Darker
Growth	Faster	Slower
Weight	Lighter	Heavier
Density	Low	High
Annual rings	Distinct	Indistinct
Heart-wood	Can not be distinguished	Can be distinguished
Strength	Strong along grains	Strong along and across grains
Conversion	Easy	Difficult
Resinous Material	Exist in pores	Does not exist
Examples	Chir, Fir, Kali, Pine, Deodar	Teak, Sal, Shishum, Poplar and Maple



Sawing of Timber

- ***Ordinary***→ Flat/slab sawing: It is very quick & Economical method.
- ***Tangential Sawing***→ Cutting is tangential to the Annual rings & at right angles to the meduallary rays.
- ***Radial Sawing***→ Sawing is done Parallel to the rays & perpendicular to the rings: It give strongest timber
- ***Quarter/Rift Sawing***→ Quarter sawn wood wears better & shrink more evenly.

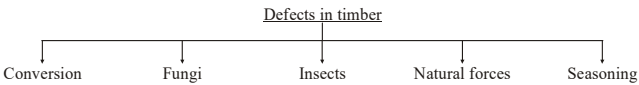
Note: Radial sawing will produce thestrongest timber piece as in redial sawing medulary rays are not out as the sawing is done parallel to the rays.

Properties of Timber:

1. Specific gravity of wood = 1.54
2. Weight of timber should be noted at 12% moisture content

3. Timber is Anisotropic & Elastic material, shrinks least along length and maximum along circuferance

4. Fibre saturation point is % moisture content at which cell walls are saturated and cell cavity contains no water.



1. Conversion defects

(*i*) **Chip mark:** These are the marks or signs placed by chips on finished surface of timber.

(*ii*) **Wane:**It is the presence of original rounded surface on the manufactured timber.

(*iii*) **Diagonal grain:** Improper sawing, Indicated by diagonal mark or straight grained surface of timber.

(*iv*) **Torn grain:** It is the small depression on the finished surface due to falling of tool

2. Defects due to fungi:

(*i*) **Blue stain:** Sap of wood is stained to bluish colour

(*ii*) **Sap Stain:** Fungi feeds on cell contents of sap wood, then the sap wood looses its colour

(*iii*) **Dry rot:** It occurs due to lack of ventilation/absence of sunlight (in basements, rooms or in damp situations like kitchen.)

(*iv*) **White rot:** The fungi attacks on lignin of wood & wood assumes the appearance of white mass consisting of cellulose compounds

(*v*) **Brown rot:** Fungi of certain type remove cellulose compounds from wood & it attains brown colour.

(*vi*) **Heart rot:** In it, heart wood is exposed to atmosphere & attacked by atmospheric agents.

(*vii*) **Wet rot:** It is the chemical decompositons of wood due to alternate dry & wet conditions

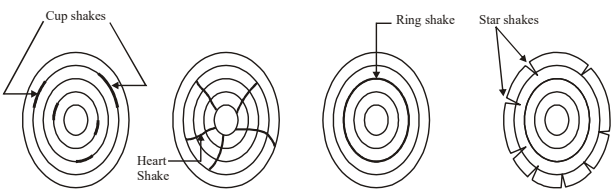
4. Defects due to Natural forces:

(*i*) **Burls,** (*ii*) **Callus,** (*iii*), **Dead wood,** (*iv*) **Knots**

(*v*) **Foxiness,** (*vi*) **Druxiness,** (*vii*) **Rind galls**

(*viii*) **Shakes:** Longitudinal separations in the wood between the annual rings

(a) Heart Shake: Occurs in overmatured trees. These are wider at centre & diminish outward.



Prevsevation of Timber (IS : 401)

Types of Preservatives:

(*a*) **Ascu Treatment:** It was developed by forest Research Institute, Dehradun. This solution is odourless Solution is made by 6 parts of posder in 100 parts of water by weight. Preservtive gives protection against

white ants.

$$AS_2O_5.2H_2O + CuSO_4.5.H_2O + K_2Cr_2O_7/Na_2Cr_2O_7.2H_2O$$

1 Part 3 Parts 4 Parts

Mixed in powdered form

(*b*) **Chemical Salts,** (*c*) **Oil points,** (*d*) **Solignum paints:**

(*e*) **Coal tar:** Surface is coated with hot coal tar with the help of brush. This process is called tarring. It is fire resistant.

(*f*) **Creosote oil:** The application of Creosote oil on timber is called creosoting. It is highly toxic in nature. It is obtained by distillations of tar. It is one of the best antiseptic. It is black or brown liquid weakly affected by water, neither volatile nor hygroscopic.

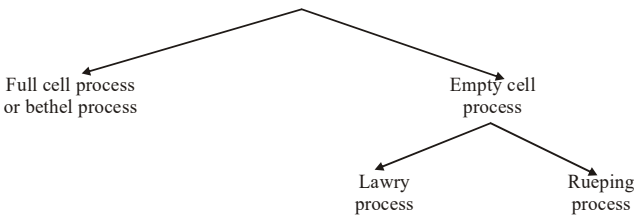
- It should not be used for interior surface of dwelling.

Methods of Treatment (IS: 401)

1. **Surface Application:**
2. **Hot and cold process:**
3. **Soaking:**
4. **Charring:** The surface to be charred is kept wet for about half an hour and then burnt to a depth of 15 mm over wood fire. Due to burning a layer of coal is formed on the surface. This layer is neither effected by moisture nor by

fungi. Major disadvantages of charring is that, there is loss of strength of timber and it can not be used for exterior surface due to black surface.

5. **Diffusion process:** It is use for treatment of poles, planks & plant material.
6. **Boucheric process:**
7. **Pressure or pneumatic process:**



Fire Resistance of timber: Timber can not be made fire proof, but it can be only made fire resistant by the following ways -

Sir Abel's process- In it, surface of wood is painted by weak solution of sodium silicate.

Seasoning of Timber (IS: 1141) : It is the process of reducing the moisture content of timber in order to prevent the timber.

Following are the methods of seasoning -

(a) Natural seasoning (b) Artificial seasoning

Natural Seasoning: It is carried out by natural air, hence even called air seasoning & Moisture content can be brought down to 15–20%. The duration of a timber usually requires for natural seasoning is 6 months (minimum).

Artificial Seasoning: It is adopted for faster drying. It is

possible to provide different drying conditions based on the species of timber. In it, we can reduced moisture content as per requirement.

Required time for artificial seasoning of wood is 5 to 10 day

Artificial Seasoning methods :

(*a*) **Boiling,** (*b*) **Kiln Seasoning,** (*c*) **Electrical Seasoning,**

(*d*) **Chemical (Salt seasoning),** (*e*) **Water Seasoning:**

Plywood: It has good & uniform tensile strength both along as well as across the grains. Useful for furniture, doors, ceiling.

- They are not suitable for applications which involve direct impact.
- It has odd no of layers & specified by thickness. The minimum number of plies in plywood is 3.
- Plywood is obtained by gluing wooden sheets at a pressure of (1.9 M Pa or 190 N/cm^2) but generally the pressure used is (1.38 Mpa or 138 N/cm^2). This variation is due to the different strength of raw material.
- It can be made from hardwood, softwood or both.

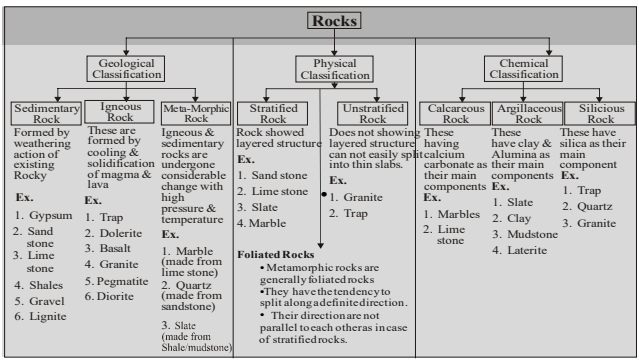
Timber	Uses
Babul	Agricultural Instruments
Bamboo	Scaffolding
Benteak	Boat Construction
Deodar	Railway sleeper
Mulberry	Sports goods
Teak	Ship Building

Classifications of Mortar on various factors -

(a) Type of material - Surkhi, Gauged, Cement, Gypsum, Lime mortar (Fat lime, Hydraulic lime and Poor lime)

(b) Bulk density based - Light density (γ_t < 15 kN/m^3), Heavy density (γ_t > 15 kN/m^3)

(c) Special types of mortar - Fire resistants, Sound absorbing, Light weight etc.



Tools for Quarrying stones

Jumper, Dipper, Crow bar, Tamping bar

Test	Purpose
Smith test	for presence of soluble matter
Brad's test	for frost resistance (durability)
Acid test	To check weather resistance
Mohs scale	Hardness test

Some Important Topic

- Distemper are white paints made with base as white chalk and thinner as water.

- Distemper is chepaer than paints.
- They are most suitable for plastered surfaces as well as white washed surface of interior walls.
- Distempers are workable and easy in application but less durable.
- Varnish is a nearly homogenous solution of resin in oil, alcohol or turpentine.
- The type of solvent depends upon the type of resin used.
- The oil dries with time and other solvents evaporate leaving behind a solid transparent resin film over the surface.

Types of varnish

(a) Spirit Varnish, (b) Oil varnish, (c) Water varnish, (d) Flat varnish, (e) Asphalt varnish, (f) Spar varnish:

- **A cement paint** is a water based paint is used to preventing water penetrating redemption of dirt collection prevent fungal and algal growth on interior as well as exterior walls.
- **Enamel paint** is a paint that air dries to a hard usually glossy, finish, used for coating sufaces that are outdoors.
- **Cellulose paint** is a normally used by enthusiast, first timer or trade professionals when an original finish is required.
- **Distempers** are the chepaer variety of paints in which chalk is used as base and water as carrier, and glue as emulsifying agent. Available in powder or paste form.

Various constituents of an oil paint are:

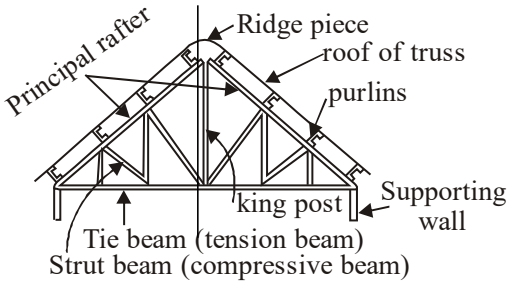
(a) Base:
It makes the paint film opaque and possesses binding properties which reduces the shrinkage cracks in the film on drying.

(c) Pigments: It is used to hide the surface imperfections and to impart the desired colour.

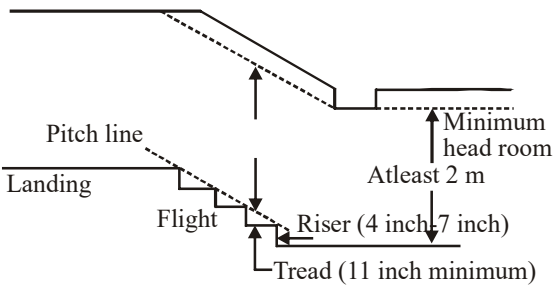
(b) Vehicle: It is also known as binder or carrier.
- It is an oil to which base is mixed.
- It imparts durability, toughness and water proofness and resistance to weathering.
- It holds the constituents of paints in suspension and helps spread it over the surface to be painted.
- Linseed oil, poppy oil, tung oil, animal oils are examples of vehicle.

(d) Solvents: These are oils used to thin the paints, increase the spread.

Name of pigment	Colour
Zinc oxide	White
Copper sulphate	Green
Indigo	Blue
Ivory black	Black
Burnt siena	Brown
Red lead	Red



Cross section of a truss roof



- For making spiral staircase, ideal material is cast iron
- Width of stair in Domestic building 90 cm & in public Building, (1.5-1.8)m.
- No. of steps are not more than 12 & not less than 3 in a flight.
- Angle of Inclination (Pitch) – (25° – 40°).
- Minimum width of stairs in residential building – 85 cm & in commercial building is 1 m.

- In public buildings the maximum riser is limited to 15 cm
- The height of hand railing above the tread should be generally in between 75 cm to 80 cm in stairs

Some Thumb Rule:

(a) $(2R + T) = 60$, (b) $(R + T) = (40 - 45)$, (c) $R \times T = (400 - 450)$.

where, R – Rise in cm, T – Tread in cm.

- For residential building, common size of steps is (16×26) cm, In Hospital etc. – (10×30) cm.
- In case of straight staircase,
  No. of Trade = (No. of Riser – 1)

$$\text{No. of Riser} = \frac{\text{Total height between floor \& roof}}{\text{Height of one riser}}$$

- Types of Stairs:
  (1) Straight stairs, (2) Turning Stairs.
  (a) Quarter Turn, (b) Half Turn Stair (Dog-legged & Open well stairs) (c) Three-Quarter, (d) Bifurcated stairs.

Mud/Muram flooring: It is cheap, Hard, fairly Impervious, easy to maintain & Construct. It has good thermal Insulation property due to which it remains cool in summer & fairly warm in winter. Commonly use in villages. This floor is washed with dilute oxalic acid.

Terazzo flooring: It is laid in thin layer over concrete topping. It is very decorative & has good wearing properties. It is mostly used in residential buildings, Hos-

pitals, offices, schools & other public buildings

- In it, marble chips size is 3 to 6 mm.
- The flooring in which base concrete of lime, cement & concrete of mix 1:5:10 is laid over well compacted sub base is called terrazao flooring

Cork flooring: It is perfectly Noiseless & is used in libraries, Theatres, Art Galleries, Broadcasting stations etc. where noiseless floor covering is desired. It is available in the form of coloured tiles/sheets.

Glass flooring: It is used for entrance of light at basement from the upper floors

Mosaic flooring: In it, we use chips of marble in coloured cement. Its thickness is 4 cm generally.

- For cleaning mosaic floors, we use muriatic acid (spirit of salts) diluted with water.

Some Special Varieties of Glass

Bullet proof glass: It is made up of several alternate layers of plate glass & vinyl resin plastic. The thickness of outer layers is small as compared to inner layers .

It is made of thick glass steel & a sandwiched layer of high strength plastic

Float glass: It is extensively used in residential & commercial buildings. It is superior to ordinary glasss in terms of energy consumption, cost effectiveness, appearance & strength.

Fibre glass : fibre glass consists of minute glass roads(fibres) made up of the parent material itself. It is soft & flexible.It is used for Thermal Insulation.

Safety glass : It is also called shatter proof glass. It is extensively used in automobile glass. the glass does not actually breaks but cracks therefore preventing damage from flying splinters, pieces of glass.

Ultra violet ray glass : This glass effectively transmits almost all of the ultra-violent rays incident on the glass irrespective of the angle of incidence.Other types of glasses made for specific purposes are Heat excluding glass, Shielding glass, Perforated glass, Structural glass.

- The common house hold glass is soda lime glass
- Foam glass is recommended while making a building air - conditioned
- The glass used for display windows of jewelry shop is laminated glass
- Glass used in railways coaches is wire glass
- Wired Glass: Used in outside window to resist fire & Breakage.
- Ground Glass: Used where light is to be admitted, but vision is to be obscured.

Physical properties of steel

Various physical properties of structural steel are given below.

Unit mass of steel, $\rho = 7850\ kg/m^3$

Modulus of elasticity $E = 2 \times 10^5\ N/mm^2$

modulus of rigidity, $G = 0.769 \times 10^5\ N/mm^2$

Poisson ratio $\mu = 0.3$

Coefficient of thermal expansion, $\alpha = 12 \times 10^{-6}/^oC$

Material	Percentage carbon
Wrought iron (purest from of Iron)	<0.1%
Steel	0.10–0. 25%
High carbon steel	0.55–0.95%
Cast Iron	2.00–4.00%

Pig iron: The crude impure iron (3-4% carbon) is known as Pig-iron. It forms the basic material for the manufacture of cast-iron, wrought iron & steel. It is used for making base plattes, column, door brackets etc.

Cast iron: Cast iron is manufactured by remelting pig iron with coke & limestone. It is used for making ornamental castings, like as lamp post, bathroom fittings, wall brackets etc.

Wrought iron: It is almost pure & it hardly contains carbon more than 0.10 percent. It is used for making roof covering, rivets, chimney gates etc.

5 STRENGTH OF MATERIAL

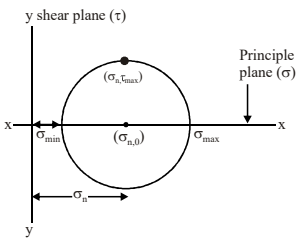
*** Normal stress When:** σ_x, σ_Y & τ_{xy} are given.

$$\sigma_n = \frac{\sigma_x + \sigma_y}{2} + \left(\frac{\sigma_x - \sigma_y}{2}\right)\cos 2\theta + \tau_{xy}\sin 2\theta.$$

- **Tangential Stress:** $\tau_t = -\left(\frac{\sigma_x - \sigma_y}{2}\right)\sin 2\theta + \tau_{xy}\cos 2\theta.$
- **Location of Principal Plane:** $\text{Tan}_{2\theta} = \frac{2\tau_{xy}}{\sigma_x - \sigma_y}$
- **Major & Minor Principle Stress:**

$$\sigma_{max}/\sigma_{min} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau^2_{xy.}}$$

Important Points:



- **Note:** On principle plane, shear stress will always 0.
- **Radius of Mohr's Circle (τ_{max}):** $R = \frac{\sigma_{max} - \sigma_{min}}{2} = \tau_{max.}$
- **Normal stress at Location of (τ_{max}):** $\sigma_n = \frac{\sigma_1 + \sigma_2}{2}$
- **Volumetric Strain of Rectangular:**

$$\frac{\Delta v}{V} = \varepsilon_v = \left[\frac{\left(\sigma_x + \sigma_y + \sigma_z\right)}{E}\right](1 - 2\mu)$$

- **Volumetric Strain of Cylindrical:** $\varepsilon_v = \varepsilon_e + 2\varepsilon_D$
- **Volumetric Strain of Spherical:** $\varepsilon_v = 3\varepsilon_D$
- **Relationship Between Elastic Constant**

$$G = \frac{E}{2(1+\mu)} \quad K = \frac{E}{3(1-2\mu)} \quad \mu = \frac{3k - 2G}{6k + 2G} \quad E = \frac{9kG}{3k + G}$$

Number of independent Elastic Constant: Homogenous & Isotropic = 2, Anisotropic = 21, Orthotropic = 9

- **Axial Elongation of the Prismatic Bar:** $\Delta L = \frac{PL}{AE}$,

$\Delta L = \frac{2PL}{AE}$ (for Instantaneous loading)

- **Deflection In Non-Prismtic Bars.**
  1. Stepped Bar $\Delta L = \frac{P_1 L_1}{A_1 E_1} + \frac{P_2 L_2}{A_2 E_2} + ---$
  2. Circular Tapering Bar $\Delta L = \frac{4PL}{\pi E D_1 D_2}$
- **Defection of Composit Bar:** $\Delta L_1 = \Delta L_2, \Delta = \frac{PL}{A_1 E_1 + A_2 E_2}$
- **Deflection due to Self Weight of Bar:**
  1. Prismatic Bar: $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{2E}$,
  2. Conical Bar: $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{6E}$
- **Thermal Expansion:** $\sigma = E\alpha\Delta T, \Delta = L\alpha\Delta T$

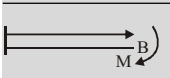
Coefficient of Thermal expansion (Aluminium > Brass > Copper > Steel)

- **In case Of Pure Bending:**

$$(\sigma_b)_{max} = \frac{M}{Z} = \frac{32M}{\pi D^3} \qquad Z = \frac{\pi}{32} D^3$$

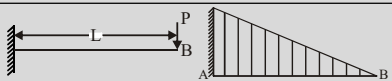
- **Bending Equation:** $\frac{\sigma_b}{y} = \frac{M}{I} = \frac{E}{R}$

Slope & Deflection



$$\theta_A = 0 \quad \theta_B = \frac{M.L}{EI}$$

$$\Delta_A = 0 \quad \Delta_B = \frac{ML^2}{2EI}$$



$$\theta_B = \frac{PL^2}{2EI}$$

$$\Delta_A = \frac{PL^3}{3EI}$$

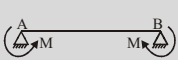
$$\theta_B = \frac{WL^3}{24EI}$$

$$\Delta_B = \frac{WL^4}{30EI}$$



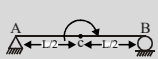
$$\theta_B = \frac{WL^3}{6EI}$$

$$\Delta_B = \frac{WL^4}{8EI}$$



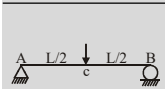
$$\theta_A = \theta_B = \frac{ML}{2EI}$$

$$D_{max\ @1/2} = \frac{ML^2}{8EI}$$



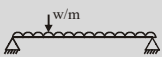
$$\theta_A = \theta_B = \frac{ML}{24EI}$$

$$\theta_c = \frac{ML}{12EI}$$



$$\theta_A = \theta_B = \frac{PL^2}{16EI}$$

$$\Delta_C = \frac{PL^3}{48EI}$$

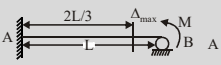


$$\theta_A = \theta_B = \frac{WL^3}{24EI}$$

$$\Delta_C = \left\{\frac{5}{384} \times \frac{WL^4}{EI}\right\}$$



$$\theta_A = \theta_B = \frac{5}{192} \times \frac{WL^3}{EI}$$



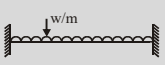
$$\theta_B = \frac{ML}{4EI}$$

$$\Delta_{Max} @ \frac{2L}{3}$$



$$\theta_A = \theta_B = \theta_C = 0$$

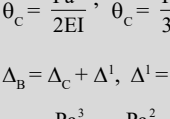
$$\Delta_C = \frac{PL^3}{192EI}$$



$$\theta_A = \theta_B = \theta_C = 0$$

$$\Delta_C @ 1/2 \quad \frac{WL^4}{384EI}$$

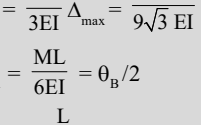
from A $\frac{ML^2}{27EI}$



$$\theta_C = \frac{Pa^2}{2EI}, \quad \theta_C = \frac{Pa^3}{3EI} + \frac{Pa^2b}{2EI} \quad (\theta_C = \theta_B),$$

$$\Delta_B = \Delta_C + \Delta^1, \quad \Delta^1 = b\,\frac{Pa^2}{2EI}$$

$$\Delta_B = \frac{Pa^3}{3EI} + b.\frac{Pa^2}{2EI}$$



$$\theta_B = \frac{ML}{3EI} \quad \Delta_{max} = \frac{ML^2}{9\sqrt{3}\,EI}$$

$$\theta_A = \frac{ML}{6EI} = \theta_B/2$$

$$\Delta_{max} @ \frac{L}{\sqrt{3}} \text{ from A,}$$

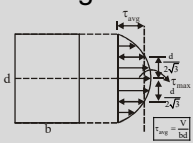
Theory	Given by	Remark
Maximum Principle Stress or Maximum Normal stress	Rankine	Suitable for Brittle
Maximum Principle Strain	St. Venant	Can be use for Brittle and Ductile
Maximum shear Stress	Guest & Treseca	Suitable for Ductile
Maximum Strain Energy	Haigh & Beltrami	Ductile
Maximum shear Strain energy	Vonmises and Hencky	Ductile

- **Pure Torsion Equation For Circular Shaft:** $\frac{T}{J}=\frac{\tau}{r}=\frac{G\theta}{L}$
- **Combined Bending & Torsion:**

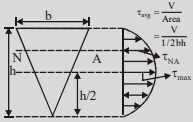
$$\sigma_{max}=\frac{16}{\pi D^3}\left[M\pm\sqrt{M^2+T^2}\right]$$

$$\tau_{max}=\frac{16}{\pi D^3}\left[\sqrt{M^2+T^2}\right]$$

- **Equivalent Moment:** $M_{eq}=\frac{1}{2}\left[M+\sqrt{M^2+T^2}\right]$
- **Equivalent Torque:** $T_{eq}=\left[\sqrt{M^2+T^2}\right]$
- **Shear Stress:** $\tau=\frac{VA\bar{y}}{Ib}$

Cross-section distribution	Shear stress
(a) Rectangle 	$\tau_{max}=\frac{3}{2}.\tau_{avg}$ $\tau=\tau_{avg}$ at distance from neutral axis $d/2\sqrt{3}$

(b) Triangular



$\tau_{max} = \frac{3}{2}\tau_{avg}$

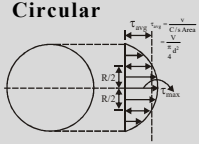
$= 1.5\tau_{avg}$.(at h/2)

$\tau_{NA} = 4/3\ \tau_{avg}$

$= 1.33\tau_{avg}$

Distance betwen N.A. & τ_{max} location = h/6

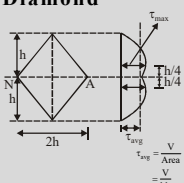
(c) Circular



$\tau_{max} = \frac{4}{3}\tau_{avg}$

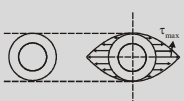
= 1.33 τ_{avg} (at R/2 distance from neutral axis)

(d) Diamond



$\tau_{max} = \frac{9}{8}\tau_{avg}$

(e) Hollow circular section



$\tau_{max} = 2\tau_{avg}$

- **Thin Cylindrical Pressure Vessels:**

$$\sigma_H = \frac{pD}{2t}, \quad \sigma_L = \frac{pD}{4t} \quad \tau_{max} = \frac{pD}{8t}$$

Where

σ_H = Hoop Shress

σ_L = Longitudinal stress.

- **Hoop Strain:** $\varepsilon_H = \frac{pD}{4tE}(2-\mu)$
- **Longitudinal Strain:** $\varepsilon_L = \frac{pD}{4tE}(1-2\mu)$
- **Thin Spherical Pressure Vessels:**

$$\sigma_n = \sigma_L = \frac{pD}{4t} \quad \text{or} \quad \sigma_t = \sigma_z = \frac{pD}{4t}$$

- **Euler's Buckling Load:** $P = \frac{\pi^2 E I_{min}}{\ell^2_{eff.}}$

- **End Condition of column.**

End condition	One end fixed one end free	Both end Hinged	Both end Fixed	One end fixed one end Hinged
L_{eff} (Theoretical)	2L 	L 	L/2 	$\frac{L}{\sqrt{2}}$ 
L_{eff} (As per IS code.)	2L	L	0.65L	0.8L

- **Shaft In seriess:**

$$\theta_{AD} = \theta_{AB} + \theta_{BC} + \theta_{CD} \qquad \theta_{AD} = \frac{T_{AB}L_{AB}}{G_{AB}J_{AB}} + \frac{T_{BC}L_{BC}}{G_{BC}J_{BC}} + \frac{T_{CD}L_{CD}}{G_{CD}J_{CD}}$$

- **Shaft In parallel:** $\theta_1 = \theta_2$ $\qquad \frac{T_1L}{G_1J_1} = \frac{T_2L}{G_2J_2}$

Spring

- **Strain Energy:** $U = \frac{32P^2R^3n}{Gd^4}$, $\delta = \frac{64PR^3n}{Gd^4}$

- **Stiffness:** $\boxed{K = \frac{Gd^4}{64R^3n}}$, • **Flexibility:** $\boxed{f = \frac{64R^3n}{gd^4}}$

$$\frac{1}{K_{eq}} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + ... + \frac{1}{K_n},$$

$K_{eqa} = K_1 + K_2 + K_3 + ...K_n$ (In Spring)

Note: It a spring is cut down by K times, then its strain energy decreased by $\frac{1}{k}$ times, its stiftness is increased by K times, and its flexibity decreased by $\frac{1}{k}$ time.

1. Shear centre = $\frac{b^2h^2t}{4I}$ (Channel Section)

2. Semi Circular $e = \frac{2R}{\pi/2}$

Force Method	Displacement Method
1. Unknown are taken redundants/ reactions.	1. Unknowns are taken displacement.
2. To find unknown forces or redundants compatibility equations are written.	2. To find unknown displacement joint equilibrium conditions are written.
3. The number of compability equations needed is equal to degree of static indeterminacy.	3. The no. of equilibrium conditions needed is equal to degree of kinematic indeterminancy.

4. $D_s < D_k$	4. $D_k < D_s$
Force Method/Flexibility Method/ Compatibility Method	Displacement Method/Stiffness Method/Equilibrium Method
5. Examples	5. Examples:
(i) Virtual work/Unit load method	(i) Slope deflection method
(ii) Method of consistent deformation	(ii) Moment distribution method
(iii) Elastic centre method method	(iii) Minimum potential energy
(iv) Column analogy method	
(v) Three moment theorem	
(vi) Castigliano's theorem of minimum strain energy	
(vii) Maxwell-Mohr equation.	

Type of Structure	Degree of Indeterminacy D_s
2D (plane) frames	(3m+r)-3j
3D frames	(6m + r)-6j
2D (plane) pin-jointed truss	(m+r)-2j
3D truss	(m+r)-3j

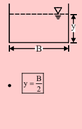
Torsional strain energy

$$U = \frac{1}{2}\ T.\theta = \frac{1}{2}\ T.\ \frac{TL}{GJ} = \frac{\tau^2_{max}}{4G} \times \text{Volume of shaft}$$

$$\text{So, Strain energy density} = \frac{\text{Strain energy}}{\text{Volume of shaft}} = \frac{1}{2} \times \tau \times \gamma$$

- **Sudden expension:** $h_l = \frac{(v_1 - v_2)^2}{2g}$
- **Entry Loss:** $h_{entry} = 0.5\frac{v^2}{2g}$, **Exist of Pipe:** $h_{exit} = \frac{v^2}{2g}$
- **Sudden Contraction:** $h_{contraction} = \frac{(v_c - v_2)^2}{2g}$
- **Bending of the Pipe:** $h_{fitting} = k\frac{v^2}{2g}$, k = constant, T-Bend, k = 1.8, 90°-Bend, k = 1.2, 45°-Bend, k = 0.4

Chart for Most Economical Sections

Geometrical Parameters	Rectangular	Triangular	Trapezoidal
Diagram			
Condition for most Economical	$y = \frac{B}{2}$	m = 1, θ = 45°	$B = \frac{2y}{\sqrt{3}}$, $m = \frac{1}{\sqrt{3}}$, θ = 60° Hor. θ = 30° Vert.
Area	$A = B.y = 2y.y$	$A = my^2$	$A = (B + my) \times y$
	$A = 2y^2$	$A = y^2$	$A = \left(\frac{2y}{\sqrt{3}} + \frac{1}{\sqrt{3}}y\right)y = \left(\sqrt{3}\right)y^2$
Perimeter	$P = 4y$	$p = 2\sqrt{2}y$	$P = 2\sqrt{3}y$
Hydraulic Radius (R = A/P)	$R = y/2$	$R = \frac{y}{2\sqrt{2}}$	$R = \frac{y}{2}$
Top width (T)	$T = 2y$	$T = 2y$	$T = \frac{4y}{\sqrt{3}}$
Hydraulic Depth $\left(D = \frac{A}{T}\right)$	$D = y$	$D = y/2$	$D = \frac{3}{4}y$

Note: Circular section (a) For maximum discharge 2θ = 302°22′, d = 0.938 D, (b) For maximum velocity 2θ = 257°27′, d = 0.81 D

Type of flow	Depth of flow	Velocity of flow	Froude No	Comments
Subcritical	$y > y_c$	$v < v_c$	$F_r < 1$	As streaming or transquil flow
Critical	$y = y_c$	$v = v_c$	$F_r = 1$	
Super Critical	$y < y_c$	$v > v_c$	$F_r > 1$	Shooting flow, rapid flow, torrential flow

Dynamic eq. for G.V.F.: $\frac{dy}{dx} = \left(\frac{S_o - S_f}{1 - \frac{q^2}{gy^3}}\right)$

Hydraulic Jump Eq.

1. $\frac{2q^2}{g} = y_2y_2(y_1 + y_2)$, 2. Energy Loss $E_L = \frac{(y_2 - y_1)^3}{4y_1y_2}$

3. $\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8F_r^2} - 1\right)$, 4. $y_1' = \frac{y_1y_2(y_1 + y_2)}{2}$

Types of Jump	Fr	E_2/E_1	Water surface
Undular	1–1.7	≈ 0	Undulating
Weak	1.7–2.5	5–18%	Small rollers form
Oscillating	2.5–4.5	18–45%	Water oscillates in random manner
Steady strong	4.5–9 ≥ 9	45–70% ≥ 70%	Roller and jump action Very rough and choppy

$N_s = \frac{N\sqrt{P}}{(H)^{5/4}}$ (for Turbine), $N_s = \frac{N\sqrt{Q}}{(H_m)^{3/4}}$ (for Pump)

	Laminar	Transition	Turbulent
Flow in pipe	$R_e < 2000$	$2000 < R_e < 4000$	$R_e > 4000$
Flow between parallel plate	$R_e < 1000$	$1000 < R_e < 2000$	$R_e > 2000$
Flow in open channel	$R_e < 500$	$500 < R_e < 2000$	$R_e > 2000$
Flow through soil	$R_e < 1$	$1 < R_e < 2$	$R_e > 2$

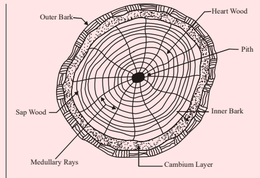
BMC

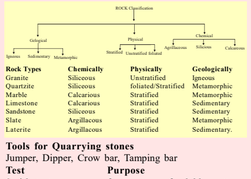
Test of Cement

- FINENESS TEST
  - Sieve Method
  - Air permeability Method
  - (Nurse and Blaine's method)
  - Sedimentation method
  - (Wanger Turbidimeter Method)
- CONSISTENCY TEST
  - Vicat's Apparatus.
- SETTING TIME
  - Vicat's Apparatus.
- SOUNDNESS TEST
  - Le-chatelier Method
  - Auto clave test
- TENSILE STRENGTH
  - Briquette test
- HEAT OF HYDRATION
  - Calorimeter test
- SPECIFIC GRAVITY TEST
  - Le-chatelier's Flask.

Test On Concrete

- WORKABILITY
  - Slump test
  - Compacting factor Test
  - Vee-bee consistometer method
- DIRECT TENSILE STRENGTH OF CONCRETE
  - Cylinder Splitting Test
- BOND B/W CONCRETE &STEEL
  - Pull out Test
- COMPRESSIVE STRENGTH
  - Rebound hammer Test
- DYNAMIC MODULUS





Rock Types	Chemically	Physically	Geologically
Granite	Siliceous	Unstratified	Igneous
Quartzite	Siliceous	foliated/Stratified	Metamorphic
Marble	Calcarious	Stratified	Metamorphic
Limestone	Calcarious	Stratified	Sedimentary
Sandstone	Siliceous	Stratified	Sedimentary
Slate	Argillaceous	Stratified	Metamorphic
Laterite	Argillaceous	Stratified	Sedimentary.

Tools for Quarrying stones
Jumper, Dipper, Crow bar, Tamping bar

Test	Purpose
Smith test	for presence of soluble matter
Brard's test	for frost resistance
Acid test	To check weather resistance
Hardness test	Mohr scale

Window Width = $\frac{1}{8}$[Width of room + Height of Room]

- The sill of a window should be located about (70 – 80) cm above floor level of the room.
- Generally Height of a Door should not be less than (1.8 – 2) m
- Commonly Width height relation used in India:
  (i) Width = (0.4 – 0.6) Height
  (ii) Height = (Width + 1.2) m
- Doors of residential Buildings:
  (a) External Door – (1 × 2) to (1.1 × 2) m
  (b) Internal Door – (0.9 × 2) to (1 × 2) m
  (c) Doors for bathrooms and Water closets:
  – (0.7 × 2) to (0.8 × 2) m
- Public Buildings (School, Hospital, library)
  (a) (1.2 × 2) m (b) (1.2 × 2.1) m (c) 1.2 × 2.25) m
  Designation of Door = Length × Type of Door × Height
  8 DS 20 – A door opening Having width (8 × 100 mm) × Height (20 × 100 mm) with S (Single SHutter) D (Door)

Types of Window

1. fixed 2. Pivoted 3. Sliding 4. Bay 5. Corner 6. Cable (7) Dormer (8) Skylights (9) Louvered (10) Lantern (11) Gable

Stairs

- No of steps are not more than 12 and not less than 3 in a flight.
- Angle of Inclination (Pitch) – (25° – 40).
- Head room must not be less than 2.05 m.
- Minimum width of stairs in residential building – 85 cm and in commercial building is 1 m.

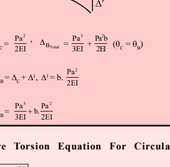
Type of Structure	Degree of Indeterminacy D_s
2D (plane) frames	(3m+r)-3j
3D frames	(6m + r)-6j
2D (plane) pin-jointed truss	(m+r)-2j
3D truss	(m+r)-3j

Slope Deflection Equations

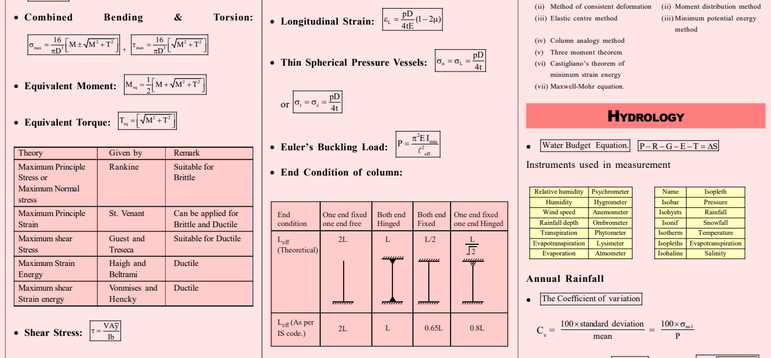
$M_{AB} = M_{FAB} + \frac{2EI}{l}\left(2\theta_A + \theta_B - \frac{3\delta}{l}\right)$ (Continuous Beam)

$M_{BA} = \frac{3EI}{L}\theta_B - \frac{3EI}{L^2}\delta = \frac{d\,\phi}{1.4}$ (one end is pin supported)

Important Points



Slope & Deflection



- **Pure Torsion Equation For Circular Shaft:** $\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{L}$
- **Combined Bending & Torsion:** $\sigma_{max} = \frac{16}{\pi D^3}\left[M \pm \sqrt{M^2 + T^2}\right]$, $\tau_{max} = \frac{16}{\pi D^3}\left[\sqrt{M^2 + T^2}\right]$
- **Equivalent Moment:** $M_{eq} = \frac{1}{2}\left[M + \sqrt{M^2 + T^2}\right]$
- **Equivalent Torque:** $T_{eq} = \left[\sqrt{M^2 + T^2}\right]$

Theory	Given by	Remark
Maximum Principle Stress or Maximum Normal stress	Rankine	Suitable for Brittle
Maximum Principle Strain	St. Venant	Can be applied for Brittle and Ductile
Maximum shear Stress	Guest and Treseca	Suitable for Ductile
Maximum Strain Energy	Haigh and Beltrami	Ductile
Maximum shear Strain energy	Vonmises and Hencky	Ductile

- **Shear Stress:** $\tau = \frac{VAy}{Ib}$
- **Shear Stress In Rectangular Section:** $q = \frac{6q}{bd^3}\left(\frac{d^2}{4} - y^2\right)$ (q = τ).
- **Hoop Strain:** $\varepsilon_h = \frac{pD}{4tE}(2 - \mu)$
- **Longitudinal Strain:** $\varepsilon_L = \frac{pD}{4tE}(1 - 2\mu)$
- **Thin Spherical Pressure Vessels:** $\sigma_x = \sigma_1 = \frac{pD}{4t}$ or $\sigma_1 = \sigma_2 = \frac{pD}{4t}$
- **Euler's Buckling Load:** $P = \frac{\pi^2 EI_{min}}{l'^2_{eff}}$
- **End Condition of column:**

End condition	One end fixed one end free	Both end Hinged	Both end Fixed	One end fixed one end Hinged
L_{eff} (Theoretical)	2L	L	L/2	$\frac{L}{\sqrt{2}}$
L_{eff} (As per IS code.)	2L	L	0.65L	0.8L

4. $D_s < D_d$
Force Method/Flexibility Method/ Compatibility Method
5. (i) Virtual work/Unit load method
(ii) Method of consistent deformation
(iii) Elastic centre method
(iv) Column analogy method
(v) Three moment theorem
(vi) Castigliano's theorem of minimum strain energy
(vii) Maxwell-Mohr equation.

4. $D_s < D_d$
Displacement Method/Stiffness Method/Equilibrium Method
(i) Slope deflection method
(ii) Moment distribution method
(iii) Minimum potential energy method

4. No eq. for bed slope
5. Recommended Kutter eq. to find velocity
6. Trial & error procedure

4. Gave eq. to calculate bed slope
5. Gave his own velocity equation
6. Direct procedure

- **Shaft In series:**

Note: On principle plane shear stress will always 0.

- **Radius of Mohr's Circle (τ_{max}):** $R = \frac{\sigma_{max} - \sigma_{min}}{2} = \tau_{max}$
- **Normal stress at Location of (τ_{max}) (τ_{max}-max shear stress):** $\sigma_n = \frac{\sigma_1 + \sigma_2}{2}$
- **Volumetric Strain of Rectangular:** $\frac{\Delta V}{V} = \varepsilon_v = \left[\frac{(\sigma_x + \sigma_y + \sigma_z)}{E}\right](1 - 2\mu)$
- **Volumetric Strain of Cylindrical:** $\varepsilon_v = \varepsilon_L + 2\varepsilon_0$
- **Volumetric Strain of Spherical:** $\varepsilon_v = 3\varepsilon_0$
- **Relationship Between Elastic Constant:**
  $G = \frac{E}{2(1+\mu)}$, $K = \frac{E}{3(1-2\mu)}$, $\mu = \frac{3k - 2G}{6k + 2G}$, $E = \frac{9kG}{3k + G}$
  Number of independent Elastic Constant: Homogenous & Isotropic = 2, Anisotropic = 21, Orthotropic = 9
- **Axial Elongation of the Prismatic Bar:**
  $\Delta L = \frac{PL}{AE}$, $\Delta L = \frac{2PL}{AE}$ (for Instantaneous loading)
- **Deflection In Non-Prismtic Bars:**
  1. **Stepped Bar:** $\Delta l = \frac{PL_1}{A_1E_1} + \frac{PL_2}{A_2E_2} + \cdots$
  2. **Circular Tapering Bar:** $\Delta L = \frac{4PL}{\pi E D_1 D_2}$
  - **Defection of Composit Bar:** $\Delta L_1 = \Delta L_2 \Delta = \frac{PL}{A_1E_1 + A_2E_2}$
  - **Deflection due to Self Weight of Bar:**
  1. **Prismatic Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{2E}$,
  2. **Conical Bar:** $\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{6E}$
- **Thermal Expansion:** σ = EαΔT, Δ = LαΔT
  Coefficient of Thermal expansion (Aluminium > Brass > Copper > Steel)
  $P_{cr} = \frac{\pi^2 EA}{\lambda^2}$ (Euler's Theory) $P_R = \frac{\sigma_c A}{1 + \alpha\lambda^2}$ (Rankine's Formula)
- **In case of Pure Bending:** $Z = \frac{\pi}{32}D^3$
- **In case of pure Torsion:** $\tau_{max} = \frac{T}{Z_p} = \frac{16T}{\pi D^3}$, $Z_p = \frac{\pi}{16}D^3$
- **Bending Equation:** $\frac{\sigma_b}{y} = \frac{M}{I} = \frac{E}{R}$

HYDROLOGY

- Water Budget Equation. $P - R - G - E - T = \Delta S$

Instruments used in measurement

Relative humidity	Psychrometer
Humidity	Hygrometer
Wind speed	Anemometer
Rainfall depth	Ombrometer
Transpiration	Phytometer
Evapotranspiration	Lysimeter
Evaporation	Atmometer

Name	Isopleth
Isobar	Pressure
Isohyets	Rainfall
Isonif	Snowfall
Isotherm	Temperature
Isopleths	Evapotranspiration
Isohaline	Salinity

Annual Rainfall

- The Coefficient of variation $C_v = \frac{100 \times \text{standard deviation}}{\text{mean}} = \frac{100 \times \sigma_{n-1}}{P}$
- Number of Stations $N = \left(\frac{C_v}{E}\right)^2$, $\varepsilon < 10\%$, $\sigma_{n-1} = \sqrt{\frac{\sum^n (P - \bar{P})^2}{m - 1}}$,

$f_c = f_c + (f_o - f_c)e^{-kt}$,
f_c = Infiltration capacity at any time t,
f_o = initial infiltration,
f_c = Final steady state infiltration.

IRRIGATION

Methods of Irrigation
Free flooding, Border flooding, Check flooding, Basin flooding, Furrow Irrigation, sprinkler Irrigation, Drip Irrigation.

- **Sodium Absorption Ratio:** $SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$
- **Depth of water stored in root zone:** $d_{rz} = \frac{d_1\gamma_d}{\gamma_w}(F_C - M_d)$
- **Relation b/w duty and Delta:** $\Delta = \frac{8.64B}{D}$(meter),
  B = Base period in days, D = Duty in hectare/cumec
- **Irrigation Efficiency**
  (a) **Water conveyance Efficiency:** $\eta_c = \frac{W_f}{W_r} \times 100$,
  W_f = water delivered to the farm, W_r = water supplied
  (b) **Water appliacation Efficiency (η_a):** $\eta_a = \frac{W_s}{W_f} \times 100$
  Below the farm root-zone $W_d = W_s + R_p + D_p$,
  W_s = Water stored in the root zone,
  W_f = Water delivered to the farm,
  R_p = Surface run off, D_p = deep percolation
  (c) **Water use efficiency (η_u):** $\eta_u = \frac{w_n}{w_d} \times 100$,
  w_n = water used beneficialy,
  w_d = water delivered.
  (d) **Water Storage Efficiency (η_s):** $\eta_s = \frac{W_s}{W_n} \times 100$,
  W_n = water needed in the root zone prior to Irrigation,
  W_s = (field capacity–Available moisture)
  (e) **Water Distribution Efficiency (η_d):**
  $\eta_d = 100\left(1 - \frac{Y}{d}\right)$, Y = average numerical deviation in depth of water average depth stored during Irrigation (d).
- **Consumption Irrigation Requirements (CIR):** $CIR = C_u - R_e$
  Field Irrigation Requirement (FIR): $FIR = \frac{NIR}{\eta_a}$
  Gross Irrigation Requirement: $GIR = \frac{FIR}{\eta_c}$
  $NIR = CIR + LR + PSR + NWR$, (GIR > FIR > NIR > CIR)
- **Kennedy's theory:** $V_o = 0.55my^{0.64}$
- **Kutter's/ chezy's Formula:** $V = \frac{23 + \frac{0.00155}{S} + \frac{1}{n}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{n}{\sqrt{R}}}\sqrt{RS}$
- **Lacey's Theory:** $V = \left(\frac{Qf^2}{140}\right)^{1/6}$, $f = 1.76\sqrt{d_{mm}}$
- $R = \frac{5}{2}\left(\frac{V^2}{f}\right)$, $S = \frac{f^{5/3}}{3340\,Q^{1/6}}$, $A = \frac{Q}{v}$
  wetted perimeter $P = 4.75\sqrt{Q}$ scour depth = $1.35\left(\frac{q^2}{f}\right)^{1/3}$

Difference B/W Lacey & Kennedy Theory

Kennedy	Lacey
1. Trapezoidal channel	1. Semi elliptical channel
2. Applicable for alluvial channels	2. Applicable for alluvial channels as well as for rivers.
3. Silt is kept in suspension due to eddies generated from bottom.	3. Silt is kept in suspension due to eddies generated both from side slope and the bottom i.e. through out the parameter.

S.SOROUT, 9255624029
FOLLOWING BOOKS AVAILABLE BY
CIVIL Ki GOLI PUBLICATION:
1. CIVIL Ki GOLI
2. CIVIL BOOSTER
3. REASONING Ki GOLI
4. HARYANA Ki GOLI
5. SOLUTION OF CIVIL Ki GOLI
6. ELECTRICAL & MECHANICAL ENGINEERING ROCKET CHART
7. CIVIL'S CAPSULE

HIGHWAY ENGINEERING

Roman Roads → Tresaguet Construction → Metcalf Construction → Telford Construction → Macadam Construction
Nov. 1927 → Jayakar Committee formed
Feb. 1928 → Recommendations by Jayakar Committee

- **By Rate of introduction of super elevation:** $L_s = e.N.(w + w_e)$ (Rotation about inner edge)
  $L_s = \frac{e.N.(w + w_e)}{2}$ (Rotation wrt centre line)
- **Empirial Formula:** $L_s = \frac{2.7v^2}{R} - (\text{Plain \& Rolling})$, $L_s = \frac{v^2}{R} - (\text{Hilly area})$
- **Length of Summit Curve:** $L = 2S - \frac{4.4}{N}$ **(L<SSD)**
  $L = \frac{NS^2}{4.4}$ **(L>SSD)**
- **Length of Valley Curve:** $L_s = 2\left(Nv^{1.3/2}\right)$ (Comfort criteria)
- **L > SSD:** $L = \frac{NS^2}{(2h_1 + 2S\sin\alpha)} = \frac{NS^2}{(1.5 + 0.035S)}$ ($h_1 = 0.75$, $\alpha = 1°$)
- **L< SSD:** $L = 2S - \frac{(2h_1 + 2S\sin\alpha)}{N}$
- **Basic Capacity of Single lane, Vehicle Per hours:** v = speed kmph, T(Sec/km) = $\frac{3600}{v}$, $q_{max} = \frac{v_s k_j}{4}$,
  Where,
  v_s= Free mean speed, (Maximum speed at zero density.),
  k_j = jam density, (Maximum density at zero speed), Maximum flow q_{max} occurs when the speed is $\frac{V_s}{2}$ and density is $k_j/2$.
  Number of potential conflicts: Both roads are two way = 24, Both road one way = 6, One road is two way, other one way = 11
- $Q = \frac{280w\left(1 + \frac{v}{d}\right)\left(1 - \frac{p}{100}\right)}{\left(1 + \frac{w}{l}\right)}$, $W_{weaving} = \frac{e_1 + e_2}{2} + 3.5$ (Types of interchange: Trumpet, Diamond, Full Cloverleaf, Partial Cloverleaf

Floating Car Method: For Speed and delay study.

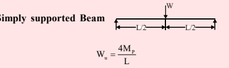
- **Aggregate crushing value:** $\frac{w_2}{w_1} \times 100$
- **Coefficient of Hardness:** $= 20 - \frac{\text{Loss of wt. in gm}}{3}$
- **Rigidity factor:** $R.F = \frac{\text{Contact Pressure}}{\text{Tyre Pressure}}$
- **California Resistance Value:** $t = \frac{k.(T.1)(90 - R)}{C^{2.5}}$
- **Elastic Modulus:** Δ is maximum vertical deflection of the flexible plate, $\Delta = \frac{1.18pa}{E_s}$, Rigid circular plate is used instead of flexible $\Delta = \frac{1.5Pa}{E_s}$, a = radius of plate, p = pressure at deflection, E_s = young's modulus of pavement material.
- **California Bearing Ratio M/D:** $t = \left(\frac{1.75P}{CBR} - \frac{A}{\pi}\right)^{1/2}$, t = Pavement thickness in Cm, P = wheel load in kg, CBR = California Bearing Ratio (%), A = Contact Area in cm^2
- **CBR TEST:** $CBR = \frac{\text{Load or pressure Substained at 2.5 or 5.0 mm Penetration}}{\text{Load or pressure Substained by standard aggregate at corresponding pressure level.}}$
- **Tri Axial Method:** $T_v = \left(\sqrt{\frac{2p_1 \times y}{2\pi E_s A}} - d\right)\frac{E_s}{E_p}$, $\frac{L_1}{L_2} = \left(\frac{E_2}{E_1}\right)^{1/2}$
- **Design of Rigid Pavement:** $k = \frac{p}{\Delta} = \frac{P}{0.125}$
- **Radius of Relative Stifness:** $l = \left[\frac{Eh^3}{12K(1 - \mu^2)}\right]^{1/4}$,
  $b = \sqrt{1.6a^2 + h^2} - 0.675h$ when (a < 1.724 h)
  $S_i = \frac{3P}{h^2}$ (Glodbeck's formula)
  $N = \frac{365A[(1+r)^n - 1]}{r} \times FD$

Bankelman Beam Deflection Method
Overlay Thickness: $h_0 = 550\log_{10}\frac{D_o}{D_a}$

Test	Purpose
CBR test	For classifying & evaluating soil subgrade & base course materials for flexible pavements
Crushing test	Strength of Aggregate
Abrasion test	Hardness of Aggregate
Impact test	Toughness of Aggregate
Soundness test	Durability of Aggregate
Shape test	Gives idea of workability & stability of mix
Bitumen Adhesion test	Gives stripping value of Aggregates
Softening point test	It is done by Ring & ball apparatus to ensure safety of Bitumen
Float test	for viscosity of Bitumen.

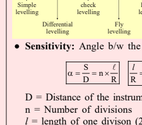
RAILWAY ENGINEERING

CSI = $\frac{S + 10H}{20}$, Sleeper density = M + x,
$D_{mm} = \frac{S - W}{2}$, $e = \frac{GV^2}{127R}$

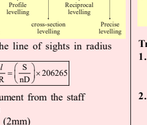


Surveying Chain: Revenue chain (33 ft), Gunter's chain (66 ft), Engineer's chain (100 ft), Metric chain
Equipments for Measurement Right Angles: Cross staff, optical square, Prism square.

- **Tap Corrections:**
- **Correction for Slope:** $C_s = L - \sqrt{L^2 - h^2}$
- **Correction for alignment or bad ranging:** $C_{al} = \frac{h^2}{2L}$
- **Correction for Temperature:** $C_t = \alpha\,(T_m - T_o)L$
- **Correction for pull or Tension:** $C_p = \frac{(P - P_o)L}{AE}$
- **Correction for Sag:** $C_S = -\frac{L(wL)^2}{24P^2}$
- **Important Terms**
- **Bearing:** Direction of a line with respect to fixed meridian is called bearing.
- **True Meridian/Bearing**
  → True meridian is a line joining True North pole, True South Pole end and point of reference. **It never changes with time.**
  → Angle measured for any line w.r.t True Meridian is called Ture bearing.
- Bearing Taken W.r.t magnetic meridian is called magnetic Bearing.



Eastern Declination



Western Declination

Magnetic Declination

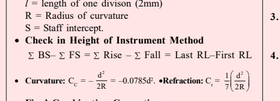
- At any place horizontal angle b/w True Meridian and Magnetic Meridian is called magnetic Declination.
  For Eastern Declination: α = B + θ_o or T.B = M.B +θ_o
  For western Declination: α = B – θ_o or T.B = M.B – θ_o

Note
(+) Sign is used for declination is to the east, sign (–) is used if declination is to west

Fore bearing and Back Bearing: B.B = F.B ± 180°
Local Attraction: F.B – B.B ≠ 180°
Latitude and Departure
→Projection of a line on N-S direction is called latitude: $L = l\cos\theta$
→Projectione of a line on E-W direction is called deparature: $D = l\sin\theta$

Adjustment of closing Error.

- Sum of all internal Angles of a closed Traverse: (2n–4)×90° where n = No. of sides.
- Sum of all deflection Angle = 360°
- Sum of latitude: $\Sigma L = 0$
- Sum of departure: $\Sigma D = 0$
- **Closing error In the Traverse:** $e = \sqrt{(\Sigma L)^2 + (\Sigma D)^2}$
- **Bowditch's Method (Compass Rule)**
  Permissible error in linear Measurment $e\alpha\sqrt{l}$
  Permissible error in angular measurement $e\alpha\frac{1}{\sqrt{l}}$
- **Correction to latitude:** $C_L = \Sigma L \times \frac{l}{\Sigma l}$
- **Correction due to departure:** $C_D = \Sigma D \times \frac{l}{\Sigma l}$
- **Transit Method:** $C_L = \Sigma L \times \frac{L}{L_r}$, $C_D = \Sigma D \times \frac{D}{D_r}$
- **Axis Method.**
  Correction of any length: That length × $\frac{\text{closing error}}{\text{Length of Axis}} \times \frac{1}{2}$



- **Sensitivity:** Angle b/w the line of sights in radius $\alpha = \frac{S}{D} = n \times \frac{l}{R} = \left(\frac{l}{R} = \frac{S}{nD}\right) \times 206265$
  D = Distance of the instrument from the staff
  n = Number of divisions
  l = length of one division (2mm)
  R = Radius of curvature
  S = Staff intercept.
- **Check in Height of Instrument Method**
  Σ BS– Σ FS = Σ Rise – Σ Fall = Last RL–First RL
- **Curvature:** $C_c = -\frac{d^2}{2R} = -0.0785d^2$. **•Refraction:** $C_r = \frac{1}{7}\left(\frac{d^2}{2R}\right)$
- **Final Combination Correction:**
  $C = C_c - C_r = -\frac{6}{7}\left(\frac{d^2}{2R}\right) = -0.06735d^2$
- **Distance of Visible Horizon**
  $d = 3.85\sqrt{h}$, d = in km and h = in meter.
- **Reciprocal Levelling:** The true difference Elevation: $H = \frac{1}{2}[(h_1 - h_2) + (h_1' - h_2')]$
- **Determining Areas:** Mid ordinate rule Δ (Area) = Average ordinate × Length of base, $\Delta = \frac{O_1 + O_2 + \ldots + O_n}{n} \times L$
- **Average ordinate Rule:** Area D = Average ordinate of the base= $\left(\frac{O_0 + O_1 + \ldots + O_n}{n+1}\right) \times L$, $D = \frac{L}{(n+1)} \times \Sigma D$,

ENVIRONMENTAL ENGINEERING

- **Variation of Demand**
  Max. daily Consump. = 1.8 × Annual avg. daily consump.
  Maximum Weekly Consumption = 1.48 ×Avg. weekly
  Maximum Monthly Consumption = 1.28 × Avg. monthly.
- **Population Forecasting Mehtod**
  Arithmetic Increase Method: $P_n = P_o + n\bar{x}$ (For old cities)
  Geometric Increases Method: $P_n = P_o\left(1 + \frac{x}{100}\right)^n$ (For new cities)
  Incremental Increase Method: $P_n = P_o + n\bar{x} + \frac{n(n+1)}{2}\bar{y}$

- **Physical characteristics**
  Turbidity: (limit 1-5 NTU) Baylis, Jackson, Nephelometer
  Colour: Tintometer (limit 5-15 TCU), **Taste & odour:** T.O.N = 1 (↓3)
  Temperature: 10°C desirable (↑25°C)
  Total solid = Dissolved solids + Suspended solids (Gravimetric Method)
- **Chemical Characteristics**
  Total solids & suspended solids: Limit 500-2000 ppm
  PH = – log H^+ (6.6 to 8.5) Methyl Orange & Phenolphthalein
  Total Hardness: $[Ca^{++}] \times \frac{50}{20} + [Mg^{++}] \times \left(\frac{50}{12}\right)$ (EDTA using EBT)
  Carbonate Hardness: min of total hardness or alkalinity
  Chloride: limit – 120mg/L (Water), 250 mg/L (Sewage)
  Nitrogen Content: Limits: Free ammonia ↓0.15mg/L, Organic Nitrogen ↓ 0.3 mg/l, nitrite should be zero, nitrate ↓ 45 mg/l
  Measurement (i) Free Ammonia-by simple boiling of water. (ii) Organic Ammonia – By adding $Kmno_4$, (i+ii) are known as **kjeldahl Nitrogen** Nitrite and Nitrate by - colour Matching Method.
  Chemical: (Mn = 0.05 mg/L) (Iron – 0.3 mg/L), (Fluride : 1.0 –1.5 mg/L) (Sulphate : 250 mg/L) (Cyanides = 0.2mg/L) (Arsenic : 0.01 ppm)
  Screening: Velocity ↑0.8 to 1m/sec
  Based on stokes law. Setting velocity: $V_s = \frac{Q}{BL}$
- **Design Criteria:** Over flow rate = $\frac{Q}{BH}$, 500–750 lit/hr/m2 for plain sedimentation, Depth = 03 to 4.5m Width B ≈ 10 m
- **Coagulants**
  1. Use of Alum
  2. Use of copperas: $(FeSo_4.7H_2O)$
  3. Use of chlorinated copperas $(Fe.(So_4)_3 + FeCl_3)$.
  4. Use sodium Aluminate $(Na_2Al_2O_4)$

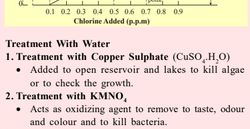
Comparision of slow sand and Rapid Gravity Filters.

Slow sand filter	Rapid sand filter
$C_u = 3–5$	$C_u = 1.2–1.6$
$D_{10} = (0.2–0.3)$ mm	$D_{10} = (0.35–0.55)$ mm
Frequency of cleaning = (1–3) months	Cleaned through Back washing
Design period = 10 year	$n = 1.22\sqrt{Q}$
Use for smaller plants in village	Rate of filtration (3000-6000)
Design on max. daily demand.	$l/m^2/hr$
Rate of filtration (100-200) $l/m^2/hr$ is very low as compared to R.S.F., but efficiency is High	Operational Troubles– (a) Air Binding (b) Mud ball formations (c) Cracking of filter

1. Minor Methods.
(i) Boiling, (ii) Treatment with excess lime, (iii) Treatment with ozone $(KMNO_4)$, (iv) Treatment with silver Process.
2. Major Method Chlorination (Disinfection with Cl_2)

- $Cl_2 + H_2O \xrightarrow{pH<3} HOCl + HCl$, • $HOCl \xrightarrow{pH>3} H^+ + OCl^-$
- $HOCl + \xrightarrow{pH<3} H^+ + OCl^-$, • $NH_2 + HOCl \rightarrow NH_2Cl + H_2O$

NH_2 + HOCl is called combined chlorine.
Chlorine forms: Free chlorine, Hypochlorites (Swimming Pool), Chloramines, Chlorine dioxide



Treatment With Water
1. Treatment with Copper Sulphate $(CuSO_4.H_2O)$

- Added to open reservoir and lakes to kill algae or to check the growth.

2. Treatment with $KMNO_4$

- Acts as oxidizing agent to remove to taste, odour and colour and to kill bacteria.

3. Aerations

- For increasing Di-oxygen to remove CO_2, upto some extent removal of Fe and Mn.

4. Fluoridation

- Necessary if F < 1mg/L. Add Naf or Na_2SiF_6 or H_2SiF_6 to keep fluorine content between 1 to 1.5 mg/L

(1) De-Fluoridation. (if F > 1.5 mg/L) In India, Treatment is done by Nalgonda Technique (Use Alum for reducing flurides)
5. Removal of Radioactive Substances By coagulation & filtration.
6. Desalination (i) By evaporation and distillation (ii) Electrodialysis (iii) Reverse Osmosis.

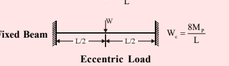
- **Hydraulic design of sewers:** $V = \frac{1}{n}R^{2/3}S^{1/2}$
- **Oxygen Demand:** $\frac{dL}{dt} = -KL, L_t = L_0 - 10^{-k_1 t}$, $BOD_t = L_o - L_t = L_o\left[1 - 10^{-k_1 t}\right]$, $[BOD_5 = 0.684L_0]$,
  $K_{(T^\circ)} = KD_{20}\,[1.047]^{T-20}$

Bar Screen	Grit chamber	Oil and Grease Trap (Skimming Tank)	Biological Unit	Disinfection
Screening	Grit		PST sludge	SST Shade

Fixed Beam

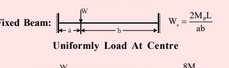
$W_s = \frac{4M_p}{L}$, $W_s = \frac{8M_p}{L}$

Eccentric Load



Fixed Beam: $W_s = \frac{2M_p L}{ab}$

Uniformly Load At Centre



$W_s = \frac{8M_p}{L}$

Member	λmax
A member carrying compressive load resulting from dead load and imposed load	180
A tension member in which reversal of direct stress due to load other than wind and seismic force	180
A member subjected to compressive forces resulting from wind EQ force provide deformation of such member does not affect stress	250
Compression flange of Beam against lateral torsional buckling.	300
A member normally act as a tie in Roof Truss	350
Tension member other than Pre-tension	400

- Strength of plate between rivet holes in Tension = $\sigma_{at} \times (p\text{-}d) \times t$
- Bearing strength of rivet = $\sigma_{at} \times d \times t$ or = $\sigma_{pr} \times d \times t$.
- Shear Strength of rivet = $T_{sr} \times \frac{\pi}{4} \times d^2$ (in single shear), $2 \times T_{sr} \times \frac{\pi}{4} \times d^2$ in double shear), d = gross diameter of rivet, $d = 6.01\sqrt{t}$ (unwins formula)
- **Diameter:** Grosss diameter = nominal diameter +