CAPSULE

CIVIL ENGINEERING

FOR QUICK REVISION

यूथ कॉम्पिटिशन टाइम्स

UPSSSC JE | UPPSC AE | NHPC JE | POLYTECHNIC LECTURER

- SSC JE
- UKPSC AE
- BPSC AE
- CGPSC AE
- MPPSC AE
- RPSC AE
- DMRC JE
- LMRC JE
- JMRC JE
- BMRC JE
- DSSSB JE
- UP Jal Nigam
- UKSSSC JE
- RSMSSB JE
- MPPEB SUB ENGINEER
- HPSSC JE
- HSSC JE
- Punjab JE
- CGPEB SUB ENGINEER
- BSSC JE
- DRDO JE
- ISRO JE
- UPPCL AE/JE
- UPRVUNL AE/JE
- JVUNL JE
- SAIL JE
- GAIL JE
- BHEL JE
- NTPC JE
- DFCCIL
- COAL INDIA LTD. JE
- RRB JE etc.

CIVIL ENGINEERING Capsule

Useful for All Civil Engineering Competitive Exams...

Scanned with CamScanner

INDEX

- Building Material ---------- 3
- Concrete Technology ---------- 10
- CPM & PERT ---------- 12
- Building Construction and Maintenance Engineering ---------- 13
- Fluid Mechanics & Hydraulic Machine ---------- 15
- Strength of Materials ---------- 28
- Applied Mechanics ---------- 34
- Soil Mechanics ---------- 36
- Highway Engineering ---------- 43
- Railway Engineering ---------- 48
- Bridge Engineering ---------- 50
- Airport Engineering ---------- 51
- Tunnel Engineering ---------- 52
- Reinforced Cement Concrete ---------- 53
- Steel Structure ---------- 58
- Structure Analysis ---------- 62
- Building Estimate, Costing & Evaluation ---------- 64
- Public Health Engineering ---------- 68
- Surveying Engineering ---------- 70
- Irrigation & Hydrology Engineering ---------- 77

Scanned with CamScanner

BUILDING MATERIALS

■ **Rock minerals-**

Quartz, Mica, Gypsum, Dolomite, Amphibole, Calcite, Feldspar etc.

■ **Hardness of stone based on Moh's scale-**

Talc	1	Scratched by the finger nail
Gypsum	2	
Calcite	3	Scratched by knife
Fluorite	4	
Apatite	5	
Feldspar	6	Scarcely scratched by knife
Quartz	7	
Topaz	8	Not scratched by knife
Corundum	9	
Diamond	10	

■ **Properties of Minerals-**

Cleavage	Measurement of the capability of some minerals to split along certain planes parallel to the crystal faces
Streak	Colour of the mineral in powder form
Lustre	Shine on the surface due to reflection of light of a mineral

■ **Classification of Rocks-**

1. Geological

- **Igneous**
  Ex.-Basalt, Trap, Dolerite, Granite, Syenite Gabbro etc.
  - **Extrusive/Volcanic/Effusive** (Extremely fine) **Ex.** Basalt, Trap, Pumice etc.
  - **Intrusive**
    - Plutonic (Deep Depth) (Coarse Grained) **Ex.** Granite, Syenite
    - Hypabyssal (Shallow depth) (Fine Grained) **Ex.** Dolerite
- **Sedimentary**
  Ex.-Sand Stone, Lime Stone, Laterite, Dolomite, Gypsum, Shale, Chalk, Magnesite etc
- **Metamorphic**
  Ex. Gneiss, Quartzite, Marble, Slate, Schist etc

■

2. Physical

- **Unstratified Rock**
  Ex.-Granite Basalt, Trap Diorite, Dolerite Dolomite, Syenite Gabbro etc.
- **Stratified Rock**
  Ex.-Lime Stone Sand Stone, Shale, Gypsum Laterite etc
- **Foliated Rock**
  Ex-All stratified Rocks except marble and quartzite

■

3. Chemical

- **Silicious Rocks**
  Ex.-Granite, Basalt, Trap, Syenite, Gneiss, Sand Stone, Quartzite etc.
- **Calcareous Rocks**
  Ex.-Gypsum, Dolomite, Lime Stone, Marble etc.
- **Argillaceous Rocks**
  Ex.-Laterite, Shale, Kaoline, Slate, Schist etc

■ **Classification of Rocks on the Basis of Mineral Available-**

Name of Rock	Example
Mono mineralic Rocks (Composed of only one mineral)	Quartzite, Marble & Gypsum
Polymineralic Rocks	Granite, Trap, Basalt, Shale, Sand Stone, Shale, Slate

■ **Metamorphism of Rocks-**

Original Rock	Metamorphic form
Granite	Gneiss
Syenite	Gneiss
Sand Stone	Quartzite
Lime Stone	Marble
Marl	Marble
Dolomite	Marble
Shale	Slate
Mud Stone	Slate
Dolerite/Basalt	Schist

Scanned with CamScanner

■

Descriptive	Elasticity (kg/cm²)
Very stiff rock	8×10^5 - 16×10^5
Stiff rock	4×10^5 - 8×10^5
Medium stiffness rock	2×10^5 - 4×10^5
Less stiffness rock	1×10^5 - 2×10^5
Yielding rock	0.5×10^5 - 1×10^5
High yielding rock	0.25×10^5 - 0.5×10^5

■

Types of rock/soil	Max. bearing capacity (tonne/m²)
Lime stone	400
Schist and shale	300
Clay shale	100
Compacted sand stone	45
Loose graval	25
Soft clay	10

■ **Compressive strength of different types of stones-**

Stone	Compressive strength (in MPa)
Trap	350-380
Gneiss	206-370
Basalt	150-185
Slate	75-207
Dolerite	90-150
Syenite	90-150
Granite	75-127
Lime stone	54
Sand stone	64

■ **Use of various types of stone-**

Name of Rock	Use
Granite	Railway ballast, Roofing, Abutment, Pier and Sea walls
Marble	Ornamental work
Lime Stone	Manufacture of cement
Slate	Flooring, roofing
Quartzite	Retaining wall
Basalt	Marine work, Rubble masonry
Kankar	Manufacture of Hydraulic lime

■ **Tools Used in Quarrying of Stone-**

Jumper	To make hole
Scraping spoon	For Cleaning hole
Dipper	For making deep hole
Priming Needle	To make space for fuse
Tamping Rod	For tamping of explosive Length- 600 mm Dia (ϕ)- 16 mm

■ **Steps for Blasting-**

Boring→ Cleaning→ Charging→ Tamping→ Firing

■ **Quantity of Explosive-**

$$N = [L.L.R(\text{in m})]^2 \times 1.5 \text{ (in gm.)}$$

$$= \frac{[L.L.R(\text{in m})]^2}{0.008}$$

$$= \frac{[L.L.R(\text{in cm})]^2}{61}$$

■ **Explosive Material Used in blasting-**

Name of Explosive	Chemical Composition
Blasting Gelatine	Nitroglycerine (93%) + Gun- cotton (7%) **Use**-In deep wells, underground works, in wet conditions.
Gun Cotton (Most powerful)	Cotton with the solution of (HNO_3+H_2SO_4) **Use**-where demolitions are required
Dynamite	Nitroglycerine (75%) + Fine sand (25%) **Use**- Both under water and surface blasting
Blasting/ Gun powder	Potassium nitrate (65%) + Sulphur (25%) + Charcoal powder 20% **Use**-In quarrying large blocks
Rock-a-Rock	Potassium Chlorate (79%) + Nitro benzol (21%) **Use**-Under water and damp situation blasting

■ **Stone crusher and equipment-**

Crusher Type	Equipment
Primary	Jaw, Impact and Gyratory crusher and Hammer mill
Secondary	Roll crusher, Cone crusher
Tertiary	Ball mill, Roll mill and Rod mill

■ **Specific Gravity of Various Types of Stone-**

Name of Stone	Specific gravity
Sand Stone	2.65 - 2.95
Marble	2.7 - 2.85
Granite	2.65 - 2.79
Basalt	2.6 - 3
Slate	2.72 - 2.89
Laterite	2 - 2.2
Lime Stone	2 - 2.75
Gniess	2.5 - 2.7

■ **Various types of test and purpose for stone-**

Type of Test	Determine for
Abrasion Test (By Dorry Testing Machine)	wearing resistance
Attrision Test (By Deval Testing Machine)	Hardness, Toughness and rate of wearing resistance
Crushing Strength Test (By C.T.M) (IS : 1121-1974)	Compressive strength
Smith's Test	Soluble minerals/ Muddy matter
Brard's Test	Frost resistance
Acid Test	Weather resistance
Crystallization Test (IS : 1126-1974)	Durability
Hardness Test (Moh's Scale)	Hardness
Impact Test (By Page Impact Machine)	Toughness
Water Absorption Test (IS 1124-1974)	% Voids (>5% for good stone)

Scanned with CamScanner

■ **Dorry Testing Machine Test-**

Friction Factor	Type of Rock
0-14	Soft rock
14-17	Medium hard
> 17	Hard rock

■ **Impact Test-**

Toughness coefficient	Toughness
19 or More	Very tough
16 to 17	Moderate tough
16 or below	Poor tough

■ **Attrision Test-**

Friction Co-efficient	Quality of Stones
2%	Good
3%	Medium
5% or More	Useless

■ **Common Brick Size-**

Brick Classification	Usual size	Nominal size
Conventional/ Traditional/ user size	$9'' \times 4\frac{3}{8}'' \times 2\frac{3}{4}''$ (23×11.2×7.0) cm	$9'' \times 4\frac{1}{2}'' \times 3''$ (23×11.4×7.6) cm
Standard/ Modular/ Normal size	(19×9×9) cm	(20×10×10) cm

■ **Ingredients of Good Brick Earth-**

Ingredients	% in brick
Silica (SiO_2)	50 - 60
Alumina (Al_2O_3)	20 - 30
Lime (CaO)	2 - 5
Iron Oxide (Fe_2O_3)	3 - 5
Magnesia (MgO)	<1
Alkalies	<1

■ **Functions of Various Brick Ingredients-**

Ingredients	Function
Silica	Imparts Strength **Excess-**Brittle (Due to loss of cohesion)
Alumina	Impart plasticity **Excess-**Cracks developed, corner deformed
Lime	Used as flux (Reduce melting point) **Excess-** Brick over burnt and shape changed
Iron Oxide	Red colour, Used as flux **Excess-** Provide dark blue or blackish colour
Magnesia	Yellow colour and its prevent to shrinkage, **Excess-**Give yellowish colour

■

Frog	10 cm × 4 cm × 1 or 2 cm
Stock Board **(To make frog)**	21 cm × 10 cm × 6 cm
Pallet Board **(To dry the brick)**	30 cm × 12 cm × 1 cm

■ **Sequence for the Preparation of Brick Earth-**

Unsoiling → Digging → Weathering→ Blending →Tempering/Kneeding

■ **Burning Zone of Bricks-**

Burning Temperature- 900 - 1200°C		
Dehydration Zone 400-650°C	Oxidation Zone 650-900°C	Vitrification Zone 900-1200°C

■ **Efficiency of Kiln-**

Types of kiln	Ist Class Brick outcome	Remark
Pazawah	50-60%	–
Allahabad kiln	60-70%	Intermittent
Bull's Trench kiln	70-80%	Semicontinuous
Hoffman's kiln	80-90%	Continuous

■ **Class of Brick on the Basis of Strength-**
IS : 10719557-1970

Class	Comp. Strength
Grade A	$\nless$ 105 kg/cm^2
Grade AA	$\nless$ 140 kg/cm^2
Grade B	$\nless$ 70 kg/cm^2
Grade C	$\nless$ 35 kg/cm^2

■ **Types of Refractory Bricks and its composition-**

Bricks	Composition
Acid Refractory	Silica- 95-97%, Lime- 1-2%
Basic Refractory	Magnesia- 85% (max) CaO- 25%(max) Silica- 5.5%(max)
Neutral Refractory	Chrome + Iron ore + Bauxite ore+ Silica + Magnesia

■ **Efflorescence Test- According to IS 3495 (part-III) : 1992**

White patches	Alkalies
Up to 10%	Slight
10 - 50%	Moderate
>50%	Severe
Presence in large amount	Serious

■ **Sample Required for Various Brick Test-**

Bricks Test	I.S. Code	No. of Sample
Compressive strength test	3495-Part I	6
Water absorption test	3495-Part II	5
Efflorescence test	3495-Part III	–
Warpage test	3495-Part IV	10
Dimension test	1077	20

Note- Tolrance in brick dimension test -

Length - 380 ± 8 cm

Width - 180 ± 4 cm

Scanned with CamScanner

Special Forms of brick-

Figure	Brick Name	Figure	Brick Name
	Rounded ended		Cant
	Double cant		Compass
	Bull nosed		Perforated
	Hollow		Coping
	Queen closer		King Closer
	$\frac{3}{4}$ Brick		Bat

General Data about bricks-

Types of bricks	Water absorption (%)	Compressive Strength (Kg/cm^2)	Use
1st Class	≤ 20	>105	Facing work R.B.Slab
2nd Class	≤ 22	>70	Hidden Structure
3rd Class	> 25	>35	Temporary brick masonry
4th Class (Jhamma or over burnt bricks)	10 -12	350	Bricks ballast, lime concrete foundation, road metals
Perforated Bricks (IS 2222)	15	70	Partition Wall
Hollow Bricks (IS 3952)	20	35	For making heat proof, sound proof, damp proof walls
Paving Bricks (IS 3583)	<5	350	Road pavement
Soling Bricks (IS 5779)	< 20	50	Soling of road
Refractory Bricks (IS 6902)	4 -10	350	Kiln lining, furnace boiler combustion
Engineering Brick Class-A	4 -5	>125	D.P.C
Class-B	7	75	Multistorey building
Sundry bricks	-	15-25 ≈ 21	-

Type of Lime Obtained After Calcination-

Pure lime stone	Pure lime
Dolomite	Magnesia lime
Kankar	Hydraulic lime
Chalk	Pure lime
Gypsum	Pure lime
Calcined lime stone	Quick lime
Calcined dolomite stone	Non-hydraulic lime
Shale	Pure lime

Chemical Formula	Name of lime
Calcium carbonate [$CaCO_3$]	Lime Stone
Calcium oxide [CaO]	Quick lime, Lump lime, white lime, Rich lime, Pure lime
Calcium Hydroxide [$Ca(OH)_2$]	Slaked lime, Fat lime
Calcium Sulphate [$CaSO_4.\frac{1}{2}H_2O$]	Plaster of Paris
Calcium Sulphate [$CaSO_4 . 2H_2O$]	Gypsum

Chemical Reaction of Lime

1. $CaCO_3 \xrightarrow[\text{Calcination}]{816°C} \underset{\text{Pure lime}}{CaO} + CO_2 \uparrow$
2. $CaO + H_2O \rightarrow Ca(OH)_2$
3. $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O + \text{Heat}$

Item description	Feedly Hydraulic lime	Moderate Hydraulic lime	Eminently Hydraulic Lime
% impurities	05 to 10%	11 to 20%	21 to 30%
Slacking action	Few minutes	1 or 2 hours	1 day or more
Setting action	3 week or more	1 week or more	1 days or more
Hydraulicity	Feebly	Moderate	Eminently
Use	Used for ordinary masonry work	For superior type of masonry work	Use in very damp places

Scanned with CamScanner

Classification of lime as Per B.I.S. (IS :712)

1. Class A
- Eminently Hydraulic lime
- Used in Hydraulic Structure
- Compressive strength of 28 days -28kg/cm²
- Initial setting time 2 hours and final setting time 48 hours

2. Class B
- Semi-hydraulic lime
- Use in masonry work and lime-concrete
- Compressive strength of 28 days-17.5 kg/cm²

3. Class C
- Fat lime
- Use in Plaster work

4. Class D
- Magnesium Lime or Dolomite lime
- Use in white washing and Finishing or Plastering

5. Class E
- Kankar lime
- Use in masonry mortar and lime-concrete

Chemical Components of Portland Cement-

Oxide/Composition /Average composition	Function
Lime (CaO) 60-65% ≈ 63%	Strength & soundness control
Silica (SiO_2) 17-25% ≈ 20%	Due to excess reduces strength
Alumina (Al_2O_3) 3-8% ≈ 6%	Responsible for quick setting excess of its lowers strength
Iron oxide(Fe_2O_3) 0.5-6% ≈ 3%	Used as flux
Magnesia (MgO) 0.1- 4% ≈ 2%	Imparts colour & hardness
Gypsum 3-6% ≈ 3%	Used as retarder
Sulphur (SO_3) 1-3% ≈ 1%	Impart soundness
Alkalies 0.2-1% ≈ < 1%	Used as flux & Imparts efflorescence

Chemical Compositions or Bogue's compound of cement-

Chemical/Bogue's Compound	Composition /Avg. composition	Function
C_3S (Alite)	25-50% ≈ 42%	7 days hardness & strength
C_2S (Belite)	20-45% ≈32%	Ultimate strength
C_3A (Celite)	8-12% ≈11.5%	Flash set
C_4AF (Felite)	6-10% ≈ 9%	Poorest cementing value

Minimum Surface Area of Various Cement-

Cement type	Surface area cm²/gm
OPC	2250
PPC	3000
LHC	3200
HAC	2250
SSC	4000
Hydrophobic cement	3500

According to IS: 10262:1982 compressive strength for various grade of OPC-

Grade	Compressive strength (MPa)
A	31.9 - 36.8
B	36.8 - 41.7
C	41.7 - 46.6
D	46.6 - 51.5
E	51.5 - 56.4
F	56.4 - 61.3

Decreasing order of Bogue's compound based on the following properties:

Strength	$C_3S > C_2S > C_3A > C_4AF$
Reaction with water	$C_3A > C_4AF > C_3S > C_2S$
Heat of hydration	$C_3A > C_3S > C_4AF > C_2S$
Rate of hydration	$C_4AF > C_3A > C_3S > C_2S$

Water required for hydration-

- Bound water = 23% by weight of cement
- Gel water = 15% by weight of cement
- Total minimum water for Complete hydration = 38%

Note- Cement reaction is an exothermic.

Required Consistency for Various Cement test at (27 ± 2°C)-

Initial & final setting time test	0.85P
Soundness test	0.78P
Compressive strength test After 3 days - 16 N/mm² After 7 days - 22 N/mm²	$\left(\frac{P}{4}+3.5\right)\%$
Tensile strength test After 3 days - 2 N/mm² After 7 days - 2.5 N/mm²	$\left(\frac{P}{5}+2.5\right)\%$

Reduction in comp. strength of cement due to aging-

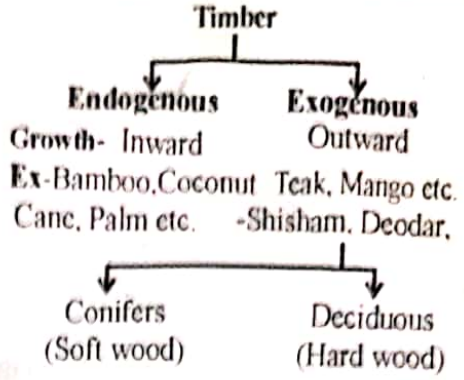
3 months	20%
6 months	30%
12 months	40%
24 months	50%

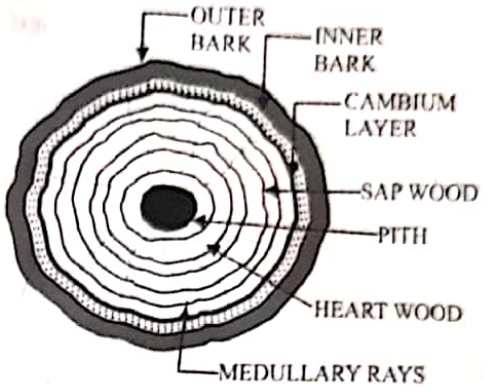
Scanned with CamScanner

Setting Time & use of various types of cement-

Cement Type	Setting time		Use
	Initial	Final	
Rapid Hardening (IS:8041)	30 Min.	10 Hrs.	Bridge, road maintenance or repairing work
High Alumina Cement (IS: 6452)	30 Min - 3.30 Hrs.	5 Hrs.	Precast structure, refractory bricks, used where chemical attacks are more
Quick Setting Cement	5 Min.	30 Min.	Foundation basement, under water structure, mass concrete raft foundation
Low Heat Cement (IS: 12600)	60 Min.	600 Min.	Mass conc. work such as Dam
Portland Pozzolana Cement (IS:1489 P-I)	30 Min.	600 Min.	Running water structure foundation, basement
Super Sulphate Portland Cement (IS: 6909)	30 Min.	600 Min.	Rcc pipes, where sulphate attack is more, Hydraulic structure
Sulphate Resisting Cement (IS:12330)	30 Min.	600 Min.	Sea water works, sewers, lining of canals
Portland Slag Cement (IS: 455-1989)	30 Min.	600 Min.	Mass concreting used as OPC
White Cement Coloured Cement (IS:8042)	.....	....	Plaster, ceiling Ornamental works Terrazo floor
Hydrophobic Cement (IS:8043)	.....	.....	Water tight structure in basement
Masonry Cement (IS:3466)	90 Min.	24 Hrs.	Masonry works

Timber classification on the Basis of Growth–





Macro Structure of Exogenous Tree-

Medulla (Pith)	The innermost part or core of the stem of a tree
Heart wood	Death portion of the tree
Sap wood	Outer layers of a log of wood
Cambium	To growth wood cells
Bark	Protect the wood against mechanical damage
Transverse septa (Medullary rays)	The vascular tissue which Encloses the pith
Annual rings	A cellular tissue and woody fibre arranged in distinct concentric circle

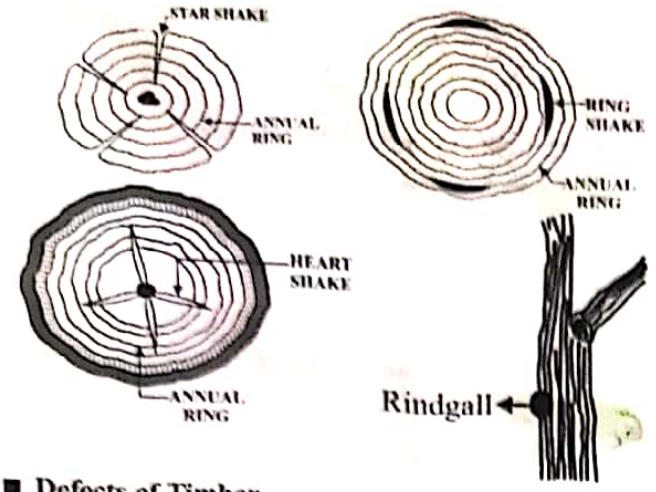
Properties of a Good Timber-

Density	540 kg/m^3
Specific gravity	1.54
Moisture content	10-12%
Shrinkage	0.1-0.3% along fibers
Swelling	0.1-0.8% along length
Sound Conductivity	2-17 time more than air

Strength of timber at 12% Moisture Content-

Shear strength	6.5 -14.5 N/mm^2
Bending strength	10.2 -18.2 N/mm^2
Compressive strength	33 -77.5 N/mm^2
Tensile strength	80-190 N/mm^2

Scanned with CamScanner



■ **Defects of Timber-**

Checks	Longitudinal cracks which is normal to the annual rings
Shakes	Longitudinal separation b/w the Annual rings.
Star shake	Wide at outside and diminish inside
Heart shake	Wide at center and diminish out side
Cup shake	Caused due to rupture of tissue in circular direction. It is developed due to non uniform growth
Ring shake	When cup shake cover the entire ring.
Radial shake	When timber is exposed to sun for seasoning after being felled down
Knots	These are the base of branches which are broken or cut-off from the trees.
Rind Galls	Abnormal growth or curved swellings on the body of tree.

■ **Use of Various type of Timber-**

Guava	Scientific instruments
Babool	Agricultural instruments
Mulberry	Sports Goods
Jackfruit	Musical instruments
Benteak	Boat
Plywood	Teak

Note-Swelling of Woods along fiber length-**0.1-0.8%**

Dry Rot-

- Turning of timber tissues into a dry powder due to fungi attack.
- It is due to imperfect seasoning or ventilation.

Wet Rot-

- Disintegration of tissues of the timber due to alternate wetting and drying.

☞ ASCU Treatment-Developed by Forest Institute Dehradun

☞ Timber can be made fire resistant by Sir Abel's Process.

■ **Ingredients of Paint-**

Ingredient	Properties
Base	• Metallic oxide is the principal constituent • Zinc white is weather resistant. • Aluminium powder used for all aluminium paints
	Ex.- White lead, Red lead, Zinc oxide, Aluminium oxide, Iron oxide, Lithophone etc.
Vehicle/ Binder	• Holds the constituent of paint and spread over surface • It forms the body of the paint • Linseed oil is the most widely used as vehicle
	Ex.- Linseed oil, Nut oil, Poppy oil and Tung oil
Solvent/ Thinners	• Used to thin the paints, increase the covering properties
	• Turpentine is used extensively **Ex.-** Petroleum, Spirit, Naptha, benzene, Turpentine oil etc.
Driers/ Plasticizers	• Accelerate drying of the vehicle • Quantity limited to 8% • Red lead is best for prime coat over steel.
	Ex.- Letharge (Oxidized lead), Lead acetate [Red lead (Pb_3O_4)]
Adultrants/ Extenders	• Reduce weight, increase durability. • Best Adultrant is Barium Sulphate.
	Ex.- Barium Sulphate, Calcium Carbonate, Magnesium Silicate and Silica.

■ **Colouring Pigments-**

Lamp black, Ivory black	Black
Prussian blue, Indigo	Blue
Chrome yellow, Yellow orchre	Yellow
Burnt umber, Burnt Sienna	Brown
Vermillion, Red lead	Red
Copper sulphate, Chromium oxide	Green
White lead Lithophone	White

Scanned with CamScanner

■ **Ingredient for Different Types of Paint-**

Types of paints	Base	Vehicle	Use
Aluminium Paint	Aluminium powder	Sprit or Oil Varnish	Painting in Poles, Tower, Metal roofs
Asbestos/ Fire proof paint	Asbestos minerals	-	Stopping leakage in sloppy roofs, painting of gutters etc.
Bitumenous Paint	Natural Asphalt or residual bitumen	Mineral spirit or Neptha	High Water Resistance
Plastic Paint	Plastic powder	Water	Interiors of auditorium, Showrooms and offices.
Cellulose Paint	Methyl or Ethyl Cellulose	Petrolium	Painting cars, ships and aeroplanes.
Cement Paint [IS :5410]	White or Coloured cement	Water	Exterior surface of building
Enamel paint	White Zinc, White Lead	Varnish	Acid resistance, alkalis & water proof
Luminous paint	Calcium Sulphide	Varnish	Metal surface & sign board

Concrete Technology

■ **Stripping Time of Formwork-**

Formwork Types	Stripping time
Vertical formwork to column, wall, beams	16-24 Hours
Soffit formwork to slab	3 days
Soffit formwork to beam	7 days
Props to slab	
(a) span upto 4.5 m	7 days
(b) span over 4.5m	14 days
(a) span upto 6 m	14 days
(b) span over 6 m	21 days

☞ $E_c = 5700\sqrt{f_{ck}}$ N/mm² [I.S.456 : 1978]

$E_c = 5000\sqrt{f_{ck}}$ N/mm² [I.S.456 : 2000]

☞ **Target mean strength of concrete**

$$f_{CM} = f_{CK} + 1.65\sigma$$

σ = Standard deviation

F_{CM} = Target mean strength

F_{CK} = Characteristic strength

☞ **Permissible shear stress of reinforced concrete**

$$\sigma_c = \frac{f_{ck}}{30}$$

☞ **Coefficient of variation** $C_v = \frac{\sigma}{\mu}$

Where,

$\mu = \frac{\sum X}{n}$ n = No. of sample

■ **Classification and Grades of the concrete-**

Designation	Mix. Proportion (Cement : Sand: Coarse Aggregate)	Characteristic Compressive Strength in N/mm²	Group	No. of grade
M-5	1:5:10	5	Lean Concrete	2
M-7.5	1:4:8	7.5		
M-10	1:3:6	10	Ordinary concrete	3
M-15	1:2:4	15		
M-20	1:1.5:3	20		
M-25	1:1:2	25	Standard Concrete	7
M-30	Design mix Conc.	30		
M-35		35		
M-40		40		
M-45		45		
M-50		50		
M-55		55		
M-60		60	High Strength Concrete	5
M-65		65		
M-70		70		
M-75		75		
M-80		80		

Scanned with CamScanner

■ **Number of sample Required for testing of conc.**

Conc. quantity	No. of Sample
1 m^3 – 5 m^3	1 sample
6 m^3 – 15 m^3	2 sample
16 m^3 – 30 m^3	3 sample
31 m^3 – 50 m^3	4 sample
> 50 m^3	4+1 for each 50m^3 work

Note - 1 Sample = 6 cube

■ **Standard deviation of concrete-**

Grade of concrete	Standard deviation (σ) (N/mm^2)
M-10 to M-15	3.5
M-20 to M-25	4
M-30 to M-55	5

■ **For Maximum 20 mm Nominal Size Aggregate-**

Exposer Condition	Min. Cement Content (Kg/m^3)		Min. Grade of Conc.		Max. Water Cement Ratio		Min. Concrete Cover (mm)
	P.C.	RCC	P.C.	RCC	P.C.	RCC	
Mild	220	300	-	M-20	0.60	0.55	20
Moderate	240	300	M-15	M-25	0.60	0.50	30
Severe	250	320	M-20	M-30	0.50	0.45	45
Very servere	260	340	M-20	M-35	0.45	0.45	50
Extreme	280	360	M-25	M-40	0.40	0.40	75

Note: P.C. = Plain Concrete, RCC= Reinforced Cement Concrete

■ **Max. Water Content Per Cum of Conc. For Nominal Max. Size of Aggregate-**

Nominal Max. Size of Agg.(mm)	Max. Water Content (Kg)
10	208
20	186
40	165

■ **Compressive Strength of Concrete at Various Age-**

Age	Strength%
1 day	16
3 days	40
7 days	65
14 days	90
28 days	99

■ **Fineness Modulus of Aggregate**

Type of Agg.	Fineness Modulus Range
Coarse Agg.	6 - 8.5
All-in one Agg.	3.5 - 6
Fine Agg.	2 - 3.5
Fine Sand	2.2 - 2.6
Medium Sand	2.6 - 2.9
Coarse Sand	2.9 - 3.2

■ **Workability, Slump and Compacting Factor of Concrete with 20 mm and 40 mm Size of Aggregate**

Degree of Workability	Slump in mm	Compacting Factor	Use for which Conc.is Suitable
Very Low	0-25	0.78	Used in road making-roads vibrated by power operated machines
Low	25-50	0.85	For foundations with light reinforcement, Roads vibrated by hand operated Machines
Medium	50-100	0.92	manually compact-flat slabs using crushed agg. Normal rein - forced concrete manually compacted and heavily rein- forced sections with vibrations
High	100-175	0.95	for sections with congested Reinforcement. Not normally suitable for vibration.

■ **General Features of the Main Types of Portland Cement-**

ASTM Type	Classification
Type-I	Ordinary Portland cement
Type-II	Moderate Sulphate Resistance (Modified cement)
Type III	Rapid Hardening cement
Type IV	Low Heat cement
Type V	Sulphate Resisting cement
Type IP	Portland Pozzolana cement
Type IS	Portland slag cement

Scanned with CamScanner

- **Permissible limit for solids in concrete water as per IS 456-2000**

Material	Permissible Limit
Organic	200 mg/l
Inorganic	3000 mg/l
Sulphate	400 mg/l
Chlorides	
(i) RCC	500 mg/l
(ii) PCC	2000 mg/l
Suspended	2000 mg/l

- **Effect of sugar in cement conc.**

Quantity	Effect
0.05%	No effect
0.15%	Retarder
0.20%	Accelerator
0.25%	Set more Rapidly but loose strength

Note - Sugar is consider as retarder

- **Strength of conc. Increase with age-**

Month	Age Factor
1	1
3	1.1
6	1.15
12	1.2

- **Consistency and Degree of Workability for Vee-Bee Degree-**

Vee-Bee Degree	Consistency	Degree of Vorkability
20-40	Very Low	Very very low workable concrete
10-20	Low	Very low Workable concrete
5-10	Medium	Low workable concrete
3-5	High	Medium workable concrete
1-3	Very High	High workable concrete
< 1	Fluid	Very high workable concrete

- **Agg. Water and W/C Ratio for Various Types of Concrete Grade-**

Concrete Grade	Agg. Per bag cement	Water per bag cement	W/C Ratio
M-5	800 kg	60 liter	1.2
M-7.5	625 kg	45 liter	0.9
M-10	480 kg	34 liter	0.68
M-15	350 kg	32 liter	0.64
M-20	250 kg	30 liter	0.60

- **Min. Grade of Conc. Required for Various Types of Construction-**

Minimum Grade	Types of Construction
M-5, M-7.5	Lean concrete base
M-15	Plain cement concrete
M-20	RCC (General construction)
M-30	Water tank, Domes
M-30	RCC in sea water and Post-tensioned
M-40	Pre-tensioned

CPM & PERT

- **PERT (Programme Evaluation and Review Technique)-**
  - Three time estimates are made
  - Follows β distribution
  - Probabilistic Approach
  - For Research and Development work
- **Some Useful Formula**

$$t_E = \frac{t_O + 4t_m + t_p}{6}$$

$$\sigma = \frac{t_p - t_O}{6}$$

$$\sigma^2 = \left(\frac{t_p - t_O}{6}\right)^2 = \text{variance}$$

Where,

σ = Standard deviation

t_O = Optimistic time

t_p = Pessimistic time

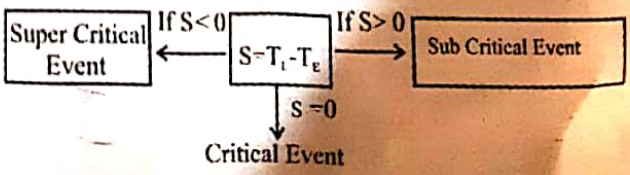
t_m = Most likely time

t_E = Expected completion time of an activity

- **Event Time-**

$T_E^j = T_E^i + t_e^{ij} \rightarrow$ only one path
$T_L^j = T_L^i - t_e^{ij} \rightarrow$ only one path

Slack: This is the time by which an event may be delayed without affecting the completion time of the project



Scanned with CamScanner

■ **Probability Factor (Z)-**

$$Z = \frac{T_s - T_e}{\sigma}$$

T_s → Scheduled Completion time

T_e → Expected Completion time

Z	P	Z	P
0	50%	±1	84.13%
±2	97.72%	±3	99.87%

■ **CPM (Critical Path Method)-**

- One time estimate
- Deterministic approach
- Minimum cost is found corresponding to optimum time
- For repetitive type of work
- Normal distribution is followed

■ **Activity Times-**

$EST = T_i^I$ or $EFT = T_i^I + t^{ij}$

$LFT = T_j^I$ or $LST = LFT - t^{ij}$

■

Float	Flot denotes the range within which activity time or its finish time may fluctuates without effecting the completion of the project.
Total float $F_T = LST - EST$ or $F_T = LFT - EFT$	
Free float $F_F = T_E^j - T_E^i - T_e^{ij}$ or $F_F = F_T - S_j$	
Independent float $F_I = T_E^j - T_L^i - T_e^{ij}$ or $F_{ID} = F_F - S_i$	

■ **Tail Event Slack-**

$F_T = 0$ For critical path
$F_T > 0$ For sub critical path
$F_T < 0$ For super critical path
Interfering float $F_{(IN)}$ $S_j = F_T - F_F$
Cost slope = $\frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}}$

Building Construction & Maintenance Engineering

■ **Classification of Building According to NBC-**

S.N.	Class	Types of Buildings
1.	Group A	Residential Building
2.	Group B	Educational Building
3.	Group C	Institutional Building
4.	Group D	Assembly Building
5.	Group E	Business Building
6.	Group F	Mercantile Building
7.	Group G	Industrial Building
8.	Group H	Storage Building
9.	Group I	Hazardous Building

■ **Maximum Built Up Area for a Building-**

Plot area	Maximum Built Up Area
< 200 m^2	60% of the plot area
200 - 500 m^2	50% " " "
500 - 1000 m^2	40% " " "
> 1000 m^2	33.33% " " "

■ **Types of Bond-**

Stretcher bond	All bricks are laid as stretchers on the faces of the wall generally used for partition wall (10 cm)
Header bond	All the bricks are laid as header on the face of wall. Use staining of well, corbels footing... etc
English bond	Alternate course of header & stretcher. Mostely used in government work. It is costly and stronger than flemish bond
Flemish bond	Each course has alternate header & stretchers. Flemish bond give better appearance then english bond
Facing bond	Bricks of different thickness are to be used in the facing or backing of the wall

■ **Classification of wall-**

Load bearing wall	Non-load bearing wall
Solid wall with piers (pilasters)	Partition wall
Vineered wall	Panel wall
Cavity wall	Free standing wall
Solid wall	Curtain wall

☞ **Frieze :** A coarse of stone provided immediately below cornice is called frieze

☞ **Bull nose/cow nose :** Use for making corner or curve shape in brick masonry.

☞ **Perpend :** It is that vertical joint on face of the wall, which lie directly above the vertical joints in the alternate course.

■ **Door and window-**

1. **Doors for residential building:**
   - External door (1×2) to (1.1×2)m
   - Internal door (0.9×2) to (1×2)m
   - Doors for bathrooms & water closet- (0.7×2) to (0.8×2) m
2. **Public building (School, Hospital, Library):**
   (a) (1.2×2) m,
   (b) (1.2×2.1) m,
   (c) (1.2×2.25) m

Scanned with CamScanner

■ **Use of Door-**

Sliding door	For AC building
Swinging door	For residential
Folding door	For covering large covering opening
Revolving door	Public building
Rolling steel shutter	Garrage, Godowns
Designations of door	Length ×type of door × height

■ **Size of Timber Chaukhat-**

(i) For door- 8×10cm-10×12cm
(ii) For window- 8×8 cm - 8×10 cm
(iii) Ventilator- 8 cm ×8 cm

■ **Window-**

- Located on Northen side (maximum day light available)
- Minimum window area = 1/8 of total floor area of room
- Total area of window - (10-20)% of floor area of room

☞ Public building : Minimum area of window = 20% of total floor area

■

Particulate	Arch	Lintel
Shape	Curved	Horizontal & straight
Bed joint	Joints are radial exception monolithic construction	Joints are horizontal
Leteral 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

■ **Property of Staircase**

- Width of stair in domestic building- **90 cm**
- Width of stair in public building- **(1.5-1.8) m**
- Number of total step in a flight $\not> 12$
- Number of steps in a flight $\not< 3$
- Angle of inclinations **25-40°**
- Maximum pitch/slope for public building - **33°**
- Minimum width of stair in commercial building **-1 m**
- Head room must be $\not< 2.05$ **m**

■ **Relation b/w Riser and Tread**

$2R + T = 60$

$R + T = 40$ to 45

$R \times T = 400$ to 450

Where, R = Rise in cm

T = Tread in cm

☞ In public building the maximum riser is limited to 15 cm

☞ **In Case of straight staircase**

No. of tread = No. of riser –1

☞ **In case of one landing and two flight**

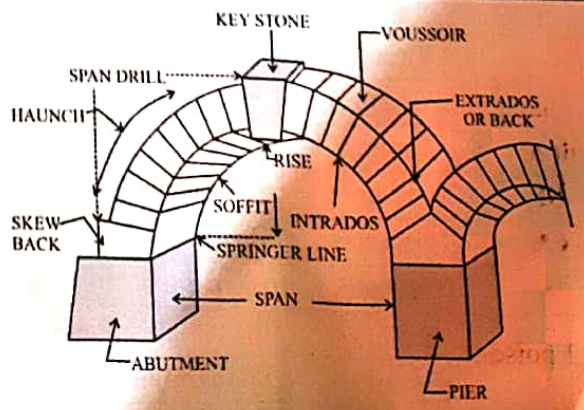
No. of tread = No. of riser –2

■ **Types of Roof Trusses and Their Span-**

Types of Roof	Max. Span
Lean to roof (Verandah)	2.5 m
Couple roof	3.5 m
Coupl close roof	4.5 m
Collar beam roof	4.8 m
King-Post truss	5 to 8 m
Queen-Post truss	8 to 12 m
Bel-Fast truss (Lattice roof)	up to 30 m
North-Light roof truss	20 to 30 m

■ **Minimum Slope for the Main Roof Covering-**

Roof Covering Materials	Slope
G.I. Sheet	$26\frac{1}{2}°$
Asbestos Sheet	30°
Roof Tiles	40°



Arch Components

Scanned with CamScanner

Fluid Mechanics & Hydraulic Machine

Properties of Fluid

Properties	Formula	Unit	Dimension
Density or Mass Density	$\rho = \frac{M}{V}$	kg/m^3	ML^{-3}
Specific Weight or Weight Density	$w = \frac{W}{V} = \frac{mg}{V} = \rho g$ $w_{water} = 9.81 \times 1000$	N/m^3 or $\frac{kg}{m^2s^2}$	$ML^{-2}T^{-2}$
Specific Gravity	$S_{liquid} = \frac{\text{Density or wt. density of liquid}}{\text{Density or wt. density of water}}$ Wt. density of liquid $= S \times 1000 \times 9.81\ N/m^3$ Density of liquid $= S \times 1000\ kg/m^3$	Unitless	Dimension less
Specific Volume	$v = \frac{V}{m} = \frac{1}{\rho}$	m^3/kg	$M^{-1}L^3$
Bulk Modulus	$K = -\frac{dp}{dV/V} = -\frac{dp}{dV}.V$	N/m^2	$ML^{-1}T^{-2}$
Compressibility	$\beta = \frac{1}{K}$	m^2/N	$M^{-1}LT^2$
Surface Tension	$\sigma = \frac{F}{l}$	SI - N/m CGS - dyne/cm	MT^{-2}
Vapour Pressure	$\frac{\text{Force}}{\text{Area}} \left(p_v = \frac{F}{A}\right)$	SI - N/m^2 CGS - $dyne/cm^2$	$ML^{-1}T^{-2}$

Newton's Law of Viscosity–

$$\tau = \mu\frac{du}{dy} = \mu\frac{d\theta}{dt}$$

$\frac{du}{dy}$ = velocity gradient

$\frac{d\theta}{dt} \Rightarrow$ Rate of shear strain or shear deformation.

Dynamic Viscosity (μ)–

$$\mu = \frac{\tau}{du/dy}$$

Unit of Viscosity-

SI – $N\text{-}s/m^2$ or Pa–s

CGS – $dyne\text{–}s/cm^2$

M.K.S– $kgf\text{–}s/m^2$

1 poise = $\frac{1}{10}$ $N\text{–}s/m^2$

1 Centipoises = 10^{-2} Poise

	Temperature	Dynamic Viscosity
For liquid	T ↑	μ ↓
For gases	T ↑	μ ↑

Kinematic Viscosity–

$$\upsilon = \frac{\text{Dynamic Viscosity}}{\text{Mass Density}} = \frac{\mu}{\rho}$$

Unit- SI – m^2/sec

CGS – cm^2/sec or stoke

1 stoke = 10^{-4} m^2/sec or 1 cm^2/sec

1 m^2/sec = 10^4 stoke

Note- $\upsilon_{air} > \upsilon_{water}$

☞ **For liquid-** surface tension ↓(decrease) with ↑ (increase) in temperature.

Excess Pressure-

• Pressure inside drop (solid like sphere)	$p = \frac{4\sigma}{d}$
• Pressure inside bubble, (soap bubble)	$p = \frac{8\sigma}{d}$
• Pressure inside liquid jet σ = Surface tension d = diameter of bubble	$p = \frac{2\sigma}{d}$

Rise or depression of liquid in capillary tube

$$h = \frac{4\sigma\cos\theta}{\rho g d}$$

$\theta = 0^0$ for pure water and glass tube

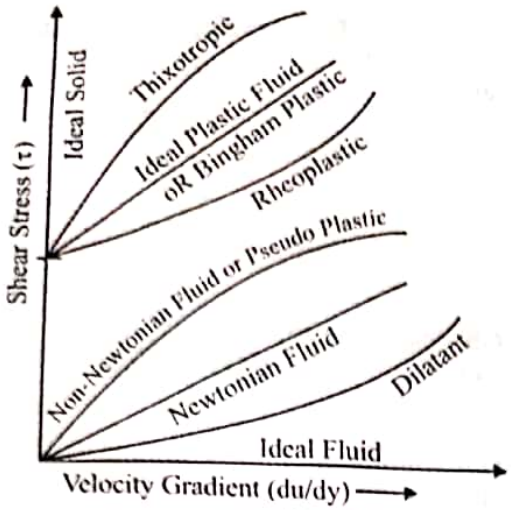
$\theta = 128^0$ for mercury and glass tube

Note- Capillary action occurs due to adhesion and cohesion both

Types of Fluid–

Ideal Fluid	It is incompressible and have no viscosity
Real Fluid	It possess viscosity and Compressibility
Ideal plastic Fluid	In this shear stress is more than yield value and shear stress $(\tau) \propto \frac{du}{dy}$ or $\frac{d\theta}{dt}$
Newtonian Fluid	In this type of fluid, shear stress is directly proportional to rate of shear strain or Newtonian fluid does not change with viscosity or with the rate of deformation or shear strain. **Ex. Water, Kerosene, Petrol, Benzene, Ethanol**
Non-Newtonian Fluid	In this shear stress is not proportional to the rate of shear strain. This fluid does not obey Newton's law of viscosity.

Scanned with CamScanner

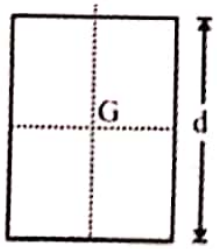
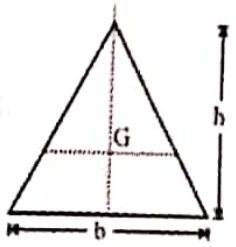
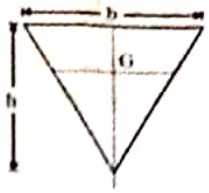
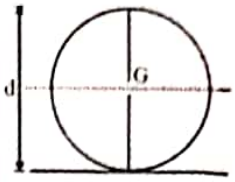
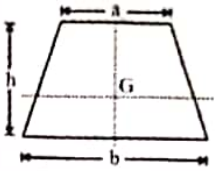
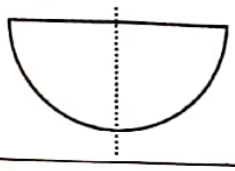


Type of Fluid

■ **Non-Newtonian Fluid–**

A. Time Independent-	
(i) Dilatent	Quick sand, Sugar Solution, butter
(ii) Bingham Plastic	Creams, Toothpaste, Drilling Muds
(iii) Pseudo Plastic	Polymer solutions, milk, blood, syrup
B. Time Dependent	
(i) Thixotropic	Lipstick, Printer inks, Enamels Paint, Jelly
(ii) Rheopectic	Gypsum pastes and Bentonite slurry

■ **Geometric properties of some important shapes-**

Plane Surface	Center of Gravity (C.G.)	Depth of center of pressure (C.P.)
Rectangle 	$x = \frac{d}{2}$	$\bar{h} = \frac{2d}{3}$
Triangle 	$x = \frac{2h}{3}$	$\bar{h} = \frac{3h}{4}$
Inverted Triangle 	$x = \frac{h}{3}$	$\bar{h} = \frac{h}{2}$
Circle 	$x = \frac{d}{2}$	$\bar{h} = \frac{5d}{8}$
Trapezium 	$x = \left[\frac{a+2b}{a+b}\right]\frac{h}{3}$	$\bar{h} = \left[\frac{a+3b}{a+2b}\right]\frac{h}{2}$
Half circle 	$\frac{4r}{3\pi}$ or $\frac{2D}{3\pi}$	$\frac{3\pi r}{16}$ or $\frac{3\pi D}{32}$

• **Metacentric height,**

$$G.M. = B.M. - B.G.$$

$$= \frac{I_{min}}{V_{immersed}} - B.G.$$

$$I_{min} = M.O.I.$$

• **Time period of Oscillation–**

$$T = 2\pi\sqrt{\frac{k^2}{G.M \times g}}$$

k = Least Radius of gyration

☛ Metacentric height for rolling condition will be less than Metacentric height for pitching condition.

■ **Floating body rotation axis in different condition–**

Pitching	Transverse axis
Rolling	Longitudinal axis
Yawing	Transverse axis (Perpendicular to the plane)

■ **Equilibrium condition for Submerged and floating body–**

Equilibrium condition	Submerged body	Floating body
Stable	B is above G	M is above G
Unstable	B is below G	M is below G
Neutral	B and G coincide	M and G coincide

Scanned with CamScanner

■ **Metacentric Height for various ships-**

Types of ship	Metacentric height
Merchant ship	< 1.0 m
sailing ship	< 1.50 m
Battle ship	< 2.0 m
River boat	< 3.50 m

☛ $G.M_{Cargo\ ship} > G.M_{Passenger\ ship}$, So cargo ship is less comfortable.

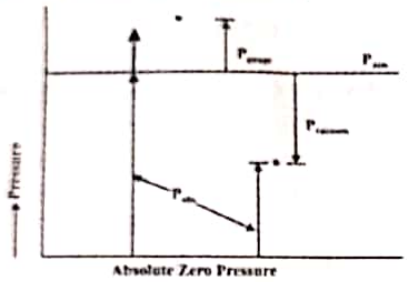
- **Pascal's Law–**

Pressure at a point in a fluid system is equally distributed in all direction. It applied to fluid at rest. Pascal's law is avoid if shear stress = 0

$$\boxed{p_x = p_y = p_z}$$

Unit of Pressure–

- $1Pa = 1N/m^2$
- $1Bar = 10^5 Pa$
- $1atm = 101325Pa$
- $1\frac{kgf}{cm^2} = 9.81\times10^4 N/m^2$
- $1Psi = 6894.76\ Pa$
- $1\ Torr = 133.3\ Pa = 1\ mm\ Hg$



$$P_{abs} = P_{atm} + P_{gauge}$$

$$P_{vaccum} = P_{atm} - P'_{abs}$$

- **Hydrostatic Law-**

The rate of increase of pressure in vertical direction is equal to weight density of the fluid at that point.

$$\left[\frac{dp}{dh} = w = \rho g\right]$$

For h, measured downward $\frac{dp}{dh} = \rho g = w$

For h, measured upward $\frac{dp}{dh} = -\rho g = -w$

- **Pressure Head-**

$$\left[h = \frac{p}{\rho g} \text{ or } \frac{p}{w}\right]$$

- **Hydrostatic force of curved surfaces-**

$$[F_H = \rho g A\bar{x}]$$

A - Projected Area

$\bar{x}$ - Vertical distance of C.O.G. of body from free surface.

- **Resultant Force 'F'** $= \sqrt{(F_H)^2 + (F_v)^2}$

F_v – Weight of liquid block above curved surface.

■ **Total pressure and center of pressure for submerged plane at different surface position-**

Surface Position	Total Pressure	Center of Pressure (h_{cp})
Horizontal Position	$F = \rho g A\bar{X}$ $= wA\bar{X}$	$h_{cp} = \bar{X}$
Vertical Position	$F = \rho g A\bar{X}$ $= wA\bar{X}$	$h_{cp} = \bar{X} + \frac{I_G}{A\bar{X}}$
Inclined Position	$F = \rho g A\bar{X}$ $= wA\bar{X}$	$h_{cp} = \bar{X} + \frac{I_G}{A\bar{X}}\sin^2\theta$
Curved Surface	$F_H = \rho g\int h.dA\sin\theta$ $F_v = \rho g\int h.dA\cos\theta$ $F_R = \sqrt{F_H^2 + F_v^2}$ $= wA\bar{X}$	

Pressure Measurement Device

- Manometer
  - Simple Manometer
    - Piezometer (Only liquid) (for small & moderate positive G.P)
    - U-Tube M.M (Positive & Negative) (Gauge pressure, High pressure)
    - Sensitive M.M (Modified form U-tube M.M
      - Vertical Single Column
      - Inclined Single Column
  - Differential Manometer
    - Inverted U-Tube Differential M.M (To measure liquid pressure)
    - U-Tube Differential M.M
    - Sensitive type D.M.M.
      - Inclined D.M.M.
      - Micrometer D.M.M.
- Mechanical Gauge
  - Diaphragm P.G
  - Bourdon Tube P.G
  - Dead Weight P.G
  - Bellows P.G

P.G - Pressure gauge
M.M - manometer

Scanned with CamScanner

■ **Types of Fluid Flow–**

Steady Flow	Fluid property like density, pressure, velocity does not change with time. $\frac{\partial v}{\partial t}=0,\ \frac{\partial p}{\partial t}=0,\ \frac{\partial \rho}{\partial t}=0$
Unsteady Flow	Fluid property changes with time $\frac{\partial v}{\partial t}\neq 0,\ \frac{\partial p}{\partial t}\neq 0,\ \frac{\partial \rho}{\partial t}\neq 0$
Uniform Flow	At a given time, fluid property does not change with respect to the space. $\left(\frac{\partial v}{\partial s}\right)_{t=\text{Constant}}=0$
Non-Uniform Flow	At a given time, velocity changes with respect to space- $\left(\frac{\partial v}{\partial s}\right)_{t=\text{Constant}}\neq 0$
Laminar Flow	Fluid particles move along well-defined path or stream line and all the stream lines are straight and parallel. Adjacent layer does not cross each other. ➢ It is also known as **stream** line flow or **viscous flow.**
Turbulent Flow	Fluid particle moves in a zig-zag or in random order.
Compressible Flow	Density of fluid changes from point to point or density is not constant in fluid flow i.e. $\rho \neq$ constant.
Incompressible Flow	Density remains constant i.e. ρ = constant.
Rotational Flow	During flow along streamline, fluid particles rotate about their own axis in both the circular as well as straight line motion.
Irrotational	Fluid particle does not rotate about its own axis in both circular as well as straight line motion.
Local or Temporal Acceleration	It is the rate of increase of velocity with respect to the time at a given point in a flow field ➢ $\frac{\partial u}{\partial t}, \frac{\partial v}{\partial t}$ or $\frac{\partial w}{\partial t}$ **Local acceleration**
Convective Acceleration	It is the rate of change of velocity due to the change of position of fluid in a fluid flow.

Type of Flow	Local or Temporal Acceleration	Convective or Advective Acceleration	Total or Max. Acceleration
Steady + Uniform Flow	0	0	0
Unsteady + Uniform Flow	✓	0	Local
Unsteady + Non-Uniform Flow	✓	✓	Local + Convective
Steady and Non-Uniform Flow	0	✓	Convective

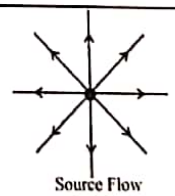
- **Forced Vortex Flow–**

$[v=\omega\times r]$ r = Radius of fluid particle, ω = Angular velocity

- **Free Vortex Flow–**

$\left[v=\frac{c}{r}\right]$ **c = constant**

Forced Vortex Flow	Free Vortex Flow
➢ For this some external force/torque required to rotate fluid mass. **Ex.** 1. Flow of water through the runner of a turbine. 2. Flow of Liquid passing through impeller of centrifugal pumps. 3. Rotation of Water in a washing machine. ➢ $z=\frac{v^2}{2g}=\frac{r^2\omega^2}{2g}=\frac{R^2\omega^2}{2g}$ z = height of parabolid formed)	➢ There is no external torque required to rotate fluid mass. **Ex.** 1. Flow through kitchen sink. 2. Liquid flow through a hole at the bottom of container. 3. A whirelpool in a river. 4. Flow fields due to tornado. 5. Liquid flow around a circular bend in a pipe.



Source Flow

Sink Flow (toward centre)

- **Kinetic Energy correction factor-**

$$\alpha=\frac{\text{Actual K.E.}}{\text{K.E. Calculated from average velocity}}$$

- **Momentum Correction factor-**

$$\beta=\frac{\text{Actual linear momentum/sec.}}{\text{Linear momentum/sec. calculated from } V_{avg.}}$$

Flow Condition	α	β
Laminar flow in pipe	2	1.33
Laminar flow b/w parallel plates	1.543	1.2
Turbulent flow in pipe	4/3 or 1.33	1.2

Scanned with CamScanner

- Continuity equation is based on **conservation of mass principle**
- Euler's equation is based on- **Conservation of Momentum principle**

- **Bernoulli's equation** = $\boxed{\frac{p}{\rho g}+\frac{v^2}{2g}+z=c}$
- Bernoulli's equation is based on- **Conservation of Energy Principle**
- Each term of Bernoulli's equation represents **Energy per unit weight**

- **Rate of Flow or Discharge**

  $[Q = A \times V]$

  where, A = Cross-sectional area of pipe

  V = Average velocity of Fluid.

  Unit = m^3/sec.

- **Continuity Equation–**

  $[\rho_1 A_1V_1 = \rho_2A_2V_2]$– Compressible Fluid

  $[A_1V_1 = A_2V_2]$– Incompressible Fluid.

  ρ = density, A = Area of Pipe, V = Average Velocity

- **Continuity Equation in 3-D–**

  $\frac{\partial}{\partial_x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)=0$ for Incompressible Fluid.

- **Velocity Potential Function–**

  $\left[\bullet\ u=\frac{-\partial\phi}{\partial x}\ \bullet\ v=\frac{-\partial\phi}{\partial y}\ \bullet\ w=\frac{-\partial\phi}{\partial z}\right]$

- **Stream Function–**

  $\left[\bullet\ \frac{+\partial\psi}{\partial x}=v\ \bullet\frac{+\partial\psi}{\partial y}=-u\right]$

- **Relation between Stream Function and Velocity Potential Function–**

  $\left[\frac{\partial\phi}{\partial x}=\frac{\partial\psi}{\partial y}\right]\left[\frac{\partial\phi}{\partial y}=\frac{-\partial\psi}{\partial x}\right]$

- **Angular Deformation–**

  $=\frac{1}{2}[\Delta\theta_1+\Delta\theta_2]$

- **Shear Strain Rate–**

  $=\frac{1}{2}\left[\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right]$

- **Rotation–**
  - $w_z=\frac{1}{2}\left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)$
  - $w_x=\frac{1}{2}\left(\frac{\partial w}{\partial y}-\frac{\partial v}{\partial z}\right)$
  - $w_y=\frac{1}{2}\left(\frac{\partial u}{\partial z}-\frac{\partial w}{\partial x}\right)$

→ Vorticity is twice the rotation '2w'.

■ **Equation of motion–**

1. **Newton's Equation of Motion**

   $F_x = F_g + F_p + F_v + F_t + F_c$

2. **Reynold's Equation of Motion**

   $F_x = F_g + F_p + F_v + F_t$

3. **Navier-Stokes Equation**

   $F_x = F_g + F_p + F_v$

4. **Euler's Equation of Motion**

   $F_x = F_g + F_p$

- **Euler's Equation–**

  $\left[\int\frac{dp}{p}+\int gdz+\int vdv=\text{Constant}\right]$

- **Bernoulli's Equation–**

  $\left[\frac{p}{\rho g}+\frac{v^2}{2g}+z=\text{constant}\right]$

  Where,

  $\frac{p}{\rho g}$ = Pressure head

  $\frac{v^2}{2g}$ = Velocity head.

  z = Potential head.

  Piezometric Head = $\frac{p}{\rho g}+z$

  Stagnation Head = $\frac{p}{\rho g}+\frac{V^2}{2g}$

- **Bernoulli's equation for real fluid**

  $$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2+h_L$$

Venturimeter–

$$\left[Q_{actual}=C_d\times\frac{a_1a_2}{\sqrt{a_1^2-a_2^2}}\sqrt{2gh}\right]$$

C_d = Co-efficient of venturimeter 0.97 - 0.99

- $h=x\left[\frac{S_h}{S_o}-1\right]$– Liquid heavier then flowing liquid in pipe
- $h=x\left[1-\frac{S_l}{S_o}\right]$– For Liquid lighter than flowing liquid in pipe)
- S_h = Specific gravity of heavier liquid.
- S_o = Specific gravity of liquid flowing in pipe
- S_l = Specific gravity of lighter liquid.
- **Orificemeter or orifice plate-**

  $$\left[Q=\frac{C_da_0a_1\sqrt{2gh}}{\sqrt{a_1^2-a_0^2}}\right]$$

  a_0 = Area of orifice

  $C_d = 0.65 - 0.70$

Scanned with CamScanner

Pitot Tube–

- $\left[V_{th} = \sqrt{2gh}\right]$, $V_{th} = \sqrt{2g\left(\frac{p_1 - p_2}{\rho g}\right)}$
- $P_1/\rho g$ – stagnation head • $P_2/\rho g$ – Static head

■ **Important point-**

Type of flow meter	Cost	Accuracy	Head loss
Venturimeter	High	High	Low
Orifice meter	Low	Low	High
Flow Nozzle	Medium	Medium	Medium

■ **Instruments & Their Measuring Parameter-**

Instrument	Measuring parameter
Venturimeter	Discharge or flow rate
Orificemeter	Discharge or flow rate
Flow nozzle	Discharge or flow rate
Elbow meter	Discharge in vertical segment or flow rate
Nozzle meter	Discharge or flow rate
Pitot tube	Velocity of fluid flow
Prandtl tube (Boundary layer theory)	Velocity of fluid flow
Current meter	Velocity in open channel
Weirs	Discharge in open channel
Rotameter	Flow rate or discharge in vertical segment
Hot-wire Anemometer	For measuring the gas or air velocity
Anemometer	Velocity with high accuracy
Pyrometer	High temperature measurement
Hydrometer	Specific gravity
Hygrometer	Humidity

Orifice-

■ **Hydraulic Co-efficient–**

- **Co-efficient of velocity, C_v**

$$= \frac{\text{Actual velocity of jet at vena-contracta}}{\text{Theoretical velocity}} = \frac{V_{act}}{V_{th}}$$

$C_v = 0.98$ for sharp edged orifices

- **Co-efficient of Contraction, C_c**

$$C_c = \frac{\text{Area of jet at vena-contracta}}{\text{Area of orifice}} = \frac{(a_c)}{(a)}$$

- **Co-efficient of Discharge, C_d**

$$C_d = \frac{\text{Actual Discharge}}{\text{Theoretical Discharge}} = \frac{Q_{act}}{Q_{th}} = \frac{Q_{act}}{a\sqrt{2gh}}$$

☛ $\boxed{C_d = C_v \times C_c}$

■ **Value of Hydraulic Co-efficient-**

Coefficient of velocity (C_v)	0.95-0.99	≃ 0.98
Coefficient of contraction, C_c	0.61-0.69	≃ 0.64
Coefficient of Discharge C_d	0.61-0.64	≃ 0.62
Coefficient of Resistance, C_r	-	≃ 0.063

■ **Coefficient of Discharge (C_d) for mouthpiece-**

Types of Mouthpiece	C_d
External Mouthpiece	0.855
Internal mouthpiece	
(i) Running full	0.707
(ii) Running free	0.50
Convergent or convergent divergent mouthpiece	1.00

■ **Discharge Over a Notch or Weir–**

1. Rectangular Notch or Weir

$$Q = \frac{2}{3}C_d.L\sqrt{2g}.H^{3/2}$$

L = Width of weir

If velocity of approach = V_a

Then, $H = H + H_a$ or $\left(H + \frac{V_a^2}{2g}\right)$

$$\therefore\ Q = \frac{2}{3}C_d.L\sqrt{2g}\left[(H+H_a)^{3/2} - H_a^{3/2}\right]$$

2. According to Francis Formula-

$$Q = \frac{2}{3}C_d\sqrt{2g}\left[L - 0.1nH\right]H^{3/2}$$

$$= 1.84\,[L - 0.1\,nH).H^{3/2}$$

Contraction value is taken 0.1H for each ends of Weir

According to Benzin's–

$$Q = mL\sqrt{2g}.H^{3/2}$$

$$m = \frac{2}{3}C_d = 0.405 + \frac{0.003}{H}$$

3. Triangular Notch or Weir–

$$Q = \frac{8}{15}C_d\sqrt{2g}\tan\theta/2.H^{5/2}$$

If $\theta = 90°$ then $\tan\theta/2 = 1$

$$Q = \frac{8}{15}C_d\sqrt{2g}H^{5/2}$$

oR

$$Q = 1.417H^{5/2}\ (\text{If } \theta = 90^0)$$

4. Trapezoidal Notch or Weir-

$$Q = Q_{Rectangular} + Q_{Triangular}$$

$$Q = \frac{2}{3}C_d\sqrt{2g}.H^{3/2}\left(L + \frac{4}{5}.H\tan\frac{\theta}{2}\right)$$

Scanned with CamScanner

■ **Effect on Discharge due to error in the measurement of head for–**

(i) Rectangular Weir or Notch

$$\frac{dQ}{Q} = \frac{3}{2}\frac{dH}{H} = 1.5\%. \text{ Error}$$

(ii) Triangular Weir or Notch–

$$\frac{dQ}{Q} = \frac{5}{2}\frac{dH}{H} = 2.5\%. \text{ Error}$$

☞ **For Cipolletti Weir or notch**

Side slope = 1 : 4 (H:V)

or $\theta/2 = 14°2'$

➢ **Broad Crested Weir-**

$$\frac{H}{L} = 0.1 - 0.4$$

or $2L > H$

➢ **Narrow Crested Weir**

$$\frac{H}{L} > 1.6$$

or $2L < H$

H = Height of Water above crest

L = Length of crest

Discharge Over a Broad Crested Weir-

$$Q = 1.705 C_d . L . H^{3/2}$$

Flow Through Pipe

■ **Loss of Energy in Pipes-**

A. Major Losses (mainly due to friction)–

(a) Darcy - Weisbach Formula–

$$h_f = \frac{f L V^2}{2gD}$$

and $h_f = \frac{4f' L V^2}{2gD}$ (Fanning equation)

Where, f = Darcy friction factor

f' = Co-efficient of friction

Note-

$f = \frac{64}{R_e}$ (For Laminar flow, $R_e < 2000$)

$f = \frac{0.3164}{R_e^{1/4}}$ (For Turbulent flow $4000 < R_e < 10^5$)

$f' = \frac{16}{R_e}$ (For Laminar Flow)

$f' = \frac{0.079}{R_e^{1/4}}$ (For Turbulent flow

Note- $f = 4f'$

(b) Chezy's Formula-

Mean Velocity,

$$V = C\sqrt{mi} \qquad \left[C = \frac{\sqrt{8g}}{f}\right]$$

Where,

$$m = \frac{\text{Area}}{\text{Wetted Perimeter}}$$

$i = \frac{h_f}{L}$ = Hydraulic gradient

$$C = \sqrt{\frac{8g}{f}}$$

B. Minor Losses–

It is due to-

1. Sudden Enlargement of Pipe-

$$h_{EL} = \frac{(V_1 - V_2)^2}{2g} = \frac{V_1^2}{2g}\left(1 - \frac{A_1}{A_2}\right)^2 = \frac{V_2^2}{2g}\left[\frac{A_2}{A_1} - 1\right]^2$$

2. Sudden Contraction-

$$h_c = \frac{0.5V^2}{2g}$$

3. Inlet Loss-

$$h_i = \frac{0.5V^2}{2g}$$

4. Exit Loss-

$$h_{ex} = \frac{V^2}{2g}$$

5. Due to pipe Bend and pipe Fitting-

$$h_{b/F} = k\frac{V^2}{2g}$$

k **depends upon**

1. Angle of bend
2. Pipe dia
3. Type of pipe fitting
4. Radius of curvature of bend.

☞ **Maximum Efficiency of Transmission of Power-**

$$\eta = \frac{H - h_f}{H}$$

(For max. Transmission power)

$H = 3h_f$ or $h_f = \frac{H}{3}$

$\therefore \eta = 2/3$ or 66.7%

☞ **Hydraulic Grade Line (H.G.L.)-**

$$= \frac{p}{\rho g} + z$$

☞ **Total Energy Line (T.E.L)-**

$$= \frac{p}{\rho g} + z + \frac{V^2}{2g}$$

∴ T.E.L. always > H.G.L.

☞ **T.E.L. always drop in the direction of flow due to loss of head.**

Scanned with CamScanner

■ **Water Hammer-**

Case of Water hammer	Pressure head
Gradual closure of valve	$\frac{p}{w} = \frac{L.V}{gt}$
Sudden closure of valve in rigid pipe	$\frac{p}{w} = \frac{VC}{g} = \frac{V}{g}\sqrt{\frac{k}{\rho}}$
Sudden closure of valve in elastic pipe t = time of closing valve in sec. x = thickness of pipe	$\frac{p}{w} = \frac{V}{\sqrt{\rho g^2\left(\frac{1}{K}+\frac{D}{xE}\right)}}$
Closure of valve will be gradual if	$t > \frac{2L}{C}$
Closure of valve will be Instantaneous if	$t < \frac{2L}{C}$

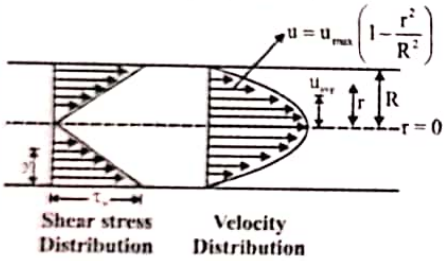
■ **Important Dimensionless Number:**

Number	Definition	Equation
Reynolds Number	$\frac{\text{Inertia force}}{\text{Viscous force}}$	$\frac{F_i}{F_v} = \frac{\rho VL}{\mu}$
Mach Number	$\sqrt{\frac{\text{Inertia force}}{\text{Elastic force}}}$	$\sqrt{\frac{F_i}{F_e}} = \frac{V}{C} = \frac{V}{\sqrt{K/\rho}}$
Froude Number	$\sqrt{\frac{\text{Inertia force}}{\text{Gravity force}}}$	$\sqrt{\frac{F_i}{F_g}} = \frac{V}{\sqrt{Lg}}$
Weber Number	$\sqrt{\frac{\text{Inertia force}}{\text{Surface tension}}}$	$\sqrt{\frac{F_i}{F_s}} = \frac{V}{\sqrt{\sigma/\rho L}}$
Euler's Number	$\sqrt{\frac{\text{Inertia force}}{\text{Pressure force}}}$	$\sqrt{\frac{F_i}{F_p}} = \frac{V}{\sqrt{P/\rho}}$
Cauchy Number	$\frac{\text{Inertia force}}{\text{Elastic force}}$	$\frac{V^2}{C^2}$

■ **Classification of flow based on mach number-**

Mach Number	Types of flow
< 1	Sub-sonic flow
= 1	Sonic flow
> 1	Super sonic flow
> 6	Hyper sonic flow

■ **Laminar flow through pipe-**



1. Shear stress distribution-

➢ $\tau = -\frac{r}{2}\frac{\partial p}{\partial x}$

at, r = 0, τ = 0

r = R, τ = max

2. Velocity distribution-

➢ $u = -\frac{1}{4\mu}\left(\frac{\partial p}{\partial x}\right)R^2\left(1-\frac{r^2}{R^2}\right)$

➢ $u_{max} = -\frac{1}{4\mu}\left(\frac{\partial p}{\partial x}\right)R^2$

➢ r' = 0.707R (Average velocity = Local velocity)

3. Discharge-

➢ $Q = \frac{\pi}{128\mu}\left(-\frac{\partial p}{\partial x}\right)D^4$

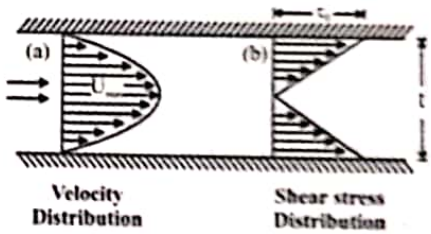
D = Diameter of pipe

4. Head Loss-

➢ $h_f = \frac{32\mu u_{avg}.L}{\rho g D^2}$ (Hagen-Poiseulle formula)

$= \frac{fLu_{avg}^2}{2gD}$ $\left(f = \frac{64}{Re}\right)$

Laminar flow through plate-



1. Shear stress distribution-

➢ $\tau = -\frac{\partial p}{\partial x}\left(\frac{t}{2}-y\right)$

at y = 0, $\tau = \tau_{max}$

2. Velocity distribution-

➢ $u = -\frac{1}{2\mu}\left(\frac{\partial p}{\partial x}\right)(ty-y^2)$

➢ $u_{max} = -\frac{1}{8\mu}\left(\frac{\partial p}{\partial x}\right)t^2$

➢ $u_{max} = \frac{3}{2}u_{avg}$

3. Discharge-

➢ $Q = \frac{1}{12\mu}\left(-\frac{\partial p}{\partial x}\right)t^3$

4. Head Loss-

➢ $h_f = \frac{12\mu u_{avg}.L}{\rho g t^2}$

Scanned with CamScanner

■

Laminar Sub-layer thickness	$\delta = \frac{11.6\,\upsilon}{V^x}$ υ = Kinematic viscosity V^x = Friction velocity
Displacement thickness	$\delta^* = \int_0^\delta \left(1 - \frac{u}{U}\right) dy$
Momentum thickness	$\theta = \int_0^\delta \frac{u}{U}\left(1 - \frac{u}{U}\right) dy$
Energy thickness	$\delta^{**} = \int_0^\delta \frac{u}{U}\left(1 - \frac{u^2}{U^2}\right) dy$
Shape factor	$H = \frac{\delta^*}{\theta}$
Von-Karman's Momentum Integral Equation **It is used for-** Laminar, Transition and Turbulent boundary layer	$\frac{d\theta}{dx} = \frac{\tau_o}{\rho U^2}$ τ_o = shear stress at surface

☞ $\boxed{\delta > \delta^* > \delta^{**} > \theta}$

■ **Drag and lift force-**

- Drag force, $F_D = \frac{1}{2} C_d \rho A V^2$
- Lift force, $F_L = \frac{1}{2} C_L \rho A V^2$

Drag force on sphere, $F_D = 3\pi\mu.V.D$

Where,

A = Projected area of body

V = Relative wind velocity

C_d & C_L = Coefficient of drag and lift

■ **Model laws and its application-**

Models	Applications
Reynolds model law	➢ Submarines completely under water ➢ Motion of air-planes ➢ Flow through venturimeter, orifice meter ➢ Flow through small sized pipes.
Mach model law	➢ Aerodynamic testing ➢ Under water testing of torpedoes ➢ Water-hammer problem.
Froude model law	➢ Open channels. ➢ Free surface flow such as flow over spillways, weirs, sluices. ➢ Flow of jet from an orifice or nozzle. ➢ Flow of different density fluids one above the other.
Weber model law	➢ Flow over weir for small heads ➢ Capillary flows ➢ Flow of very thin sheet of liquid over a surface.
Euler's model law	➢ Turbulent flow in pipeline where viscous force and surface tensile forces are entirely absent. ➢ Where the phenomenon of cavitations occurs.

■ **Important Relations (Blasius Results) :**

Characteristics	Laminar Boundary layer	Turbulent boundary layer
Boundary layer thickness (δ_x)	$\delta_x = \frac{5x}{\sqrt{Re_x}}$ $(\delta_x \propto x^{1/2})$	$\delta_x = \frac{0.377x}{(Re_x)^{1/5}}$ $(\delta_x \propto x^{4/5})$
Local skin friction coefficient (C_{fx})	$C_{fx} = \frac{0.664}{\sqrt{Re_x}}$	$C_{fx} = \frac{0.059}{(Re_x)^{1/5}}$
Average skin friction coefficient or drag coefficient (C_{fa} or C_d)	$C_{fa} = \frac{1.328}{\sqrt{Re_x}}$	$C_{fa} = \frac{5}{4} C_{fx} = \frac{0.073}{(Re_x)^{1/5}}$
Displacement thickness (δ)	$\delta = \frac{1.72x}{\sqrt{Re_x}}$	$\delta = \frac{0.048x}{(Re_x)^{1/5}}$
Momentum Thickness (θ)	$\theta = \frac{0.669x}{\sqrt{Re_x}}$	$\theta = \frac{0.037x}{(Re_x)^{1/5}}$

Scanned with CamScanner

■ **On the basis of Nikuradse's experiment the boundary layer is classified as-**

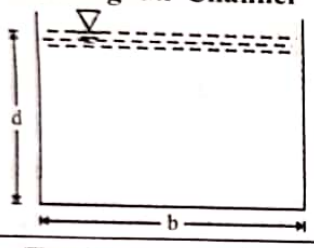
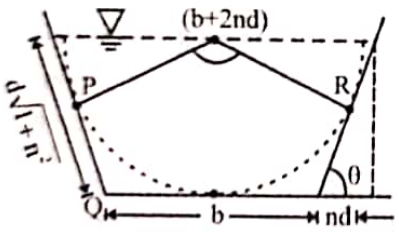
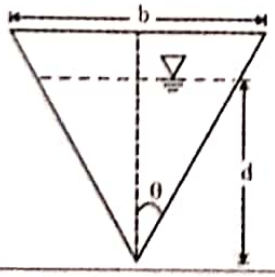
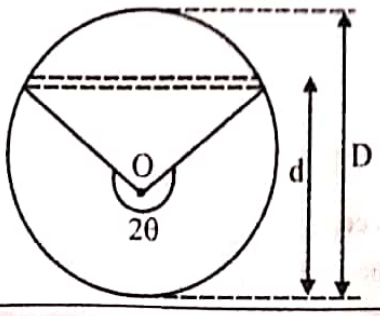
$\frac{k}{\delta^*} < 0.25$	Smooth boundary layer	$\frac{V^*K}{\upsilon} < 5$
$0.25 < \frac{k}{\delta^*} < 6.0$	Transition boundary layer	$5 < \frac{V^*K}{\upsilon} < 70$
$\frac{K}{\delta^*} > 6.0$	Rough boundary layer Where, V^* = average shear velocity υ = kinematic viscosity K = Avg. roughness	$\frac{V^*K}{\upsilon} > 70$

Open channel flow -

■ **Nature of flow according to Reynolds number for pipe, and open channel flow–**

Nature of flow	Reynolds No, $R_N = \rho VD/\mu$		b/w parallel plates	Flow through Soil
	Pipe Flow	Open channel flow		
Laminar flow	$R_N < 2000$	$R_N < 500$	$R_N < 1000$	$R_N < 1$
Transitional flow	$2000 < R_N < 4000$	$500 < R_N < 1000$	$1000 < R_N < 2000$	$1 < R_N < 2$
Turbulent flow	$R_N > 4000$	$R_N > 1000$	$R_N > 2000$	$R_N > 2$
Lower critical flow point	$R_N = 2000$	$R_N = 500$	$R_N = 1000$	$R_N = 1$
Higher critical flow point	$R_N = 4000$	$R_N = 1000$	$R_N = 2000$	$R_N = 2$

■ **For most Economical channel section-**

Rectangular Channel  	Width of channel, b = 2d Depth of flow, d = b/2 Hydraulic radius, (R) or Hydraulic mean depth m = d/2
Trapezoidal Section  	➢ Length of sloping side = Half the top width $d\sqrt{1+n^2} = \frac{b+2nd}{2}$ ➢ m = R = d/2 ➢ $\theta = 60^0$ ➢ A circle of radius (d) should be inscribed in trapezoidal section. ➢ Semi circle touch the three sides of trapezoidal section (P, Q,R)
Triangular Channel  	➢ m or $R = \frac{d}{2\sqrt{2}}$ ➢ Side slop = 1 :1 ➢ $\theta = 45^o$
Circular Section  	**For Max. discharge-** $\frac{d}{D} = 0.95$ **For Max. velocity-** $\frac{d}{D} = 0.81$ ➢ **Area of flow,** $A = R^2\left(\theta - \frac{\sin 2\theta}{2}\right)$

Scanned with CamScanner

Type of flow	Depth of flow	Velocity of flow	Froude Number
Subcritical/Tranquil streaming or Tangential flow	$y > y_c$	$v < v_c$	$F_r < 1$
Critical flow (At this flow specific energy in min)	$y = y_c$	$v = v_c$	$F_r = 1$
Supercritical/Torrential/Rapid	$y < y_c$	$v > v_c$	$F_r > 1$
or shooting flow	y_c = Critical, depth	v_c = Critical, Velocity	

■ **Classification of jump based on Froude number–**

Froude number (F_r)	Types of jump	Water Surface
1-1.7	Undular/Unsteady	Undulating
1.7-2.5	Weak	Small Rollers form
2.5-4.5	Oscillating	Water moving in random manner
4.5-9	steady	Roller and jump action
>9	strong	Very rough and choppy

■ **Some Important formula for open channel-**

Hydraulic mean Depth	$m = \frac{\text{Area}}{\text{Wetted perimeter}} = \frac{A}{P}$
Manning's Formula	$V = \frac{1}{N} m^{2/3} \times i^{1/2}$
Chezy Formula	$V = C\sqrt{m \times i}$
Specific Energy	$E = y + \frac{V^2}{2g} = y + \frac{Q^2}{2g.A^2}$ (y = depth of flow) $A = By + Sy^2$ (Trepezoidal section)
Critical Depth	$y_c = \left(\frac{q^2}{g}\right)^{1/3}$ (q = Discharge per unit width of channel = $\frac{Q}{b}$)
Critical velocity	$V_c = (q.g)^{1/3} = \sqrt{g \times y_c}$
Condition for Critical flow	$\frac{Q^2}{g} = \frac{A^3}{T}$
Energy loss due to Hydraulic jump	$E_L = \frac{(y_2 - y_1)^3}{4y_1y_2}$
	$\frac{2q^2}{g} = y_1.y_2(y_1 + y_2)$
Laplace equation-	$\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} = 0$

Relation Between y_c and E

(i) For Rectangular channel- $y_c = \frac{2}{3}E$

(ii) For Triangular channel- $y_c = \frac{4}{5}E$

(iii) For Parabolic channel- $y_c = \frac{3}{4}E$

Force acting in moving fluid –

1. **Inertia Force, $F_i = \rho AV^2$**
2. **Viscous Force, $F_V = \frac{\mu VA}{L}$**
3. **Gravity Force, $F_g = \rho ALg$**
4. **Pressure Force, $F_p = pA$**

Scanned with CamScanner

Efficiency of Turbines

- **Hydraulic efficiency-**

$$\eta_h = \frac{R.P.}{W.P.}$$

- **Mechanical efficiency-**

$$\eta_m = \frac{S.P.}{R.P.}$$

- **Volumetric efficiency-**

$$\eta_v = \frac{Q - \Delta Q}{Q}$$

- **Overall efficiency-**

$$\eta_o = \frac{S.P.}{W.P.}$$

- **Relation between efficiencies-**

$$\eta_{hydraulic} = \eta_{nozzle} \times \eta_{runner}$$

$$\eta_{overall} = \eta_{nozzle} \times \eta_{runner} \times \eta_{mech}$$

$$= \eta_m \times \eta_h = \frac{S.P.}{W.P.}$$

■ Classification of Hydraulic Turbine According to the-

1. Type of energy at inlet-

Type of Turbine	Energy available at inlet	Example
Impulse Turbine	Only Kinetic Energy	Pelton Turbine, Turgo Cross flow
Reaction Turbine	Both Kinetic and pressure Energy	Francis, Kaplan, Girard, Fourneyron propeller Turbine

2. Direction of flow through runner-

Type of Turbine	Example
Tangential flow Turbine	Pelton Turbine
Radial flow Turbine	Francis Turbine
Axial flow Turbine	Kaplan, Propeller Turbine
Mixed flow Turbine	Modern Francis Turbine

3. Head available and discharge-

Types of Turbine	Discharge	Head (m)	Example
High Head	Low	> 300	Pelton Turbine
Medium Head	Medium	60-300	Francis Turbine
Low Head	High	< 60	Kaplan & Propeller Turbine

4. Specific speed (N_s)-

Specific speed (N_s)		Suitable Turbine
M.K.S. Unit	S.I. Unit	
10-35	8.5-30	Pelton wheel with single jet
35-60	30-51	Pelton wheel with two or more jet
60-300	51-225	Francis Turbine
300-1000	225-860	Kaplan or Propeller Turbine

Type of Turbine	Velocity Ratio	Overall efficiency η_o
Pelton wheel	0.43-0.48	85%-90% = 86%
Francis Turbine	0.6-0.9	88%
Kaplan, Propeller Turbine	1.5-2.2	88.35% = 90%

■ Model Relationship for Turbine

Specific Speed	$N_s = \frac{N\sqrt{P}}{H^{5/4}}$ $[M^{1/2}L^{-1/4}T^{-5/2}]$
Shape Number	$S = \frac{N\sqrt{P/\rho}}{(gH)^{5/4}}$
Unit Speed	$N_u = \frac{N}{\sqrt{H}}$
Unit Power	$P_u = \frac{P}{H^{3/2}}$
Unit Discharge	$Q_u = \frac{Q}{\sqrt{H}}$

Scanned with CamScanner

Discharge Through a Turbine

Type of Turbine	Discharge
Pelton wheel	$Q = \frac{\pi}{4} d^2 . C_v \sqrt{2gH}$
Francis	$Q = \pi D_1 B_1 \times V_{f_1}$
Kaplan	$Q = \frac{\pi}{4}(D_o^2 - D_b^2).V_{f_1}$

- **Flow Co-efficient,** $C_Q = \frac{Q}{ND^3}$
- **Head Co-efficient,** $C_H = \frac{H}{N^2D^2}$
- **Power Co-efficient,** $C_P = \frac{P}{N^3D^5}$

Degree of Reaction-

$$D.O.R = \frac{\text{Change in pressure energy inside the runner}}{\text{Change in total energy inside the runner}}$$

- For impulse Turbine, D.O.R = 0
- For reaction Turbine, D.O.R= $1 - \frac{\cot\alpha}{2(\cot\alpha - \cot\theta)}$
- For pure reaction Turbine, D.O.R = 1
- Percentage of slip = $\frac{Q_{th} - Q_{act}}{Q_{th}} \times 100$
- Max. Hydraulic efficiency of an impulse Turbine-

$$\eta_{max} = \frac{1+\cos\phi}{2}$$

ϕ = Angle of blade tip at outlet

- Max. Number of jets, generally, employed on Pelton wheel are six (6)
- Minimum Dia of Braking jet = 0.6 × d
- Width of Bucket for a Pelton wheel = 5d
- Depth of Bucket for a Pelton wheel = 1.2d
- Angle of deflections, ϕ = 160°–170° (Avg. Angle, ϕ = 165°)
- Vane Angle at outlet, ϕ = 10°– 20° (Avg. Angle, ϕ = 15°)
- No. of Blades on Francis Turbine = 16 – 24

Kaplan Turbine

Runner Power	$\dot{m} v_{w_1} u_1$
Speed Ratio, (K_a)	$\frac{u_1}{\sqrt{2gH}} = (1.4 - 2.0)$
Flow Ratio, (ψ)	$\frac{V_{f_1}}{2gH} = (0.7)$
Breadth Ratio	$\frac{B_1}{D_1} = (0.1 - 0.3)$
No. of Blades (Generally)	4
Degree of Reaction	(0.5-1.0)
Peripheral velocity at inlet and outlet	$u_1 = u_2 = \frac{\pi D_o N}{60}$

- **Types of pump:**

Pump
- Rotodynamic pump
  - Mixed flow pump
  - Axial Flow Pump
  - Radial Flow Pump
- Positive displacement pump
  - Reciprocating Pump
    - Piston Pump
    - Plunger Pump
    - Bucket Pump
  - Rotary Pump
    - Gear Pump
    - Screw Pump
    - Vane Pump

Efficiencies of pump

- **Hydraulic/Manometric efficiency-**

$$\eta_h = \frac{\text{Manometric Head}}{\text{Manometric Head + Hydraulic loss}}$$

$$\frac{\text{Manometric Head}}{\text{Head imparted by impeller to water}} = \frac{M.P.}{I.P.}$$

- **Mechanical efficiency-**

$$\eta_m = \frac{\text{Power at the impeller}}{\text{Power at the shaft}} = \frac{I.P.}{S.P.} = \frac{\rho(Q+q)v_{w_2}v_2}{P}$$

- **Volumetric efficiency-**

$$\eta_v = \frac{Q}{Q+q}$$

- **Overall efficiency-**

$$\eta_o = \frac{M.P}{S.P.}$$

$$\eta_o = \eta_h \times \eta_m \times \eta_v$$

$$\eta_o = \eta_h \times \eta_m \quad (\eta_v = \text{Neglected})$$

Model Relationship for Pumps-

Dimensional Parameter	Dimensionless Parameter
$C_H = \frac{H}{N^2D^2}$	$C_H = \frac{gH}{\omega^2D^2}$
$C_Q = \frac{Q}{ND^3}$	$C_Q = \frac{Q}{\omega D^3}$
$C_P = \frac{P}{N^3D^5}$	$C_P = \frac{P}{\rho\omega^3D^5}$
$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$	$N_s = \frac{\omega\sqrt{Q}}{(gH)^{3/4}}$

Scanned with CamScanner

Strength of Material

■ **Types of Material-**

Homogeneous Material	A material which have same elastic properties at any point in a given direction.
Isotropic Material	This material has same identical properties in all direction at a point.
Anisotropic Material	It has different properties in all direction at a point in the body.
Orthotropic Material	A material which has different properties in three mutually perpendicular planes.

Material		Poission's Ratio
Cork	-	0
Glass	-	0.02 - 0.03
Cast Iron	-	0.23 - 0.27
Elastic Material	-	0.25 - 0.40
Steel	-	0.27 - 0.33
Rubber	-	0.50
Human Tissues	-	–1
Wrought Iron	-	0.30
Concrete	-	0.10 - 0.20

■ **Elastic Constant-**

Elastic Constant	Formula
Young's Modulus or Modulus of Elasticity	$E = \frac{\text{Longitudinal Stress}}{\text{Longitudinal Strain}} = \frac{\sigma}{\varepsilon} = \frac{Fl}{\delta l \times A}$
Modulus of Rigidity/ Shear Modulus	$G = \frac{\text{Shear stress}}{\text{Shear strain}} = \frac{\tau}{\phi}$
Poisson's Ratio	$\mu = -\frac{\text{Lateral Strain}}{\text{Linear Strain}} = -\frac{\delta d/d}{\delta l/l}$
Bulk Modulus	$K = \frac{\text{Direct stress}}{\text{Volumetric Strain}} = \frac{\sigma_d}{\varepsilon_v}$

Where,

σ_d= Compressive stress or direct stress

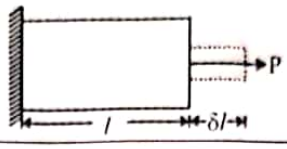
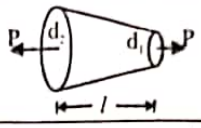
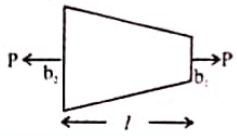
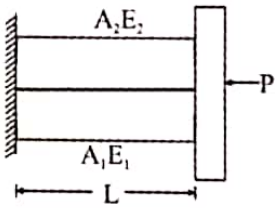
ε_v = Volumetric strain

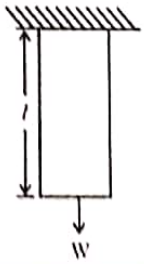
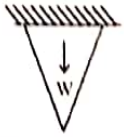
■ **Relation between E, G, K & μ**

- $E = 2G(1+\mu)$
- $E = 3K(1-2\mu)$
- $E = \frac{9KG}{3K+G}$
- $\mu = \frac{3K-2G}{6K+2G}$

Types of Material	Total number of Elastic Constants	No. of Independent Elastic Constant
Homogeneous and Isotropic	4	2
Orthotropic (wood)	12	9
Anisotropic	∞	21

■ **Axial Elongation in Different Types of Bar-**

Type of bar	Elongation δl
Prismatic bar 	Due to external load $\delta l = \frac{Pl}{AE} = \frac{\sigma l}{E}$
Circular tapered bar 	$\delta l = \frac{4Pl}{\pi d_1 d_2 E}$
Rectangular tapered bar 	$\delta l = \frac{Pl \log_e\left(\frac{b_2}{b_1}\right)}{(b_2 - b_1)Et}$ t = thickness
Composite bars 	$P = P_1 + P_2$ Change in length $\delta_1 = \delta_2 = \frac{P_1 L}{A_1 E_1} = \frac{P_2 L}{A_2 E_2}$ $P_1 = \frac{A_1 E_1}{A_1 E_1 + A_2 E_2} \times P$ $P_2 = \frac{A_2 E_2}{A_1 E_1 + A_2 E_2} \times P$

Types of bar	Elongation due to self weight
1. Prismatic bar 	$\delta l_p = \frac{\gamma l^2}{2E} = \frac{Wl}{2AE} = \frac{wl^2}{2E} = \frac{\rho g l}{2E}$ (w or $\gamma = \rho g$)
2. Uniform tapering or conical bar 	$\delta l_c = \frac{WL}{6AE} = \frac{\gamma l^2}{6E}$ or $\delta l_c = \frac{1}{3} \times \frac{Wl}{2AE} = \frac{1}{3} \times \delta l_p$
3. Prismatic bar due to external load & self weight	$\delta l = \frac{PL}{AE} + \frac{WL}{2AE}$

Scanned with CamScanner

■ **Modulus of Elasticity for different types of Material-**

Material	Young's Modulus (E) (MP_a)
Steel	2×10^5
Copper	1.17×10^5
Cast Iron	1.7×10^5
Timber (wood)	0.10×10^5
Aluminum	0.70×10^5
Glass	0.80×10^5

■ **For Gradually applied loads-**

- **Resilience** $= \frac{\sigma^2}{2E} \times$ Volume
- **Proof resilience** $= \frac{\sigma_p^2}{2E} \times$ Volume
- **Modulus of resilience** $= \frac{\sigma_p^2}{2E}$

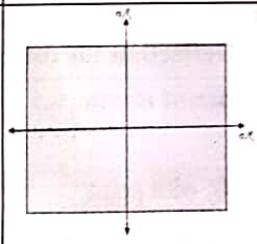
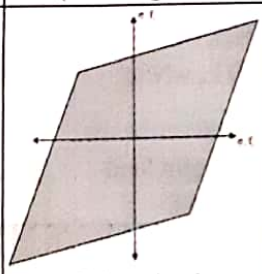
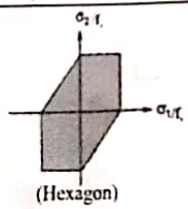
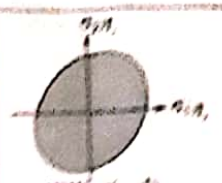
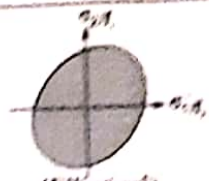
σ_p = Proof Stress

Stress $\sigma = \frac{P}{A}$

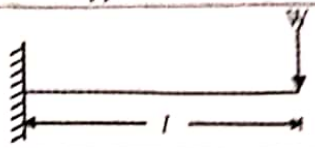
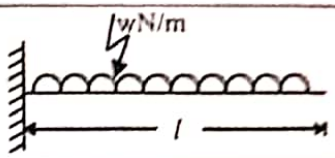
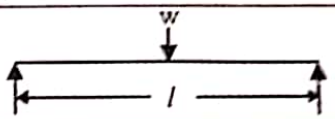
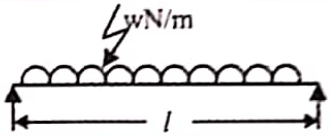
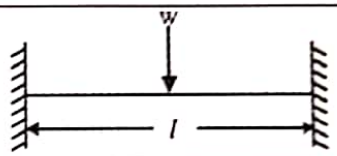
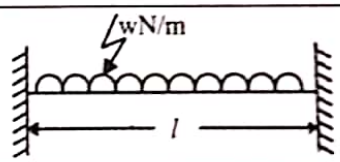
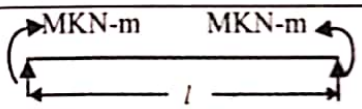
$\sigma = \frac{2P}{A}$ (for sudden applied load)

- Strain Energy due to gradually applied load $= \frac{W^2L}{2AE}$
- Strain energy due to sudden applied load $= \frac{W^2L}{AE}$

■

Theory	Given by	Suitable for Material	Graphical representation
Maximum Principal Stress or normal stress	Rankine	Brittle	 (Rectangular)
Maximum Principal Strain	St. Venants	Brittle	 (Rhombus)
Maximum Shear Stress	Guest & Trasca's	Ductile	 (Hexagon)
Maximum Strain Energy	Haigh & Beltrami	Ductile	 (Elliptical)
Maximum Shear Strain Energy	Vonmises and Hencky	Ductile	 (Elliptical)

■

Types of Beam	Strain Energy
	$\frac{W^2l^3}{6EI}$
	$\frac{w^2l^5}{40EI}$
	$\frac{W^2l^3}{96EI}$
	$\frac{w^2l^5}{240EI}$
	$\frac{W^2l^3}{384EI}$
	$\frac{w^2l^5}{1440EI}$
	$\frac{M^2l}{2EI}$

■ **Important Formula**

- Normal stress, σ_n

$$= \frac{\sigma_x + \sigma_y}{2} + \left(\frac{\sigma_x - \sigma_y}{2}\right)\text{Cos}2\theta + \tau_{xy}\text{Sin}2\theta$$

- Tangential or shear stress, σ_t

$$= -\left(\frac{\sigma_x - \sigma_y}{2}\right)\text{Sin}2\theta + \tau_{xy}\text{Cos}2\theta$$

- Principal Plane

$$\tan 2\theta = \frac{2\tau_{xy}}{\sigma_x - \sigma_y}$$

Scanned with CamScanner

- Principal stress $\sigma_{Max/min}$

$$= \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$= \frac{\sigma_x + \sigma_y}{2} \pm \frac{1}{2}\sqrt{(\sigma_y - \sigma_x)^2 + 4\tau_{xy}^2}$$

- Radius of Mohr Circle

$$\tau_{max} = \frac{\sigma_{max} - \sigma_{min}}{2}$$

$$= \frac{1}{2}\sqrt{(\sigma_y - \sigma_x)^2 + 4\tau_{xy}^2} = R$$

- Center of circle $= \left[\left(\frac{\sigma_x + \sigma_y}{2}\right), 0\right]$
- Maximum shear stress= $\tau_{xy_1} = \left(\frac{\sigma_x - \sigma_y}{2}\right)$
- Minimum shear stress= $\tau_{xy_2} = -\left(\frac{\sigma_x - \sigma_y}{2}\right)$

■

Cross Section	M.O.I	Section Modulus $Z = \frac{I}{y}$
Rectangular section	$I_{XX} = \frac{bd^3}{12}$ $I_{yy} = \frac{db^3}{12}$ $I_{base} = \frac{bd^3}{3}$	$Z = \frac{bd^2}{6}$
Triangular section	$I_{XX} = \frac{bh^3}{36}$ $I_{base} = \frac{bh^3}{12}$ $I_{top} = \frac{bh^3}{4}$	$Z = \frac{bh^2}{24}$
Solid Circular section	$I_{XX} = I_{YY} = \frac{\pi D^4}{64}$	$Z = \frac{\pi D^3}{32}$
Hollow circular section	$I_{xx} = I_{yy} = \frac{\pi(D^4 - d^4)}{64}$	$Z = \frac{\pi}{32D}(D^4 - d^4)$
Diamond section	$I_d = \frac{a^4}{12}$	$Z = \frac{a^3}{6\sqrt{2}}$
Square section	$I_{xx} = I_{yy} = \frac{a^4}{12}$	$Z = \frac{a^3}{6}$

■ **Ratio of $\frac{\tau_{max.}}{\tau_{avg.}}$, $\frac{\tau_{max.}}{\tau_{NA}}$ and $\frac{\tau_{NA}}{\tau_{Avg.}}$ for different Cross-section**

Cross-Section	$\frac{\tau_{max}}{\tau_{avg.}}$	$\frac{\tau_{max}}{\tau_{NA}}$	$\frac{\tau_{NA}}{\tau_{avg.}}$
Rectangular/square	3/2	1	3/2
circular	4/3	1	4/3
Triangle	3/2	9/8	4/3
Diamond	9/8	9/8	1

- **Bending equation-** $\frac{M}{I} = \frac{\sigma_b}{y} = \frac{E}{R}$

  y = Distance of outer most fiber from N.A.
- **Bending Stress (σ_b)** $= \frac{My}{I}$
- **Radius of curvature (R)** $= \frac{EI}{M}$
- **Curvature of Section** $= \frac{M}{EI}$

EI/l – Flexural stiffness
I/y – Section modulus
GI_p – Torisional rigidity
GI_p/l – Torisional stiffness

- **Flexural Rigidity** = EI

■ **Types of Load and shape of S.F.D, B.M.D-**

Load	Shape	
	S.F.D.	B.M.D
Point Load or Concentrated Load	Rectangular/ Uniform	May be Horizontal and may be inclined/Triangular/ linear/1°
U.D.L. (Uniformly Distributed Load)	Inclined /Triangular Linear/1°	Square Parabola (2°)
G.V.L. (Gradually Varying Load)	Square Parabola (2°)	Cubical Parabola (3°)

■ **Max. Shear force, Bending moment, Slope and Deflection for different types of Beam-**

Types of Beam	$S.F_{max.}$	$B.M_{max.}$	Slope (θ_{max})	Deflection (y_{max})
S.S.B. with point load at centre	$\pm\frac{W}{2}$	$+\frac{WL}{4}$	$\frac{WL^2}{16EI}$	$\frac{WL^3}{48EI}$
S.S.B. with U.D.L, wN/m	$\pm\frac{wL}{2}$	$+\frac{wL^2}{8}$	$\frac{wL^3}{24EI}$	$\frac{5wL^4}{384EI}$
Cantilever beam with point load at its end	$-W$	$-WL$	$\frac{WL^2}{2EI}$	$\frac{WL^3}{3EI}$
Cantilever beam with U.D.L wN/m	$-wL$	$-\frac{wL^2}{2}$	$\frac{wL^3}{6EI}$	$\frac{wL^4}{8EI}$
Gradually varying load zero at free end & max. at fixed support	$-\frac{wL}{2}$	$-\frac{wL^2}{6}$	$\frac{wL^3}{24EI}$	$\frac{wL^4}{30EI}$

Scanned with CamScanner

Cantilever beam with moment (M kN-m) at its free end	0	M	$\frac{ML}{EI}$	$\frac{ML^2}{2EI}$

■ **Method to Determine Slope and Deflection-**

1. Double Integration Method
2. Macaulay's Method
3. Area Moment Method/ Mohr's Method
4. Strain energy Method
5. Conjugate Beam Method
6. Superposition Method

■ **Important point-**

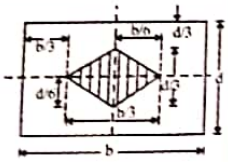
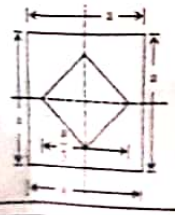
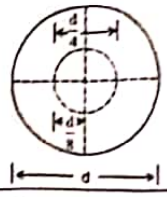
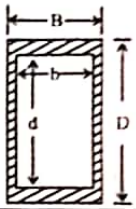
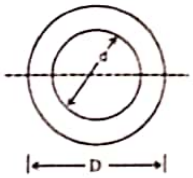
Deflection equation	EI.y
Slope equation	$EI\left(\frac{dy}{dx}\right)$
Moment equation	$EI\left(\frac{d^2y}{dx^2}\right)$
Shear equation	$EI\left(\frac{d^3y}{dx^3}\right)$
Load equation	$EI\left(\frac{d^4y}{dx^4}\right)$

■ **Max. and min. stress in column due to eccentric load-**

$$\sigma_{max} = \frac{P}{A}\left(1+\frac{6e}{b}\right)$$

$$\sigma_{min} = \frac{P}{A}\left[1-\frac{6e}{b}\right]$$

■ **Max. Limit of eccentricity–**

Section	Max. Eccentricity Limit	Shape of core
Solid Rectangular Section 	$e_{x-x} \le \frac{d}{6}$, $e_{y-y} \le \frac{b}{6}$ Side of core = $\frac{\sqrt{b^2+d^2}}{6}$ This known as middle third rule.	Rhombus
Square Cross section 	$e \le \frac{a}{6}$ Kernel size, $\frac{a}{3}\times\frac{a}{3}$	Square
Solid Circular Section 	$e_{max} \le \frac{d}{8}$ Dia of core, d/4 Known as middle fourth rule.	Circular
Hollow Rectangular Section 	$e_{x-x} \le \frac{BD^3-bd^3}{6D(BD-bd)}$ $e_{y-y} \le \frac{DB^3-db^3}{6B(BD-bd)}$	Rhombus
How Circular Section 	$e_{max} \le \frac{D^2+d^2}{8D}$ Dia of core, $\frac{D^2+d^2}{4D}$	Circular

■ **Classification and failure of Column Based an Slenderness Ratio–**

S.R	Types of column	Fails in
< 32	Short column	Crushing
32-120	Intermediate column	Combined, crushing and buckling
>120	Long column	Buckling

$\frac{l_e}{b_{min}} \ge 12$ long column

$\frac{l_e}{b_{min}} < 12$ Short column

$\frac{l_e}{b_{min}} < 3$ Pedestal

■ **Important Formula-**

• **Euler's Formula-**

$$P_b, P_{cr} \text{ or } P_e = \frac{\pi^2 EI_{min}}{l_e^2}$$

$$= \frac{\pi^2 EA}{\lambda^2}$$

P_e = Euler, Crippling or Buckling Load

Note- Euler's Formula is Applicable only for long column.

Scanned with CamScanner

- **Slenderness Ratio-**

$$\lambda = \frac{l_e}{k_{min}}$$

and $k_{min} = \sqrt{\frac{I_{min}}{A}}$

- **Rankine's Formula-**

(Applicable for any types of column)

$$\boxed{\frac{1}{P_R} = \frac{1}{P_c} + \frac{1}{P_e}}$$

Crushing load $P_c = \sigma_c \times A$

σ_c = Compressive stress

P_R = Rankine load

$$P_R = \frac{\sigma_c . A}{1 + \left(\frac{\sigma_c}{\pi^2 E}\right) . \left(\frac{l_e}{k}\right)^2}$$

$$= \frac{\sigma_c . A}{1 + \alpha \left(\frac{l_e}{k}\right)^2}$$

$$= \frac{\sigma_c . A}{1 + \alpha \lambda^2}$$

Rankine constant $(\alpha) = \frac{\sigma_c}{\pi^2 E}$

■ **Effective length of column based on end condition-**

End Condition	One end Fixed and other end Free	Both end Hinged	Both end Fixed	One end Fixed and other Hinged
Effective length	$l_e = 2L$	$l_e = L$	$l_e = L/2 = 0.5L$	$l_e = \frac{L}{\sqrt{2}} = 0.70L$
l_e (As per IS Code)	2L	L	0.65L	0.8L
Buckling Load/ Euler load $P_e = \frac{\pi^2 EI}{l_e^2}$	$\frac{\pi^2 EI}{4L^2}$	$\frac{\pi^2 EI}{L^2}$	$\frac{4\pi^2 EI}{L^2}$	$\frac{2\pi^2 EI}{L^2}$

■ **Secant formula for max deflection $U_{max.}$ and max. stress $\sigma_{max.}$ due to eccentric load- :-**

$$U_{max} = e\left[\text{Sec}\left(\sqrt{\frac{P}{EI}} . \frac{L}{2}\right) - 1\right]$$

$$\sigma_{max} = \frac{P}{A}\left[1 + \frac{e.y_c}{r^2}\sec\left(\frac{L}{2r}\sqrt{\frac{P}{EA}}\right)\right]$$

Material	σ_C (N/mm^2)	Rankine's Constant When both ends are hinged
Cast Iron	550	$\frac{1}{1600}$
Wrought Iron	250	$\frac{1}{9000}$
Mild Steel	320	$\frac{1}{7500}$
Strong Timber	50	$\frac{1}{750}$

■ **Pure Torsion Equation-**

$$\boxed{\frac{T}{J} = \frac{G\theta}{l} = \frac{\tau}{R}}$$

Note:- Torsional Rigidity/ Stiffness (GJ) = $\frac{Tl}{\theta}$

- Torsional rigidity (GJ) $\propto$ strength (Polar Modulus of Section)

(1) Strain Energy in solid shaft-

$$U_s = \frac{1}{2}T\theta = \frac{1}{2} . \frac{T^2 l}{G.J}$$

$$= \frac{1}{4} . \frac{Q^2}{G} \times \text{Volume of shaft}$$

(2) Strain Energy in Hollow shaft-

$$U_H = \frac{1}{4} . \frac{\tau^2}{G} . \frac{(d_o^2 + d_i^2)}{d_o^2} \times \text{Volume of shaft}$$

(3) Strain energy due to shear stress-

$$U = \frac{\tau_s^2}{2G} \times \text{Volume}$$

Scanned with CamScanner

(4) Strength of solid shaft-

$$T_s = \frac{\pi}{16}\tau_s d^3$$

(5) Strength of hollow shaft-

$$T_H = \frac{\pi}{16}.\tau_H\left(\frac{d_o^4 - d_i^4}{d_o^4}\right).d_o^3$$

☞ **Ratio of strain energy for-**

$$\frac{U_H}{U_s} = \left(\frac{d_o^2 + d_i^2}{d_o^2}\right)$$

☞ **Ratio of torque for-**

$$\frac{T_H}{T_S} = \frac{d_o^4 - d_i^4}{d_o^4}$$

■ **Important Formula-**

- **Effect of pure bending on shaft-**

  Principal stress, $\sigma = \frac{32M}{\pi D^3}$

- **Effect of pure torsion on shaft-**

  Max. shear stress $\tau_{max} = \frac{16T}{\pi D^3}$

- **Combined effect of bending and torsion-**

  $$\sigma_{max} \text{ or } \sigma_{min} = \frac{16}{\pi D^3}\left[M \pm \sqrt{M^2 + T^2}\right]$$

  $$\tau_{max} = \frac{16}{\pi D^3}\sqrt{M^2 + T^2}$$

- **Equivalent torque–**

  $$T_e = \sqrt{M^2 + T^2}$$

- **Equivalent bending moment-**

  $$= \frac{1}{2}\left[M + \sqrt{M^2 + T^2}\right]$$

■ **If shaft is subjected to shear and bending stress then-**

$$\frac{\text{Maximum bending Stress}}{\text{Maximum shear Stress}} = \frac{2M}{T}$$

$$\frac{\text{Maximum shear Stress}}{\text{Maximum bending Stress}} = \frac{T}{2M}$$

■ **Thin Cylindrical Pressure Vessel-**

- Hoop/ Circumferential stress $\sigma_H = \frac{pd}{2t}$
- Longitudinal stress, $\sigma_L = \frac{pd}{4t}$
- Hoop strain, $\varepsilon_H = \frac{pd}{4tE}(2-\mu)$
- Longitudinal strain, $\varepsilon_L = \frac{pd}{4tE}(1-2\mu)$
- Volumetric strain

  $$\varepsilon_V = 2\varepsilon_H + \varepsilon_L = \frac{pd}{4tE}(5-4\mu)$$

- $$\frac{\text{Hoop strain}}{\text{Longitudinal Strain}} = \frac{\varepsilon_h}{\varepsilon_L} = \frac{2-\mu}{1-2\mu}$$

- $$\frac{\text{Circumferential/Hoop stress}}{\text{Longitudinal Stress}} = 2.0$$

- $$\frac{\text{Longitudinal stress}}{\text{Circumferential/Hoop Stress}} = 0.50$$

■ **Stiffness of close coil helical spring**

- **Parallel combination**

  $S_{eq} = S_1 + S_2 + S_3 + ---$

  S_1, S_2, S_3 = Stiffness

- **Series combination**

  $$S_{eq} = \frac{S_1 S_2}{S_1 + S_2}$$

■ **Deflection and angle of twist of close coil helical spring-**

$$\delta = R.\theta = \frac{32TDN}{Gd^4} \times R = \frac{64WR^3N}{Gd^4}$$

$$\theta = \frac{32TDN}{Gd^4} = \frac{64WR^2N}{Gd^4}$$

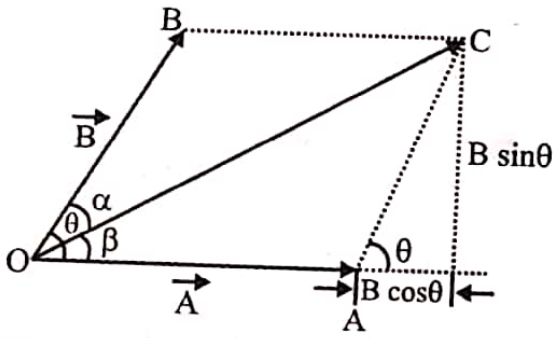
Scanned with CamScanner

Applied Mechanics

■ **Types of Forces -**

Force System	Definition
Coplanar forces	Line of action of all forces lying on single plane.
Non-coplanar forces	Line of action of all forces not lying on a single plane.
Concurrent force	Line of action of all forces passes through a single point.
Non-concurrent forces	Line of action of all forces do not pass through a single point.
Collinear forces	Line of action of all forces passes through a single line.
Parallel forces	Line of action of all forces are parallel to each other.
(a) Like parallel forces	Line of action of all forces are parallel to each other in same direction.
(b) Unlike parallel forces	Line of action of all forces are parallel to each other in different direction.
Non-parallel forces	Line of action of all forces are not parallel each other.
Non-coplanar concurrent forces	Line of action of all forces are not lying on a single plane but passes through a single point.

➤ **Parallelogram law of forces-**



➤ **Resultant force,**

$$R=\sqrt{A^2+B^2+2AB\cos\theta}$$

$\theta=0^0$, $\cos 0^0=1$

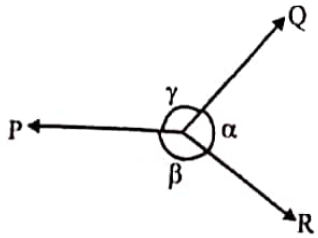
if $\theta=90^0$, $\cos 90^0=0$

If $\theta=180^0$, $\cos 180^0=-1$

Direction of resultant,

$$\tan\alpha=\frac{B\sin\theta}{A+B\cos\theta},\quad \tan\beta=\frac{A\sin\theta}{B+A\cos\theta}$$

➤ **Lami's Theorem–**



$$\frac{P}{\sin\alpha}=\frac{Q}{\sin\beta}=\frac{R}{\sin\gamma}$$

■ **Equation of motion-**

- **1st Law of motion-** $v=u+at$
- **2nd Law of motion-** $S=ut+\frac{1}{2}at^2$
- **3rd Law of motion-** $v^2=u^2+2aS$

Where,

u = initial velocity

v = final velocity

S = travelled distance by object

■ **Projectile motion-**

1. Max. height- $h_{max}=\frac{u^2\sin^2\theta}{2g}$

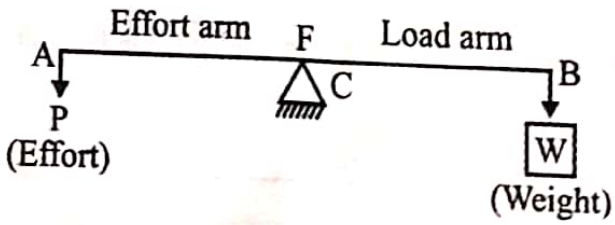
2. Time of flight- $T=\frac{2u\sin\theta}{g}$

3. Range- $R=\frac{u^2\sin^2\theta}{g}$

for R_{max}, $\theta=45°$

■ **Class of lever-**

1. Ist Class of lever –

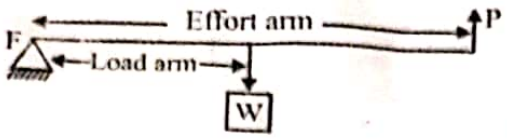


$1 \le M.A.$

Ex.- Scissor, Hand Pump

Scanned with CamScanner

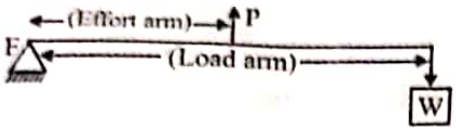
2. 2nd Class of lever–



M.A. > 1 always

Ex.- Wheel barrow, Nut-Cracker

3. 3rd Class of lever–



Ex.- Sugar tongs ,Fishing rod

➢ Mechanical Advantage-

$$V.R. = \frac{\text{Effort Arm}}{\text{Load Arm}} = \frac{P}{W}$$

$$M.A. = \frac{\text{Load}}{\text{Effort}} = \frac{W}{P}$$

➢ General condition of equilibrium-

(i) $\sum X$ or $\sum H = 0$

(ii) $\sum Y$ or $\sum V = 0$

(iii) $\sum M = 0$

➢ Co-efficient of friction-

$$f \propto R \Rightarrow f = \mu R$$

➢ Static friction coefficient-

$$\mu_s = \frac{f_s}{R}$$

➢ Kinetic friction coefficient-

$$\mu_k = \frac{f_k}{R}$$

Note- $\mu_s > \mu_k$

➢ Newton's first law of motion-

If a body is at rest or moving at a constant speed in a straight line, it will remains at rest or keep moving in a straight line at constant speed unless it is acted upon by a some external forces.

- It is known as law of inertia.

➢ Second law of motion–

The rate of change of momentum of a body is directly proportional to the applied force.

$$\boxed{\vec{F} \propto \frac{dp}{dt} = ma}$$

$$\vec{P} = m\vec{v}$$

➢ Third law of motion-

Every action has equal and opposite reaction.

Kinetic Energy- $K.E. = \frac{1}{2}mv^2$

■ Centroid of regular plane figure-

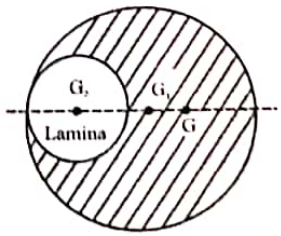
Lamina	Area	$\bar{x}$	$\bar{y}$
Triangle	$\frac{1}{2}b.h$	$\frac{b}{3}$	$\frac{h}{3}$
Rectangle	b.h	$\frac{b}{2}$	$\frac{h}{2}$
Circle	πr^2	r	r
Semicircle	$\frac{1}{2}\pi r^2$	r	$\frac{4r}{3\pi}$
Quadrant Circle	$\frac{1}{4}\pi r^2$	$\frac{4r}{3\pi}$	$\frac{4r}{3\pi}$
Three quadrant circle	$\frac{3}{4}\pi r^3$	$\frac{4r}{9\pi}$	$\frac{4r}{9\pi}$

➢ Center of gravity of an any area-

$$\boxed{\bar{x} = \frac{a_1x_1 + a_2x_2 + a_3x_3 + ---}{A}}$$

$$\boxed{\bar{y} = \frac{a_1y_1 + a_2y_2 + a_3y_3 + ----}{A}}$$

➢ C.G. for remains part after cut out a lamina-



$$\boxed{\bar{x} = \frac{a_1x_1 - a_2x_2}{a_1 - a_2}}$$

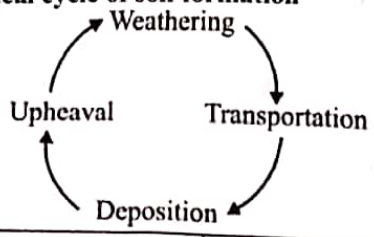
$$\bar{y} = \frac{a_1y_1 - a_2y_2}{a_1 - a_2}$$

Scanned with CamScanner

Soil Mechanics

- Father of Soil Mechanics → Dr. Karl Terzaghi

■ **Geological cycle of soil formation**



Type of Soil	Deposited by
Alluvial Soil	River / running water (Ex. –Sand, Gravel)
Marine Soil	Sea water
Lacustrine Soil	Lakes /still water
Aeolian Soil	Wind (Ex.– Loess, Dune Sand)
Glacial Soil	Ice (Ex.–Till, Drift)
Colluvial Soil	Gravity (Ex.– Talus)

Loam = Sand + Silt + Clay

- Water content (w) = $\frac{W_w}{W_s}$, $(w \geq 0)$
- Effective Water content $w' = \frac{W_w}{W}$ $(0 \leq w' < 1)$
- $w' = \frac{w}{1+w}$ or $w = \frac{w'}{1-w'}$
- Void ratio (e) = $\frac{V_v}{V_s}$, $(e > 0, \text{always})$
- Porosity (n) = $\frac{V_v}{V}$ $(0 < n < 1)$
- Degree of saturation (S) = $\frac{V_w}{V_v}$ $(0 \leq S \leq 1)$
- Air content (a_c) = $\frac{V_a}{V_v}$, $(0 \leq a_c \leq 1)$
- Percentage air voids (n_a) = $\frac{V_a}{V}$, $(0 \leq n_a < 1)$
- Bulk unit weight (γ_t) = $\frac{W}{V}$
- Dry unit weight (γ_d) = $\frac{W_s}{V}$ ($\gamma_d \uparrow$ –Denseness $\uparrow$)
- Saturated unit weight (γ_{sat}) = $\frac{W_{sat}}{V}$
- Submerged unit weight (γ_{sub}) = $\gamma_{sat} - \gamma_w = \frac{\gamma_{sat}}{2}$
- Unit weight of water (γ_w) = $\frac{W_w}{V_w}$
- Unit weight of soil solid (γ_s) = $\frac{W_s}{V_s}$

♦ Shrinkage Ratio (S.R.)–

$$S.R. = \frac{\frac{V_1 - V_2}{V_d}}{W_1 - W_2} \times 100 = \frac{\gamma_d}{\gamma_w} \left(\begin{array}{c} \text{At shrinkage limit} \\ V_2 = V_d \ \& \ W_2 = W_d \end{array} \right)$$

- **Specific gravity for soil Solid** $G_s = \frac{\gamma_s}{\gamma_w} = \frac{W_s}{V_s \gamma_w}$

For Organic Soil Solid	G_s = 1.2 to 1.4
For Inorganic Soil Solid	G_s = 2.6 to 2.75

- Mass specific gravity for soil $G_m = \frac{\gamma_t}{\gamma_w}$

■ Some Important Relations

- $W_s = \frac{W}{1+w}$ • $V_s = \frac{V}{1+e}$ • $e = \frac{n}{1-n}$ • $n = \frac{e}{1+e}$
- $e = \frac{wG_s}{S}$ • $\gamma_t = \left(\frac{G_s + Se}{1+e}\right)\gamma_w = \frac{G_s \gamma_w (1+w)}{1+e}$
- $n_a = n \times a_c$ • $a_c = 1 - S$
- $\gamma_d = \left(\frac{G}{1+e}\right)\gamma_w = \frac{(1-n_a)G\gamma_w}{1+wG}$ • $\gamma_{sat} = \left[\frac{(G+e)}{1+e}\right]\gamma_w$
- $\gamma_{sub} = \left(\frac{G-1}{1+e}\right)\gamma_w$

☞ **Imp.–** $\gamma_s > \gamma_{sat} > \gamma_t > \gamma_d > \gamma_{sub}$

- **Density Index / Relative density (I_D)** = $\frac{e_{max} - e_{natural}}{e_{max} - e_{min}}$
- $I_D = \frac{\gamma_{dmax}(\gamma_d - \gamma_{dmin.})}{\gamma_d(\gamma_{dmax} - \gamma_{dmin})}$

■

I_D (%)	Soil Condition
0 – 15	Very loose
15 – 35	Loose
35 – 65	Medium dense
65 – 85	Dense
85 – 100	Very dense

■ **Methods for determination of water content–**

Methods	Specialised
(i) Oven dry method	• Standard Lab method • Most accurate
(ii) Sand bath method	• Not very accurate • Rapid field method
(iii) Torsion balance moisture meter method	• Laboratory method • Rapid + accurate • Drying & weighing simultaneously • Useful soil for reabsorb moisture after drying

Scanned with CamScanner

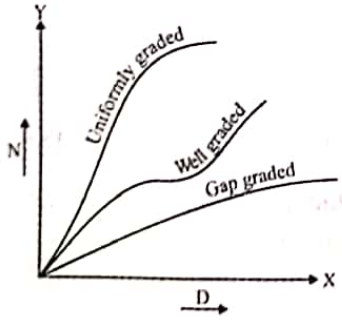
(iv) Calcium carbide method	• Field method • Rapid method (result in 5-7 mint) • Not very accurate • Remove C_2H_2 (Acetylene gas)
(v) Pycnometer method	• Laboratory Method • Useful for cohesionless soil
(vi) Alcohol method	• Field method • Not suitable for organic soil
(vii) Radiation method	• Field method • Radio active material (cobalt - 60) used.

■ **Methods to determine the unit wt. of soil-**

Method	Suitable for
Core cutter method	Soft, fine grained and clayey soil
Sand replacement method	Gravelly, sandy and dry soil
Water displacement method	Cohesive soil
Submerge density method	Cohesive soil
Rubber Balloon method	All type of soil

■ **Methods for specific gravity determination-**

1. **Density bottle method**
   - Most accurate and useful for all type of soil
   - it is standard laboratory method.
2. **Measuring flask method**
   - For coarse grained soil
3. **Gas Jar method**
   - For coarse grained soil
4. **Pycnometer method**
   - For coarse grained cohesionless soil



■ **Grading of soil-**

Type of Soil	Explanation
Well graded soil	All size of soil particle available.
Poorly/Gap graded soil	It has excess or deficiency of a certain particle size. In gap graded soil some particle size are missing.
Uniformly graded soil	Most of the particles has same size.

- $D_{60} \rightarrow$ size of the particle such that 60% particle are finner.
- $D_{10} \rightarrow$ Effective size of particle.
- **Coefficient of uniformity** $C_u = \frac{D_{60}}{D_{10}}$

  for well graded Gravel, $C_u > 4$
  for well graded sand, $C_u > 6$
  for uniform soil $C_u = 1$
- for well graded soil, $1 \le C_c \le 3$

C_u	Soil
1-5	Uniformly graded
5-15	Poorly graded
>15	Well graded

- **Coefficient of curvature,** $C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$
- **Relation between C_c and C_u**

  (i) $C_c \times C_u = \left(\frac{D_{30}}{D_{10}}\right)^2$

  (ii) $\frac{C_c}{C_u} = \left(\frac{D_{30}}{D_{60}}\right)^2$

Note : D_{10} =effective particle size
C_u- to determine or range of particle size
C_c- to determine shape of particle and PSD curve in soil mass

■ **Stoke's Law-**

$$V = \frac{(G-1)\gamma_w D^2}{18\mu} = \frac{(\gamma_s - \gamma_w)D^2}{18\mu} \qquad \left\{G = \frac{\gamma_s}{\gamma_w}\right\}$$

Note- Stoke's Law is valid in laminar flow which maintained when particle size is in the range of 0.2 mm to 0.0002 mm.

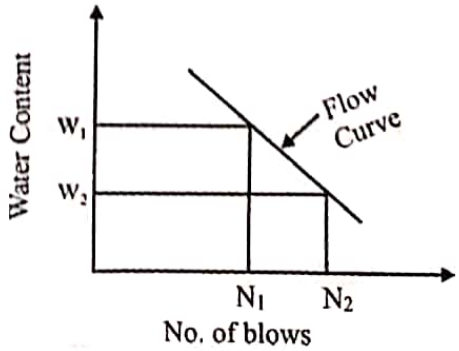
■ **Hydrometer corrections –**

Meniscus correction, C_m	always +ve
Temperature correction, C_t	+ve or –ve both
Dispersing agent correction, C_d	always –ve

- Corrected hydrometer correction

  $R_H = R + C_m \pm C_t - C_d$

- **Flow Index** $(I_f) = \frac{w_1 - w_2}{\log_{10}(N_2/N_1)}$

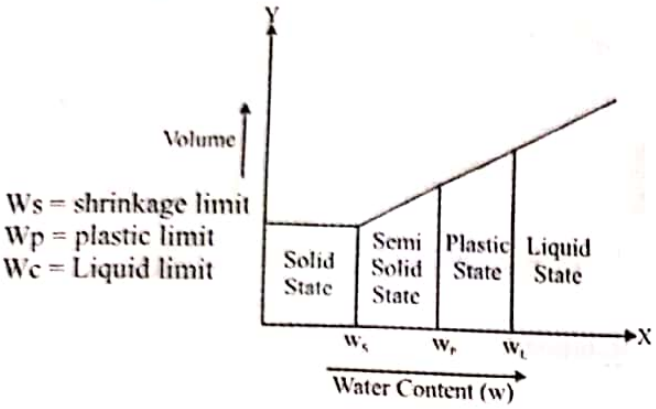


Scanned with CamScanner

■ **Toughness Index** $I_T = \frac{I_p}{I_f}$

- For most soil, toughness index is b/w 0-3.
- For friable soil, $I_T < 1$
- For clayey soil, $1 \le I_T \le 3$

■ **Consistency limit/Atterberg limits of soil-**



■ **Plasticity Index** $I_P = w_L - w_P$

I_P	Plasticity
0	Non Plastic
< 7	Low Plastic
7–17	Medium Plastic
> 17	Highly Plastic
I_P	**Soil Type**
O (Non-plastic)	Sand
10-15	Silt
15-100	Clay
20-40	Kaolinite
35-60	Illite
50-100	Montmorillonite

- **Liquidity Index** $(I_L) = \frac{w - w_p}{w_L - w_P} = \frac{w - w_P}{I_P}$
- **Consistency Index** $I_C = \frac{w_L - w}{w_L - w_P} = \frac{W_L - w}{I_P}$

[w = water content in bulk soil)

- $I_C + I_L = 1$

Consistency	I_C	I_L
Very Stiff	> 1	< 0
Stiff	1 – 0.75	0 – 0.25
Medium Stiff	0.75 – 0.50	0.25 – 0.50
Soft	0.50 – 0.25	0.50 – 0.75
Very Soft	0.25 – 0	0.75 – 1.0
Liquid state	< 0	> 1

■ **Sensitivity** $(S_t) = \frac{(q_u)\text{ undisturbed}}{(q_u)\text{ remoulded}}$

Sensitivity (S_t)	Soil Classification
1	Insensitive (Gravel, Coarse sand)
2 – 4	Normal sensitive or moderate
4 – 8	Sensitive (Silt + Clay)
8 – 16	Extra sensitive
> 16	Quick clay/unstable

■ **Activity** $(A_c) = \frac{\text{Plasticity Index}}{\%\text{ of clay particles (size} < 2\mu)}$

A_c	Classification
< 0.75	Inactive
0.75 – 1.25	Normal
> 1.25	Active

- **Thixotropy**– Increase in strength of remoulded soil with passage of time.

■ **Group Index** $(GI) = 0.2a + 0.005ac + 0.01\,bd$

a = (P–35) $\not>$ 40 [Range 0 to 40]
b = (P–15) $\not>$ 40 [Range 0 to 40]
c = (W_L–40) $\not>$ 20 [Range 0 to 20]
d = (I_P–10) $\not>$ 20 [Range 0 to 20]

Where,
W_L = Liquid limit (in%)
I_P = Plasticity Index
P = Percentage fine passing from 0.075 mm (75μ)

$0 \le GI \le 20$

- Soil classified into 8 groups from A_1 to A_7 with A_8 for muck or peat soil.

■ **Classification of Soil based on ISSCS (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

Scanned with CamScanner

■ **Properties of clay minerals–**

Minerals	Bond	Example
Kaolinite	Hydrogen (strongest)	China clay
Illite	Ionic	Green clay sand
Montmorillonite	Vander wall force, Water bond (Weakest bond)	Black soil Bentonite soil.

■ **Bond Strength**

Kaolinite > Illite > Montmorillonite

Shrinkage/Swelling/Plasticity Index/dry strength

Montmorillonite > Illite > Kaolinite

■ **Size of clay Mineral in descending order**

Kaolinite > Illite > Montmorillonite

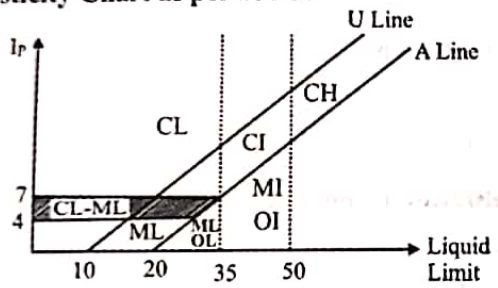
■ **Activity of clay minerals-**

Mineral	Activity value.
Kaolinite	0.1-0.4
Illite	0.5-1.0
Montmorillonite	1-7

■

Soil structure	Found in
Single grained	Cohessionless soil
Honey Comb	Fine Sand & Silt
Flocculated	Clayey soil
Dispersed	Clay

- **Plasticity Chart as per ISSCs–**



A – Line equation → $I_P = 0.73\,(W_L - 20)$

U – Line equation → $I_P = 0.9\,(W_L - 8)$

- **Critical hydraulic gradient-**

$$i_c = \frac{\gamma_{sub}}{\gamma_w} = \frac{G-1}{1+e}$$

$$= (G-1)\times(1-n)$$

- **Darcy Law–** $V \propto i$

$$V = Ki$$

$$i \propto \frac{\Delta h}{\ell} \qquad q = KiA$$

- $V_s = \frac{V}{n}$ • $K_p = \frac{K}{n}$

[K_P = Coefficient of percolation]

V_s = Seepage velocity

V = Discharge velocity

■ **Determination of Coefficient of permeability–**

(A) Laboratory Method-

(i) Constant head permeability test

- for coarse grained soil

- $K = \frac{QL}{t.h_L.A}$

(ii) Falling head permeability test–

- for fine grained soil

- $K = \frac{2.303\,aL}{At} \times \log_{10}\left(\frac{h_1}{h_2}\right)$

(B) Field Method-

- **Pumping out test :** useful for homogeneous coarse grained soil.

Unconfined Aquifer	Confined Aquifer
$K = \frac{2.303q}{\pi(h_2^2 - h_1^2)} \log_{10}\left(\frac{r_2}{r_1}\right)$	$K = \frac{2.303q}{2\pi D(h_2 - h_1)} \log_{10}\left(\frac{r_2}{r_1}\right)$

- **Pumping in test-** Useful for high permeable soil.

$$K = \frac{q}{5.5rH}$$

Where,

q = Rate of discharge in well

r = Radius of well

H = Depth of water in well

■ **Theoretical/Indirect Methods–**

(i) **Consolidation Method**

$K = C_v \times M_v \times \gamma_w$

(ii) **Allen Hazen's Method**

$K = CD_{10}^2$ or $K = 100D_{10}^2$ [C = 100 to 150]

(iii) **Kozney - Karman Method**

$$K_k = \frac{1}{C} \times \frac{\gamma_w}{\mu} \times \frac{e^3}{1+e} \times \frac{1}{S^2}$$

$D \propto \frac{1}{S}$

K_k = Kozney – Karman Constant

e = void ratio

μ = Dynamic viscosity coefficient

γ_w = Unit weight of water.

Note : $k \propto e^2$

(iv) **Louden's formula**

$\log_{10}(KS^2) = a + bn$

■ **Permeability Coefficient of Stratified Soil–**

(i) In case of Horizontal flow (Parallel to bed)

$$K_H = \frac{K_1H_1 + K_2H_2 + \ldots\ldots\ldots + K_nH_n}{H_1 + H_2 + \ldots\ldots\ldots + H_n}$$

(ii) In case of Vertical flow (Normal to bed)

$$K_V = \frac{H_1 + H_2 + \ldots\ldots\ldots H_n}{\frac{H_1}{K_1} + \frac{H_2}{K_2} + \ldots\ldots\ldots + \frac{H_n}{K_n}}$$

(iii) In case of two dimensional flow

$K_{equivalent} = \sqrt{K_x \times K_y}$

(iv) In case of three dimensional flow

$K_{equivalent} = \sqrt[3]{k_x \times k_y \times k_z}$

Scanned with CamScanner

■ **Typical value of permeability-**

Soil Type	Coefficient of permeability (k) cm/sec	Drainage Characteristics
Gravel	>1	Pervious
Sand	$1-10^{-3}$	Pervious
Silt	$10^{-3}-10^{-6}$	Slightly
Clay	$<10^{-6}$	Impervious

- **Laplace Equation–** $\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0$ for 2D

- **Discharge through a flow net–** $\boxed{q = k.h\frac{N_f}{N_d}}$

$$\left.\begin{aligned} N_f &= N_\psi - 1 \\ N_d &= N_\phi - 1 \end{aligned}\right\} \frac{N_f}{N_d} = \text{Shape factor}$$

- **Filter specification by Terzaghi–**

  - $\frac{D_{15}(\text{filter})}{D_{85}\ (\text{Protected material})} < 5$
  - $4 < \frac{D_{15}(\text{filter})}{D_{15}\ (\text{Protected material})} < 20$
  - $\frac{D_{50}(\text{filter})}{D_{50}\ (\text{Protected material})} < 25$

■

			IS equipments to proctor test	
	Standard proctor test	Modified proctor test	Light compaction	Heavy compaction
Weight of hammer	2.54	4.54	2.60	4.9
Fall of hammer (mm)	304.8	457.2	310	450
Number of blows per layer	25	25	25	25
Number of layer	3	5	3	5
Volume of mould	944	944	1000	1000

■ **Compaction energy ratio for-**

$$\frac{\text{Modified standard proctor test}}{\text{Standard proctor test}} = 4.5$$

$$\frac{\text{Standard proctortest}}{\text{Modified standard proctor test}} = 0.22$$

■

Type of equipment	Suitability for soil
Rammers or tampers	all types of soils
Smooth wheeled rollers	Crushed rocks, gravels, sands
Pneumatic tyred Rollers	Sands, gravels, silts, clayey Soils but not suitable for Uniformly graded soils.
sheep foot rollers	Clayey Soil
Vibratory rollers	Sands

- **Primary settlement**

$$\Delta H = \frac{a_v.\Delta\bar{\sigma}}{1+e_0}\times H_0 = m_v.\Delta\bar{\sigma}.H_0$$

- **In case of normally consolidated Soil**

$$\Delta H = \frac{C_c H_0}{1+e_0}\log_{10}\left[\frac{\bar{\sigma}_0+\Delta\bar{\sigma}}{\bar{\sigma}_0}\right]$$

- $\frac{\Delta H}{H_0} = \frac{\Delta e}{1+e_0}$

- **Co-efficient of consolidation-**

$$C_V = \frac{K}{m_v \times \gamma_w}$$

Unit of C_V = cm^2/sec

$$\boxed{C_V \propto \frac{1}{W_L} \propto \frac{1}{I_P} \propto \text{Temperature}}$$

■ **Methods to find C_V–**

i) Square root of time fitting method-

$$C_V = \frac{T_{90}\times d^2}{t_{90}}$$

ii) Logarithm of time fitting method

$$C_V = \frac{T_{50}\times d^2}{t_{50}}$$

- **Total settlement** $\boxed{S_t = S_{immediate} + S_P + S_s}$

$$\boxed{\frac{\Delta H}{H} = \frac{\Delta V}{V} = \frac{\Delta e}{1+e_0}.\frac{1}{\Delta\bar{\sigma}}}$$

- **Co-efficient of compressibility**

$$\boxed{(a_v) = \frac{e_1-e_2}{\sigma_2-\sigma_1} = \frac{\Delta e}{\Delta\bar{\sigma}}}$$

- **Co-efficient of compression** $\boxed{(C_c) = \frac{e_1-e_2}{\log_{10}\left(\frac{\bar{\sigma}_2}{\bar{\sigma}_1}\right)}}$

- **C_c = 0.009 (w_L–10),** undisturbed soil of medium sensitivity
- **C_c = 0.007 (w_L–10),** Remoulded soil of low sensitivity
- Co-efficient of volume compressibility $\boxed{m_v = \frac{a_v}{1+e_o}}$,

  e_0 = Initial Void Ratio

- **Compression modulus** $\boxed{E_c = \frac{1}{m_v}}$

- **Over consolidation ratio–**

$$OCR = \frac{\text{Max effective stress applied in past}}{\text{Existing effective stress}}$$

  - OCR > 1, for over consolidated soil
  - OCR = 1, for normally consolidated soil
  - OCR < 1, for under consolidated soil

Scanned with CamScanner

- **Time factor-**

$$T_v = \frac{C_v \times t}{d^2}$$

d = H for one way drainage

$d = \frac{H}{2}$ for two way drainage

- $T_{50} = 0.196$, $T_{90} = 0.848$, $T_{60} = 0.287$
- $T_v = \frac{\pi}{4} \times \left(\frac{U}{100}\right)^2$ if $U \le 60\%$
- Degree of consolidation $\% U = \frac{\Delta h}{\Delta H} \times 100$

■ **Stress distribution in soil-**

- Boussineg's equation (For isotropic Soil)

$$\sigma_{ZB} = \frac{3}{2\pi} \times \frac{Q}{z^2} \times \frac{1}{\left[1+\left(\frac{r}{z}\right)^2\right]^{5/2}} = K_B \times \frac{Q}{z^2} = 0.4775\frac{Q}{z^2}$$

- **Westerguard's equation (for anisotropic soil)**

$$\sigma_{ZW} = \frac{1}{\pi} \times \frac{Q}{z^2} \times \frac{1}{\left[1+2\left(\frac{r}{z}\right)^2\right]^{3/2}}$$

- **Newmark's influence chart–**

$$\sigma_z = \frac{1}{m \times n} \times q \times N$$

m = No. of concentric circles (normally 10)
n = No. of radial lines (normally 20)
N = equivalent no. of areas
q = Intensity of load

■ **Shear Strength of Soil-**

- Shear strength is the capacity to resist shear stress.
- Columb's Hypothesis– $\tau_f = C + \sigma \tan\phi$

$$\tau_f = C' + \bar{\sigma} \tan\phi'$$

Where, C, □ are total stress parameter
C', □' are effective stress parameter

- **Angle of repose–** Minimum angle of an inclined plane which causes an object to slide down on the plane.
- **Angle of friction–** Angle between the normal reaction force and resultant force between friction and normal reaction forces when object just begins to move along surfaces.

■ **Some Important test for soil**

Direct shear Test	• Shear applied at constant rate of strain. • Effective stress and total stress are same. $U = 0$ • Used for free draining soil– sand, gravel. • Shear plane is pre determine.
Tri-axial Test	• Drainage can be controlled. • Pore water pressure, volume changes measured. • Axial strain, deviator stress are determined. • Suitable for all types of soil.
Unconfined Compression Test	• Can be conducted in field easily. • Used to test cohesive soil, rapid assessment of consistency of soil for clay classification, and find sensitivity of clay soil.
Vane shear Test	• Suitable in plastic cohesive soil which is very sensitive. • **When top & bottom end shear the soil–** Shear strength- $\tau_f = \frac{T}{\pi d^2\left(\frac{h}{2}+\frac{d}{6}\right)}$ • **When only bottom end shear the soil–** Shear strength- $\tau_f = \frac{T}{\pi d^2\left(\frac{h}{2}+\frac{d}{12}\right)}$
Consolidated Drained Test [CD]	• Drainage allowed in both stages. • It takes long time. • Used in analysis of gradual loading condition.
Consolidated undrained Test (CU)	• Drainage allowed in 1st stage. • done for check stability under sudden unloading.
Unconsolidated undrained (UU)	• Drainage not allowed in any stage.

- **Active earth pressure–** by this min. pressure exerted by the soil on the retaining wall

$$K_a = \frac{1-\sin\phi}{1+\sin\phi}, \quad K_a = \tan^2\left(45^\circ - \frac{\phi}{2}\right)$$

- **Passive earth pressure–**

$$K_p = \frac{1+\sin\phi}{1-\sin\phi} = \tan^2\left(45^\circ + \frac{\phi}{2}\right) = \frac{1}{K_a}$$

- **Earth pressure at rest–**

$$K_0 = \frac{\mu}{1-\mu} \quad : \text{ for cohessionless soil } K_0 = 1 - \sin\phi$$

Note- K_0 for dense sand is lesser than that of loose sand.
For NC clays $K_0 < 1$
For OC clays $K_0 > 1$

Min. Depth of foundation $D = \frac{p}{\gamma}\left[\frac{1-\sin\phi}{1+\sin\phi}\right]^2$

Scanned with CamScanner

Parameter	General shear failure	Local shear failure
Friction angle (ϕ)	>36%	<28°
Strain at failure	≤ 5°	≥15°
Relative Density	>17%	20%
SPT Number	<30	≤ 5
Void Ratio	<0.55	>0.75
Unconfined Compressive Strength	>100 kN/m²	<80 kN/m²

- **Taylor's stability Number (C-ϕ soil)–**

$$S_n = \frac{C}{\gamma.H_c} = \frac{C}{\gamma.F_C.H_C}$$

- Max. theoretical value of S_n = 0.5, Max. particle value = 0.261

$$S_n = \left[\tan_\beta - \tan\phi\right]\cos^2\beta$$ for c-ϕ soil

- **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**

$$S = k.q.\sqrt{A\frac{(1-\mu H^2)}{E}}$$

■ **Bearing capacity for different types of footing-**

- **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**

$$q_{ult} = 1.3CN_c + \gamma D_f N_q + 0.4\gamma b N_\gamma$$

Note: Load carrying capacity in order strip < circular < square footing

- **Plate Load test (IS 1888-1982)**

$$S_p = \left[\frac{B_f(B_p+0.3)}{B_p(B_f+0.3)}\right]^2$$ for sandy soil

$$\frac{S_f}{S_p} = \left[\frac{B_f}{B_p}\right]^{n+1}$$ = for silts

For C-ϕ soil n = 0.5

For clayey soil n = 0

Permissible Differencial settlement and total settlement of soil

Specification of Foundation	Total settlement	Permissible Diff.Settlement
Isolated Raft footing on sand	40-65 mm	25 mm
Isolated footing on sand	40 mm	25 mm
Isolated Raft footing on clay	65-100 mm	40 mm
Isolated footing on clay	65 mm	40 mm

■ **Classification of piles based on various factors-**

(a) **Function/ Action** - Fender, sheets, 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**-Displacement and non- displacement piles.

(e) **Mode of load transfer**- end bearing, friction and combined piles.

- **Engineering News Formula : Ultimate load on pile**

$$Q_{ap} = \frac{WH}{6(S+C)} = \frac{Q_{UP}}{6}$$

Where, W = load in kg

H = Height of fall in cm

S = Settlement/below in cm

■ **Soil sampler**

- **Inside Clearance:**

$$c_i = \frac{D_3 - D_1}{D_1}\times 100\% \quad (1 < C_i < 3)$$

- **Out side clearance:**

$$c_O = \frac{D_2 - D_4}{D_4}\times 100\% \quad (0 < C_O < 2)$$

Note: $C_O > C_i$ always

- **Area ratio :** $A_r = \frac{D_2^2 - D_1^2}{D_1^2}\times 100$

Where,

D_1 = Inner dia. of cutting edge

D_2 = Outer dia. of cutting edge

D_3 = Inner dia. of sampling tube

D_4 = Outer dia. of sampling tube

■ **Recovery Ratio :**

$$L_r = \frac{\text{Recovery length of the Sample.}}{\text{Penertration length of the Sample}}$$

Recovery value	Soil Property
$L_r = 1$	Good recovery
$L_r < 1$	Compressed soil
$L_r > 1$	Soil has swelled

Scanned with CamScanner

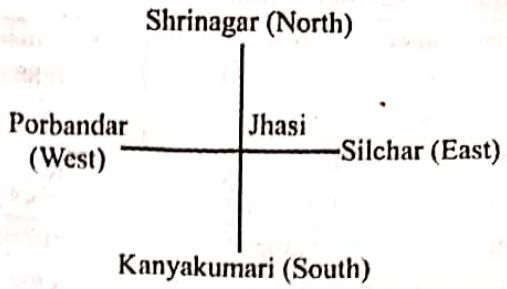
Highway Engineering

Organization	Establishment year
Central Public Works Department (C.P.W.D.)	1854
Public works Department (P.W.D.)	1855
Jayakar Committee	Formed in Nov. 1927 Recommendation Feb. 1928
Central Road Fund (C.R.F.)	1 March, 1929
Central Road Organization (C.R.O.)	1930
Indian Road Congress (I.R.C.)	1934
Motor Vehicle Act	1939 (Revised - 1988)
C.R.R.I	1950
National Highway Act	1956
Border Road Organization (B.R.O.)	1960
Highway Research Board	1973
NHAI	1988

■ **Highway Development and Planning-**

Specification	Ist 20 year plan	IInd 20 year plan	IIIrd 20 year plan
Name of Plan	Nagpur road plan	Bombay road plan	Lucknow Road plan
Duration	1943-1963	1961-1981	1981-2001
Target Density	16km/100 km^2	32km/100km^2	82km/100km^2
Road Pattern	Star and Grid	---	Square and Grid
Provision of expressway	---	1600km	2000 km
Road Classification	(i) NH (ii) SH (iii) MDR (iv) ODR (v) VR	Expressway was added	Primary [Expressway, NH]; Secondary [SH, MDR]; Tertiary [ODR, VR]

- **National Corridors –**



Total length = 7300 km
North-South = 4000 km
East – West = 3300 km

- **Golden Quadrilateral Plan –**

■ **Classification of Road –**

As per traffic		As per load	
Type of Traffic	**Vehicle per – day**	**Type of Road**	**Vehicle load (Tonnes)**
Extra Heavy Traffic	>600	Extra Heavy Road	1500
Heavy Traffic	250-600	Heavy Road	1001-1500
Medium Traffic	70-250	Medium Road	500-1000
Light Traffic	1-70	Light Road	500

■ **Age of different type of roads –**

Earthen Road	2 year
WBM Road	5 year
Bituminous Road	10-15 year
Concrete Road	30 year

Note-
- Value of lateral friction coefficient – 0.15
- Value of longitudinal friction coefficient – 0.35 – 0.40

Skid- Longitudinal Distance > Circumference Distance
Slip - Longitudinal Distance < Circumference Distance

Scanned with CamScanner

■ **Roughness Index in mm/km-**

Unevenness Index mm/km	Speed of Vehicle	Pavement Surface
1500	High	Good
2500	100 kmph	Satisfactory
3500	50 kmph	Uncomfortable

Note :- The unevenness of pavement surface is measured by **'Bump integrator'** in terms of 'Unevenness index'

- **Width of formation of Roadway =**

Carriageway + Median width +Shoulder width

Road land or right of way-

= Carriageway + shoulder + road margin

■ **Camber for different types of road surface-**

Type of Road Surface	Rainfall Range	
	Heavy	Light
Bitumen, Cement Concrete Surface	1 IN 50, 2.0%	1 IN 60, (1.7%)
Thin Bitumen Surface	1 IN 40, 2.5%	1 IN 50, (2.0%)
Water Bond Macadam (W.B.M.)	1 IN 33, 3.0%	1 IN 40, (2.5%)
Metal / Gravel	1 IN 33, 3.0%	1 IN 40, (2.5%)
Earthen Surface	1 IN 25, 4.0%	1 IN 33, (3.0%)

■ **Roadway width for various classes of road-**

Road Classification	Width of formation or Roadway (m)	
	Plain and Rolling Terrain	Mountainous and Steep Terrain
1. N.H. & S.H.		
a) Single Lane	12.0	6.25
b) Double Lane	12.0	8.80
2. Major District Road		
a) Single Lane	9.0	4.75
b) Double Lane	9.0	--
3. Other District Road		
a) Single Lane	7.5	4.75
b) Double Lane	9.0	--
4. Village Road Single Lane	7.5	4.00

■ **Width of carriageway or Pavement Recommended by IRC**

Types of Road	Width of Carriage way
Single lane	3.75m
Two lane, without raised kerb	7.0m
Two lane, with raised kerb	7.5m
Intermediate carriage way except an important road.	5.5m
Multi-lane	3.5m/lane

- **Stopping Sight Distance (S.S.D.)**

S.S.D.=Lag Distance + Breaking Distance

Lag Distance = 0.278 V.t

$$\text{Breaking Distance} = \frac{V^2}{254(f \pm s\%)}$$

$$S.S.D. = vt + \frac{v^2}{2gf}$$

v = in m/sec, t = 2.5 sec

V = in Km/hr

g = acceleration (m/sec^2)

f =

speed (km/hr)	<30	40	50	60	> 80
f	0.40	0.38	0.37	0.36	0.35

$$f = \begin{cases} 0.40 \text{ for } V = 20\text{-}30 \text{ km/hr} \\ 0.35 \text{ for } V = 100 \text{ km/hr} \end{cases}$$

$$s = \begin{cases} \text{gradient} \\ +\text{ve} = \text{ascending gradient} \\ -\text{ve} = \text{descending gradient} \end{cases}$$

- **Intermediate sight distance**

I.S.D = 2 × S.S.D

- **Stopping sight Distance**

Single Lane, Two way Traffic = 2SSD

Single Lane, One way Traffic = SSD

Two Lane, Two way Traffic = SSD

- **Overtaking Zone for OSD**

Minimum length of overtaking zone = 3OSD

Desirable overtaking zone = 5OSD

■ **Design Speed of Vehicle-**

Road	Plain	Rolling	Hilly	Steep
NH, SH	100–80	80–65	50–40	40–30
MDR	80–65	65–50	40–30	30–20
ODR	65–50	50–40	30–25	25–20
VR	50–40	40–35	25–20	25–20

Scanned with CamScanner

■ **Super–Elevation / Banking / Cant→**

$$e+f=\frac{v^2}{gR}$$ [v = in m/sec]

$$e+f=\frac{V^2}{127R}$$ [V = in km/hr] R = in 'm' f = 0.15

■ **Maximum super elevation (e_{max})-**

Condition	e_{max}
For urban road	0.04 (4%)
For plain and rolling terrain or Hilly terrain covered with snow	0.07 (7%)
Hilly terrain is not covered with snow	0.10 (10%)

■ **Minimum Superelevation–**

e_{min} = Camber

From drainage consideration

$$P=\frac{Wv^2}{gR}, e+f=\frac{v^2}{gR}=\frac{V^2}{127R}$$

W = width of pavement (m)
v = speed of vehicle (m/s)
V = Speed in km/hr
R = Radius of curve (m)

- **Design Superelevation-**

$$e_{min}=\frac{V^2}{225R}=\frac{(0.75V)^2}{127R} \text{ or } 75\% \text{ of } e_{min}$$

Minimum Radius of Horizontal Curve –

$$R_{ruling}=\frac{V^2}{127(e+f)}=\frac{v^2}{(e+f)g}$$

V = Ruling design speed (kmph)

- **Grade compensation –**

$$G.C.=\text{Min. of } \frac{30+R}{R}\% \text{ or } \left(\frac{75}{R}\right)\%$$

Compensated gradient = Ruling gradient – G.C. ≮4%

■ **Extra widening of pavement**

(1) Mechanical Extra Widening

$$W_m=\frac{nl^2}{2R}$$

(2) Psychological extra widening-

$$W_{ps}=\frac{V}{9.5\sqrt{R}}$$ When V in kmph

$$W_{ps}=\frac{v}{2.64\sqrt{R}}$$ When v in m/s

Total extra widening-

$$W_e=W_m+W_{ps}=\frac{n\ell^2}{2R}+\frac{V}{9.5\sqrt{R}}$$ $$W_e=\frac{n\ell^2}{2R}+\frac{v^2}{2.64\sqrt{R}}$$

Note- Formula is applicable for two-lane or more

R > 300m	No extra widening provided
50 < R < 300m	Extra widening provided on both side
R < 50m	Extra widening provided on inner side

■ **Length of transition curve**

- **According to IRC** [By Empirical Formula]

For Plain & Rolling Terrain $L_s=\frac{35v^2}{R}=\frac{2.7V^2}{R}$

For Hilly & Steep Terrain $L_s=\frac{12.96v^2}{R}=\frac{V^2}{R}$

- **By rate of change of centrifugal acceleration**

$$L_s=\frac{v^3}{CR}=\frac{0.0215V^3}{CR}$$ $$C=\frac{80}{75+V}$$ [0.5 < C < 0.8] C = m/sec³

- **Shift for circular curve–** $S=\frac{L_s^2}{24R}$

■ **Indian Highway coloured mile stone-**

NH	Yellow & white
SH	Green & white
MDR/ODR	Blue/Black & white
VR	Orange & white

■ **Ruling gradient / Design gradient (L.R.C.)-**

Terrain	Ruling		Limiting		Exceptional	
	%	Friction	%	Friction	%	Friction
Plain & Rolling	3.3	1/30	5.0	1/20	6.7	1/15
Hilly	5.0	1/20	6.0	1/16.67	7.0	1/14.25
Steep	6.0	1/16.66	7.0	1/14.28	8.0	1/12.5

■

Types of Speed	Applications
Space mean Speed	Traffic flow studies
Journey Speed	Delay studies
Running Speed	Road condition studies
Spot Speed	Regulatory measurement

■

Indicator	Respective Test Result
Flakiness Index	≯15%
Elongation	≯15%
Angularity Number	0-11
Soundness Index	≯18% ($MgSo_4$) ≯12% (Na_2So_4)
Water absorption value	≯0.6%
Stripping value	≯5%

Scanned with CamScanner

■ **Test for Road Aggregate –**

Type of Test	For Base Course	For Surface Course and bearing course
Aggregate abrasion value	≯50%	≯30%
Aggregate Crushing Value	≯45%	≯30%
Aggregate Impact Value	≯45% (for bitumen road) ≯35%(for WBM)	≯30%

■ **Bitumen Test –**

Properties of Bitumen	Type of Test
Viscosity	Viscometer
Specific gravity	Pycnometer
Grade of bitumen (hardness of bitumen)	Penetration test
Softening Point	Ring and ball test
Ductility	Standard briquette of bitumen
Purity of bitumen	Measured by solubility test with trichloro ethylene
Consistency of bitumen	Float test
Fire and Flash point	Pensky martens appartus

■ **Maximum Dimension of Road Vehicles –**

Maximum width of vehicles = 2.44 m

Maximum Height

- Single Decker Vehicle = 3.80m
- Double Decker Vehicle = 4.75m

■ **Maximum Length of Vehicles –**

(a) Single unit truck with two or more axles = **11.00m**

(b) Single unit bus with two or more axles = **12.00 m**

(c) Semi-trailer tractor combination = **16.00 m**

(d) Tractor trailer combination = **18.00 m**

■ **Origin and Destination (O & D) Study Mass Rapid Transit System –**

1. Road side interview method
2. License plate method
3. Return post card method
4. Tag on car method
5. Home interview method
6. Work spot interview method

• **Theoretical maximum or Basic capacity of a single lane is given as –**

$$C = \frac{1000V}{S}$$

S = Average center to center spacing between two vehicle.

$S = 0.2V + L$

L → Average length of vehicle

V = speed of Vehicle in km/hr.

• **Maximum Theoretical Capacity from Time Headway –**

$$C = \frac{3600}{H_t}$$

Where,

H_t = Minimum time headway in second

■ **Method of Signal Design –**

- Trial cycle method [For two phase only]
- Approximate method [for one phase only]
- Webster method [for any in No. of phase]
- IRC method [combination of approximate and Webster method]

■ **Number of Space (N)–**

$N = \frac{L - 1.25}{5}$ For 30° angle parking

$N = \frac{L - 2.0}{3.6}$ For 45° angle parking (Best angle parking)

$N = \frac{L - 2}{2.9}$ For 60° angle parking

$N = \frac{L}{2.5}$ For 90° angle parking (Maximum vehicle parked)

■ **Type of conflict points in Rotary –**

Type	No. of Conflict Points
Two Lane with two way traffic	24
One way regulation on one road	11
One way regulation on both road	6

■ **Maximum wheel load –**

$$\sigma_4 = \left[1 - \frac{z^3}{(a^2 + z^2)^{3/2}}\right]$$

• Contact pressure = $\frac{\text{Load on wheel}}{\text{Area of imprint}}$

• Rigidity factor = $\frac{\text{Contact Pressure}}{\text{Tyre pressure}}$

• Tyre pressure $\propto \frac{1}{\text{R.F.}}$

Scanned with CamScanner

Tyre pressure	Contact pressure	Rigidity factor
$= 7\ kg/cm^2$	$= 7\ kg/cm^2$	$= 1$
$> 7\ kg/cm^2$	$< 7\ kg/cm^2$	< 1
$< 7\ kg/cm^2$	$> 7\ kg/cm^2$	> 1

■ **Methods of flexible pavement design –**

1:- Group Index Method –

$G.I. = 0.2a + 0.005\ ac + 0.01\ bd$

2:- Burmister Method –

$$\Delta = 1.5\frac{P.a}{E_s}.F \quad \text{(for flexible plate)}$$

$$\Delta = 1.18\frac{P.a}{E_s}.F \quad \text{(for rigid plate)}$$

■ **Design of Rigid Pavement method -**

1. Modulus of Subgrade reaction –

$$K = \frac{P}{\Delta} = \frac{P}{0.125}\ kg/cm^3$$

where

P = Contact Pressure Δ = Displacement

$K_{75cm} = 0.4K_{30cm}$ (Theoretically)

2. Radius of relative stiffness

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{1/4} cm$$

3. Equivalent radius (b) of resisting section for an interior loading -

i) $b = \sqrt{1.6a^2 + h^2} - 0.675h$ when $a < 1.724h$

ii) $b = a$ when $a > 1.724h$

■ **Critical Stress Combination –**

1. Summer and Mid-day –

Critical Combination of stresses

= Load stress + warping stress – frictional stress

(at edge region)

- The load stress at edge region is higher than the interior

2. Winter Mid-day –

Critical Combination of stresses

= Load stress + warping stress + frictional stress

(at edge region)

3. Mid-Night –

Critical Combination of stresses

= Load stress + warping stress

(at corner region)

$S_c > S_e > S_i$

■

Flexible Pavement Design Method	Example	Based on
Empirical Method	G.I. Method CBR Method Mc. Load Method Stabilometer Method	Physical Properties
Semi-Empirical or semi-theoretical	Triaxial test Method	Stress strain function.
Theoretical Method	Burmister Method	Mathematical Method

■

Test	Reason
CBR Test	Classify and evaluating soil sub-grade and base course material for flexible pavements.
Plate Bearing Test	Evaluate the support capability of soil for both rigid and flexible pavements.
Crushing Test	Find out strength of Aggregates.
Abrasion Test	Find out hardness of aggregates.
Impact Test	Find out toughness of aggregates.
Soundness Test	Find out durability of aggregates.
Shape Test	Workability & stability of mix.
Bitumen Adhesion Test	Find the stripping value of aggregates.
Penetration Test	Resistance to flow & hardness of bitumen.
Float Test	Viscosity of bitumen.

■ **Pavement–** Load bearing and load distribution component of road.

Pavement →
- Flexible Pavement
- Rigid Pavement
- Semi-rigid Pavement
- Composite Pavement

Scanned with CamScanner

Railway Engineering

■ **Composition of Rails-**

Composition	For ordinary rails (%)	For rails on point and crossing (%)
Carbon	0.55 - 0.68	0.50 - 0.60
Maganese (maximum)	0.65 - 0.90	0.95 - 1.25
Silicon	0.05 - 0.30	0.05 - 0.20
Sulphur	0.05	0.06
Phosphorus	0.06	0.06

■ **Some important railway terminology-**

Ballast crib - It is loose ballast between two adjacent sleepers.

Coning of wheels- The wheel are coned at a slope of 1 IN 20 to prevent from rubbing the inside face of the rail head and to prevent lateral movement of the axle with its wheel.

Boxing- It is the process of filling the ballast around the sleepers.

Packing- It is the process of ramming the ballast underneath the sleeper.

Buffer stop- The dead end of railway line is provided with a barrier erected across the track to prevent the vehicles running off the track.

Cant or superelevation- Rising of outer rail over the inner rail to counteract the effect of centrifugal force on curve.

Creep of Rails- It is the longitudinal movement of rails in a track.

Note- Creep is measured with **creep indicator**

Flangeway clearance- It is the distance between the adjacent faces of the stock rail or running rails and the check or guard rails.

Hauling capacity- It is the total load which can be hauled by it. It indicate the power of the locomotive.

Goods yard- A yard in which goods wagons are shunted and sorted for loading and unloading is called a goods yard.

Heel divergence- It is the distance between the running face of stock rail and gauge face of tongue rail.

Hogged rails- Those rails which get battered due to impact action of wheel over the end of the rails are called hogged rails.

Marshalling yard- Yard in which wagons are sorted and new trains are formed.

■ **Gauge distance for rail gauge-**

Rail Gauge	Gauge distance (mm)
Broad Gauge	1676
Standard Gauge	1435
Meter Gauge	1000
Narrow Gauge	762
Light Gauge	610

- **Sleeper Density** = (N + X).

where N = Length of one rail in meter.

X = Constant value 3 to 6.

■

Track	Length of one rail
B. G. Track	13m
M. G. Track	12m

■ **Material Required per km. of Railway Track-**

(i) No. of Rails/km $= \dfrac{1000}{\text{Length of rail in (m)}} \times 2$

(ii) Weight of Rails in Tonnes/km =

$$\text{No. of rails} \times \text{Length of rails} \times \frac{\text{wt. of rail per m.}}{1000}$$

(iii) No. of Sleeper/km

$$= \frac{1}{2}\text{No. of rail/km} \times \text{sleeper density}$$

(iv) No. of Fish Plate = 2 × No. of rails/km

- 2 Fish plate per joint
- 4 Fish bolt per joint

(v) No. of Bearing Plates = 2×No. of sleeper/km

■ **Safe speed on curve by Martin's Formula**

- **For Transition Curve–**

for B.G. & M.G. $V = 4.35\sqrt{R-67}$

For N.G. $V = 3.65\sqrt{R-6}$

V is in kmph

- **For Non-transition curve–**

$V = 0.80 \times$ Calculated Speed on transition curve

- **For High speed Trains–** $V = 4.58\sqrt{R}$ for B.G.

■ **Safe Speed on curve Based on Superelevation**

- **For Transition Curves–**

(a) **For B.G.** $V = 0.27\sqrt{(C_a + C_d)R}$

(b) **For M.G.** $V = 0.347\sqrt{(C_a + C_d)R}$

(c) **For N.G.** $V = 3.65\sqrt{R-6}$

C_a = Actual cant (mm)

C_d = Cant deficiency (mm)

R = Radius of curve (mm)

■ **Permissible limit of cant deficiency-**

Gauge	Speed< 100 km/h	Speed > 100 km/h
B.G.	7.6 cm	10.0 cm
M.G.	5.1 cm	–
N.G.	3.6 cm	–

Scanned with CamScanner

■ **Max. Permissible value of superelevation-**

Gauge	Speed< 120 km/h	Speed > 120 km/h
B.G.	16.5 cm	18.5 cm
M.G.	10.00 cm	–
N.G.	7.6 cm	–

■ **Speed based on Length of Transition Curve**

- Speed up to 100 km/hr.

$$V_{max} = \frac{134L}{e} \text{ OR } \frac{134L}{D}$$ minimum of both are taken.

L = Length of transition curve.

- **For high speed train, speed > 100 km/h**

$$V_{max} = \frac{198L}{e} \text{ OR } \frac{198L}{D}$$ Minimum of both are taken

Relation between Radius and Degree of Curve–

- $D = \frac{1720}{R}$ For 30m chain
- $D = \frac{1150}{R}$ For 20m chain

■

Track	Max.Degree of Curve (D)	Min. Radius
B. G.	10°	175m
M. G.	16°	109m
N. G.	40°	44m

Note - Versine of curve = $\frac{L^2}{8R}$

■ **Grade Compensation –**

Gauge	% Per Degree of Curve
Broad Gauge	0.04%, $\left(\frac{70}{R}\right)$
Meter Gauge	0.03%, $\left(\frac{52.5}{R}\right)$
Narrow Gauge	0.02%, $\left(\frac{35}{R}\right)$

■

- **Super Elevation / Cant–**

$$e = \frac{GV^2}{127R}$$

G = Gauge distance in mm
V = Kmph
R = Radius of curve in m

- **Equilibrium cant –**

$$e' = \frac{GV_{Av}^2}{127R}$$ V_{Av} =Average speed

Composite Sleeper Index CSI–

$$CSI = \frac{S+10H}{20}$$ S=Strength Index
H = Hardness Index

■ **Minimum CSI prescribed on Indian Railways -**

Types of Sleeper	Min.CSI
Track Sleeper	783
Crossing Sleeper	1352
Bridge Sleeper	1455

■ **Standard Size of Ballast for Sleepers-**

Type of Sleeper	Size of Ballast
Wooden and CI pot Sleeper	50 mm
CST 9 and Through Sleeper	40 mm
Points and Crossing	25 mm

■ **Size of Sleeper-**

Gauge	Size (cm)	Bearing Area per Sleeper (in sq.ft.)
B.G.	275×25×12.5	5.00
M.G.	180×20×11.5	3.33
N.G.	150×18×11.5	2.25

■ **Comparison of Different types of sleeper-**

Property	Wooden sleeper	C.I. sleeper	Steel sleeper	Conc. sleeper
Cost / sleeper	Low	Medium	High	Depend upon Design
Life (years)	10-15 for untreated 20-25 for treated	35-40	35-50	40-60
Maintenance cost	Higher than other sleeper	Minimum	Moderate	Moderate
Elasticity	Good	Not very good	Not very good	Not good
Scrap value	very less	Highest	next to C.I	–

■ **Transition curve–**

- **Equation of cubic parabola-** $y = \frac{x^3}{6RL}$
- **Deflection Angle-** $\theta = \tan^{-1}\left(\frac{1}{3}\tan\phi\right)$
- **Spiral Angle-** $\phi = \tan^{-1}\left(\frac{x^2}{2RL}\right)$
- **Shifts-** $S = \frac{L^2}{24R}$
- **Curve lead** = 2 GN N = crossing number = cotα

- **Length of transition curve as per railway code-**
  Length, $L = 4.4\sqrt{R}$ {L, R (in m)}
- **Change of Radial Acceleration-**

Length of transition curve, $L = \frac{3.28V^2}{R}$ V = m/sec.

Note – Cubic parabola transition curve mostly used in railway.

Scanned with CamScanner

Bridge Engineering

■ **Codes used for bridge Design-**

IRC-5	Code of practice for specification of bridge
IRC-6-2010	Loads & stress (L.S.M.)
IRC-6-2000	Loads & stress (W.S.M.)
IRC-21	Code of practice for cement concrete (L.S.M.)
IRC-22	For composite structure
IRC-78	For foundation design

■ **Classification of bridge**

- **According to span**

Type of Bridge	Span (m)
Culvert	< 6
Minor Bridge	6-30
Major Bridge	30-120
Long span Bridge	> 120

- **According to Railway**

Major Bridges:-Total waterways more than 18m or having any span of clear waterways of 12m or over.

Minor Bridges:-Total waterways < 18m or any span of clear waterway <12m.

- **According to Loading**

Permanent Bridge:-

Class A loading:- The I.R.C. Class A Loading is based on the heaviest type of commercial vehicle.

Class B loading:- This is an additional loading which is sometimes specified for use in place of class AA Loading.

- It is based on one of the various other hypothetical vehicles as per revised classification.

Temporary Bridge

Class AA Loading:- I.R.C. Class AA Loading is based on the heavy military vehicles likely to run on certain routes.

- It is the usual practice to design the structures on national & state highway for class AA Loading.

Class A Loading:-It is to be adopted for the design of temporary structures such as timber bridge etc.

- **Waterway:-** The area of opening sufficient to pass the maximum flood discharge expected in the river without increasing velocity of flow beyond safe limits is called the water way.

- Generally the safe limits of velocity under bridges is taken as 3.0 m/s

■ **Roadway width:-**

Type of traffic	Min. Width
1. Vehicular traffic	
Single lane	4.25m
Double lane	7.50m
Multi lane	3.50m for every lane over two lane
2- Cycles	
Without overtaking	2.00 m
With overtaking	3.00 m

■ **Maximum Span for different types of Steel bridge-**

Bridge Types	Maximum span
Steel arch bridge	500m
Steel bow- string girder bridge	240m
Steel cable suspension bridge	1200m
Steel plate girder bridge	30m
Steel rolled beam bridge	10m
Steel truss bridge	180m

■ **Centrifugal forces(C)**

(i) Road Bridges-

$$C = \frac{WV^2}{12.95R}$$

W = Live load(kN)

(ii) Railways Bridges-

$$C = \frac{wV^2}{12.95R}$$

w = Equivalent UDL (kN/m length)

V = Design speed(kmph)

R 10 m
P 30
T 180
B 240
A 500
C 1200

■

Type of Bridge	Freeboard
Arch bridge	30 cm
Girder bridge	60-90 cm
Navigable Rivers	240-300 cm
High level bridges	60cm

Note:- As per IRC, for high level bridges, the freeboard should not be less than 600 mm.

Scanned with CamScanner

Airport Engineering

ICAO = International Civil Aviation Organization

CWC = Cross Wind Component-

■

Types of Aircrafts (km/hr)	Allowable limit of C.W.C.
Big Aircraft	35
Mixed Aircraft	25
Small Aircraft	15

■ **Geometric Runway Design**

Runway width- According to ICAO Range is 18 to 45 m

Length of Safety Area- Length of Runway +120 m

■ **Width of Safety Area According to ICAO**

Airport type	Instrumental Runway	Non-Instrumental Runway
A, B and C	300m	150m
D and E	-	78m

- **Transverse Gradient According to ICAO**
  - For A,B,C type = Max. 2 %
  - For D.E Type = Max. 1-1.5%

■ **Max. longitudinal and effective gradient-**

Type of Airport	Max. Longitudinal gradient(%)	Max. effective gradient(%)
A, B and C	1.5	1
D and E.	2	2

■ **Rate of change of Gradient Per 30 m. Length of Vertical Curve-**

A, B type	0.1%
C type	0.2 %
D, E type	0.4 %

■ **According to I.C.A.O. classification of Runway**

Code	Length of Runway in 'M'
A	More than 2500
B	2150 to 2500
C	1800 to 2150
D	1500 to 1800
E	1280 to 1500
F	1080 to 1280
G	980 to 1080

Apron- Paved Area for aircraft parking, loading & Unloading of passengers and cargo.

- Size of Apron depend upon no. of gate position.

$$\text{No.of Gate position} = \frac{\text{R.C.}}{120} \times \text{Avg.Gate occupancy time}$$

Runway Capacity - Ability of a runway system to accommodate aircraft landing & take offs.

$$\text{R.C.} = \frac{\text{Operation}}{\text{Hour}} \text{ or } \frac{\text{Operation}}{\text{year}}$$

Gate- It is aircraft parking space, used by single aircraft for loading and unloading of passengers baggage.

Gate Capacity- Ability of specified no. of gates to accommodate aircraft loading & unloading operations.

$$\text{G.C.} = \frac{\text{No.of Gate}}{\text{Gate Occupancy Time}}$$

Hanger- It is covered area for repair and servicing of the aircraft.

- Number of hangers depends on peak hour volume of aircraft.

■ **Important Point-**

- All runway marking are done with white paint.
- All taxiway marking are done with yellow paint.
- All runway side light are usually white.
- All taxiway side lights are usually blue.

■

Description of planning	Type of development
Basic runway length	Engine failure class
Runway capacity	Location of exit taxiway
Runway geometric design	Width and length of safety area of airport
Hangar	Housing servicing of aircrafts

Scanned with CamScanner

Tunnel Engineering

■ **Methods of tunneling -**

A. In soft Rock

(a) Without timber

1. Shield method

   (for sub aqueous strata)

2. Linear plate method

   (Suitable for sub aqueous strata)

3. Compressed Air tunneling method

   (for clay)

(b) With timber

1. **Needle Beam method** (suitable in brick lining)
2. **English method**
3. **American method**

   (For large size of tunnel)

4. **Fore poling method**

   (Suitable for Running ground)

5. **German and Austrian method**
6. **Belgium method**

   (All classes of moderately firm or hard soil)

7. **Army method**

   (Laying underground sewer

B. In Hard Rock

1. Full face method
2. Heading method
3. Drift method
4. Pilot method
5. Heading and bench method
6. Perimeter method
7. Cantilever car dump

■ **Method of tunneling in running ground-**

1- Needle beam method

2- Flying arch method

3- Linear plate method

■ **Methods of ventilation in tunnels:-**

A. Natural ventilation

B. Mechanical ventilation

(a) Blowing air (Blow in) method

(b) Exhausting air (Blow out) method

(c) Combination of blow in and blow out method

■ **Cross section adopted for tunnels:-**

1. **D section or segmental roof section**

   (suitable for sub ways or navigation tunnels

2. **Circular section** - Suitable for heavy internal or external radial pressure

   - It is most desirable section

3. **Rectangular section**- suitable for hard rocks
4. **Egg shaped section** -used for carrying sewage
5. **Horse shoe section** -suitable for traffic purpose
6. **Polycentric section** - (for railway tunnels)
7. **Elliptical**

Sequence of operation in tunnel construction:-

Drilling → Blasting → Mucking → Placing of Steel → Placing → Concrete.

Components of shield in tunneling-

1. Skin or outer shell
2. Cutting edge
3. propelling jacks
4. Hood
5. Tail
6. Inner box structure
7. Pockets

Note:- Tunnel alignment is carried out by **Triangulation.**

Scanned with CamScanner

Reinforced Cement Concrete

Modular Ratio, $m = \frac{E_s}{E_c} = \frac{280}{3\sigma_{cbc}}$

■ **Value of modular ratio (m)**

Conc. Grade	M-10	M-15	M-20	M-25	M-30	M-35	M-40
Modular ratio	31	18	13	11	9	8	7

■ **Direct tensile strength for different grades of Conc.-**

Conc. Grade	M-10	M-15	M-20	M-25	M-30	M-35	M-40	M-45
Direct tensile strength N/mm^2	1.2	2.0	2.8	3.2	3.6	4.0	4.4	4.8

■ **Permissible limits of solid in water as per IS : 456-2000.**

Types of Solid	Permissible limit (mg/ℓ)
Organic matter	200
Inorganic Matter	3000
Sulphates	400
Chlorides	
R.C.C.	500
P.C.C & C.C.	2000
Suspended matter	2000
pH value	≮6

■ **Factor of safety for stress-**

	working stress method	Limit state method
For Concrete	3.00	1.50
For steel	1.78	1.15

■ **Effective span of different types of concrete section-**

1. Beam and slab

A. For Simply supported beam and slab-

a. Clear span + effective depth
b. c/c distance between supports
} which is minimum

B. For cantilever beam-

$$\ell_e = \text{Clear span} + \frac{d}{2}$$

C. For continuous Beam and slab-

- If width of support < $\frac{\text{Clear span}}{12}$

$$\ell_e = \text{min. of} \begin{cases} \text{Clear span + width of support} \\ \text{Clear span + effective depth} \end{cases}$$

- If width of support > $\frac{\text{Clear span}}{12}$

(a) If one end fixed and other end continuous or both end continuous,

$$\ell_e = \text{Clear Span}$$

(b) If one end continuous and other is simply supported-

$$\ell_e = \text{min. of} \begin{cases} \text{Clear span} + \frac{\text{width of support}}{2} \\ \text{Clear span} + \frac{\text{effective depth}}{2} \end{cases}$$

■ **Grade of steel Bars-**

1. Fe-250 — 250 N/mm^2] Plane mild steel bar
2. Fe-415 — 415 N/mm^2
3. Fe-500 — 500 N/mm^2

} High strength bar

■ **Important Data related to reinforced beam-**

Types of section	Neutral Axis condition	Formula for N.A.	Moment of Resistance	Failure condition
Under Reinforced section	A.N.A < C.N.A.	$X_c = \frac{m\sigma_{cb} d}{m\sigma_{cb} + \sigma_{st}}$	$M_r = \sigma_{st} A_{st}\left(d - \frac{x}{3}\right)$	Steel failure/Ductile failure
Over Reinforced section	A.N.A > C.N.A.	$\frac{bx^2}{2} = mA_{st}(d - x)$	$M_r = \frac{bx\sigma_{cb}}{2}\left(d - \frac{x}{3}\right)$	Concrete failure/Brittle failure
Balanced section	A.N.A= C.N.A.	$x = x_c$	$M_r = \frac{bx\sigma_{cb}}{2}\left(d - \frac{x}{3}\right)$ or $\sigma_{st} A_{st}\left(d - \frac{x}{3}\right)$	X = Actual N.A.

Scanned with CamScanner

■

Parameter	Formula	M-15, $\sigma_{cb} = 5N/mm^2$, m = 18		
		Fe-250 $\sigma_{st} = 140\ N/mm^2$	Fe-415 $\sigma_{st} = 230\ N/mm^2$	Fe-500 $\sigma_{st} = 275\ N/mm^2$
Neutral axis	$x = \frac{m\sigma_{cb} \times d}{m\sigma_{cb} + \sigma_{st}}$	0.39d	0.281d	0.246d
Lever arm	$z = \left(d - \frac{x}{3}\right)$	0.87d	0.906d	0.918d
Resisting moment	$M_r = \frac{b.x.\sigma_{cb}}{2}\left(d - \frac{x}{3}\right)$	$0.85bd^2$	$0.64bd^2$	$0.564bd^2$
Percentage of tensile Reinforcement	$P = \frac{A_{st}}{b \times d} \times 100$	0.70%	0.31%	0.22%
Area of tensile reinforcement	$A_{st} = \frac{P \times b \times d}{100}$	0.007bd	0.0031bd	0.0022bd

■ **Permissible bond stress for concrete-**

a. With tensile reinforcement-

Grade	M-15	M-20	M-25	M-30	M-35	M-40	M-45
(1) Fe-250/Plain bar	0.6	0.8	0.9	1.0	1.1	1.2	1.3
(2) Tor Bar	0.96	1.28	1.44	1.60	1.76	1.92	2.08
For Fe-250 , L_d	58ϕ	44ϕ	39ϕ	35ϕ	32ϕ	29ϕ	27ϕ

b. With compression reinforcement-

Grade	M-15	M-20	M-25	M-30	M-35	M-40
Fe-250	0.75	1.00	1.125	1.25	1.38	1.50
Fe-415, Fe-500	1.20	1.60	1.80	2.0	2.21	2.40

- **Average shear stress,** $\tau_{av} = \frac{V}{b \times D}$
- **Nominal shear stress,** $\tau_v = \frac{V}{b \times d}$

$\tau_{max} = 1.5\tau_{av}$ For rectangular beam

$\tau_{max} = 1.33\tau_{av}$ For triangular beam

■ **Shear reinforcement is provided in the form of-**

1. Vertical stirrups
2. Bent-up Bars or inclined bars
3. Both Inclined bars and vertical stirrups

■ **Development/bond length (L_d)-**

(a) For tension bar-

$L_d = \frac{\sigma_{st}\phi}{4\tau_{bd}}$ (For WSM)

$L_d = \frac{0.87f_y\phi}{4\tau_{bd}}$ (For LSM)

(b) For compression bar- τ_{bd} increased by 25%

$L_d = \frac{\sigma_{st}\phi}{5\tau_{bd}}$ (for WSM) $L_d = \frac{0.87f_y\phi}{5\tau_{bd}}$ (for LSM)

■ **Permissible bond stress (τ_{bd}) for plane bars in tension as per IS 456-2000-**

	M-15	M-20	M-25	M-30	M-35	M-40
WSM	0.6	0.8	0.9	1.0	1.1	1.20
LSM	-	1.2	1.4	1.5	1.7	1.9

■ **Max. Shear stress (τ_{cmax}) for Beam**

	M-15	M-20	M-25	M-30	M-35	M-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

■ **Design of shear reinforcement-**

- $\tau_v \le \tau_c/2$ Not required any types of shear reinforcement
- $\tau_c/2 \le \tau_v \le \tau_c$ minimum shear reinforcement required.
- $\tau_c < \tau_v < \tau_{c\,max}$ needs to provide shear reinforcement.
- $\tau_v \ge \tau_{c\,max}$ section redesign.

■ **Strength of shear reinforcement for vertical stirrups-**

$V_{us} = \frac{0.87f_yA_{sv}.d}{S_v}$ (LSM) $V_u = \frac{A_{sv}\sigma_{sv}.d}{S_v}$ (WSM)

■ **Maximum spacing for shear reinforcement-**
Minimum of-

(i) $S_v = \frac{2.175f_yA_{sv}}{b}$

(ii) 300 mm

(iii) 0.75d, for vertical stirrups

(iv) d, for inclined stirrups

■ **Lap length of bar-**

(i) **in tension** $\not< L_d$ or 30ϕ

(ii) **in compression** $\not< L_d$ or 24ϕ

Scanned with CamScanner

Note- If Dia. of bar > 36 mm, then Lap splice should not be used.
If dia. of bar > 32 mm the lap splice should not be used as per amend. no. 3 I S-Code 456:2000

- In this condition it is suitable to provide weld.

■ **Permissible deflection for beam section- (upto 10 m Span)**

Types of Section	Max. ratio of $\frac{\text{span}}{\text{eff.depth}}$
1. For beam	
(i) Simply supported Beam and T-beam	20
(ii) Fixed and Continuous beam	26
(iii) Cantilever beam	7
2. For slab (upto 3.5 m)	
(i) One way slab	30
(ii) Two way slab	35
(iii) Continuous slab	40
(iv) Cantilever slab	12

- **For span > 10 m,**

$$\text{Effective depth} = \frac{(\text{Span})^2}{10 \times A}$$

A = Span to effective depth ratio for span upto 10 m.

■ **Slenderness limit for lateral stability of beams-**

A. For S.S.B. or continuous beam-

$$\ell_0 \not> \text{Minimum of} \begin{cases} 60b \\ \frac{250b^2}{d} \end{cases}$$

ℓ_0 = Clear span
b = Width of beam
d = Effective depth

B. For cantilever beam-

$$\ell_0 \not> \text{Minimum of} \begin{cases} 25b \\ \frac{100b^2}{d} \end{cases}$$

Note-

- Minimum tension reinforcement of beam,

$$\boxed{A_{st} = \frac{0.85bd}{f_y}}$$

- Max. tension reinforcement = 0.04bD or 4%
- If D > 750 mm, then side face reinforcement provided equal to 0.1% of cross sectional area or 0.001bD
- Max. spacing of side face reinforcement is 300 mm or width of web of beam which is less.
- Maximum reinforcement size for slab/beam $= \frac{1}{8} \times D$

D = Total thickness of the member

A. Reinforcement spacing for beam-

(i) Min. horizontal spacing, maximum of

(a) Equal to dia. of bar if the dia. is equal.

(b) Dia. of larger bar if the dia. are unequal.

(c) 5 mm more than nominal maximum size of coarse aggregate.

(ii) Vertical spacing $\not<$ maximum of

(a) Dia of thicker bar

(b) 15 mm

(c) $\frac{2}{3} \times$ Max. nominal size of coarse aggregate

(iii) Max. Horizontal spacing $\not>$ $\begin{cases} 300\text{mm} & \text{for Fe250} \\ 180\text{mm} & \text{for Fe450} \end{cases}$

B. Spacing of bars for slab-

Min. horizontal distance- Same as A (i)

Spacing of Bars is $\not>$

(i) Minimum of $\begin{cases} 3d \\ 300\text{mm} \end{cases}$ **For main bar**

(ii) Minimum of $\begin{cases} 5d \\ 450\text{mm} \end{cases}$ **For distribution bar**

■ **Nominal cover for different members-**

Members	Cover
Beams	25 mm
Slab	15 mm
Column	40 mm
RCC wall	20 mm
Footing	50 mm

■ **Effective width of flange for T-Section–**

(i) For monolithic T-beam-

$$b_f = \text{Min.of} \begin{cases} \frac{l_0}{6} + b_w + 6D_f \\ b_w + \frac{1}{2} \times \text{clear distance b/w nearest beams} \end{cases}$$

(ii) For Isolated T- beam-

$$b_f = \text{Min.of} \begin{cases} \left[\frac{l_0}{\frac{l_0}{b} + 4}\right] + b_w \\ b_f = b \end{cases}$$

Note- $l_0 = 0.70\times$ effective span (in continuous beam)

$$\text{Width of rib in T-beam} = \frac{1}{2} \text{ to } \frac{2}{3} \text{ of total depth}$$

■ **Effective width of Flange for L-beam–**

(i) For monolithic L- beam

$$b_f = \text{Min.of} \begin{cases} \frac{l_0}{12} + b_w + 3D_f \\ b_w + \frac{1}{2} \times \text{clear distance b/w nearest beams} \end{cases}$$

(ii) For Isolated L-section-

Scanned with CamScanner

$$b_f = \text{Min.of}\begin{cases}\left[\dfrac{0.50 l_0}{\dfrac{l_0}{b}+4}\right]+b_w \\ b_f = b\end{cases}$$

■ **Depth of T- Beam–**

$\frac{\text{Span}}{10}$ to $\frac{\text{Span}}{12}$	For Heavy load
$\frac{\text{Span}}{12}$ to $\frac{\text{Span}}{15}$	For Medium load
$\frac{\text{Span}}{15}$ to $\frac{\text{Span}}{20}$	For Light load
$\frac{\text{Span}}{12}$ to $\frac{\text{Span}}{15}$	If T-beam is simply supported

■ **Actual depth of neutral axis (x_a)–**

(a) When Neutral axis is in Flange–

$$\boxed{\frac{bx_a^2}{2} = mA_{st}(d - x_a)}$$

(b) When Neutral axis is in web area–

$$\boxed{b_f \times d_f\left(x_a - \frac{d_f}{2}\right) = mA_{st}(d - x_a)}$$

(by Neglecting web area)

Note– Max dia of bar for ribbed slab = 22 mm

- **One Way Slab** – $\frac{L}{B} > 2$

  (Supported only two edges)

- **Two way Slab** – $\frac{L}{B} \le 2$

  (Supported on all edges)

Note- Max. B.M. occurred at the shorter span

■ **Design of two way slab–**

1. By Grasoff Rankine Method–

(used for corners not held down position)

Load at shorter span, $W_B = \left[\frac{L^4}{L^4 + B^4}\right].w = \left[\frac{1}{1+r^4}\right].w$

Load at longer span, $W_B = \left[\frac{B^4}{L^4 + B^4}\right].w = \left[\frac{r^4}{1+r^4}\right].w$

■ **Shear Force–**

(i) At shorter span, $V_B = \frac{1}{3} \times w \times B$

(ii) At larger span, $V_L = \left(\frac{L/B}{2 + L/B}\right) \times w \times B$

$$= \left(\frac{1}{2+r}\right) \times w \times B$$

2. By Pigeauds Method–

(Corner's held down position)

$$M_x = r_x' \frac{wl_x^2}{8}$$

$$M_y = r_y' \frac{wl_y^2}{8}$$

3. IS Code Method

- Spacing of bars $\boxed{s = \frac{1000 \times a_1}{A_{st}}}$
- Area of distribution bar

  $A_{sd} = 0.15\%$ of bD (For Fe 250)

  $= 0.12\%$ of bD (For HYSD bars)
- Curtailment of bars -

  L/7 for slab

  L/10 for beam
- Width of slab assumed for design – **1000 mm**
- Diameter of main reinforcement bars in slab, **8-14mm**
- Diameter of Distribution bar in slab, **6-8 mm**

■ **Load carrying capacity of column-**

(i) For short column

$$\boxed{P = \sigma_{sc}A_{sc} + \sigma_{cc}A_c}$$

Where, $A_c = A_g - A_{sc}$

(ii) For long column-

$$\boxed{P = C_r(\sigma_{sc}A_{sc} + \sigma_{cc}A_c)}$$

C_r = Reduction factor

$$C_r = 1.25 - \frac{\ell_e}{48b_{min}} \quad (\lambda \ge 12)$$

or

$$C_r = 1.25 - \frac{\ell_e}{160\, r_{min}} \quad (\lambda > 40)$$

Where, b = Least lateral dimension

C_r always less than 1.

■ **Strength of column with helical reinforcement-**

$\boxed{P = 1.05\ (\sigma_{sc}.A_{sc} + \sigma_{cc}.A_c)}$ For short column

$\boxed{P = 1.05\ C_r\ (\sigma_{sc}.A_{sc} + \sigma_{cc}.A_c)}$ For long column

Note :-

- Helical reinforcement is provided only for circular column.
- Its strength increased by 5%

■ **Minimum number of bar–**

For Rectangular column – 4

For circular column – 6

■ **Transverse reinforcement (Tie bar)–**

(i) Dia–

$$\text{Maximum of}\begin{cases}\frac{1}{4} \times \text{dia of longitudinal bar} \\ 6\text{mm}\end{cases}$$

(ii) Pitch–

Scanned with CamScanner

$$\text{Minimum of}\begin{cases}\text{Least lateral dimension}\\ 16\phi\ (\phi = \text{longitudinal bar dia})\\ 300\,\text{mm}\end{cases}$$

■ **Helical or spiral bar–**

(i) Pitch

(a) Maximum pitch–

$$\text{Minimum of, } 75\text{mm or } \frac{\text{core dia}}{6}$$

(b) Minimum pitch–

Minimum of, 25 mm or 3 ×dia. of spiral bar

■ **Slenderness limit–**

(i) Unsupported length between end restrains $\not>$ 60 times least lateral dimension

(ii) If in any given plane one end of column is unrestrained than its unsupported length $\not> \frac{100B^2}{D}$

■ **Minimum eccentricity of column–**

$$e_{min} = \text{Max.of}\begin{cases}\frac{\ell_e}{500}+\frac{B}{30}\\ 20\,\text{mm}\end{cases}$$

- **Failure of Isolated column Footing is due to–**
  (i) Bending moment
  (ii) Punching or shear force

■ **Critical section for the footing–**

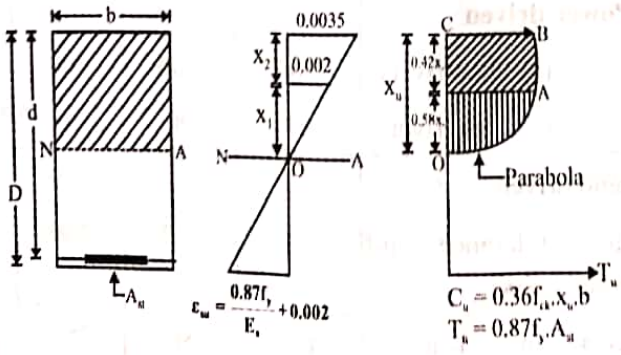
(i) For one way shear-
Distance **"d"** away from the column face

(ii) Punching or two way shear -
d/2, away from the column face

(iii) To check vertical shear– At the column face
Where d = effective depth

■ **Permissible punching shear stress for footing–**

- $\tau_{cp} = k_s \times 0.16\sqrt{f_{ck}}$ (W.S.M.)
- $\tau_{cp} = k_s \times 0.25\sqrt{f_{ck}}$ (L.S.M.)
- $k_s = (0.5+\beta_c)$



Stress & Strain Diagram in RC Section

1. Area of stress block = $0.36 f_{ck}.\ x_u$
   x_u = Depth of neutral axis
2. Depth of the centre of gravity of the stress block from the upper end $\bar{y} = 0.42\ x_u$
3. Total compression force in concrete
   C_u = Area of stress block × width of Beam
   $= 0.36 f_{ck}.\ x_u b$
4. Total Tension force in reinforcement steel,
   T_u = Area of steel × Permissible stress
   $= 0.87 f_y.\ A_{st}$
5. Neutral Axis, $x_u = \frac{0.87 f_y.A_{st}}{0.36 f_{ck}.b}$
6. Limiting depth of neutral axis
   $x_{u\,max} = \frac{700}{1100+0.87 f_y}.d$
7. Depth of compression force from the top of the beam section. $\bar{y} = 0.42\ x_u$
8. Lever Arm
   $\boxed{Z = d - 0.42\ X_u}$
   $\boxed{Z = d - \bar{y}}$
   $\boxed{Z = d - \frac{f_y.A_{st}}{f_{ck}.b}}$

■ **Moment of resistance, M_r**

- **For Under Reinforcement Section, when $X_u < X_{u\,max}$**
  $M_{u\,lim} = 0.87 f_y.A_{st}(d - 0.42x_u)$
- **For Balance Section**
  $M_{u\,lim} = Q_u.bd^2.f_{ck}$
  $Q_u = 0.36\left(\frac{x_{u\,max}}{d}\right)\left(1-0.42\frac{x_{u\,max}}{d}\right)$

■

Important data for concrete in L.S.M.			
Steel Grade	**X_{umax}**	**ε_{max}**	**M_{ulim} (N-mm)**
Fe - 250	0.53d	0.00308	$0.149bd^2 f_{ck}$
Fe - 415	0.48d	0.00380	$0.138bd^2 f_{ck}$
Fe - 500	0.46d	0.00417	$0.133bd^2 f_{ck}$

Note–

- In limit state of collapse in flexural, the ultimate strain in concrete is limited to 0.0035 in bedning
- In ultimate strength design the maximum compressive strain permitted at collapse in R.C.C. column is about 0.002.
- In limit state method of design, for bars in compression the value of bond stress will be 25% more.
- In limit state method of Design, for HYSD bar the value of bond stress will be 60 % more.

Scanned with CamScanner

Steel Structure

■ **Physical properties of structural steel-**

Unit mass of steel, ρ	7850 kg/m³
Modulus of elasticity, E	2.0×10^5 N/mm²
Poission Ratio, μ	0.3
Modulus of rigidity, G	0.769×10^5 N/mm²
Coefficient of thermal expansion, α	12×10^{-6}/°C

Nominal diameter of rivet (d)- It is the diameter of the shank of a rivet before riveting.

Effective or gross rivet diameter (d')- It is equal to the diameter of the hole after riveting.

$d' = d + 1.5$ mm for $d \le 25$ mm,

$d' = d + 2$ mm for $d > 25$ mm,

Unwin's formula $d_{mm} = 6.05\sqrt{t}$ mm

or $1.91\sqrt{t}$ cm

t = Min. thickness of plate

Pitch – It is the distance between c/c of any two adjacent rivets.

Gauge line – A row of rivets parallel to the direction of force.

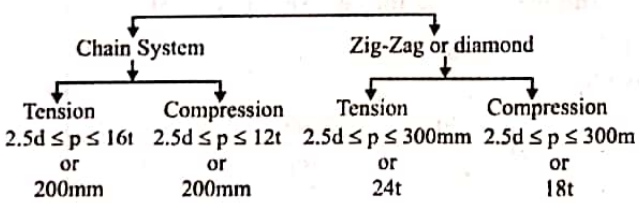
Gauge distance – Perpendicular distance between two adjacent gauge lines.

Edge distance – It is the distance between the edge of a member or cover plate and the centre of the nearest rivet hole.

Slip factor – Coefficient of friction in friction type joint is know as slip factor.

- **Minimum width of riveted section = 3d**

■ **Value of pitch in different types of joint-**



Note- For staggered pitch, pitch values in chain system is increased by 50%.

- **Minimum edge distance-**

(i) For hand flame cutting or rough edge– 1.7 d_h

(ii) For machine cutting or smooth edge– 1.5 d_h

(d_h = Rivet hole dia.)

- **Maximum pitch of tacking rivet in case of–**

(i) Tension member $\not> 1000$ mm

(ii) Compression member $\not> 600$ mm

- **Members are not exposed to weather**

Min.of $\begin{cases} 32t \\ 300\,mm \end{cases}$

- **Member are exposed to weather** Min.of $\begin{cases} 16t \\ 200\,mm \end{cases}$

- **Minimum pitch for rivet joint** $\not< 2.5d$

- **Maximum pitch of rivet joint in case of-**

(i) Tension member → Min.of $\begin{cases} 16t \\ 200\,mm \end{cases}$

(ii) Compression member → Min.of $\begin{cases} 12t \\ 200\,mm \end{cases}$

■ **Strength of Riveted/Bolted joint-**

(i) By tearing of plate between rivet holes in tension

$P_t = \sigma_{at} \times (p - d') \times t$

(ii) Due to bearing strength of rivet $P_b = \sigma_{pf} \times d' \times t$

(iii) Shearing strength of rivet

$P_s = \tau_{vf} \times \frac{\pi}{4} \times d'^2$ (in single shear)

$= 2 \times \tau_{vf} \times \frac{\pi}{4} \times d'^2$ (in double shear)

(iv) Rivet value, R_v = Min. of P_t, P_b or P_s

(v) Efficiency of joint,

$$\eta = \frac{\text{Strength of joint or min. of } P_t, P_b, P_s}{\text{Strength of solid plate}}$$

- **Number of rivet,** $n = \frac{\text{Force}}{\text{Rivet value}}$

■ **Maximum permissible stress in rivets and bolts-**

Type of fastener	Axial tension (MPa)	Shear (MPa)	Bearing (MPa)
Power driven			
(a) Shop rivets	100	100	300
(b) Field rivets	90	90	270
Hand driven rivets	80	80	250
Close tolerance and turned bolts	120	100	300
Bolts in clearance holes	120	80	250

- **Dia. of bolt hole =**

Nominal size of fastener + Standard clearance

Scanned with CamScanner

■ **Permissible stresses–**

Types of stresses	Permissible stress	FOS
Axial Tension and compression	$0.6\ f_y$	1.67
Bending stress	$0.66\ f_y$	1.515
Shear stress-		
$\tau_{v\,avg}$	$0.4\ f_y$	2.5
$\tau_{v\,max}$	$0.45\ f_y$	2.22
Bearing stress σ_b	$0.75\ f_y$	1.33

■ **Minimum size of fillet weld–**

Thickness of thicker plate (mm)	Min. size of weld (mm)
0-10	3
10-20	5
20-32	6
32-50	8 mm first run 10 mm second run

- **Throat of fillet Weld-**

Throat thickness, $t = k \times S$

S = size of weld

k = angle between fusion faces

k, for 60-90° = 0.70

so, $\mathbf{t = 0.70 \times S}$

- **Effective length of filled weld**

$$l_e = l - 2S$$

- **Strength of fillet weld;** $P = f_s \times l_e \times t$

f_s = permissible shear stress

l_e = effective length

- **Eccentric Connections-**

Force due to axial load on each rivet

$$F_a = \frac{W}{n}$$

Force due to moment on any rivet-

$$F_m = \frac{m \times r}{\sum r^2}$$

- **Resultant force-**

$$F_r = \sqrt{F_a^2 + F_m^2 + 2 \times F_a \times F_m \times \cos\theta}$$

- **Eccentric load lying in plane of rivets-**

$$\text{No. of Rivets, } n = \sqrt{\frac{6 \times M}{m \times p \times R_v}}$$

- **Eccentric load not lying in the plane of rivets**

$$n = 0.8 \times \sqrt{\frac{6 \times M}{m \times p \times R_v}}$$

- **Butt-Welded joint loaded eccentrically-**

Shear stress at weld, $P_s = \dfrac{W}{d \times t}$

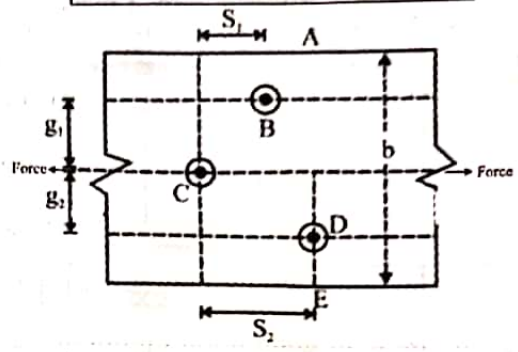
Tensile/Compressive stress due to bending at extreme fibre,

$$P_b = \frac{6M}{t \times d^2}$$

■ **Tension Members-**

(i) Net sectional area for plate

$$\boxed{A_{net} = t \times \left[b - n \times d' + \left(\frac{S_1^2}{4 \times g_1} + \frac{S_2^2}{4 \times g_2} \right) \right]}$$



(ii) For single Angle, one leg connected to gusset plate

$$\boxed{A_{net} = A_1 + A_2 \times k_1}$$

A_1 = Net cross-sectional area of the connected leg.

A_2 = Gross cross-sectional area of unconnected leg.

$$k_1 = \frac{3A_1}{3A_1 + A_2}$$

(iii) For angle placed back to back-

$$\boxed{A_{net} = A_1 + A_2 k_2}$$

$$k_2 = \frac{5A_1}{5A_1 + A_2}$$

☞ The outstanding legs of the pair of angles should be tacked by rivets at a pitch not exceeding 1 m.

■ **Permissible Stress-**

For	Thickness/Diameter	σ_{at} (MPa)
Plates, angles, I beam, Channels flats.	Up to including 20 mm 20 - 40 mm > 40 mm	150 140 138
Bar (round, square, hexagonal)	Up to including 20 mm > 20 mm	150 144

- **Strength of an axially loaded compression member**

$$P = \sigma_{ac} \times A$$

- **Permissible stress,**

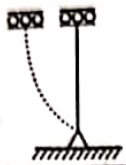
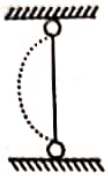
$$\sigma_{ac} = 0.6 \times \frac{f_{cc} \times f_y}{\left[f_{cc}^n + f_y^n \right]^{1/n}} \quad \textbf{[Merchant Rankine formula]}$$

f_{cc} = elastic critical stress in compression $= \dfrac{\pi^2 \times E}{\lambda^2}$

λ = Slenderness ratio

Scanned with CamScanner

■ **Effective Length of Prismatic Compression Members-**

Boundary Condition				Schematic Representation	l_e
At one end		At the other end			
Translation	Rotation	Translation	Rotation		
Restrained	Restrained	Free	Free		2.0L
Free	Restrained	Free	Restrained		2.0 L
Restrained	Free	Restrained	Free		1.0L
Restrained	Restrained	Free	Restrained		1.2L
Restrained	Restrained	Restrained	Free		0.8L
Restrained	Restrained	Restrained	Restrained		0.65L

Note- L is the unsupported length of the compression member.

■ **For different types of compression and tension member maximum value of effective slenderness ratio-**

Types of Member	Maximum Effective S.R (l_e/r_{min})
A member carrying compressive load resulting from dead and imposed load.	180
A member subjected to compression forces resulting only from combination with wind/earthquake action, provided the deformation of such member does not adversely affect the stress in any part of the structure.	250
Compression flange of a beam against lateral torsional buckling.	300
A tension member in which a reversal of direct stress occurs due to loads other than wind or seismic forces.	180
A members normally acting as a tie in a roof truss or a bracing system. But subjected to possible reversal of stress resulting from the action of wind or earthquake forces.	350
Members always under tension (other than pre-tensioned member).	400

Note: Tension members, such as bracings, pre-tensioned to avoid sag, need not satisfy the maximum slenderness ratio limits.

- **To prevent the buckling of flange plate & web plate-**

$$\frac{b}{t_f} \ngtr 16, \quad \frac{d_w}{t_w} \ngtr 50$$

■ **Diameter of tack rivet should not less than the minimum value-**

Thickness of member	Min. dia (mm)
upto 10 mm	16
10-16 mm	20
> 16 mm	22

■ **In lacing system-**

- The angles of inclination = 40° - 70°
- Slenderness ratio (S.R.) $\ngtr$ 145

■ **Maximum Slenderness Ratio,** $\lambda = \frac{l_e}{r_{min.}} = \frac{l_e\sqrt{12}}{t} \ngtr 145$

- **For Riveted or welded lacing system-**

$$\frac{l_e}{r_{min}} \ngtr 50 \text{ or } 0.7 \times S.R$$ (whichever is less)

■ **Minimum width of lacing bars-**

Rivet diameter (mm)	22	20	18	16
Width (mm)	65	60	55	50

Note- For laced column 16 mm ≤ rivet dia. ≤ 22 mm

Scanned with CamScanner

- **Min. thickness of Lacing bars-**

$t \not< \ell/40$ For Single Lacing

$t \not< \ell/60$ For Double lacing

☞ The lacing of compression members should be designed to resist a transverse shear V= 2.5% of axial force in the member.

- **For Single lacing system-**

$$F = \frac{V}{2\sin\theta}$$

- **For Double Lacing System-**

$$F = \frac{V}{4\sin\theta}$$

- **No. of Rivets Required**

$$n = \frac{F}{\text{Rivet Value}} \text{(For single lacing)}$$

$$= \frac{2F\cos\theta}{\text{Rivet value}} \text{(For Double Lacing)}$$

- **Spacing of battens-**

$$\boxed{\frac{C}{r_{min}} \not> 50, \text{ or } 0.7 \times \text{S.R.}}$$ (whichever is less)

C = spacing of battens

Note- In case of batten system l_e are increased by 10%

■ **For Welded Connections-**

- Lap $\not<$ 4t
- Total length of weld at edge of batten $\not<$ D/2.
- Length of weld at each edge of batten $\not<$ 1/3 total length of weld required.
- Return weld along transverse axis of column $\not>$ 4t

■ **Slab base-**

- **Thickness of a rectangular slab base -**

$$t = \sqrt{\frac{3}{\sigma_{bs}} w \left(a^2 - \frac{b^2}{4}\right)}$$

σ_{bs} = Permissible bending stress in slab base

a = Greater projection of the plate beyond the column (mm)

- **Thickness of a square slab base plate under a solid round column-**

$$t = 10\sqrt{\frac{90W}{16\sigma_{bs}} \times \frac{B}{(B - d_0)}}$$

W = Total Axial load (kN)

B = Length of the side of cap or base (mm)

☞ The cap or base plate should not be less 1.5 (d_0 + 75) mm in length or diameter.

■ **Vertical transverse/stiffeners-**

If shear/local buckling of web is used to prevent-

- Min. spacing $\not>$ 0.33 d
- Max. spacing $\not>$ 1.5 d

■ **Horizontal/Longitudinal stiffeners-**

- Used to resist compression or bending buckling in web

■ **Bearing stiffeners-**

- Use at support or under point load
- Used to prevent web buckling
- To provide strength the web
- used in plate girders, design as column.

Note-

- For angle section outstanding leg length

$$\not> \text{Min.of}\left(\frac{256t}{\sqrt{f_y}} \text{ or } 16t\right)$$

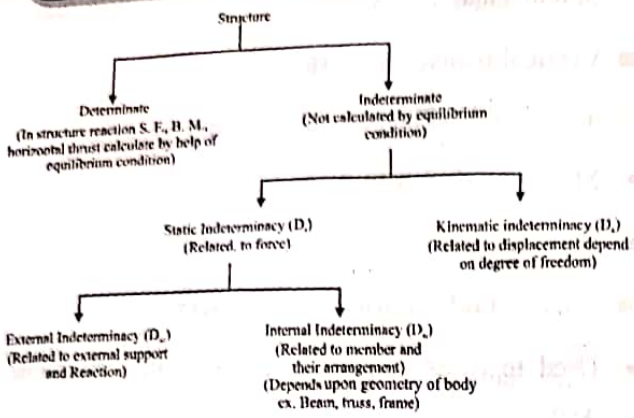
- For flats outstanding length should not exceed 12t

■ **Stiffeners in plate girder-**

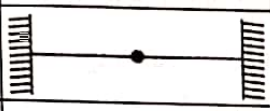
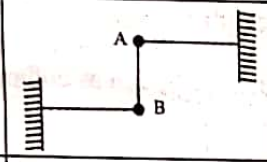
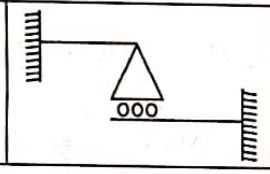
Ratio	Stiffeners required
$\frac{d_1}{t_w} \le 85$	None
$85 < \frac{d_1}{t_w} < 200$	Transverse (Vertical)
$200 < \frac{d_1}{t_w} < 250$	Both Horizontal and Vertical
$250 < \frac{d_1}{t_w} < 400$	Both vertical and horizontal One extra at neutral axis

Scanned with CamScanner

Structure Analysis



■ Hybrid Joint and released reaction:-

Hybrid Joint	Diagram	2D	3D
internal hinge		(m-1)	3(m-1)
Link		2	-
shear Roller		2	-

Note-

- Pin Joint plane frame structure (2D)- $D_s = m - (2J - r)$
- Pin Jointed space frame structure (3D)- $D_s = m - (3J - r)$
- Rigid Joint plane structure (2D)- $D_s = 3m - (3J - r) - r_r$
- Rigid Joint space structure (3D)- $D_s = 6m - (6J - r) - r_r$
- Kinematic indeterminacy for (2D) truss joint- $D_k = 2J - r$
- Kinematic indeterminacy for (2D) Frame or (3D) truss joint- $D_k = (3J - r)$
- Kinematic indeterminacy for (3D) Frame joint- $D_k = 6J - r$

Where m = No of members connect at the joint.

Note-

$D_s < 0$, $m < 2J - r$	Deficient or unstable truss
$D_s = 0$, $m = 2J - r$	Perfect stable truss, Determinate truss
$D_s > 0$, $m > 2J - r$	Redundant or over stiff truss indeterminate truss

Important theorems:-

■ Super position theorem:-

- Principal of super position theorem - $EI\frac{dy^4}{dx^4} = -w(x)$

(i) Load is linearly related to deflection.

(ii) Load is assumed not to change significantly

(iii) It is valid for beams, frames for both determinate and indeterminate structure.

■ Castigliano's theorem:-

- **First theorems:-** for linearly elastic structure, where external force cause deformation

$$\frac{\partial u}{\partial \delta} = P, \quad \frac{\partial u}{\partial \theta} = M$$

- **Second Theorems:-** Applicable to linearly elastic structure with constant temperature and unyielding support.

$$\frac{\partial u}{\partial p} = \delta, \quad \frac{\partial u}{\partial M} = \theta$$

- **Slope deflection method**-In this method, if the slopes at the ends and the relative displacement of the ends are know, the end moment found in terms of slope defection stiffness and length of members.
- **Moment Area method**-The moment area method is one of the most effective methods for obtaining the bending displacement in beam and frames.

$$d\theta = \frac{M}{EI}dx$$

■ Horizontal thrust on different type of arch)-

Sr.	Type of structure	Horizontal thrust
Three hinged arch-		
(A) Parabolic arch-		
	With point load	$\frac{W}{2}$
	With U.D.L	$\frac{w\ell^2}{8h}$

Scanned with CamScanner

(B) Semicircular Arch	
With point load	$\frac{W}{2}$
With U.D.L	$\frac{wR}{2}$
2-Hinged Arch	
(A) Parabolic Arch-	
With Point load	$\frac{25wl}{128h}$
With UDL	$\frac{w\ell^2}{8h}$
(B) Semi circular arch	
With Point load	$\frac{W}{\pi}$
With UDL	$\frac{4}{3}\frac{wR}{\pi}$

- **Eddy's theorem:-** The bending moment at any section of an arch is equal to the vertical intercept between the linear arch and the centre line of actual arch.

$$[M_{xx}]_{Arch} = (M_{xx})_{Beam} - Hy$$

$$(M_{xx})_{Arch} \propto \Delta y$$

Arch subjected to loading bending moment at any section proportional to difference of ordinate of imaginary arch to real arch called funicular arch.

- **Muller Breslau principle:-** The Muller - Breslau principal is a method to determine influence lines.
- **Influence lines:-** Variation of reaction shear, moment or deflection at a specific point Due to a concentrated force moving on beam or frames.
- **Shape factor:-** Represent reserve strength beyond yielding.

$$\text{Shape factor} = \frac{Z_P}{Z_e} = \frac{M_P}{M_e}$$

■ **Shape factor for different section.**

Section	Shape factor
I- section	
(a) about strong axis	1.22
(b) about weak axis	1.55
T- section	1.90-1.95
Rectangular section	1.5
Solid circular section	1.7
Triangular section (vertex upward)	2.34
Triangular section (Vertex downward)	2.00
Hollow circular section k = Ratio of inner diameter to outer diameter	$1.7\left(\frac{1-k^3}{1-k^4}\right)$
(a) diamond section rhombus	2.0
(b) Thin hollow rhombus	1.50
thin circular ring solid	1.27
H- section	1.5

■ **Collapse load for different section:-**

Simply Supported beam with point load	Collapse load
Simply supported beam with point load	$w_u = \frac{4M_P}{\ell}$
Simply supported beam with UDL load	$w_u = \frac{8M_P}{\ell^2}$
Cantilever beam with end point load	$w_u = \frac{2M_P}{\ell}$
Cantilever beam with UDL load	$w_u = \frac{2M_P}{\ell^2}$
Fixed beam with point load	$w_u = \frac{8M_P}{\ell}$
Fixed beam with UDL load	$w_u = \frac{16M_P}{\ell^2}$
Fixed beam with unsimtrical point load	$w_u = \frac{2M_P\ell}{ab}$
Prop cantilever beam with mid-sec. point load	$w_u = \frac{6M_P}{\ell}$
Prop cantilever beam with UDL load	$w_u = \frac{11.656M_P}{\ell^2} \approx \frac{12M_P}{\ell^2}$

Scanned with CamScanner

Building Estimate, Costing & Evaluation

■ **Types of Estimate-**

A. Preliminary/Approximate or Abstract Estimate

1. Unit Rate Estimate
2. Plinth Rate Estimate
   (Approximate estimate = plinth area × plinth area rate)
3. Cubic Rate Estimate
   (Approximate estimate = Volume of building × Rate per volume)
   Volume = L × B × H
4. Percentage Rate Estimate

B. Detailed Estimate (Most reliable estimate)-

1. Item Rate or Detailed Estimate
2. Revised Estimate
3. Supplementary Estimate.
4. Annual repair and maintenance estimate

- **Revised Estimate is prepared when-**

1. Original sanctioned estimate exceed by more than 5%.
2. Expenditure of the work exceed more than 10% of an administrative approval.
3. If there is change of rate or quantity of material.

- **Purpose of Detailed Estimate-**

1. Technical Sanction
2. Administrative approval
3. Framing and inviting tender
4. To know material required and project duration
5. Accurate idea of cost of construction
6. To determine earnest money and security deposit

■ **Deduction for opening-**

- **In Masonry-**

1. Openings each up to $0.1 m^2$ or $1000 cm^2$
2. Ends of beam, post rafters, purlins etc. up to $0.05 m^2$ or $500 cm^2$ in section.
3. Wall plate, bed plate, bearing of chajjas and the like up to 4 inch or 10 cm.
4. No deduction is made for bearing of floor and roof slab.

- **In plastering and pointing-**

1. No deduction is made for ends of beams, posts and rafters.
2. No deduction is made for small opening up to $0.5 m^2$ or 5 sq. ft.
3. Deduction is made for one face only if opening is between $0.5 m^2$ to $3.0 m^2$
4. If opening is more than $3m^2$, deduction is made for both face of the openings.

■ **Measurement accuracy for different item-**

Item	Measurement Accuracy
All dimension/Linear Measurement	0.01 m
Area	$0.01 m^2$
Cubic content	$0.01 m^3$
wood work	$0.002 m^3$
steel work	0.005 m
volume	$0.01 m^3$
volume of wood work	$0.001 m^3$

■ **Multiplying factor for painting area calculation-**

Irregular shape	Multiplying factor	
	For one side	For both side
Flush Door	1.20	2.00
Paneled, framed, batten and Braced door.	1.125	2.25
Fully glazed or gauged door.	0.50	1.00
Partially paneled and partially glazed or gauzed door.	1.00	2.00
Corrugated iron sheet **(G.I. Sheet)**	1.14	2.28
Corrugated asbestos sheet **(A.C. sheet)**	1.20	2.40
Semi Corrugated Asbestos sheet	1.10	2.20
Steel Rolling shutter	1.25	2.50
Corrugated Asbestos Traford sheet	1.10	2.20

■

Work/Item/Name/ Expenditure	% Cost of total cost of project
Water charge	1.5%
Annual Repair	1.5%
T & P or Tools and plants	1-1.5%
Work charge Establishment	1.5-2%
Earnest money	2%
Contingencies	3-5%
Sanitary work	8%
Electrification	8%
Water Distribution work	8%
Departmental charge	10-15%
Contractor profit	10%
Bond or guarantee	10%
Labour Expenditures	30-35%

■ **Most Important definition-**

1. **Plinth Area-** It is a built-up covered area of a building measured at the floor level excluding plinth offset of any storey.
2. **Floor Area-**
   - It is the total area of floor between the walls.
   - Floor Area = plinth area – Area occupied by walls.
3. **Carpet Area-**
   - It is an useful or liveable area or rentable/Lettable area.
   - **Carpet Area** = Total floor area – circulation area.
4. **Circulation Area-**
   - It is the floor area which are used for movement of persons using the building. It is two types.

1. **Horizontal circulation area–** Area of verandah, passages, corridors, balconies, porches.
   - It is 10-15% of plinth area.

Scanned with CamScanner

2. **Vertical circulation area–** Area occupied by staircase, lift and entrance halls.

- It is 4-5% of plinth area.

■ **Unit of Measurement and payments for various item of Civil work-**

Particular of Item	M.K.S. System	
	Measurement unit	Payment unit
Brick, Earth Tile (with measurement)	Thousand	Per Thousand
Floor Tile, glass Tiles	Hundred	Per Hundred
Stone Ballast	Cu.m	Per Cu. m
C.C./R.C. Chajja	Cu.m	Per Cu. m
Reinforcement Bars	Quintal	Per Quintal
Electrification Light, Fan, Plug points	Point	Per Point
Surface-dressing 15 cm upto depth	Sq.m	Per Sq. m
Foundation excavation	Cu.m	Per Cu. m
Earth work dressing	Sq. m	Per Sq. m
Shuttering work	Sq. m	Per Sq. m
Reinforcement Cement Concrete	Cu. m	Per Cu. m
Centering and form work	Sq. m	Per Sq. m
Concrete Jaffier,	Sq. m	Per Sq. m
D.P.C.	Sq. m	Per Sq. m
On Roof bitumen painting	Sq. m	Per Sq. m
Half brick thick masonry (upto 10 cm Thick)	Sq. m	Per Sq. m
In Super Structure brick masonry work (> 10 cm thick)	Cu. m	Per Cu. m
Honey - Comb brick masonry work	Sq. m	Per Sq. m
Flat soling of brick	Sq. m	Per Sq. m
Cornice, string course	m	Per m
Roof of Corrugated sheet	Sq. m	Per Sq. m
Doors/windows of Chowkhat, Beam etc.	Cu. m	Per Cu. m
Door and window shutters or leave	Sq. m	Per Sq.m
Paneled, partition wall	Sq. m	Per Sq.m
Fabric reinforcement, wire netting	Sq. m	Per Sq.m
Barbed wire facing	metre	Per metre
Rivet, Bolts and Nuts, Anchor bolts, Lewis bolts, Holding down bolts, etc.	quintal	Per quintal
Iron grill, Collapsible gate	Sq. m	Per Sq. m
Rolling Shutter	Sq. m	Per Sq. m
Iron gate (may also be by weight, quintal)	Sq. m	Per Sq. m
Painting, Varnishing (No. of Coat specified)	Sq. m	Per Sq. m
Removing of point or Varnish	Sq. m	Per Sq. m
Plastering - cement mortar, Lime mortar and mud mortar	Sq. m	Per Sq. m
Pointing - struck, flush, weather, etc.	Sq. m	Per Sq. m
Dado (Thickness and type specified)	Sq. m	Per Sq. m
Skirting (Thickness type and height specified)	metre	Per m
Earth filling on base of road, with rolling	Cu.m	Per Cu. m
Soling coat of brick	Sq. m	Per Sq. m
Pile driving or Sinking	metre	Per m
Painting Furniture's	no.	Per no.
Supply of water closet, W.C. (size specified)	no.	Per no.
Supply of paint ready mix.	litre	Per Litre
Explosive for blasting	kg	Per kg

■ **Methods of estimation of the building-**

1. **Long wall-short wall method or out-to-out and in-to in method or P.W.D. method.** (useful for all types of wall)

Length of long wall = C/C Length of wall + Thickness of wall.

Length of short wall = C/C Length of wall – Thickness of wall.

2. **Centre Line method-**

- Best method for symmetrical cross section.
- Most rapid and easy method

3. **Crossing method.**

Earth work estimation in roads-

1. **Mid Sectional area method-**

$$V = \left[Bd_m + S.d_m^2\right] \times L$$

$$d_m = \frac{d_1 + d_2}{2}$$

- **Area of sloping side of road-**

$A = L.d\sqrt{1+S^2}$ (for one side slope)

$A = 2L.d\sqrt{1+S^2}$ (for both side slope)

2. **Mean Area Method-**

$$V = \frac{A_1 + A_2}{2} \times L$$

$$A_1 = B.d_1 + Sd_1^2$$

$$A_2 = B.d_2 + Sd_2^2$$

Scanned with CamScanner

3. **Prismoidal Method-**

$$V = \frac{L}{6}(A_1 + A_2 + 4A_m)$$

$$A_m = Bd_m + Sd_m^2$$

L = Length of the section (cutting/filling)

- **Simpson's formula-**

$$V = \frac{d}{3}[(A_1 + A_n) + 4(A_2 + A_4 + ...A_{n-1})] + 2(A_3 + A_5 + ... + A_{n-2})$$

$$= \frac{D}{3}[(A_1 + A_n) + 4(\text{Even area}) + 2(\text{Odd Area})]$$

- **Volume by Trapezoidal formula–**

$$V = D\left[\frac{A_0 + A_n}{2} + A_1 + A_2 + A_3 + ...A_{n-1}\right]$$

■ **Earthwork in hilly Road-**

1. **Earthwork in cutting/filling-**

$$V = \frac{L \times [S.b^2 + m(2bd + S.d^2)]}{m^2 - S^2}$$

2. **Earthwork in partially cutting and filling-**

(a) **In partially cutting**

$$V = L \times \frac{1}{2}\left[\frac{(b + md)^2}{(m - S_1)}\right]$$

(b) **In partially filling-**

$$V = L \times \frac{1}{2}\left[\frac{(b - md)^2}{(m - S_2)}\right]$$

■ **Work done per day per mason for a particular item-**

Item Description	Work Done per day per mason
Brick Work in Foundation and Plinth with Mud-mortar	1.50 m^3
Brick Work in Super Structure with Mud-mortar	1.25 m^3
Brick Work in foundation and Plinth (Sub-Structure) with Lime or Cement Mortar.	1.25 m^2
Brick Work in Super Structure with Lime Mortar or Cement Mortar.	1 m^3
Brick Work in Partition Wall	5.0 m^2
Random Rubble Stone Masonry in lime or cement mortar	1.0 m^3
Course Rubble Stone Masonry lime or cement mortar	0.80 m^3
Lime Concrete or Cement Concrete (P.C.C.) in foundation and Plinth	8.5 m^3
Lime Concrete in Roof Terracing	6.0 m^3
1 : 2 : 4 C. C. Work	5.0 m^3
R. C.C. Work	3.0 m^3
Earth Work in Excavation in Rock	1.0 m^3
12 mm Thick Plaster Work	8.0 m^2
Pointing Work	10.0 m^2
White Washing or Colour Washing in Double Coat	100 m^2

■ **Dry volume for different types of item:**

Item Description	Dry Volume masonry work
P.C.C. work, C.C. and all types of concrete work excluding C.C. floor	1.52 to 1.55
For brick masonry	0.30 cum
Random Rubble masonry	0.42 cum
Coursed Rubble masonry	0.40 cum
12 mm thick plaster work	0.0196 m^3 to 0.02 m^3
Painting work	0.006 m^3
2.5 cm thick C.C. floor	0.04125 m^3
5 cm thick C.C. floor	0.0825 m^3
7.5 cm thick C.C. floor	0.12375 m^3

■ **Capacity of truck-**

Truck	3 Tone Capacity	5 Tone Capacity	8 Tone Capacity
Brick transport	1000 brick	1500 brick	2500 brick
Ballast, Brick, Kankar, Sand	2.80 m^3 (100 $feet^3$)	4.20 m^3 (150 $feet^3$)	5.60 m^3 (200 $feet^3$)

■ **Minimum height of stack and allowance to be deducted for shrinkage and/or shrinkage when measured in fresh stacks-**

Materials	Minimum height of stacks cm	Allowance to the deduced for sinkage and/or shrinkage
Stone metal, ballast chips, shingles or gravel	32.5	1/13
Stone boulders 15cm or above size	53	1
Stone boulders below 15 cm size	45	1/7
Jhama bats or bricks bats	53	1/7
Jhama metal, khoa or chips	34	1/9
Sand	61	1/4
Surkhi	61	1/4
Lime	61	1/4
Moorum	2.5	1/13
Carried earth	34	1/9
Rubbish (building or kiln)	34	1/9
Stream Coal or slack coal	61	1/8
Cinder	61	1/9

Scanned with CamScanner

■ **Important unit conversion-**

1 m	=	39.37 inch
	=	3.28 feet
1 mile	=	1.6 km
1 feet	=	0.3048 m
1 m^2	=	10.75 $feet^2$
1 $feet^2$	=	0.093 m^2
1 cum	=	35.29 C.ft.
1 C.ft.	=	0.0283 cum
1 yard	=	3 feet

- Number on Brick in 1 cum masonry = **500**
- Number on Brick in 1 cum Lot = **650**
- Length of bent up bar
  (i) for 45° crank – $L + 2 \times 0.42\,d$
  (ii) for 30° crank – $L + 2 \times 0.27\,d$

■ **Weight of mild steel bars for per m Length a given dia.-**

$$= 0.0062\phi^2$$

$$= \frac{\phi^2}{162.2}\,kg/m$$

ϕ = dia. of bar

Salvage value-

- The value of an item at the end of its utility period without being dismantled.
- It is 10% of the total cost of construction.

Scrap value-

- It is the dismantled value of an item at the end of its useful life.
- Scrap value may be (+Ve) or (–Ve).

Book value-

- It is the amount shown in the account book after allowing necessary depreciation.

Book value after n_1 years = $\boxed{C - n_1 \times D}$

= original cost – $n_1 D$

Annuity–

- The net installment of periodical payment for repayment of the capital amount invested in a property for a specified period.

Obsolescence/uncirculation-

- Due to end of circulation of shape or design of the property is called obsolescence.

Capital Cost-

- It is the total cost of construction, including lands or the original total amount required to possess a property.

Year's Purchase

$$Y.P = \frac{100}{\text{Rate of interest}} = \frac{100}{i}$$

$$\boxed{\text{Capitalized value} = \text{Net income} \times Y.P.}$$

Sinking fund, $\boxed{S_c = \frac{S.i}{(1+i)^n - 1}}$ S = capital cost

■ **Rate of Depreciation based on life of structure-**

Life of structure (years)	Annual Depreciation (per year)	Total Depreciation
0-5	0	0
5-10	$\frac{1}{2}$%	2.5%
10-20	$\frac{3}{4}$%	7.5%
20-40	1%	20%
40-80	$1\frac{1}{2}$%	60%
	Total =	90%

■ **Methods of Depreciation-**

(i) Straight line method-

Annual depreciation,

$$\boxed{D = \frac{\text{Original cost - Scrap value}}{\text{Life in year}} = \frac{C-S}{n}}$$

(ii) Constant percentage method/Declining balance method-

Annual Depreciation, $\boxed{D = 1 - \left(\frac{S}{C}\right)^{1/n}}$

(iii) Sinking fund method- In this method the depreciation of property is assumed to be equal to the annual sinking fund plus the interest on the fund for that years, $\boxed{S_c = \frac{i}{(1+i)^n - 1}}$

- The value of sinking fund at the end of useful life of the property is 90%.

(iv) Quantity Survey method- In this method the property is studied in detail and loss in value due to life, wear and fear, decay, obsolescence, etc., worked out. Each and every step is based on some logical ground without any fixed percentage of the cost of the property.

■ **The different classes of plots may be taken-**

A. Type plot	1200 Sq. m
B. Type plot	800 Sq. m
C. Type plot	500 Sq. m
D. Type plot	250 Sq. m

■ **The minimum covered area of building shall be as follows-**

Area of plot	Max. permissible covered area
Up to 200 Sq. m	60% of the site area on ground and first floor only
201 to 500 Sq. m	50% of the site area
501 to 1000 Sq. m	40% of the site area
More than 1000 Sq. m	$33\frac{1}{3}$ of the site area

Scanned with CamScanner

Public Health Engineering

- First national water policy 1987.
- Air prevention & control of pollution Act - 1981.
- Water prevention & control of pollution Act - 1974.
- The Environment protection Act - 1986

Per Capita Demand (q)-

$$q = \frac{\text{Total yearly water requirement of the city in litre}}{365 \times \text{Design population}}$$

- Max. daily demand = 1.8 × Avg. daily demand.
- Max. hourly demand = 1.5 × Avg. demand hourly of Max. day.
- Max. hourly demand or peak demand = 2.7 × Avg. hourly demand.

■ **Fire Demand-**

(i) As per GOI Fire Demand

$$Q = 100\sqrt{P} \quad (kL)$$

(ii) Kuichling's Formula

$$Q = 3182\sqrt{P}$$

(iii) Freeman's Formula

$$Q = 1136\left[\frac{P}{5} + 10\right]$$

(iv) Buston's formula

$$Q = 5663\sqrt{P}$$

P = Population in thousand

■ **Population forecasting method-**

(i) Arithmetic increase method-

(Suitable for older and larger cities)

$$\boxed{P_n = P_o + n\bar{x}}$$

(ii) Geometric increase method-

(For young and rapidly developed cities)

$$\boxed{P_n = P_o\left(1 + \frac{r}{100}\right)^n}$$

(iii) Incremental Increases method-

$$\boxed{P_n = P_o + n\bar{x} + \frac{n(n+1)\bar{y}}{2}}$$

■

Contributory population	Peak factor
up to 50000	3.00
50001 to 200000	2.50
more than 200000	2.00

■

Design period values component	Design period (years)
Storage by dams	50
Water treatment units	15
Main supply pipes	30
Demand reservoir	50
Distribution system	30

■ **Hardness of water-**

Total Hardness =

$$\left[\frac{[Ca^{2+}]}{\text{Equivalent weight of } Ca^{2+}} \times \text{Equivalent wt. of } CaCO_3\right] + \left[\frac{[Mg^{2+}]}{\text{Equivalent wt. of } Mg^{2+}} \times \text{Equivalent Wt. of } CaCO_3\right]$$

☞ Total Hardness (TH) in mg/ℓ expressed as $CaCO_3$

- 1 British degree of hardness = 14.25 mg/l
- 1 French degree of hardness = 10 mg/l
- 1 American degree of hardness = 17.1 ppm

Zeolite process/base exchange/cation exchange method-

- This method is very effective and can be produces zero hardness.
- It is not suitable for water with Fe and Mn
- pH of water is not affected.
- No sludge is formed.

■

Water Quality Parameter	Permissible Units	Cause for rejection value
Suspended solids	500 mg/l	2000 mg/l
Turbidity	1 NTU	10 NTU
Colour	5 TCU	25 TCU
Taste and odour	1 TON	3 TON
Alkalinity	200 mg/l	600 mg/l
pH	6.5-8.5	< 6.5 and > 9.2
Hardness	200 mg/l	600 mg/l
Chloride content	250 mg/l	1000 mg/l
Free NH_3	0.15 mg/l	0.15 mg/l
Nitrate	45 mg/l	-
Fluoride	1 mg/l	1.5 mg/l

■

Parameters	Diseases
Absence of fluorides	Dental, Fragile bones
Excess of lead	Anemia
Presence of excess nitrate	Methemoglobinemia or blue baby syndrome
Absence of Iodine	Goitre
Excess of chlorides	Hyperchloremia

■

Property of Water	Types of test/instrument
Hardness	EDTA method
Turbidity	Turbiditymeter/Nephlometer
Bacteria count	MPN test membrane filter technique
pH	Potentiometer, Aquascope
Colour	Tintometer
Dissolved Oxygen	Winkler's method
Organic matter	BOD test, COD test
Taste and odour	Osmoscope

Scanned with CamScanner

■ **Water borne diseases and their control-**

(a) Diseases	Caused by bacteria
(i) Typhoid fever	- Salmonella typhi
(ii) Cholera	- Vibrio-cholera
(iii) Bacillary dysentery	- Shigella bacillus or Flexner-bacillus

(b) Diseases caused by viral infection-

(i) Hepatitis (Infectious jaundice) - Hepatist virus

(ii) Poliomyelitis - Polio virus

■ **Design Criteria of Sedimentation tank-**

- Over flow rate = Overflow rate or surface loading.
  = 500 – 750 Ltr./hr/m^2 (for plain sedimentation with coagulation)
  ≃1000–1250 Ltr./hr/m^2 (for Sedimentation with coagulation)
- Depth = 3 to 4.5m (< 1.8m and > 6.0m)

■ **Slow sand filter-**

- Sand size - 0.20 - 0.30 mm
- Depth of filter - 2.5 - 4.0 m.
- Plan area of filter - 100 - 200 m^2
- Design period - 10 years.
- Cleaning period - 1 - 3 months.
- Rate of filtration - 2400 - 4800 Ltr./m^2/day or 100 - 200 Ltr./m^2/hr.
- Efficiency of bacteria removal - 98 - 99%.

■ **Rapid Sand filter-**

- Depth of tank - 2.5 - 3.5 m.
- Area - 10 - 80 m^2 each unit.
- Rate of washing - 15 - 90 cm Rise/minute.
- Rate of filtration - 3000 - 6000 Ltr./m^2/hour. (Slow sand filter × 30)
- 30 min. used for back wash.

(iv) Break point chlorination-

- Chlorine is added beyond breakpoint to ensure a residual 0.2 – 0.3 ppm as free chlorine.
- Residual chlorine is tested by DPD test.

(v) Super chlorination-

- When excess chlorine (5 - 15 mg/*l*) is added in water during epidemic such that it gives a residual of 1 - 2 mg/*l* beyond break point is called super chlorination.
- **Air relief valves** are used to release air.
- **Sluice valves** are used to stop the water supply in pipe.
- **Scouring Valve** are used at low levels of pipe to remove impurities such as sand, silt etc.
- **Pressure relief valves** are used to release pressure occurring due sudden closure of valves.
- **Pilot valve** are often used in critical application (e.g., emergency and SIS control)
- **Check valve/reflux valve/non-returning valve:-** These possess some automatic device which allows the water to flow in one direction only.

☞ Sonoscope is used in detection of leakage in underground water mains.

■ **Different types of pipes and their uses-**

- **Anti siphonage pipe** is installed for the purpose of preserving the water seal of traps in drainage system.
- **Soil pipe** carries human excreta from water closet to septic tank.
- **Vent pipe** is provided for the ventilation purpose to facilitate the exit of foul gases in to atmosphere.
- **COD** = Biodegradable organics + Non-Biodegradable organics.
- THOD ≥ COD ≥ BOD ≥ TOC (Total organic compound)
- BOD = (DO_i – DO_f) Dilution factor.
- Dilution factor = $\frac{\text{Volume of the diluted sample}}{\text{Volume of the undiluted sewage sample}}$

■

Spacing of Manhole lines as per IS 1742-1960	Size of Sewer (m)
45 m	≤ 0.3 m (upto)
75 m	≤ 0.6 m (upto)
90 m	≤ 0.9 m (upto)
120 m	≤ 1.2 m (upto)
250 m	≤ 1.5 m (upto)
300 m	≤ 1.5 m (greater than)

☞ HNO_3, H_2CO_3, H_2SO_4 present in acidic rain.

■ **Oxidation Ponds-**

- Depth - 1.0 - 1.8 m
- Detention period - 2 - 6 weeks
- Organic loading - 150 - 300 kg/ha/day.
- Under hot condition - 60 - 90 kg/ha/day.
- Length to width ratio - 2
- Sludge Accumulation - 2 - 5 cm/year
- Minimum depth to be kept - 0.3 m

■ **Septic tank-**

- Detention time - 12 - 36 hr.
- Sludge accumulation rate - 30 Ltr./cap/year
- Sewage flow - 90 - 150 Ltr./cap/day
- Cleaning period - 6 - 12 month
- Length to width ratio - 2 - 3 m
- Depth - 1.2 - 1.8 m
- Width < 0.9 m
- Free board - 0.3 m

■ **Primary Air Pollutants-**

- Finer particles (< 100μ in diameter)
- Coarse particles (> 100μ in diameter)
- Sulphur compounds, (SO_2)
- Oxides of Nitrogen, (NO, NO_2)
- Carbon monoxides (CO)
- Halogen compounds
- Organic compounds
- Lead (Pb)
- Radio active substances

■ **Secondary Air Pollutants-**

1. H_2SO_4 2. PAN (Peroxyacetyl-nitrate)
3. Formaldehydes 4. Ozone (O_3)
5. Photo chemical smog.

■ **An acceptable noise level for by IS 4594-1968**

- Rural 25 - 35
- Sub-urban 30 - 40
- Residential (Urban) 35 - 45
- Urban 40 - 50
- City 40 - 50
- Industrial 50 - 60

Scanned with CamScanner

Surveying Engineering

Shape of earth - **Oblate Spherical**

Polar axis length - **12713.80 km**
Equatorial axis length - **12756.75 km** } Difference → 42.95 km

■ **Primary Classification of Survey-**

Plane Surveying	Geodetic Surveying
• Mean surface of the earth is considered as plane.	• Actual surface of the earth is taken into account.
• Used for small area < 195.5 km^2.	• Use for large area > 195.5 km^2
• Line joining two points is a line.	• It is an arc.
• It is less accurate.	• It is more accurate.
• Used in engineering projects on large scale like, Bridge, dam.	• It is used to establishing control points for plane survey.
	• All plumb lines are radial

1. **Plane Scale** - There is possible to measure two dimensions, only such as unit and length or km and m.
2. **Diagonal Scale** - In this it is possible to show units, lengths, and hundredths or there are three successive dimensions can be measured at a time.

Note- Diagonal scale is based on principle of similarity of triangle.

3. **Vernier Scale-**

(a) Direct Vernier - Calibrated in same direction as of main scale.

- In this n division of vernier scale is equal to (n-1) divisions of main scale.

  i.e $nV = (n-1)S$ in this $V < S$

(b) Retrograde Vernier- Vernier scale moves in opposite direction of main scale.

- For it $nV = (n+1)S$ for this $V > S$

Extended vernier - $nV = (2n-1)S$

Least count $V = \frac{S}{n}$

Shrunk Scale-

$= \text{Original Scale} \times \text{shrinkage factor}$

and, $\text{Shrinkage factor} = \frac{\text{Shrunk length}}{\text{Actual length}}$

Note- Graphical scale does not affects due to shrinkage of map.

■ **Types of drawing sheet and its size-**

Types of sheet	Size in (mm)
A_0	1189 × 841
A_1	841 × 594
A_2	594 × 420
A_3	420 × 297
A_4	297 × 210
A_5	210 × 148

- **Representative Fraction-**

$$R.F = \frac{\text{Map distance}}{\text{Ground distance}}$$

- Shrinkage ratio or S.F. $= \frac{\text{Shrunk length}}{\text{Original length}} = \frac{\text{Shrunk scale}}{\text{Original scale}}$
- Correct distance on map $= \frac{\text{Measured distance on map}}{\text{S.F.}}$
- Correct area on map $= \frac{\text{Measured area on map}}{(\text{S.F.})^2}$

■ **Error due to use of wrong scale-**

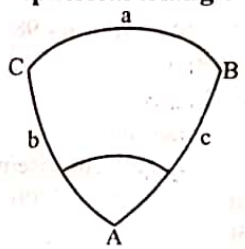
$$\text{Correct Length} = \frac{\text{RF of wrong scale}}{\text{RF of correct scale}} \times \text{Measured Length}$$

$$\text{Correct Area} = \left(\frac{\text{RF of wrong scale}}{\text{RF of correct scale}}\right)^2 \times \text{Measured Area}$$

Note-

- Minor control points are measured with higher degree of precision.
- Major control points are measured with lower degree of precision.

■ **Properties of a spherical triangle-**



- Any angle,

  $A \text{ or } B \text{ or } C < \pi \text{ or } 180^0$

- Sum of three angle,

  $\pi \text{ or } 180^0 < (A+B+C) < 3\pi \text{ or } 540^0$

- Sum of any two sides should be greater than third i.e.

  $(a+b) > c,\ (b+c) > a,\ (a+c) > b$

■ **Least Count of Surveying Instrument-**

Instrument	Least Count
Vernier Theodolite	20"
Electronic Theodolite	1"
Prismatic compass	30'
Surveyor compass	15'
Levelling staff	5 mm or 0.005 m
Dumpy level	5 mm
Meteric chain	20 cm
Theodolite-	
Main Scale	20'
Vernier Scale	20"
Total Station-	
Angle	1"
Distance	5 mm

Scanned with CamScanner

■ **Principal of different types of surveying work-**

Surveying Types	Principal
1. Surveying	1. To work from whole to part. 2. To locate a new station by at least two measurements (Linear or angular) from fixed reference point.
2. Chain Survey	Triangulation
3. Compass Survey	Traversing
4. Plane table Survey	Parallelism
5. Optical square	Double reflection

■ **Types of Surveying -**

Topographical Surveys	It is used to determine the natural features of a country like, lakes, hills, roads, canal etc.
Cadastral Survey	Made to fixing of property line, calculation of area, etc.
City Survey	It is used to construction or layout for water supply system, sewer and other work.
Marine or hydrographic survey	It is deals with large water bodies such as navigation, harbour works etc.
Astronomical Survey	It is consists of observation of the heavenly bodies such as Sun or any Star.

■ **Types of instrument used in survey and its application-**

Instrument	Application
Chain and compass	Linear and angular measurements
Chain and level	Linear measurements
Plane table	Plot plans of field observation for small scale in plane surface
Tacheometry	To measure horizontal and vertical angle in hilly regions

■ **Basic measurements in surveying-**

Horizontal Distance	By chain, tape, tacheometer, total station
Vertical Distance	Level, total station, tacheometer, sextant, abney level
Horizontal Angle	Theodolite, compass, clinometer, total station
Vertical Angle	Theodolite, sextant, total station

■ **Types of Chain and its length-**

Types of Chain	Length	No. of Links
Engineers Chain	100 ft	100
Gunter's chain/surveyor chain	66 ft	100
Revenue chain (use in cadastral survey)	33 ft	16
Metric Chain	30m, 20m	150, 100

- Length of each links - 20 cm
- Tallies provided - every 5 m
- Brass ring provided - every meter except tallies place

■ **Maximum tolerance for chain-**

10 m	-	± 3 mm
20 m	-	± 5 mm
30 m	-	± 8 mm
Per m length	-	± 2 mm

■ **Order of measurements and its application-**

Order of measurements	Application
Ist order	To determine length of base line
IInd order	In traverse line
IIIrd order	Chain surveying

■ **Important survey lines-**

Base line	Longest survey line passing through the centre of area.
Check line/proof line	Used to check the accuracy of the survey work.
Tie line/subsidiary line/ auxiliary line	To collect the details of nearby objects in an area.

■ **Chain Survey instrument property-**

Instrument	Dimension
Arrows	4 mm dia, 400 ± 5 mm length Top ring 50 mm
Pegs	Area 2.5 × 2.5 cm^2 to 3 cm × 3 cm length - 15 cm
Ranging rod	Length, 2-3 m, strip length 20 cm each
Ranging pole	Length, 4-8 m

■ **Angle measuring instrument-**

1. Cross staff	Used to setting out a right angle on chain line.
(i) Open cross staff	Set out for 90° only
(ii) French cross staff	for 45° and 90°.
(iii)Adjustable cross staff	for any angle 0° – 360°
2. Optical Square	Only for 90°
3. Prism Square	Only for 90°
4. Site Square	Only for 90°

Note- Angle b/w horizontal glass and index glass = 45°

- **Offset-** Lateral measurement from chain line it is two types.
  (a) Perpendicular offset
  (b) Oblique offset

Note-

- Long offset > 15 m
- Short offset < 15 m
- **Horizontal glass** - Half silvered
- **Index glass** - Full silvered

■ **Ranging-**

To locating intermediate point on survey line b/w two fixed end point.

Scanned with CamScanner

(a) Direct Ranging -

- Possible when stations are intervisible.
- It is done by **Eye** or **Line Ranger**

(b) Indirect ranging-

- It is done if stations are invisible due to elevated area or long sight distance

■ Types of error occurred during surveying

Cases	Errors
Incorrect length of tape	Cumulative +ve or –ve
Bad ranging	Cumulative +ve
Tape not stretched horizontally	Cumulative +ve
Tape not stretched tight and straight, but both ends in line	Cumulative +ve
Error due to temperature	Cumulative +ve or –ve
Variation in pull	Compensating +ve or –ve
Error due to sag	Cumulative +ve
Error in marking tape lengths	Compensating +ve or –ve
Disturbing arrows after they are set	Blunder
Errors in reading the tape	Mistake
Incorrect counting of tape length	Blunder
Careless holding and marking	Compensating +ve or –ve

■ Tape Correction-

S.N.	Correction	Condition	Error	Correction	Formula
1.	Length	(a) Increases (b) Decreases	–Ve +Ve	+Ve –Ve	$l = l'\left(\frac{L'}{l}\right)$
2.	Temperature	(a) Increases (b) Decreases	–Ve +Ve	+Ve –Ve	$C_t = \alpha(T_m - T_0)L$
3.	Pull/Tension	(a) Increases (b) Decreases	–Ve +Ve	+Ve –Ve	$C_p = \frac{(P_m - P_0)}{AE} \times L$
4.	Sag	–	Always +Ve	Always –Ve	$C_s = \frac{w^2 l^3}{24P_m^2}$ or $\frac{W^2 l}{24n^2p^2}$
5.	Slope	–	Always +Ve	Always –Ve	$C_{SL} = h^2/2L$ or $C_v = 2L\sin^2\theta/2$
6.	Bad Ranging	–	Always +Ve	Always –Ve	$C_h = d^2/2L$

- **Error due to Incorrect chaining-**

$$\text{Correct length} = \text{Measured length} \times \frac{\text{Incorrect chain length}}{\text{standard chain length}}$$

- In chain surveying field work limited to linear measurement only.

Note-

- Size of field book - **20 cm × 12 cm**
- Correction per chain length for 10 links at a slope of $a = \frac{1.5a}{100}$
- Correction applied for each chain length along 0° slope. $= l(1 - \cos\theta)$
- Hypotensual allowance $= l(\sec\theta - 1)$

Types of error in linear measurement-

1. Cumulative/systematic error-

- Occurs in same direction and tends to accumulate.
- Cumulative error ∝ length of line (l)

2. Compensative/Accidental error-

- Not occurred in same direction.
- Compensative error ∝ $\sqrt{l}$.

Compass Survey

Prismatic Compass	Surveyor compass
➢ Magnetic needle is a broad needle	It is edge bar type
➢ Graduated ring is attached with the needle do not rotate with the box	Attached with the box and rotate along with the box
➢ Readings are taken with the help of the prism	Taken directly by seeing through top of the box
➢ Sighting and reading are taken simultaneously	Cant be done simultaneously
➢ Whole circle bearing (W.C.B.) are calculate	Quadrantal bearing (Q.B.) system is calculated.
➢ Bearing of line measured with magnetic north in clockwise direction.	Bearing of a line measured eastward or westward from north or south whichever is nearer

Scanned with CamScanner

■ **Important definition-**

Azimuth/True bearing - Bearing of a line in reference to the horizontal true north (meridian).

Magnetic bearing - Horizontal angle b/w the magnetic meridian and a line.

Arbitrary bearing - Horizontal angle b/w the arbitrary meridian of a line.

■ **Conversion of Q.B (Reduced bearing) to W.C.B.-**

Q.B.	Quadrant	W.C.B.	Angle
NθE	I^{st}	W.C.B. = Q.B	0° - 90°
SθE	IInd	180° – Q.B.	90° - 180°
SθW	IIIrd	180° + Q.B.	180° - 270°
NθW	IVth	360° – Q.B.	270° - 360°

■ **Conversion of W.C.B. to Q.B.-**

W.C.B	Quadrant	Q.B.	R.B./Q.B. value
0° - 90°	I^{st}	Q.B = W.C.B.	NθE
90° - 180°	IInd	180° – W.C.B	SθE
180° - 270°	IIIrd	W.C.B. – 180°	SθW
270° - 360°	IVth	360° – W.C.B.	NθW

■ **Bearing of a line-**

Fore Bearing - Bearing of a line in the progress of survey.

Back bearing - Bearing of a line taken opposite direction of the survey.

Relation b/w F.B. and B.B. \-

$$\boxed{B.B. = F.B \pm 180^0}$$

use, +Ve if F.B.< 180°

– Ve if F.B. > 180°

Note-

➢ In R.B. System, angle value does not change but direction (N → S and E → W) changes.

■ **Temporary adjustment of prismatic compass sequence-**

$$\boxed{\text{Centering} \rightarrow \text{Levelling} \rightarrow \text{Focusing of prism}}$$

■ **Local Attraction-** Disturbance the magnetic needle from its normal under the influence of magnetic substance.

If, $\boxed{B.B - F.B = 180}$ (No local attraction)

$\boxed{B.B - F.B \neq 180}$ (Affected by local attraction)

■ **Important term-**

Lines	The line joining
Isoclinic lines	Points of equal dip
Aclinic lines	Points of zero dip
Isogonic lines	Points of equal declination
Agonic lines	Points of zero declination

■ **Variation of magnetic declination-**

Secular variation	Due to over a long period of time due to gradual shift in earth's magnetic field
Annual variation	Due to revolution of earth around the sun. (Yearly)
Diurnal variation	Due to rotation of earth about its own axis. It's more at pole, in day & summer time.
Irregular variation	Due to magnetic disturbances in earth's magnetic field.

Note-

- **Magnetic declination-**

$$\boxed{M.D. = \text{True meridian} - M.M.}$$

or horizontal angle b/w true meridian and magnetic meridian.

- **Angle of dip-**It is the inclination angle of needle to the horizontal plane.
- The angle of dip = 0° at equator

  = 90° at Magnetic poles

■ **Closing errors-** The actual distance by which the traverse fails to close in a traverse survey.

i.e., $\boxed{\Sigma L \neq 0,\ \Sigma D \neq 0}$

Closing Error in the traverse,

$$e = \sqrt{(\Sigma L)^2 + (\Sigma D)^2}$$

■ **Balancing of Traverse-**

1. Bowditch/compass rule-

- used where Angle and distance are measured with same precision.
- Used in closed traverse

Assumption-

- Error in linear measurement $\propto \sqrt{\ell}$
- Error in angular measurement $\propto \frac{1}{\sqrt{\ell}}$

2. Transit method-used where angular measurement are more precise than linear measurement

$$\boxed{C_L = \Sigma L \times \frac{L}{L_r}},\ \boxed{C_D = \Sigma D \times \frac{D}{D_r}}$$

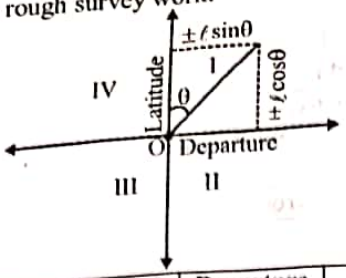
3. Axis Method- Corrections are applied only to length and angles are measured very precisely.

$$\textbf{Correction of any length} = \text{That length} \times \frac{\frac{1}{2}\text{Closing error}}{\text{Length of Axis}}$$

Scanned with CamScanner

3. Graphical method-

➢ Use for rough survey work.



W.C.B.	Quadrant	Latitude	Departure		Remark
0°-90°	I	+	+	Latitude	North +Ve
90°-180°	II	−	+		South −Ve
180°-270°	III	−	−	Departure	East +Ve
270°-360°	IV	+	−		West −Ve

■ **Check for close traverse by included angle-**

Sum of included angle = (2N − 4) × 90°

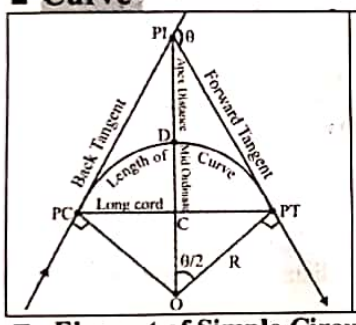
Sum of external angle = (2N + 4) ×.90°

■ **Degree of accuracy in traversing-**

Order of traversing	Accuracy
I^{st}	$6''\sqrt{N}$
2nd	$15''\sqrt{N}$
3rd	$30''\sqrt{N}$
Minor theodolite for detailing	$1'\sqrt{N}$
Compass traversing	$15'\sqrt{N}$

N = Number of angle measured

■ **Curve-**



PC → Point of Curve

PI → Point of Intersection

PT → Point of Tangent

■ **Element of Simple Circular Curve**

Tangent length	R tan θ/2
Mid ordinate	$R(1-\cos\theta/2) = 2R\sin^2\theta/4$
Apex distance	R(Sec θ/2 − 1)
Length of long chord	2R Sin θ/2
Length of Curve	$\frac{\pi R\theta}{180^0}$
Radius and versine relation in curve	

$$v = \frac{C^2}{8R}(C, V, R \text{ in m.})$$

$$V = \frac{125C^2}{R}(V \text{ in cm } C \text{ and } R \text{ in m})$$

$$V = \frac{1.5C^2}{R}(C \,\&\, R \text{ in feet } V \text{ in inch})$$

■ **Setting out of Curve –**

1. By ordinates from long chord-

$$O_x = \sqrt{(R^2 - x^2)} - (R - O_o)$$

2. By Successive bisection of arch-

Offsete = R(1 − cos θ/2)

3. By offsets from tangent- $O_x = \frac{x^2}{2R}$

4. By offsets from chord produced or deflection distance-

$$= \frac{C_n}{2R}(C_{n-1} + C_n)$$

■ **Relation between radius and degree of curve-**

Length of Arc	Relation
30 meter	$R = \frac{1720}{D^0}$ m
20 meter	$R = \frac{1146}{D^0}$ m
10 meter	$R = \frac{573}{D^0}$ m
100 feet	$R = \frac{5730}{D^0}$ feet

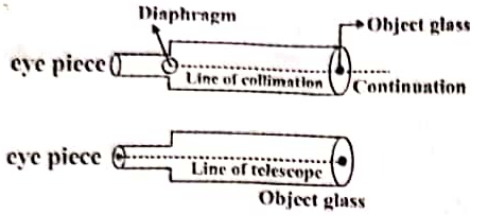
■ **Levelling-**

Level line	• Line laying on level surface normal to the plumb line or a line parallel to the mean spherical surface of the earth.
Horizontal line	• It is tangential to the level line lying in the horizontal plane.
Level Surface	• Parallel to the mean spheroidal surface of the earth.
Horizontal Surface	• A surface tangential to the level surface at any point.
Datum	• The Surface to which elevations are referred.
Bench mark	• It is a fixed reference point of known elevation. • It is stablish by spirit levelling.
Reduced level	• It is height of any point w.r.t. either M.S.L. on any bench mark of known R.L.
Level line	• Line laying on level surface normal to the plumb line or a line parallel to the mean spherical surface of the earth.
Achromatic lense	• Compound lense free from spherical aberration.
Resolving power	• Power of a telescope to form distinguishable image of objects seperated by small angular distance.
Alpanation combination	• A compound lense free from spherical aberration.
Chromatic aberration	• The defection which is blurred and coloured image formed.

Scanned with CamScanner

Line of sight	• A line joining intersection of the cross hairs to the optical centre of objective and its continuation.
Line of collimation	• If line of sight is horizontal the it is called line of collimation.
Definition	• The capability of a telescope to produce sharp image.

Note- Mean sea level (MSL) adopted by survey of India for reference is located at Mumbai.



- **Axis of bubble tube-**
  An imaginary line tangential to the longitudinal curve of the bubble tube at its middle point.

■ **Permanent adjustment of level-**

1. Axis of bubble tube should be perpendicular to the vertical axis of instrument.
2. Horizontal cross hair should lie in the plane perpendicular to the vertical axis.
3. Line of sight should be parallel to the axis of level/bubble tube. **Two peg test performed to insure its.**

■ **Levelling staff-**

(i) Target staff (**L.C. - 0.001 m**)

➢ Reading taken by staff man

(ii) Self Reading staff-

➢ Reading taken by directly Instrument man

Ex.-Solid staff, folding staff, Telescopic staff, invar precision staff.

■ **Important Terms used in levelling-**

Vertical axis	• Axis about which telescope can be rotate in horizontal plane.
Horizontal/ Trunion axis	• Axis about which telescope can be rotate in vertical plane.
Back Sight (B.S)	• It is the first reading taken after setting up the instrument.
Fore Sight (F.S.)	• It is the last reading taken from on instrument station. • It indicate shifting the shifting of instrument.
Intermediate sight (I.S.)	• All reading excepts B.S. and F.S.
Change Point (C.P.)	• The point where F.S. and B.S. both are taken.

■ **Height of Instrument -**

$$H.I. = B.M./R.L. + B.S.$$

- **Arithmetic check-**

(i) For rise and fall method-

$$\sum B.S. - \sum F.S. = \sum Rise - \sum Fall = Last\ R.L. - First\ R.L.$$

Total check point = 3

(ii) For H.I. method-

$$\sum B.S. - \sum F.S. = Last\ R.L. - First\ R.L.$$

Total check point = 2

Rise and fall method	H.I. method
➢ It is more tedious method.	➢ It is rapid method
➢ Check provided for B.S., F.S. and I.S.	➢ Check provided only for B.S. and F.S.
➢ Have less error	➢ Have more error

■

Types of Correction	Correction to staff reading
Curvature Correction	$C_c = -\frac{d^2}{2R}$ or $-0.0785d^2$ d, in km C_c in m
Refraction Correction	$C_R = \frac{1}{7} \times \frac{d^2}{2R} = +\frac{1}{7}C_c$ $= 0.01121d^2$ m
Combined correction	$C = -\frac{6}{7} \times \frac{d^2}{R}$ $= -0.06728d^2$ m

Note- Distance of visible horizon,

$$d = 3.8553\sqrt{c}\ km$$ c, height of object in m

■ **Reciprocal levelling-**

➢ Error due to refraction not eliminated completely.

Average level difference,

$$H = \frac{(h_a - h_b) + (h_a' - h_b')}{2}$$

■ **Sensitiveness of bubble tube-**

$$\alpha' = \frac{\ell}{r} = \frac{S}{nD} \times 206265$$ Second

Factors affecting the sensitiveness of bubble-

Factors	Sensitivity of bubble
Length of bubble ↑	↑
Internal smoothness ↑	↑
Diameter of tube ↑	↑
Viscosity ↑	↓
Temperature ↑	↓
Radius of curvature ↑	↑

Note-

➢ Correct sequence of temporary adjustment of level-

Centering → Levelling → Focusing

➢ **Elimination of parallax-**

1. By focusing eye-piece
2. By focusing objective lens.

Contouring-

Contour Line	Imaginary line joining point of equal elevation on ground
Contour Interval	Vertical distance b/w two contour lines
Horizontal equivalent	Horizontal distance b/w two contour lines

Scanned with CamScanner

■ **Some suitable values of contour interval**

Scale of map	Types of ground	Contour interval in meter
Large, (1 cm = 10 m or less)	Flat	0.2 to 0.5
	rolling	0.5 to 1
	Hilly	1, 1.5 or 2
Intermediate (1 cm = 10 m to 100 m)	Flat	0.5, 1 or 1.5
	rolling	1, 1.5 or 2
	Hilly	2, 2.5 or 3
Small (1 cm = 100 m or More)	Flat	1, 2 or 3
	rolling	2 to 5
	Hilly	5 to 10
	Mountainous	10, 25 or 50

■ **Methods of contouring and its suitability-**

Methods	Suitability
1. **Direct method**	• Regular ground surface for large scale maps and small area. • It is very slow, tedious and costly.
2. **Indirect method** (Mostly used) (i) Method of cross section (ii) Method of square (iii) Tacheometric method	• For road, canal, railway or alignment survey. • For small open area where close vertical interval contours required • For hilly areas.

■ **Method of interpolation-**

(i) Estimation method **(Simple and rapid method)**
(ii) Arithmetic/computation method **(Best method)**
(iii) Graphical method

Note- $\boxed{\text{Contour interval} = \dfrac{25}{\text{No. of cm per km}}}$

Plane table-

Size of plane table- 60 cm × 50 cm, 75 cm × 60 cm, and 100 cm × 75 cm

■ **Method of orientation-**

(i) Trough compass/magnetic meridian method
(ii) Back sighting method

■ **Methods to solve three point problem-**

(i) Mechanical/Tracing paper method
(ii) Graphical/Bessel's method
(iii) Lehman's/Trial and error method

■ **Methods of Plane table survey-**

(i) Radiation method **(for small and open areas)**
(ii) Intersection method
(iii) Traversing method
(iv) Resection method

Transit Theodolite	Can be rotate (180°) about horizontal/trunnion axis in the vertical plane.
Swinging the theodolite	It is the process of turning the telescope in horizontal plane. **Right swing→** Telescope rotated in clockwise direction. **Left Swing-** Rotated Anticlockwise direction.
Face Right	Vertical circle of theodolite is on the right hand side of the surveyor.
Face left	vertical circle is in left hand side
Transiting	Operation of revolving the telescope by 180° about horizontal/trunion axis in the vertical plane.

Parallax-

- It is an error occurred when image formed by objective lense is not in the same plane with cross hair of telescope.

Elimination of parallax-

(i) By focusing of eye-piece
(ii) By focusing of objective lens

■ **Fundamental relation between axis of theodolite and test-**

Axis relation	Test
Horizontal axis should be perpendicular to vertical axis.	Spire test
Vertical axis should be perpendicular to axis of level tube	Plate level test
Line of collimation should be perpendicular to horizontal	Azimuth test
Axis of bubble tube should be parallel to line of collimation	Vertical arc index test

■ **Tacheometer-**

Multiplying constant $= \dfrac{f}{i} = 100$

Additive constant $= f + i = 0$

Techeometer Survey methods-

(i) Fixed hair or stadia method
(ii) Movable hair or substance tacheometer method
(iii) Tangential method.

• **Stadia Method-**

1. **Distance and elevation for staff vertical inclined sight-**

Horizontal distance,

$$\boxed{D = k.s\cos^2\theta + c\cos\theta}$$

Vertical intercept-

$$\boxed{V = k.s\frac{\sin 2\theta}{2} + c\sin\theta}$$

2. **Distance of Elevation formulae for staff normal.**

$$\boxed{D = (k.s + c)\cos\theta \pm r\sin\theta}$$

$$\begin{pmatrix} +, \text{Elevation Angle} \\ -, \text{Depression Angle} \end{pmatrix}$$

$$\boxed{V = (k.s. + c)\sin\theta}$$

3. **Distance elevation formulae for horizontal sight-**

$$\boxed{D = k.s. + c}$$

■ **Minor Survey instrument and their use-**

Instrument	Use
Abney level (use as clinometer)	Measurement of slope, vertical angle, tracing grade contour, setting of grade
Clinometer	Angle
Hand level	Locating a contour, preliminary survey
Pantagraph	Enlarge or reduce the map
Planimeter	To measure undulated area
Sextant	To measure horizontal and vertical angle

Scanned with CamScanner

Irrigation & Hydrology Engineering

Soil Water-

1. Capillary water
2. Hygroscopic water- Can not be remove easily from soil particles.
3. Gravitational water

Important formula-

$$\text{Available moisture for plant} = F.C. - \phi$$

ϕ = Permanent wilting point (P.W.P)

- **Field capacity-**

$$F.C. = \frac{\text{Weight of water stored in soil of unit area}}{\text{Weight of same soil of unit area}}$$

$$F.C. = \frac{\gamma_w . d_w}{\gamma_d} = \frac{n}{G}$$

Where

d_w = depth of water stored in root zone

γ_d = dry unit weight of soil

- **Available moisture depth to plant-**

$$d_w = \frac{\gamma_d . d}{\gamma_w}[F.C. - P.W.P.]$$

- **Readily available moisture depth to plant-**

$$d_w = \frac{\gamma_d . d}{\gamma_w}[F.C. - m_0]$$

m_0 = Readily available moisture content

Irrigation requirements of crop-

(1) Consumptive Irrigation requirement -

$$CIR = C_u - R_e$$

C_u = total consumptive use

R_e = effective rainfall

(2). Net Irrigation requirement -

$$N.I.R. = C.I.R. + L_e$$

$$= C_u - R_e + L_e$$

L_e = Leaching requirement

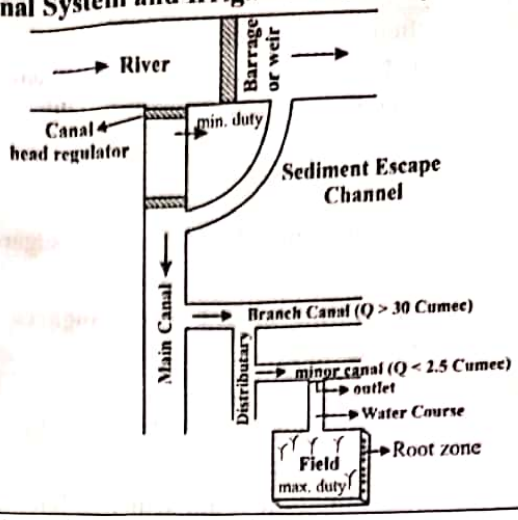
(3). Field Irrigation requirement -

$$F.I.R. = \frac{N.I.R}{\eta_a}$$

(4). Gross Irrigation requirement-

$$G.I.R. = \frac{F.I.R.}{\eta_c} = \frac{N.I.R}{\eta_a . \eta_c}$$

Canal System and Irrigation Efficiency-



(i) Water Conveyance Efficiency

$$\eta_c = \frac{W_f}{W_r} \times 100$$

Where W_f = water delivered to the field.

W_r = water delivered from the reservoir

(ii) Water Application Efficiency-

$$\eta_a = \frac{W_s}{W_f} \times 100$$

Where W_s = water stored in the root zone

(iii) Water Use Efficiency

$$\eta_u = \frac{W_u}{W_f}$$

Where W_u = water use consumptively

(iv) Water Storage Efficiency

$$\eta_s = \frac{W_{s'}}{W_\eta}$$

Where $W_{s'}$ = Actual water stored in the root zone.

W_η = Water needed to store to bring the water content up to field capacity.

(v) Water Distribution Efficiency

$$\eta_d = \left(1 - \frac{y}{d}\right) \times 100$$

Where y = Average numerical deviation in the depth of water stored from the average depth of irrigation stored.

d = Average depth during irrigation

(vi) Consumptive Use Efficiency-

$$\eta_{cu} = \frac{W_{cu}}{W_d} \times 100$$

Where W_{cu} =Water used by plant consumptively.

W_d = Net amount of water depleted from root zone

Scanned with CamScanner

■ **Duration of Indian crop season-**

Kharif	June - September (Mansoon crops)
Rabi	October - March
Zaid	April - June

Note-

- **Cash crop** - Cotton (8 month), Coffee, Tea, sugarcane, spices.
- **Perennial crop - (Time taken 1 year) - Sugarcane**

■ **Important terminology-**

Field capacity	• Maximum amount of moisture which can be held by soil against gravity. • Soil is not saturated but still a very wet condition
Permanent wilting point (PWP)	It is the state of soil when plants fail to extract sufficient water for their requirements.
Saturation capacity	It is the amount of water required to fill all the pore spaces between soil particles by replacing all air held in pore spaces.
Temporary wilting point	It is the phenomena that the soil water content at which the plant wilts at day time, but recovers during night or when water is added to soil.
Crop period	The total time period that elopes from the instant of its showing to the instant of its harvesting.
Base period (B)	Time between the first watering of a crop at the time of its sowing to its last watering before harvesting. **Note-** Base period < crop period
Paleo Irrigation	• It is the watering done prior to the sowing of a crop. • It is done to prepare the land for sowing and to add enough moisture to the soil. • It is the first watering given to the field.
Kore watering	• It is the first watering after the plants have grown a few centimeter high. • It is the first watering after sowing the crops. • Kore watering required max. discharge in limited time.
Kore depth	Depth of water applied during kore watering.
Outlet factor	It is the duty of canal water at the outlet.
Time factor	It is the ratio of number of days the canal has actually run to the number of days or irrigation period.
Capacity Factor	It is the ratio of mean supply discharge to the full supply discharge.
Crop Ratio	$= \frac{\text{Irrigated area of Rabi season}}{\text{Irrigated area of Kharif seasons}}$
Duty (D)	It represents the irrigating capacity of a unit water.
Delta (Δ)	It is total depth of water required for a crop during the entire period of the crop's

G.C.A = Culturable area + unculturable area

C.C.A = G.C.A. – unculturable area

G.C.A = Gross commanded area

Irrigated area = C.C.A × Irrigation Intensity

- **Relation b/w Duty and Delta-**

$$\Delta = \frac{8.64B}{D} m$$

B = base period in days

D = Duty in hectares/cumec

OR

$$D = \frac{864B}{D} cm$$

- **Kore depth-**

Rice	19 cm
Wheat	13.5 cm
Sugarcane	16 cm

■ **River training works-**

Aggrading River- This is because of silting

Degrading River- This is because of scouring

$$\text{Meandring Ratio} = \frac{\text{Meander belt}}{\text{Meander length}} = \frac{M_B}{M_L}$$

$$\text{Cut off Ratio / Tortusity} = \frac{\text{Curved length of cut off}}{\text{Straight length of cut off}}$$

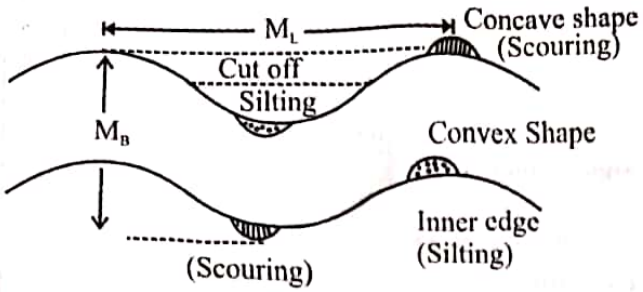
$1.7 \le C.O.R. \le 3.0$

Meander Length $M_L = 65.8\sqrt{Q_{dominant}}$

- **Dominant Discharge -**

$$Q_{dominant} = \frac{1}{2} \text{ or } \frac{2}{3} \text{ of } Q_{max} = \frac{9}{16}.Q_{max}$$

Scanned with CamScanner



Meandering River

■ **River Training-**

Type of river training	Training for	Example
Low	Depth	Navigation
Medium	Velocity	Silt control
High	Discharge	Flood control

■ **Design Parameter of lacey's theory-**

1. Velocity, $V = \left(\frac{Qf^2}{140}\right)^{1/6}$ V = Velocity in (m/sec.)

   Q = Discharge in cume (m^3/sec)

   Silt factor, $f = 1.76\sqrt{d_{mm}}$

2. Hydraulic mean depth, $R = \frac{5}{2}\left(\frac{V^2}{f}\right)$

3. Wetted perimeter, $P = 4.75\sqrt{Q}$

4. Scour depth, = $1.35\left(\frac{q^2}{f}\right)^{1/3}$

Note- According to Lacey's theory, eddies generate from canal bed and side both or total wetted perimeter.

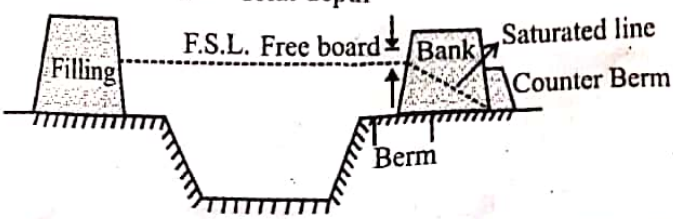
Lacey's Equation for regime flow, $V = 10.8R^{2/3}.s^{1/2}$

■ **Ideal shape of canal-**

- For lined canal - Trapezoidal
- For unlined canal or Alluvial soil - Semicircular
- Best section of canal, when it is in - Partially cutting and filling
- Kennedy's critical velocity, $V = 0.55\ MD^{0.64}$

  M = Critical velocity ratio

  D = Trial depth



■ **Cross drainage work and its Suitability**

Cross drainage work	Suitable for	Remark
Aqueduct	• HFL of drain is sufficiently below the bottom of the canal • Drainage water flows	FSL > CBL > HFL FSL- Full supply level CBL- Canal bed level
Syphon aqueduct	• HFL of drain is higher than canal bed • Water passes through aqueduct barrels under syphonic action	FSL > HFL > CBL HFL- High flood level
Super passage	• FSL of canal is sufficiently below the bottom of the drain trough • Canal water flows freely under gravity	HFL > DBL > FSL DBL- Drainage Bed level
Canal Syphon or syphon	• FSL of canal is sufficiently above the bed level of drainage trough • Canal flows under syphonic action under the trough	HFL > FSL> DBL
Level crossing	• Generally provided when a large canal and huge drainage (such as a stream or river) approach each other practically at the same level	

■ **Types of rain gauge-**

(1) Non recording rain gauge Symon's rain gauge (Extensively used in India)

Inlet dia of collector - 11.29 or 15.96 cm

Area - 100 cm^2 or 200 cm^2

Rainfall measurement - Per day 8: 30 AM.

(2) Recording type rain gauge

(i) Tipping bucket type

(cylinder dia 30 cm)

(ii) Weighing-bucket type

(It gives a plot of the accumulated rainfall against the elapsed time as mass curve of rainfall)

(iii) Float/ Natural syphon type

(Adopted as standard recording type rain gauge)

■ **Hyetograph-** It is a graphical representation of the relationship between the rainfall intensity and time.

- It is a bar diagram
- Derived from the mass curve
- Area under hyetograph represents the total rainfall occurred in that period.

Scanned with CamScanner

■ **Rainfall Intensity according to British Ministry of health formula-**

$$I = \frac{760}{t+10} \text{ (For storm duration 5 – 20 minute)}$$

$$I = \frac{1020}{t+20} \text{ (For storm duration 20 – 100 minute)}$$

■ **Instruments used in measurement**

Relative humidity	Psychomotor
Humidity	Hygrometer
Temp and Humidity	Thermohygrometer
Intensity of Radiation	Pyrheliometer
Wind speed	Anemometer
Rainfall depth	Ombrometer/Pluviometer
Transpiration	Phytometer
Evapotranspiration	Lysimeter
Evaporation	Atmometer
Hydraulic conductivity	Permeameter
Infiltration capacity	Rainfall simulator

■

Evaporation	A process by which water goes into the atomosphere from a water body.
Precipitation	Water reaches to the earth surface from the atmosphere.
Transpiration	Water goes into atomosphere from the body of the plant
Run-off	Water flows on earth surface under gravity action

Forms of Precipitation-

Rain	Droplet size is 0.5–6 mm
Drizzle	• Droplet size < 0.5 mm • Rainfall intensity < 1 mm/hr
Hail	Lumps of ice size > 8 mm
Snow	Density = 0.1 gm /cc

Note- Annual average rainfall in India is 1.20 m

• **Aridity Index** $AI = \frac{PET - AET}{PET} \times 100$

PET→ Potential Evapotranspiration

AET→ Actual Evapotranspiration

Note- (Used for measure Agricultural drought)

% Value	Types Arid region
0–25%	Mild
25–50%	Moderate
> 50%	Severe/High

• **Run off co-efficient-** $k = \frac{\text{Run off}}{\text{Rain fall}}$

k = 0.46 in India

Hyetograph	It is a graph b/w rainfall intensity v/s time interval
Mass curve	Graph b/w Accumulated rainfall v/s time
Double mass curve	To check and correct Inconsistency of rainfall data

■ **Calculation of Average rainfall depth-**

(i) Arithmetic mean method	Less accurate but quick method
(ii) Thiessen polygon method	More accurate than arithmetic mean method
(iii) Isohytel method	Most accurate

• **Depth Area duration curve-**

$$\bar{P} = p_0 e^{-KA^n}$$

$\bar{P}$ = Average depth

p_0 = Highest storm at storm centre

⇒ Depth ↓ with ↑ Area

Pan coefficient - Used for calculating lake evaporation

Lake evaporation = Pan coefficent × Pan evaporation

Types of pan	Pan coefficient
Class A evaporation pan	0.70
ISI pan (modified class A)	0.80
Colarado sunken pan	0.78
USGS floating pan	0.80

■ **Evapotranspiration measurement method-**

A. Penman's Equation- Based upon energy balance and mass transfer

B. Blaney Criddle method- Mayar's equation measured Evaporation

Infiltration index- Average infiltration rate is called infiltration index. It is two types

(i) ϕ- Index- It is the average rainfall above which rainfall volume = Run off volume

• ϕ - Index derived from rainfall Hyetograph

$$\phi\text{-Index} = \frac{P-Q}{t} \text{ cm/hr}$$

P = Total rainfall depth

Q = Total run off depth

t = Rain fall duration

2. W- Index- This is average infiltration rate during the time if, Rainfall Intensity > Infiltration Rate

• w - Index is more accurate than ϕ-Index

$$w - \text{Index} = \frac{P - Q - I_L}{t_w} \text{ cm/hr}$$

Note- $\phi - \text{Index} \geq w - \text{index}$

if $\phi - \text{index} = w - \text{index}$

Same then, initial losses

Rainfall duration = Whole storm period.

Scanned with CamScanner