AIR-1 Notes

Pages: 90

PERT & CPM

Handwritten notes by

Kartikay Kaushik

AIR-1 ESE 2021

IES Master classroom Student

PERT AND CPM

CONTENT

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PERT - CPM {rated as the most ~~profitable topic~~}

→ Part of PTE and MCE + Also part of GATE
{10-12 ques/150}

→ Helps in "Project Management" - topic of GS paper.
{4-5 ques/100}

Sub-Topics

1. Project Management
2. Fundamentals of Network
3. PERT
4. CPM
5. Crashing
6. AON diagram
7. Resource Allocation
8. Updating
9. Engineering Economy }
10. Construction Equipments } → Pure Theory

1. Project Management {Initiation: Defining the objective of the project}

→ Every project has a definite start and end time {temporary nature}

→ Output of project → Product
→ Service
→ Result

→ Every project is unique in nature.

PMI (Project Management Institute)
⇓
PMBOK (Book of knowledge)

→ Project is a temporary endeavour undertaken to provide a unique product, service and result.

→ A project involves series of activities that consumes resources to achieve specific objectives.

Objectives of Project

1. Project should be completed in optimum amount of time.
2. Project should use locally available manpower and resources.
3. Project should finish on time with minimum investment cost.

Project Management →

→ Project Management is application of knowledge, skill, tools and techniques to meet requirements of project.

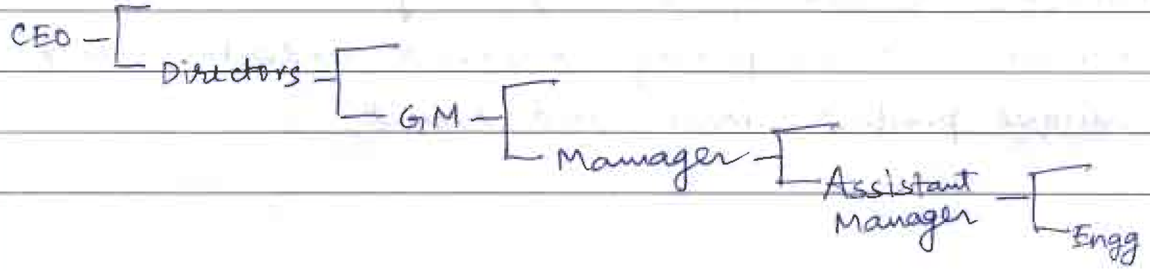
Elements of Project Management

1. Planning: Planning is one of the most important part of project management. Planning means defining objectives of project, to identify various activities and resource required for timely completion of project.

WBS – Work Breakdown Structure

→ we can identify all the activities which are required for completion of the project.

OBS – Organizational Breakdown Structure.



→ Merge the WBS and OBS in order to assign roles and responsibilitie

→ In planning phase, a plan is made along with WBS and OBS. WBS and OBS identifies group of activities that is needed to achieve the completion of project and assigning roles and responsibilities to various people in the project.

2\. Scheduling → It is the process of fixing the order of all the activities and allocation of resources to these activities.

4 M's → Manpower
→ Machine
→ Material + Time and space are the resouces
→ Money.

3\. Controlling → Controlling is the process performed to observe execution of project such that potential problems can be identified in a timely manner and necessary action can be taken.

→ During this process, project performance is regularly monitored and measured to identify deviation b/w plan & Execution.

NOTE:
Planning and Scheduling are done before execution of project whereas controlling is generally done during the execution of project.

4\. Directing: It is a function of the project leader to give instruction to sub-ordinates, supervise their work and respond to reports of sub-ordinates.

5. Coordination: Process of interaction between various departments of project.

6. Organising: It is integration of resources.

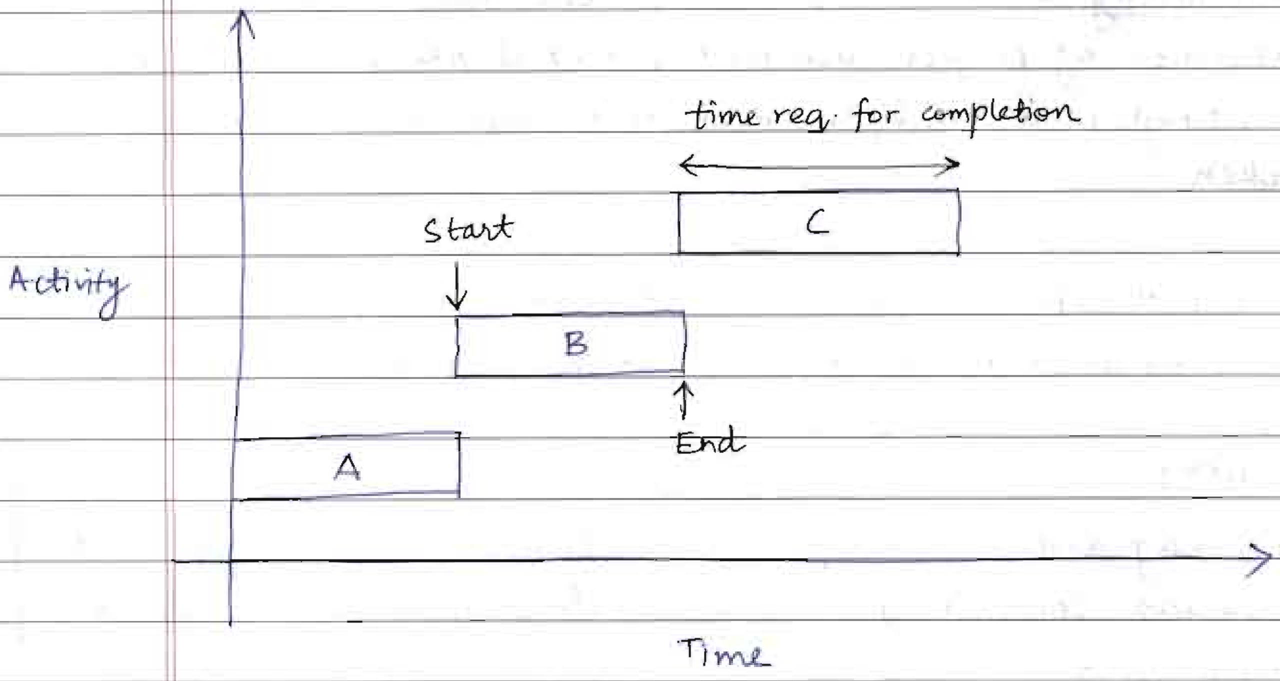
⇒ Methods of Project Scheduling

① Bar Chart (Gantt Chart)

Henry Gantt, 1900AD

→ It was introduced by Henry Gantt around 1900 AD.

→ Bar chart is a graphical representation between activity and time.



→ Beginning of bar → Start of activity

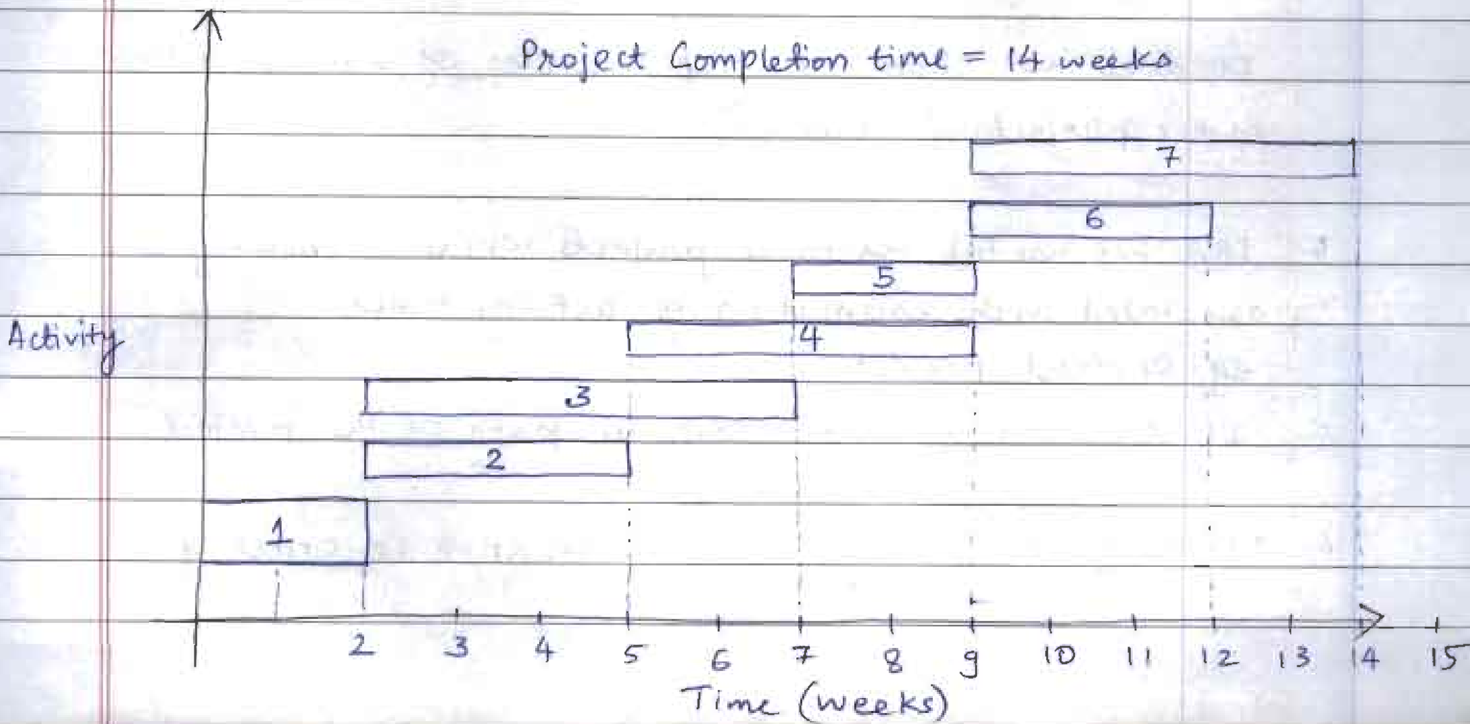
→ End of bar → finish of activity

→ Length of bar → time required for the completion of activity.

Q- For a construction project, certain activities are to be performed, which are as given below:

Activity	Duration (weeks)
1	2
2	3
3	5
4	4
5	2
6	3
7	5

Activity 2 and 3 can be perfomed simultaneously and can start only when activity 1 is completed. Activity 4 can start only after activity 2 ends. Activity 5 cannot begin until activities 2 and 3 are completed. Activity 6 can start only after 4 & 5 are completed. Activity 7 is the last activity and can start only after completion of Activity 5.
Draw a bar chart and determine project completion time.



Advantages of Bar chart

1. Simple to draw and easy to understand.
2. No skilled person is required.
3. It can be used for determining resource required at any stage of project. Hence, progressive cost of project can also be determined.
4. Project progress can be expressed in terms of percentage
   ↳ called a modified bar chart

Limitations of Bar chart

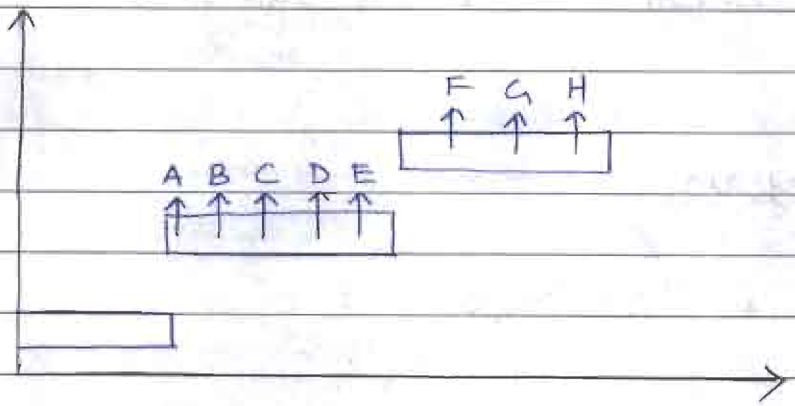
1. Lack of degree of detail
   → In case of big projects, only major activities can be shown otherwise it will become over crowded and clumsy.
   → Hence, bar chart is not preferred for big projects.
2. Review of project progress
   A bar chart does not show progress of work. Hence, it cannot be used as a control device. As progress made at A particular instant of time is required for control of project.

3. It does not show interdependencies of various activities of the project. (not clear)

4. It is not useful for those projects where uncertainty is associated with estimation of activity times.
   eg. Research project
5. It does not indicate critical path in the project.

6. It does not allow cost optimization i.e. Crashing.

② Milestone chart (Modified version of bar chart)



→ It is an improvement over original bar chart.

→ In any activity, there are certain key events which are to be carried out for the completion of activity. Such key events are called as milestones.

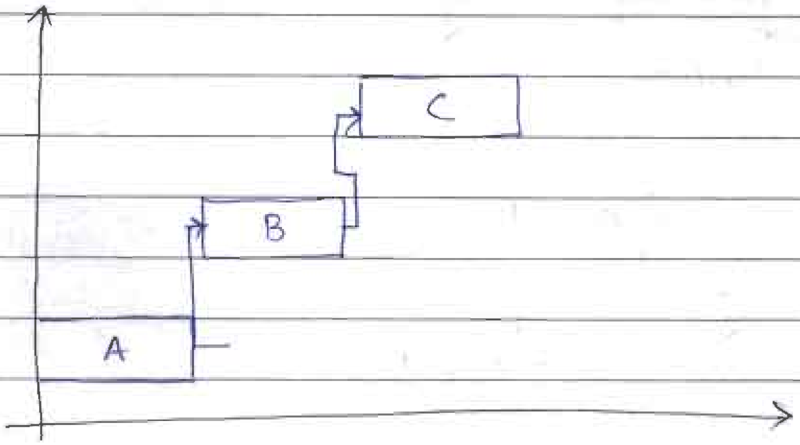
→ Milestones can be represented by →, ☐ or ○

→ If a particular activity is very long, then details of sub-activities will be lacking. which can be shown with the help of milestones. Hence, it provides better controlling in the project.

Limitation of milestone chart

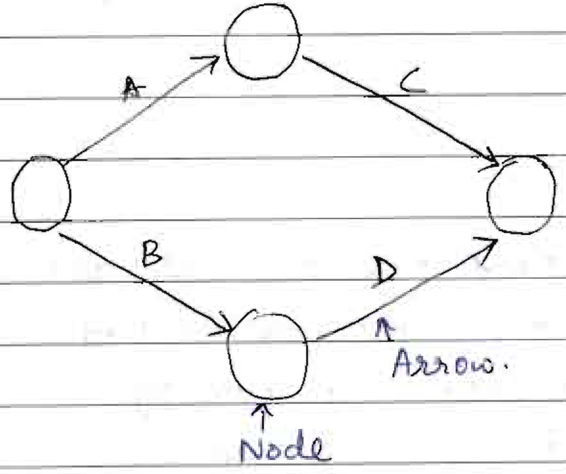
1. Relationship between sub-activities of an activity is clear but inter-relationship between various other activities is not clear.

③ Linked Bar chart



→ An improvement over Bar chart and milestone chart
Activities are linked with arrows and lines.

4. Network Diagram

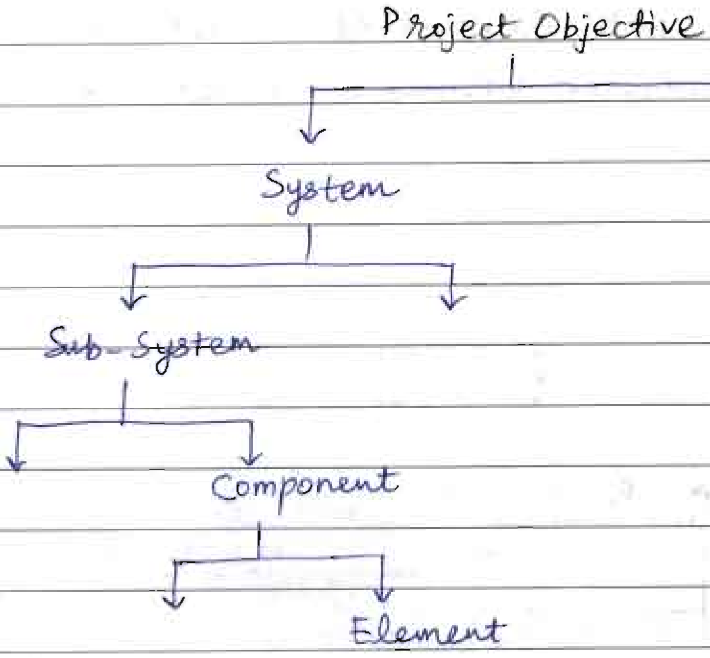


→ Network diagram is a graphical representation of logical sequence of activities

→ It is of 2 types:

1. A-O-A : Activity over Arrow
2. A-O-N : Activity over Node

→ Work Breakdown Structure (WBS)



→ Work breakdown Structure (WBS) is a graphical representation of functional elements of entire project. It follows top to bottom approach.

→ It is a process of breaking a complex project into system, sub-system, component and element.

→ It helps in :

a) Determining what work needs to be done.
b) Accountability & responsibility of project team.
c) Ground-work for estimation of time and cost.

NOTE:
Functional Organization system of working was introduced by F.W. Taylor.

2. Fundamentals of Network

→ **Definition of Network Diagram**

Network diagram is a graphical representation of arrow and nodes indicating their Logical Sequence.

→ **Types of Network**

(a) A-O-A : Activity over Arrow / Arrow Diagram
Activities are represented by arrows and nodes represent events.

(b) A-O-N : Activity over Node / Precedence diagram.
Activities are represented by nodes and their precedence relationship (inter relationship) with arrows.

→ **Basic definition**

1. Activity

→ An activity is a task or job that consumes resource and time.
→ It has definite starting point and end point.
→ It is represented by:

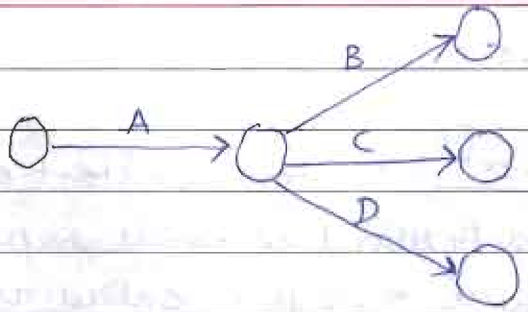
$$\xrightarrow[\text{Time}]{\text{Description}}$$

→ Length, shape and orientation of arrow has no significance.

→ Types of Activities

(a) Parallel Activities / Concurrent activities

These can be performed simultaneously and are independent of each other.



(b) Serial activities

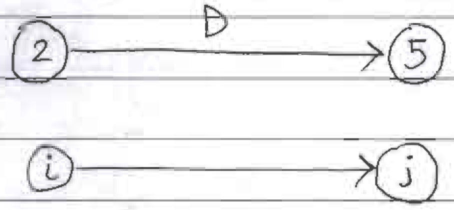
These activities can be performed one after another.

2. Event

→ Event is an instant of time in the project at which something specific / significant is achieved i.e. start of activities or completion of activities.

→ Events do not consume resource and time.

→ Events can be represented by nodes, shape of node can be any regular geometrical figure such as ○, ▭, ⬯, □
↓
generally used



NOTE:

→ Events are numbered for their identification.

→ Activities are also named using terminal nodes.
eg. Activity D is 25

→ A general and most usual convention shown for any activity is ij.

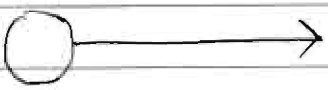
→ Types of Event

(a) Tail Event : It signifies start of an activity.

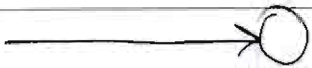
→ If a particular tail event represents start of the project, then it is called as initial event.

(b) Head Event : It signifies compeltion of an activity.

→ If a particular head event represents completion of the project, then it is called as final/end event.



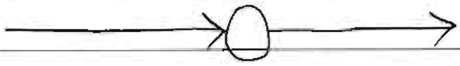
Tail Event



Head event

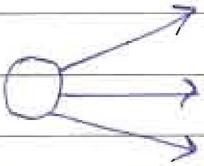
(c) Dual role events : These events are tail event for some activities and head event for other activities

→ All the events other than initial & final events are Dual role events.



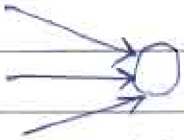
NOTE:

→ Burst Events



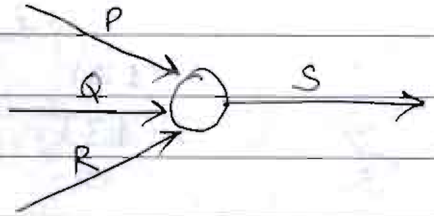
when more than 1 activity is coming out from a node.

→ Merge Events



when more than one activity entering into a node.

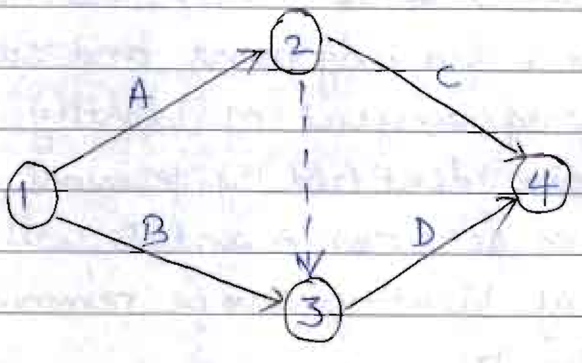
→ Interface Event



→ An interface event is a common event which shows linkage between activities performed by ~~one or~~ more than 1 agents / agencies.

→ It may also denote linkage between 2 or more sub-projects.

3. Dummy Activity / zero time activity



→ Here Dummy 2 3 represen that activity D depends on A and B.

→ Dummy is an artificial activity which neither consumes any resource nor time.

→ Dummy is used to show inter-relationship of activities.

→ Since Dummy is not an activity, it is not represented by arrow. Rather, it is represented by dotted arrow.

→ Dummy is identified by terminal nodes.

→ Dummy are used to keep logical sequence and inter-relationship of activities correct.

→ Use of Dummies

(a) Grammatical purpose

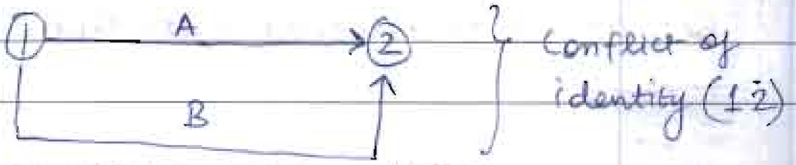


Fig (a): Wrong representation

AIR-1 Notes

Pages: 448

Environmental Engineering

Handwritten notes by

Kartikay Kaushik

AIR-1 ESE 2021

IES Master classroom Student

Environmental Engineering

① Water Supply and Treatment → (a) Source
*(b) Quality Parameter
*(c) Treatment
(d) Distribution
} 40%

② Sewage Treatment → (a) Sewage collection
*(b) Characteristics
*(c) Treatment
(d) Disposal.
} 55%

③ Air Pollution
④ Solid waste
⑤ Noise Pollution
} 5%

Ch-① Water Supply & Treatment

Q- A ~~Scientif~~ synthetic sample of water is prepared by adding 100 mg of Kaolinite, 200 mg glucose, 168 mg of NaCl, 120 mg of $MgSO_4$ and 111 mg of $CaCl_2$ to 1 litre of pure water. Find the concentration of Total solids and Fixed Dissolved solids in mg/L
↓
Inorganic Dissolved solids.

Total solids = 100 + 200 + 168 + 120 + 111 = 699 mg/L

Kaolinite → Inorganic SS
Glucose → Organic Dissolved
NaCl
$MgSO_4$
$CaCl_2$
} Inorganic Dissolved

So, Fixed Dissolved Solids = 168 + 120 + 111 = 399 mg/L

→ Molecular weight	→ Equivalent wt
→ $CaCO_3 = 100$	→ $CaCO_3 = 100/2 = 50$
→ $Ca^{2+} = 40$	→ $Ca^{2+} = 40/2 = 20$
→ $Al^{2+} = 27$	→ $Mg^{2+} = 24/2 = 12$
→ $Mg^{3+} = 24$	→ $Al^{3+} = 27/3 = 9$
→ $Al_2(SO_4)_3 \cdot 18H_2O = 666$	→ $Al_2(SO_4)_3 \cdot 18H_2O = 666/6 = 111$
→ $OH^- = 17$	→ $OH^- = 17$
→ $CO_3^{2-} = 60$	→ $CO_3^{2-} = 30$
→ $HCO_3^- = 61$	→ $HCO_3^- = 61$

→ $\text{Moles} = \dfrac{\text{Weight in gram}}{\text{Molecular weight}}$

→ $\text{Milli moles} = \dfrac{\text{Weight in mg}}{\text{molecular weight}}$

→ $\text{No of gram equivalent} = \dfrac{\text{Weight in grams}}{\text{Equivalent weight}}$

→ $\text{Milli eq} = \dfrac{\text{Weight in mg}}{\text{Equivalent wt}}$

→ No. of gram eq = No of moles x Valency.

Valency = 6 Valency = 2 Valency = 2 Valency = 3

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \longrightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2$$

1 mole 3 mole 3 mole 2 mole

↓ ↓ ↓ ↓

6 g-eq 6 gm-eq → 6 gm-eq 6 gm eq

$$\boxed{\text{1 gm-eq of Anything} \equiv \text{1 gm-eq of any other thing}}$$

$$\boxed{333 \text{ gm of } Al_2(SO_4)_3 \cdot 18H_2O \equiv 150 \text{ gm of } CaCO_3}$$

→ Normality : N = No of gm-eqs / litres

→ Molarity : M = No. of moles / Litres

→ 1 mL of 0.02 N H_2SO_4 ≡ 1 mg of $CaCO_3$.

⇒ Chemical Kinetics

depends on temperature

mole/Litre

→ $HOCl \rightleftharpoons H^+ + OCl^-$ ⇒ $K = \frac{[H^+][OCl^-]}{[HOCl]}$

K ↓ Reaction constant

1	0	0
$1-x$	x	x

→ $K = \frac{x^2}{1-x}$

⇒ Alkalinity

Q- A water sample contains 100 mg/L of CO_3^{2-} and 75 mg/L of HCO_3^{-} at a pH of 10. Calculate alkalinity exactly at 25°C and approximate the alkalinity by ignoring $[H^+]$ and $[OH^-]$

pH = 10 ⇒ $[H^+] = 10^{-10}$ mol / litre ≡ 10^{-7} meq/L as $CaCO_3$ ≡ 5×10^{-6} mg/L as CaCO₃

pOH = 4 ⇒ $[OH^-] = 10^{-4}$ mol / litre ≡ 10^{-4} gm-eq / litre = 0.1 meq/Litre
≡ 0.1 meq/l as $CaCO_3$
≡ 5 mg/L as $CaCO_3$

So, Exact Alkalinity = $\frac{100}{30} \times 50 + \frac{75}{61} \times 50 + 5 \mp 5 \times 10^{-6} \simeq 233.142$ mg/L as $CaCO_3$

Approximate Alkalinity = $\frac{100}{30} \times 50 + \frac{75}{61} \times 50 + 5 = 233.142$ mg/L as $CaCO_3$

After neglecting $[H^+]$ and $[OH^-]$ = 228.142 mg/L as $CaCO_3$.

Q. A 200mL sample of water has initial pH = 10. 11 mL of 0.02 N H_2SO_4 is required to reduce the pH to 8.3. and 30mL of 0.02 N H_2SO_4 is required to titrate the sample to pH of 4.5. Find out the total alkalinity of water in mg/L as $CaCO_3$ and also find the alkalinity species.

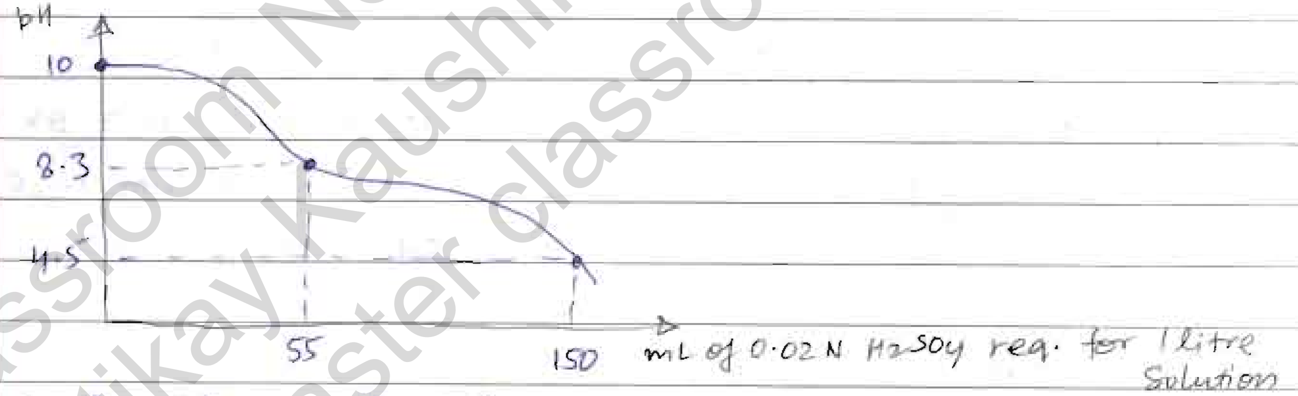
→ $pH = 10 \Rightarrow [OH^-] = 10^{-4} \frac{mol}{litre} \equiv 5\ mg/L$ as $CaCO_3$
↳ Caustic Alkalinity.

→ $[OH^-] + \frac{1}{2}[CO_3^{2-}] = \frac{11\ mg}{200mL}$ as $CaCO_3$ $= 55\ mg/L$ as $CaCO_3$

$\Rightarrow [CO_3^{2-}] = (55 - 5) \times 2 = 100\ mg/L$ as $CaCO_3$
↳ Carbonate Alkalinity

$\Rightarrow [HCO_3^-] = \underset{\text{Total Alkalinity}}{150} - 5 - 100 = 45\ mg/L$ as $CaCO_3$.
↳ Bicarbonate Alkalinity.

Approximate Approach

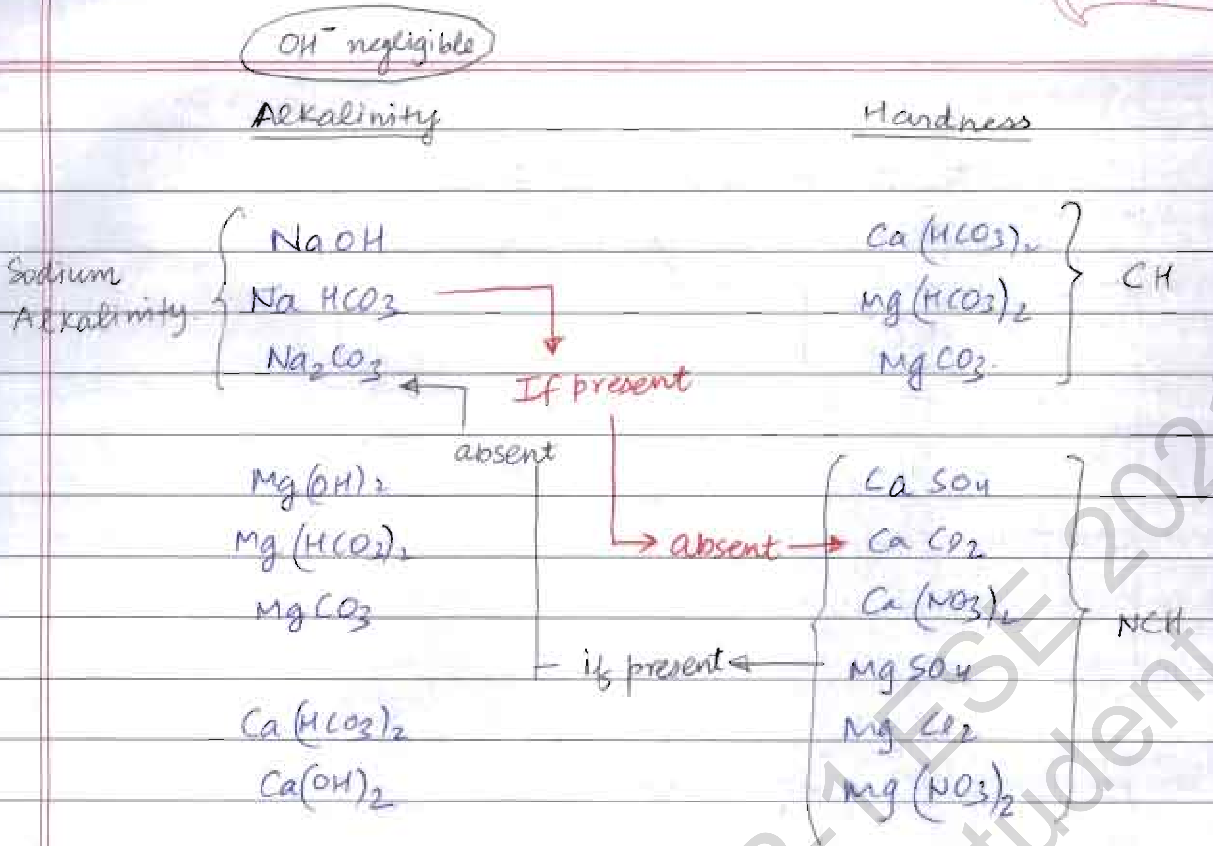


∴ $[HCO_3^-]$ and $[CO_3^{2-}]$ are the predominant species

$\Rightarrow [OH^-] = 0$

$\Rightarrow \frac{1}{2}[CO_3^{2-}] = 55 \Rightarrow [CO_3^{2-}] = 110\ mg/L$ as $CaCO_3$

$\Rightarrow 55 + [HCO_3^-] = 150 - 55 \Rightarrow [HCO_3^-] = 40\ mg/L$ as $CaCO_3$.



$CH = \min\{TH, \text{Alkalinity}\}$

$NCH = [TH - \text{Alkalinity}]$, take zero if −ve

⇒ Hardness

Q. Water contains the following dissolved ions: $[Na^+] \rightarrow 56$ mg/L, $[Ca^{2+}] = 40$ mg/L, $[Mg^{2+}] \rightarrow 30$ mg/L, $[Al^{3+}] \rightarrow 3$ mg/L and $[HCO_3^-] = 190$ mg/L, $[Cl^-] = 165$ mg/L and pH=7.
Find TH, Alkalinity, CH and NCH.

→ $\text{Alkalinity} = \frac{190}{61} \times 50 = 155.74$ mg/L as $CaCO_3$

* at pH=7, majority of alkalinity causing species are in the form of HCO_3^-

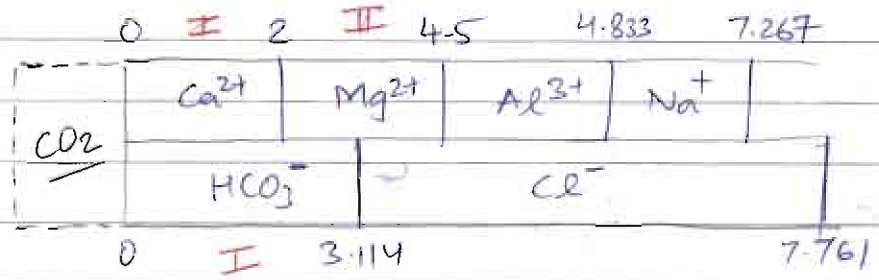
→ $TH = 50 \times \left(\frac{40}{20} + \frac{30}{12} + \frac{3}{9}\right) = 4.833 \times 50 = 241.67$ mg/L as $CaCO_3$

→ $CH = \min\{TH, \text{alkalinity}\} = 155.74$ mg/L as $CaCO_3$

$NCH = TH - \text{Alkalinity} = 241.67 - 155.74 = 85.93$ mg/L

↓
NCH is present
Hence, Na-Alkalinity is absent
So, Na will not combine with $[HCO_3^-]$ present

⇒ Bar chart



⇒ MPN

Q- Multiple Tube Fermentation Test was conducted on a sample of water and the result of analysis for confirmed test are as given below:

Sample size	No. of Positive results out of 5-tubes
1 mL	4
0.1 mL	3
0.01 mL	1

MPN / 100 mL can be obtained from the following chart:

for 10 mL, 1 mL and 0.1 mL

Combination of positive	MPN / 100 mL
4-2-1	26
4-3-1	33
2-1-0	7

Ans → 33 × 10 = 330

So MPN = 330 / 100 mL

Q-

Sample size	No. of +ve result
10 mL	4
1 mL	2
0.1 mL	1
0.01 mL	0

⇒ None of the dilutions have all 5 +ve

⇒ Select least diluted with middle result +ve.

⇒ MPN = 26 / 100 mL

Q⇒ Water sample having particle distribution as shown below:

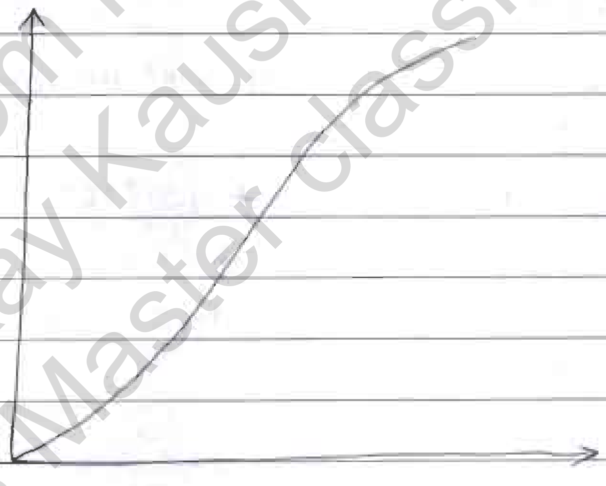
Size	Quantity	Settling velocity in m/s	fraction removed
0.1 mm	10%	0.2	4/7
0.2 mm	20%	0.25	5/7
0.3 mm	15%	0.3	6/7
0.4 mm	5%	0.35	1
0.5 mm	30%	0.40	1
0.6 mm	20%	0.5	1

→ Overflow rate of tank is 0.35 mm/s. Find the efficiency of the tank.

$$\eta = \frac{\frac{4}{7} \times 0.1 + \frac{5}{7} \times 0.2 + \frac{6}{7} \times 0.15 + 0.55}{1}$$

$$= 0.8786 \Rightarrow 87.86\%$$

⇒ For continuous distribution of particles,



Q- Determine the overall removal for a sedimentation tank having the following data:

Particle size	Wt fraction greater in size	% removal	% finer
0.1 mm	0.1	100	0.9
0.08 mm	0.15	100	0.85
0.07 mm	0.40	100	0.60
0.06 mm	0.7	100	0.30
0.0597mm		100	0.2965
0.04 mm	0.93	44.87	0.07
0.02 mm	0.99	11.22	0.01
0.01 mm	1.00	2.80	0

Overflow rate = 32.6 ~~litre~~ m/day Gs of particles = 1.2

Dynamic viscosity = 1.027 centiPoise , $\rho_w = 0.997 g/cm^3$

Use stoke's law to find out the settling velocity.

Find out the overall efficiency

$$v_s = \frac{(\gamma_s - \gamma_w) d^2}{18\mu} = \frac{\gamma_w (G_s - 1) d^2}{18\mu}$$

For $v_s' = 32.6$ m/day

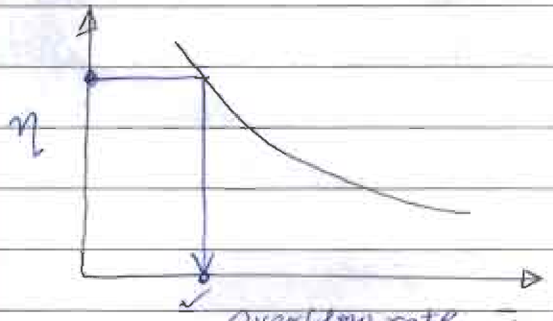
$d = 0.0597$ mm

So particles of size > 0.0597 mm will be removed completely

$$\text{Removal Efficiency} = \left[(1 - 0.2965) + (0.2265 \times 0.7244) + (0.06 \times 0.2804) + (0.01 \times 0.0701) \right] \times 100\%$$

$= 88.51\%$

⇒ Design of settling tank



Overflow rate $= \frac{Q}{LB} = \frac{\text{Discharge}}{\text{Plan Area}}$

① $\frac{Q_{design}}{\text{Overflow rate}} = \frac{1.8\ Q_{avg}}{\text{Overflow rate}} = \text{Plan Area} < \begin{matrix} L \times B \\ \frac{\pi D^2}{4} \end{matrix}$

② Adopt L/B ratio ⇒

③ Find L, B.

④ Take $t_d = \frac{LBH}{Q_{design}}$ ⇒ Find H

⇒ For circular tanks, weir loading rate can also govern the Diameter of tank as $\boxed{\pi D = \frac{\text{Discharge}}{\text{weir loading rate}}}$

⇒ Coagulation

Q. A water treatment plant treating 10 MLD of water requires 20 mg/L of filter Alum ($Al_2(SO_4)_3 \cdot 18H_2O$). The water has 6 mg/L of alkalinity as $CaCO_3$. Find the total Alkalinity requirement in kg/day matching the filter alum as $CaCO_3$.
Also calculate the quantity of quick lime required in kg/year.

Total alkalinity requirement $= \frac{20}{111}$ meq/L

$= \frac{20}{111} \times 50 \frac{mg}{L} = 90.09$ kg/day as $CaCO_3$.

Alkalinity present $= \frac{6}{50}$ meq/L

Alkalinity required $= \frac{20}{111} - \frac{6}{50} = \frac{167}{2775}$ meq/L $= \frac{167}{2775} \times 28 \frac{mg/L}{CaO}$

⇒ 6150.41 kg/year ~~⇒ 172211.6 kg/year~~

Q- A coagulation treatment plant with a flow of 0.5 m^3/s is ~~the~~ dozing alum at 23 mg/L and no other chemicals are being added Raw water Suspended solid concentration is 37 mg/L and effluent Suspended solid conc. is 12 mg/L. Sludge solid content is 1%. The specific gravity of sludge solid is 3.01. What volume of sludge must be disposed off every day.

→ SS conc in sludge = 37-12 = 25 mg/L

$$= 25 \times 0.5 \times 10^3 \times 86400 \times 10^{-6} = 1080 \frac{kg}{day}$$

→ Alum ppt in sludge = $\frac{23}{\cancel{111}} \times 0.234 \times 0.5 \times 10^3 \times 86400 \times 10^{-6}$

$$= 232.5 \frac{kg}{day}$$

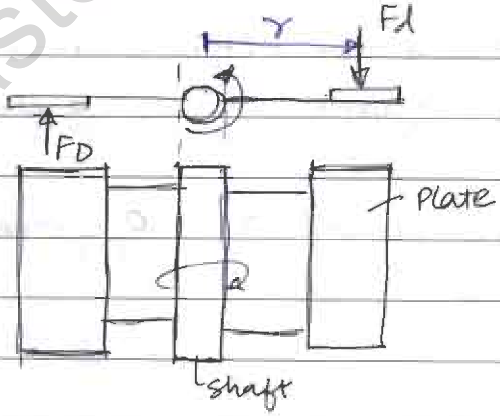
→ Total Solid in sludge = 1312.5 kg/day.

$$\frac{W_S}{W_w + W_S} = 0.01$$

$W_w = 129937.5/day$

So, V = 130.374 m^3/day

⇒ Calculation of G value



Q. A flocculation chamber is 30m long, 12 m wide and 4.5m deep is to treat 75 MLD of water. It is equipped with 12 m long, 0.3 m wide ~~panels~~ paddles supported parallel to and moved by 4 horizontal shafts which rotate at a speed of 25 rpm. The centre line of the paddle is 1.8m from the shaft which is at the mid depth of the tank. 2 Paddes are mounted on each shaft. If the mean velocity of water is $\frac{1}{4}^{th}$ of the velocity of pedal, find:

(a) Power consumption

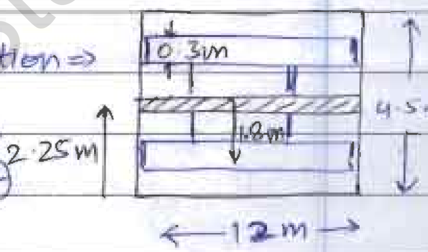
(b) Time of Flocculation

(c) G, temporal mean velocity gradient.

Take ~~μ~~ $= 1.31 \times 10^{-6}$ ~~kg~~ m^2/s and C_d for pedal $= 1.8$

$P = F_D \cdot V_r = \frac{1}{2} C_D \rho A V_r^3$ x-section ⇒

for 1 shaft



$= \frac{1}{2} \times 1.8 \times 1000 \times (2 \times 0.3 \times 12) \times (0.75 \times 0.4712)^3$

$= 286\ W$

$V_p = \omega r = 0.4712\ m/s$

(a) Power consumption $= 4 \times 286 = 1144\ W$

(b) Time of flocculation $= \frac{30 \times 12 \times 4.5}{75 \times 10^6 \times 10^{-3}} \times 86400 = 31.104$ min.

(c) $G = \sqrt{\frac{P}{\mu V}} = 23.22\ s^{-1}$

⇒ Backwashing

Say $Q_{avg} = 24 \times 10^5\ l/day$

→ if backwashing takes 30 min., backwashing is done everyday, and 5% of filtered water is used for backwashing.

$Q_{design} = \frac{1.8 \times 24 \times 10^5 + 0.05(24 \times 10^5)}{23.5}\ l/hr$

→ if backwashing is done after 48 hrs.

$$Q_{design} = \frac{(1.8 \times 48 \times 10^5) + 0.05\,(48 \times 10^5)}{47.5} \; l/hr$$

⇒ Design Steps

① $\frac{Q_{design}}{\text{Rate of filtration}}$ = Plan Area

↳ 2-20 m/hr = 2000 to 20000 l/hr/m² of plan Area

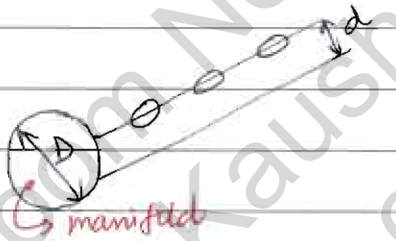
② $n = 1.22\sqrt{Q_{design}} + 1$

↳ Standby

③ Obtain size of 1 unit

④ $\frac{L}{B}$ = 1.25 to 1.33 and adopt depth b/w 3 to 4 m

⇒ Design of Under drainage system



To be determined:

① D
② d
③ hole size
④ hole spacing
⑤ no. of holes on each lateral drain.

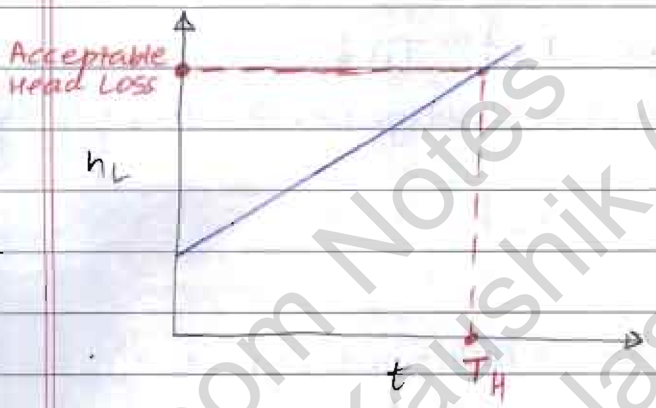
⇒ Sand incrustation means formation of hard coating on the surface of sand. It occurs due to deposition of sticky materials coming from the sedimentation tank in the form of precipitates which do not settle in the sedimentation tank. This will lead to increase in overall size of sand. Can be avoided by Carbonation (addition of CO_2) which dissolves ppts like $CaCO_3 \rightarrow Ca(HCO_3)_2$ and $Mg(OH)_2$ to $MgCO_3$. Done after sedimentation and before filtration. Sodium hexametaphosphate may be added to keep $CaCO_3$ in dissolved form.

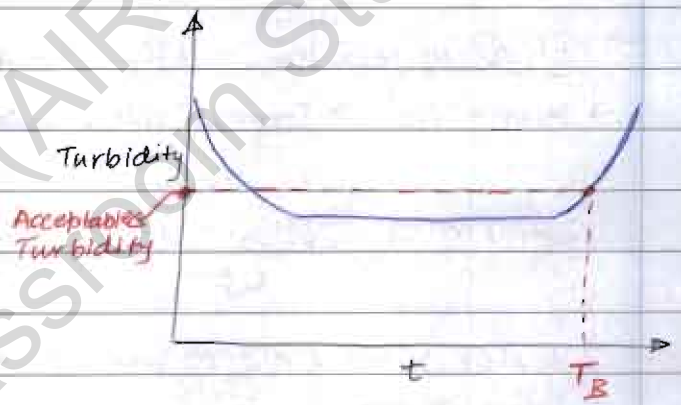
⇒ Bumping of filter → Due to blockage of the under-drainage perforations backwash application will be non-uniform and hence more water can be added at a particular location at high velocity which causes the sand in localised location to boil up and also gravel to rise to the surface.

To avoid it air scouring of the under-drain is done to open up the clogged perforations.

⇒ When to do Backwashing?

① Particle Breakthrough } in rapid sand filter
② Head Loss }





→ The time at which cleaning of filter should start = min { T_H , T_B }

→ As more impurities are trapped, resistance against motion increases and hence, head loss increases.

→ As more impurities are trapped, pore size decreases and velocity of flow through pores increases, thus shearing action increases and impurities trapped on sand grain may get dislodged and thus turbidity in effluent starts increasing.

⇒ Effect on T_B and T_H of various parameters in flow

① Effect of increase in filter depth $T_B \uparrow$, $T_H \downarrow$

Since more depth of sand is available, there is greater opportunity for particles to be attached to sand grains, $T_B \uparrow$

③ Since more depth of sand will lead to greater head loss → $T_H \downarrow$

② → Effect of increase in porosity $T_B \downarrow$ $T_H \uparrow$

→ There is lesser opportunity of contact with grains $T_B \downarrow$

→ There is lesser resistance against flow $T_H \uparrow$

③ Effect of increase in velocity of flow $T_B \downarrow$ $T_H \downarrow$

→ Increase in shearing action → $T_B \downarrow$

→ Greater loss at higher velocity → $T_H \downarrow$

④ Effect of increase in influent particle concentration $T_B \downarrow$ $T_H \downarrow$

→ Greater conc. of influent ⇒ early choking ⇒ increased velocity of flow

⑤ Effect of increase in floc strength $T_B \uparrow$ $T_H \downarrow$

→ Strong floc ⇒ Stronger attachment with sand grains ⇒ difficult to shear off

⑥ Effect of increase in collector dia $T_B \downarrow$ $T_H \uparrow$
(Bigger size of sand grain dia)

→ Lesser surface are of sand particles ⇒ lesser attachment → $T_B \downarrow$

→ Losses are less, pore size being larger ⇒ $T_H \uparrow$

⑦ Effect of Non-Addition of Coagulant $T_B \downarrow$ $T_H \uparrow$

→ Attachment with sand grain is not efficient due to lack of coagulation → $T_B \downarrow$

→ Lesser loss through filter media since impurity collection is less.

AIR-1 Notes
Pages: 258

Fluid Mechanics
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

FLUID MECHANICS

CONTENT

Fluid Mechanics

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② Fluid Statics
  - Fluid Pressure and its measurement
  - Hydrostatic forces on plane and curved surface
  - Liquid in relative equilibrium
  - Buoyancy and Floatation

③ Fluid kinematics

④ Fluid Dynamics
  - energy equations
  - momentum.

⑤ Flow measurement

⑥ Laminar Flow

⑦ Turbulent Flow

⑧ Boundary layer theory

⑨ Drag and lift

⑩ Model Analysis

⑪ Pipe flow.

Introduction

$\tau = G\gamma \rightarrow$ solids

$\tau \propto \frac{d\gamma}{dt} \Rightarrow \gamma = \tau t + c \rightarrow$ fluid.

① Substance in liquid or gaseous phase is referred to as fluid. They are capable of deforming continuously under the influence of shear stress, however small the shear stress might be.

② In solids $\boxed{\tau \propto \gamma}$ but in fluids $\boxed{\tau \propto \frac{d\gamma}{dt}}$

→ Study of fluid at rest Is called fluid statics.

→ Study of fluid in motion, when forces responsible for motion are not the point of concern then the study is called fluid kinematics.

→ Study of fluid in motion when forces responsible for motion are the point of concern is called fluid dynamics.

⇒ Continuum Approach

→ We, in fluid mechanics, generally assume that fluid is a continuous homogenous mass with no holes. Thus, at every point in the flow space, we can define the flow parameters like velocity, acceleration etc.

→ This assumption is called continuum approach.

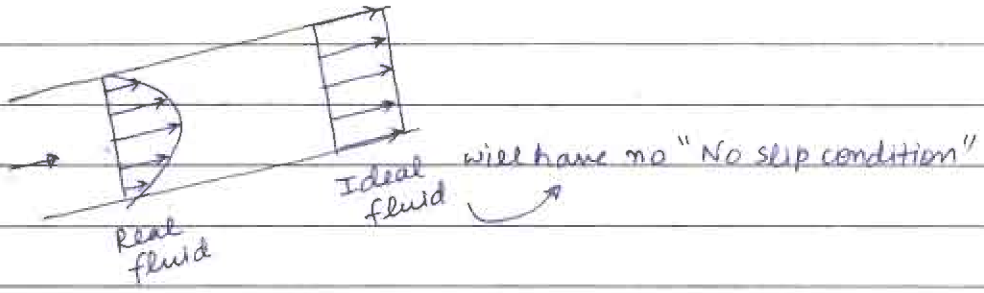
→ The continuum approach will not be applicable when the mean free path becomes large as compared to the characteristic dimensions of study. [alternate → Rarefied Gases Approach]

⇒ Ideal and Real Fluid

→ Fluid having no surface Tension, viscocity and which are incompressible are called ideal fluid.

→ There is no fluid as ideal fluid. It is just a theoretical conception.

⇒ No slip condition



→ A fluid having viscocity will be said to have no slip condition at the boundary of the solid surface i.e. the fluid molecule at the boundary will not move relative to the boundary surface.

→ Hence if boundary is stationary, fluid at the boundary will also be stationary and if boundary is moving, fluid at the boundary will also move with the same velocity in the same direction

NOTE: No wetting property is due to Surface Tension and not due to viscosity or no slip condition.

Properties of Fluid

⇒ Vapour pressure and cavitation

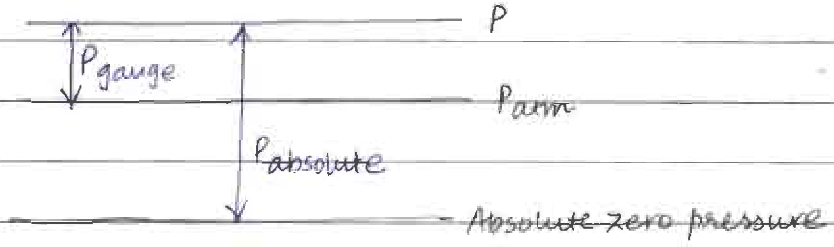
→ Saturation Vapour pressure is the pressure exerted by vapour molecules in phase equilibrium with it's liquid at a given temperature.

→ Saturation vapour pressure increases with increase in temperature and is independent of externally applied pressure.

→ whenever in a flow absolute pressure of flow exceeds the saturation vapour pressure the vapours and liquid will remain in dissolved form, however, if $P_{absolute} < P_{vap\ pressure}$, the dissolved gases and vapour will start coming out and will create cavity in the flow

→ These cavities move due to momentum of flowing fluid and when they go to high pressure zone, cavity collapses giving rize to noise, vibrations, surface pitting (erosion) and fatigue failure. This phenomenon is called cavitation.

→ It generally occurs at the inlet of pump, exit of reaction turbine, top of siphon and on the surface of spillway.



→ As the saturation vapour pressure increases with temperature, therefore chances of cavitation are more at higher temperature

→ Cavitation can be prevented by maintaining higher pressure in the flow and cavitation damage can be prevented by air entrainment.

→ Rise in Elevation, increase in velocity, decrease in atm pressure and increase in temperature will favour cavitation.

⇒ Bulk Modulus

$$\boxed{K = \frac{-dP}{\left(\frac{dV}{V}\right)}}$$

$$m = \rho V$$

$$dm = \rho dV + d\rho V = 0 \Rightarrow \boxed{\frac{-dV}{V} = \frac{d\rho}{\rho}}$$

$$K = \frac{dP}{\left(\frac{d\rho}{\rho}\right)} \Rightarrow \boxed{K = \rho \frac{dP}{d\rho}}$$

$$\boxed{\frac{1}{K} = \text{compressibility} = \frac{1}{\rho}\frac{d\rho}{dP}}$$

→ Ideal gas eq^n → $PV = nRT$ ⇒ $\boxed{P = \rho RT}$

→ Isothermal condition

$$dP = RT\,d\rho \Rightarrow \boxed{\frac{dP}{d\rho} = RT}$$

$$\text{So,} \quad K = \rho \frac{dP}{d\rho} \Rightarrow K = \rho RT$$

$$\Rightarrow \boxed{K_{Isothermal} = P}$$

→ Adiabatic condition

$$PV^{\gamma} = \text{constant}$$

$$\frac{P}{\rho^{\gamma}} = \text{constant}$$

$$P = c\rho^{\gamma}$$

$$\frac{dP}{d\rho} = c\gamma\rho^{\gamma-1} \Rightarrow \rho\frac{dP}{d\rho} = c\gamma\rho^{\gamma} = \gamma P$$

So, $\boxed{K_{adiabatic} = \gamma P}$ → adiabatic constant $= \frac{C_P}{C_V}$

C_P → specific capacity at constant pressure

C_V → specific capacity at const volume

Q- Density of sea water at free surface is 1030 Kg/m³ and atm. pressure is 98KPa. Bulk modulus of elasticity of sea water is 2.34×10^{9} N/m² (constant) and the variation of pressure with depth z is given by $\boxed{dP = \rho g dz}$ then determine the density and pressure at a depth of 2500 m.

$$K = \rho\frac{dP}{d\rho} \Rightarrow \boxed{dP = \frac{K d\rho}{\rho}} \Rightarrow \left[P\right]_{98000}^{P} = K\ln\left(\frac{1041.24}{1030}\right)$$

$P = \cancel{25487.21\text{KPa}}$ 25495.21 KPa

So, $K\frac{d\rho}{\rho_{\rho}} = \rho g dz$

$$K\int_{\cancel{90000}\,1030}\frac{d\rho}{\rho^{2}} = \cancel{\rho}\, g\int_{0}^{2500}dz$$

$$K\left[\frac{-1}{\rho}\right]_{\cancel{90000}\,1030}^{\rho} = g(2500)$$

P/7

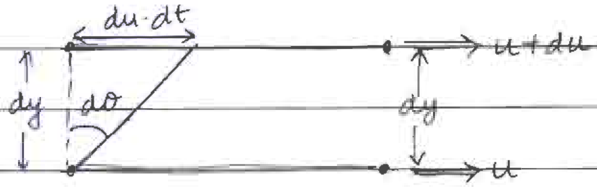
$$\frac{-1}{\rho} + \frac{1}{\cancel{90000}\,1030} = \frac{2500g}{2.34\times10^{9}}$$

⇑

$$\rho = \frac{1}{\frac{1}{\cancel{90000}\,1030} - \frac{2500g}{2.34\times10^{9}}} = 1041.24\ \text{kg/m}^3$$

⇒ Viscosity

→ Viscosity is a measure of resistance of fluid to deformation. It is due to the internal frictional forces that develop b/w different layers of fluid that are forced to move relative to each other.



$$d\theta = \frac{du\cdot dt}{dy} \Rightarrow \boxed{\underbrace{\frac{d\theta}{dt}}_{\text{Rate of shear strain}} = \underbrace{\frac{du}{dy}}_{\text{Velocity gradient}}}$$

→ Between the fluid layers, a shear stress develops due to resistance to movement. The fluid in which the shear stress developed is directly proportional to the rate of shear deformation is called Newtonian fluid

Hence, for Newtonian fluid ⇒ $\boxed{\tau \propto \frac{d\theta}{dt}}$

$$\Rightarrow \tau = \mu \frac{d\theta}{dt}$$

$$\Rightarrow \boxed{\tau = \mu \frac{du}{dy}}$$

→ μ is called the coefficient of viscosity or absolute viscosity or dynamic viscosity.

→ Unit of μ → $\frac{Ns}{m^2}$, $\frac{Kg}{m\cdot s}$, Pa·s, Poise $\boxed{10\ \text{Poise} = 1\ \frac{Ns}{m^2}}$

NOTE: Dynamic viscosity of water is approx. 50 times that of air.

Kinematic viscosity ⇒ $\boxed{\nu = \frac{\mu}{\rho}}$

Unit → m^2/s , stoke [1 stoke = 1 cm^2/s]

NOTE: Kinematic viscosity of air is approx. 15 times that of water.

⇒ Effect of temperature on viscosity

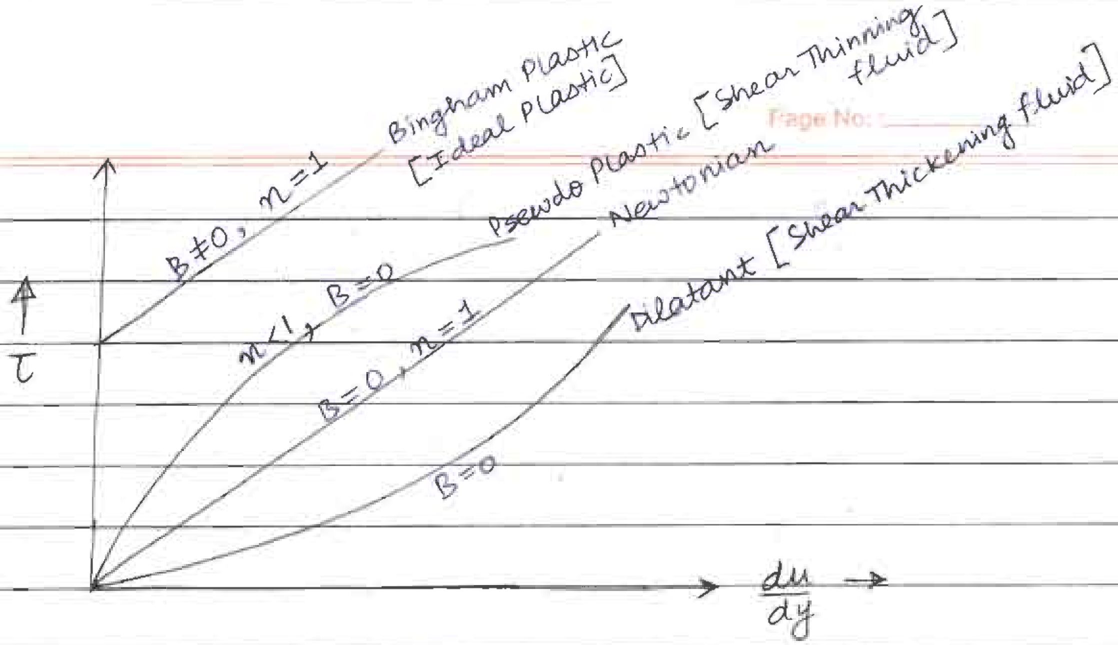
→ In case of liquids, cohesive force b/w the molecules cause viscosity. At higher temperature, molecules posses greater energy and hence can easily overcome the intermolecular cohesive forces, hence can move more freely, resistance to flow decreases.
Hence, for liquids, viscosity decreases with increase in temperature.

→ In case of gases, viscosity is caused by transfer of molecular momentum due to molecular collisions. Hence at higher temperature, since the no. of collisions per unit volume per unit time will be more, resistance to flow increases.
Hence, for gases, viscosity increases with increase in temperature.

→ For liquids, and gases, dynamic viscosity is independent of pressure.

⇒ Newtonian and Non-Newtonian fluid

$$\boxed{\tau = A\left(\frac{du}{dy}\right)^n + B}$$



$$\frac{d(\tau)}{d\left(\frac{du}{dy}\right)} = A n \left(\frac{du}{dy}\right)^{n-1}$$ ⇒ Apparent viscosity

[Apparent viscosity = Dynamic viscosity for Newtonian fluid]

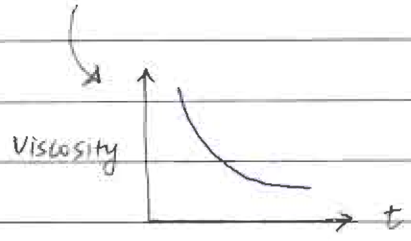
→ Newtonian → eg- Water, air, gasoline, alcohol.

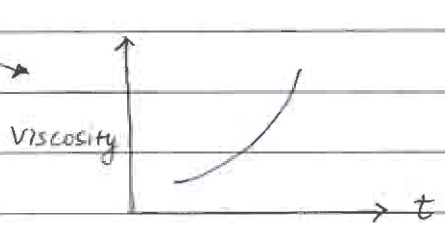
→ Dilatant → eg- solution with suspended starch or sand, sugar in water

→ Pseudo-Plastic → eg-Paints, polymer solution, blood, paper pulp, syrup, molasses, milk

→ Bingham Plastic → Bingham plastic fluid requires some minimum shear stress before they start moving called yielding.
Eg- Sewage sludge, ~~toothpaste,~~ drilling mud, mayonnaise.

⇒ Thixotropic and Rheopectic fluids have time dependent viscosity.





→ Printer's ink, certain paints and enamels, honey.

→ Gypsum paste, lubricants, synovial fluids.

→ Thixotropic fluids have time dependent pseudo plastic behaviour

→ Rheopectic fluids have time dependent dilatant behaviour.

→ Study of Non-newtonian fluids is called Rheology.

Q-

du/dy	0	0.5	1.1	1.8
τ	0	2	4	6

Identify the fluid.

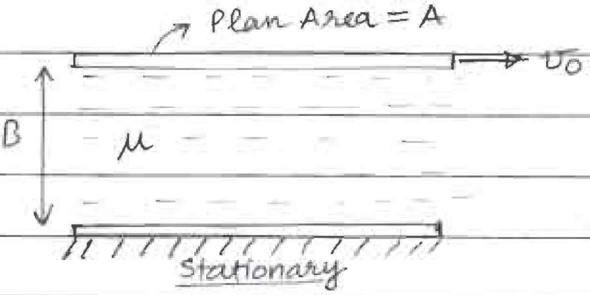
$d(du/dy)$	0.5	0.6	0.7
$d\tau$	2	2	2
Apparent viscosity	$\frac{2}{0.5}$	$\frac{2}{0.6}$	$\frac{2}{0.7}$

$\longrightarrow$ Apparent viscosity decreases as $\left(\frac{du}{dy}\right)$ increases.

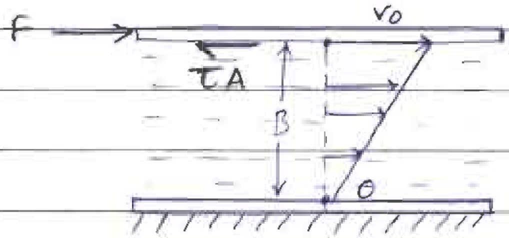
at $\tau=0$ the $\frac{du}{dy} = 0$ +

There fore, Pseudo plastic fluid.
↳ shear thinning fluid.

Q-



Find the force required to maintain the motion of top plate.

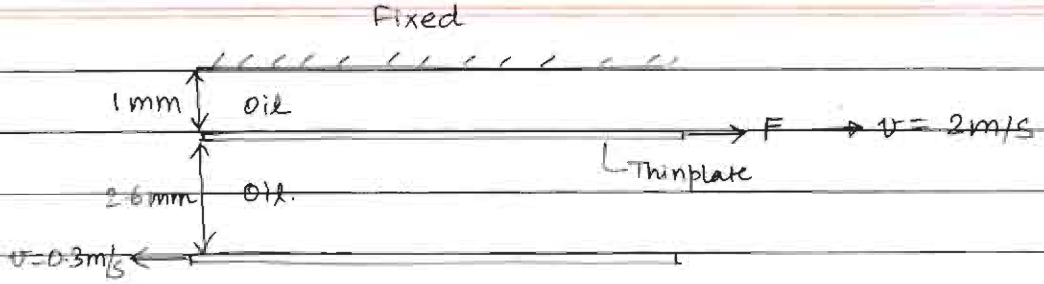


$$\frac{du}{dy} = \frac{v_0}{B}$$

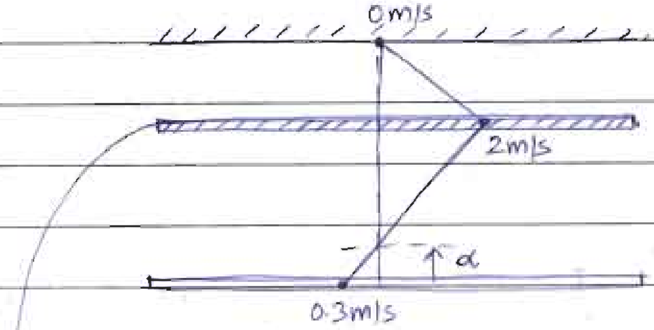
So, $\tau = \mu \frac{v_0}{B}$.

So, $\boxed{F = \tau A = \frac{\mu A v_0}{B}}$

Q-

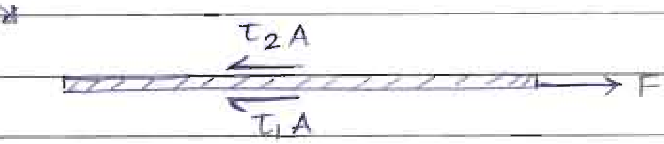


Thin plate has a plan Area of 40cm x 40cm
Assume the velocity in each oil layer to vary linearly.
Plot the velocity profiel and find the location where the velocity is zero. Also find the force that needs to be applied on the thin plate to maintain it's motion. Take $\mu = 0.027$ Pa.s.



$$\frac{0.3}{\alpha} = \frac{2}{2.6-\alpha} \Rightarrow 0.78 - 0.3\alpha = 2\alpha$$

$$\Rightarrow \alpha = \frac{0.78}{2.3} = 0.339 \text{ mm}$$



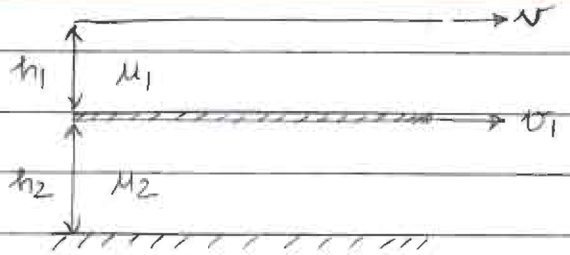
$$F = (\tau_1 + \tau_2)A$$

$$\text{Now, } \tau_1 = \mu\left(\frac{du}{dy}\right)_1 = \mu\frac{2.3}{2.6\times10^{-3}} = \frac{23\mu}{26\times10^{-3}} = \frac{23000\mu}{26}$$

$$\tau_2 = \mu\left(\frac{du}{dy}\right)_2 = \mu\frac{2}{1\times10^{-3}} = 2000\mu$$

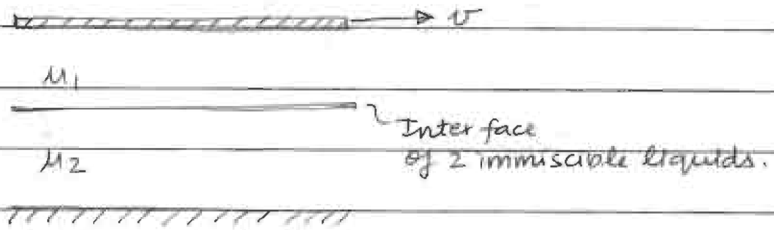
$$F = \left(2000\mu + \frac{23000\mu}{26}\right)\frac{40\times40}{10^4} = 12.46\text{N}$$

Q-



The top plate is being pulled with velocity v and the middle plate moves due to the pulling of upper plate with a uniform velocity v_1 $(v_1 < v)$. Find the ratio of v_1/v with the assumption that the velocity variation b/w the plates is linear

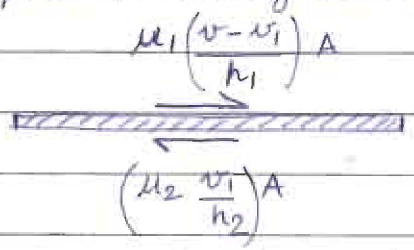
NOTE:



At the interface we will have → ① Continuity in velocity

② Continuity in shear.

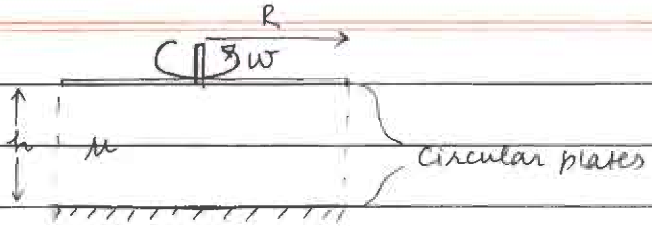
Since, the middle plate is moving with constant velocity, net F=0.

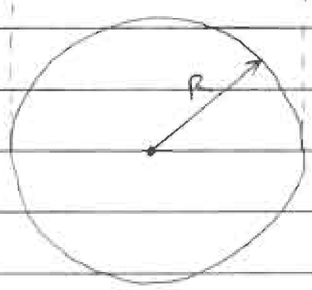


There fore,
$$\mu_1\left(\frac{v-v_1}{h_1}\right)\cancel{A} = \left(\mu_2\frac{v_1}{h_2}\right)\cancel{A}$$

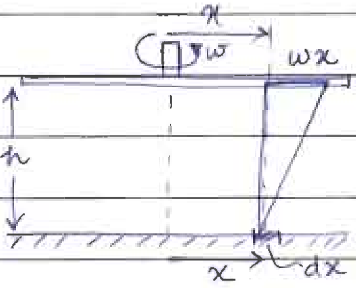
$$\boxed{\frac{v_1}{v} = \frac{\mu_1/h_1}{\mu_1/h_1+\mu_2/h_2} = \frac{1}{1+\frac{\mu_2}{\mu_1}\cdot\frac{h_1}{h_2}}}$$

Q-





Find the Torque experienced by the bottom plate.



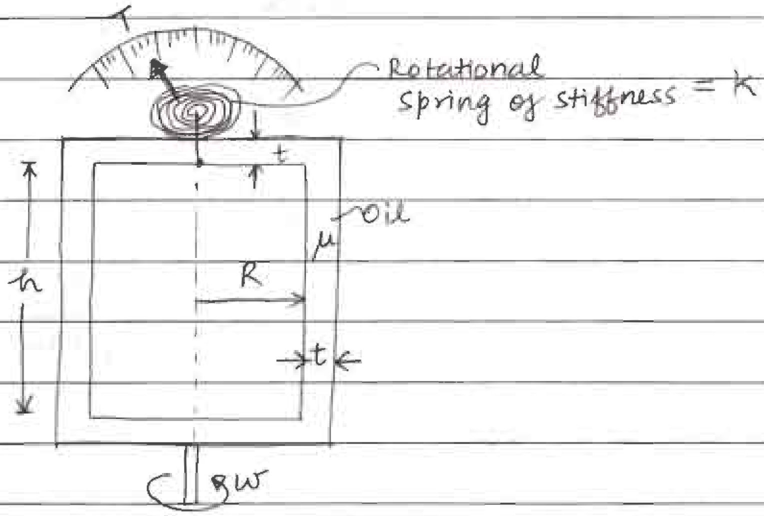
$$\left(\frac{du}{dy}\right)_x = \frac{\omega x}{h}$$

$$\tau = \mu \frac{\omega x}{h}$$

$$T = \int \tau \, dA \, x = \int \frac{\mu \omega x}{h} \, 2\pi x \, dx \cdot x$$

$$T = \frac{2\pi\mu\omega}{h} \int_0^R x^3 \, dx = \frac{\pi \mu \omega R^4}{2h}$$

NOTE : Rotating cylinder viscometer



$$T_{bottom} = T_{top} = \frac{\pi \mu \omega R^4}{2t}$$

For calculation of T_{side}.

$$\tau = \mu \frac{\omega(R+t)}{t}, \quad F = \frac{\mu\omega(R+t)}{t}(2\pi R h)$$

$$T_{side} = \frac{\mu\omega(R+t)(2\pi R h)}{t} \times R$$

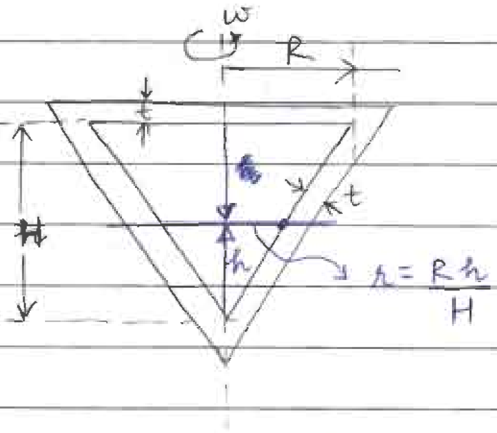
So, Torque experienced by the inner cylinder,

$$\boxed{T = 2\left[\frac{\mu\pi\omega R^4}{2t}\right] + \frac{\mu\omega(R+t)(2\pi R h)}{t} \cdot R}$$

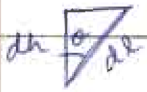
measured from calibrated rotational spring

⇒ Hence μ of the fluid can be calculated.

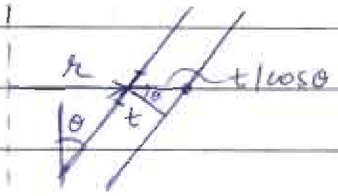
⇒



$$T_{top} = \frac{\pi\mu\omega R^4}{2t}$$



$$dl = \frac{dh}{\cos\theta}$$



$$\frac{du}{dy} = \frac{\omega\left(r+\frac{t}{\cos\theta}\right)}{\left(\frac{t}{\cos\theta}\right)}$$

$$\tau = \frac{\mu\omega\left(r+\frac{t}{\cos\theta}\right)}{\left(\frac{t}{\cos\theta}\right)}$$

$$\boxed{T_{side} = \int_0^H \frac{\mu\omega\left(r+\frac{t}{\cos\theta}\right)}{\left(\frac{t}{\cos\theta}\right)} 2\pi r\left(\frac{dh}{\cos\theta}\right) r}$$

→ Put $r = \frac{Rh}{H}$

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Highway
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Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

HIGHWAY

CONTENT

DATE

PAGE

Highway Engineering

[ESE → 4-6 Ques, Conventional → 30-60 marks, GATE → 3-5 Ques]

1) Geometric Design
2) Traffic Engineering
3) Pavement Design
4) Highway materials

1. Geometric Design

→ Geometric design of highway deals with the visible elements of the road. Various geometric design components depends on:

1) Type of Road

(A) Rural Roads

(i) Expressway: Speed ~~upto~~ 120 kmph

(ii) National Highway : Joins various states

(iii) State Highway : Joins various districts.

(iv) Major District Roads (MDR) : Joins areas of population or production with the main highway

(v) Other District Roads (ODR) : Joins rural areas to the market place

(vi) Village Roads : Joins various villages

NOTE: IRC:73 deals with the geometric design of rural highways

(B) Urban Roads

(i) Expressway (120kmph) [Divided Arterial Roads]

(ii) Arterial Roads (80kmph)

(iii) Sub-Arterial Roads (60 kmph)

(iv) Collector Streets (50 kmph)

(v) Local streets (30kmph)

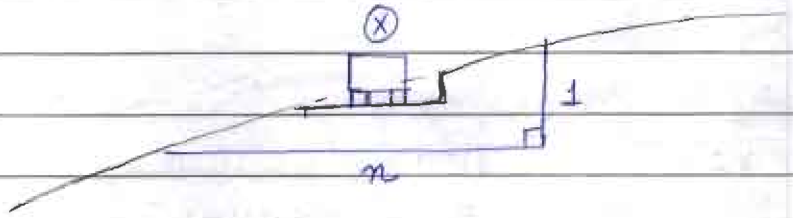
2) Type of Vehicle : The vehicle for which road elements are designed is called design vehicle.

→ Length, width, height of design vehicle are used as design parameters for the roads.

NOTE : IRC : 003 deals with the dimension of design vehicle.

→ Width of vehicle = 2.5 m
→ Height of vehicle = 3.8 to 4.75 m [4.75 m is for Double Decker bus]

3) Topography : It is classified on the basis of general country slope across the road alignment. It is expressed as 1 in n or x%.
[x% = x in 100]



Cross-country slope	Class	
0 – 10%	Plain	
10 – 25%	Rolling	
25 – 60%	Mountaneous	Hill Roads.
>60%	Steep	

→ If cross-slope of the country is large then large expenditure has to be made in altering the alignment for design speed to provide a larger radius of curve to counteract against centrifugal force which causes skidding or overturning problems.

→ Hence when cross-country slope is large, the velocity should be restricted.

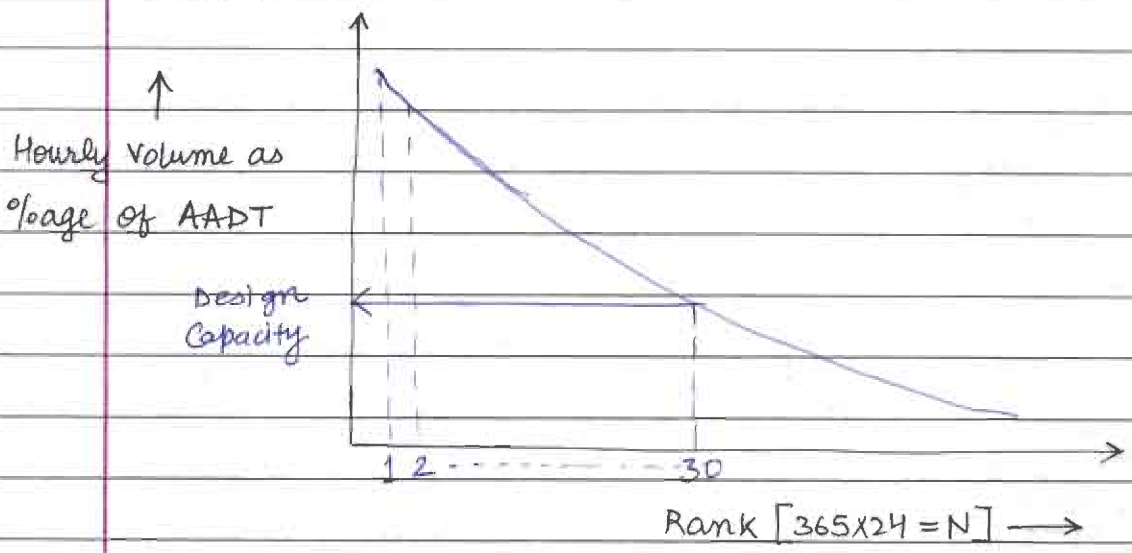
4) ⇒ Traffic Capacity

→ Traffic capacity is the ability of road to accommodate maximum traffic volume.

→ Traffic volume is the no. of vehicles crossing a point or section on the road in unit time.

→ Capacity and volume are both expressed in veh/hr.
[At a particular Level of Service (LOS)]

→ Normally design capacity is taken as 30th highest hourly volume.



AADT → Average annual Daily Traffic i.e. $\left[\frac{\text{Yearly Traffic}}{365}\right]$

→ Generally 30th highest hourly volume for Indian conditions comes around 8-10% of AADT

eg → if AADT = 2000 veh/day
then Design capacity = 160-200 veh/hr
or 30th highest hourly volume

→ Depending upon traffic capacity width of road is decided.

5) Design speed

→ It is theoretically decided as 98th percentile speed i.e. the speed at or below which 98% of vehicles are moving.

→ However, from economical POV, IRC has limited the design speed based on topography.

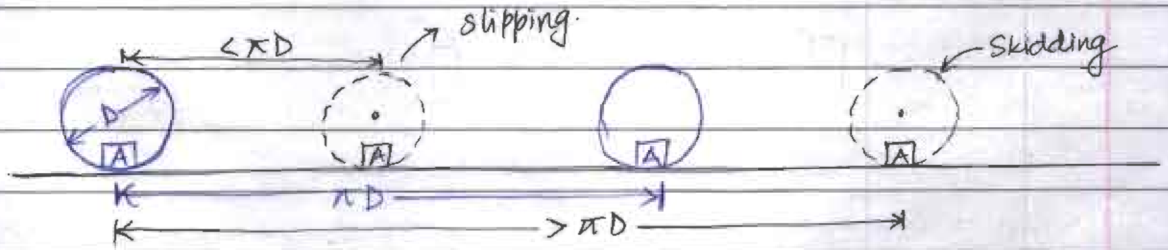
→ Normally ruling speed should be the guiding criteria however, minimum design speed can be adopted in localised sections where cost consideration does not permit ruling speed.

Type of Road	Plain		Rolling	
	Ruling (kmph)	Minimum (kmph)	Ruling (kmph)	Minimum (kmph)
Expressway	120	100	100	80
NH / SH	100	80	80	65

6) Surface characteristics

(i) Friction: Longitudinal friction coefficient as recommended by IRC is 0.35 to 0.40 and lateral friction coeff is 0.15 as recommended by IRC.
or transverse

→ Lack of friction causes slipping or skidding

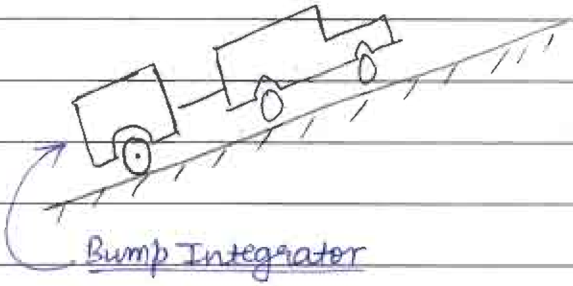


→ If one revolution of wheel leads to longitudinal movement less than πD, it is called slipping and if one revolution of the wheel leads to longitudinal movement greater than πD it is called skidding.

(ii) Unevenness Index

→ This index is a cumulative measure of vertical undulations per unit length of the road.

→ It is measured using Bump Integrator

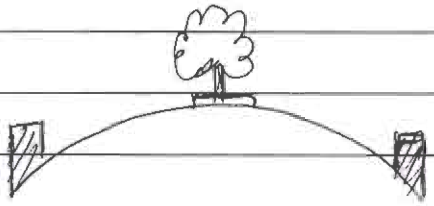


→ Classification of roads based on unevenness Index.

(i) Unevenness Index < 1500 mm / Km → good surface
(ii) " " upto 2500 mm / km [→100 kmph] → Satisfactory surface
(iii) " " > 3200 mm / km [55 kmph] → unsatisfactory surface

⇒ Various geometric design components of highway

1) Cross-sectional Element

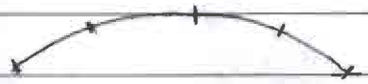


2) Sight Distance
3) Horizontal Alignment details
4) Vertical alignment details
5) Intersection detail

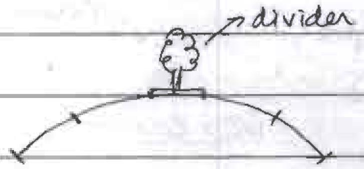
I) Cross-Sectional Elements

(a) Carriage way - It is the part of pavement designed to carry vehicles.

Type of road	Carriage way width
Single Lane	3·75 m
Two lane with no kerb	7.00 m
Two lane with raised kerb	7.50 m
Intermediate Lane	5·50 m
Multi Lane	3. 50 m / Lane
Multi lane bridge	3.50 m / Lane + 0.5m per carriage way



3.5 X 4 + 0.5 = 14.5m



3.5 X 4 + 2 X 0.5 = 15m

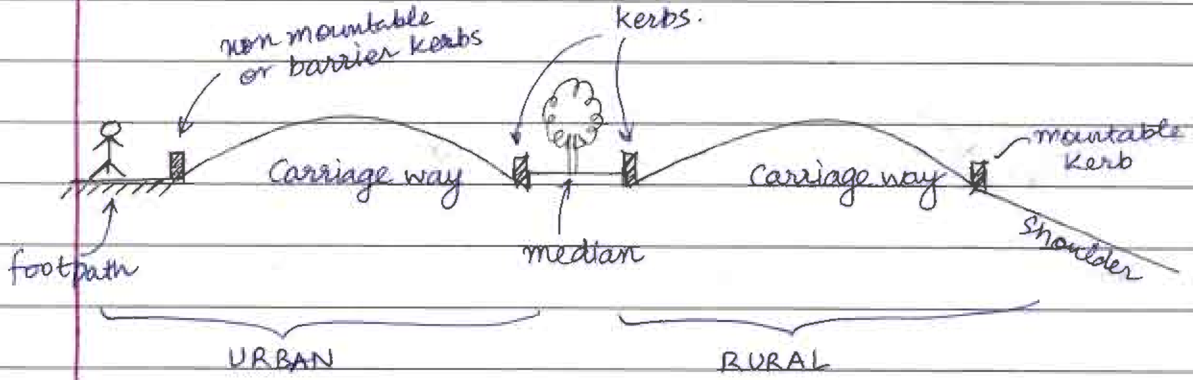
(b) Shoulder - shoulders are provided to accommodate stopped vehicles and to provide lateral confinement to the pavement layers

→ Desirable width of shoulder is 4.6m with a minimum of 2.5m for 2 lane rural highway.

NOTE: Formation width for single / two lane NH section is 12m as per IRC

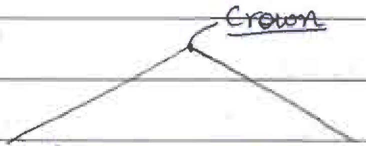
(c) Kerb

→ It indicates the boundary between pavement and shoulder or median or footpath.

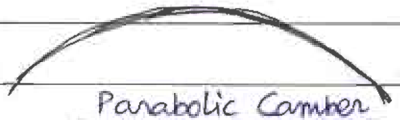


(d) Camber or cross-slope or cross-fall

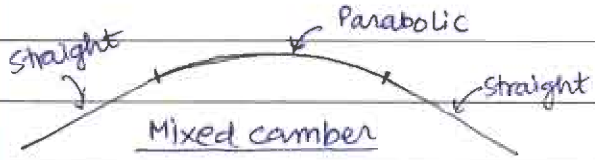
It is the slope provided to the road surface in transverse direction to drain off rain water.



Straight camber



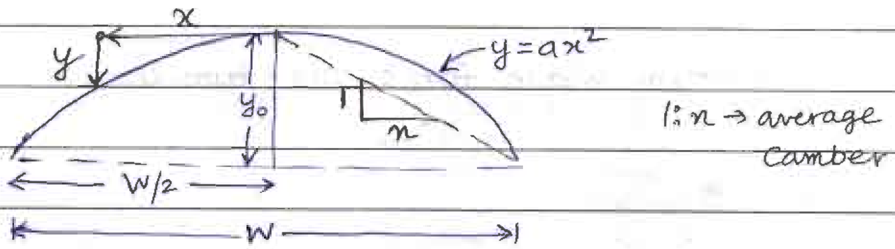
Parabolic Camber



Mixed camber

→ For slow moving traffic straight camber can be adopted but for high speed traffic where crown has to be crossed frequently during overtaking, parabolic camber is preferred.

→ Equation of parabolic camber



From similar Δ

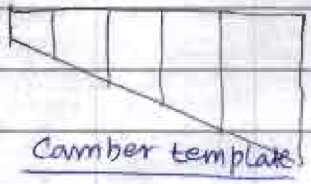
$$\frac{1}{n} = \frac{y_0}{W/2} \Rightarrow \boxed{y_0 = \frac{W}{2n}} \text{ — ①}$$

$$@\ x = W/2,\ y = y_0 \Rightarrow \boxed{y_0 = a\left(\frac{W}{2}\right)^2} \text{ — ②}$$

$$\text{From ① and ②} \Rightarrow \frac{\cancel{W}}{\cancel{2}n} = \frac{aW^{\cancel{2}}}{\cancel{4}2} \Rightarrow \boxed{a = \frac{2}{nW}}$$

So, $\boxed{\text{equation of parabolic camber} \Rightarrow y = \frac{2}{nW}x^2}$

→ In field camber is checked by camber boards or templates.



NOTE : Bituminous pavement ⇒ Parabolic camber
Rigid pavement → Straight camber

→ IRC recommendations for camber

# Type of Road	RAINFALL Low (<100cm)	Heavy (>100cm)
1) Cement concrete or High type Bituminous pavement	1.7%	2%
2) Thin bituminous pavement	2%	2.5%
3) WBM / gravel	2.5%	3%
4) Earthen	3%	4%

NOTE: Slope of shoulder should atleast be 0.5% steeper than the slope of camber subjected to a minimum of 3%.

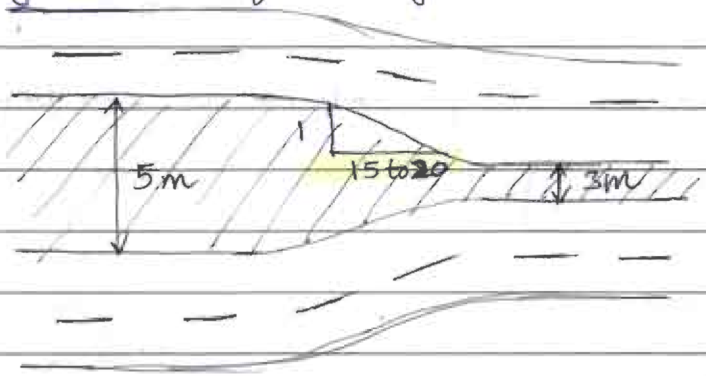
→ **Median**

→ The purpose of median is to prevent head-on collision b/w vehicles

→ Also known as traffic separator

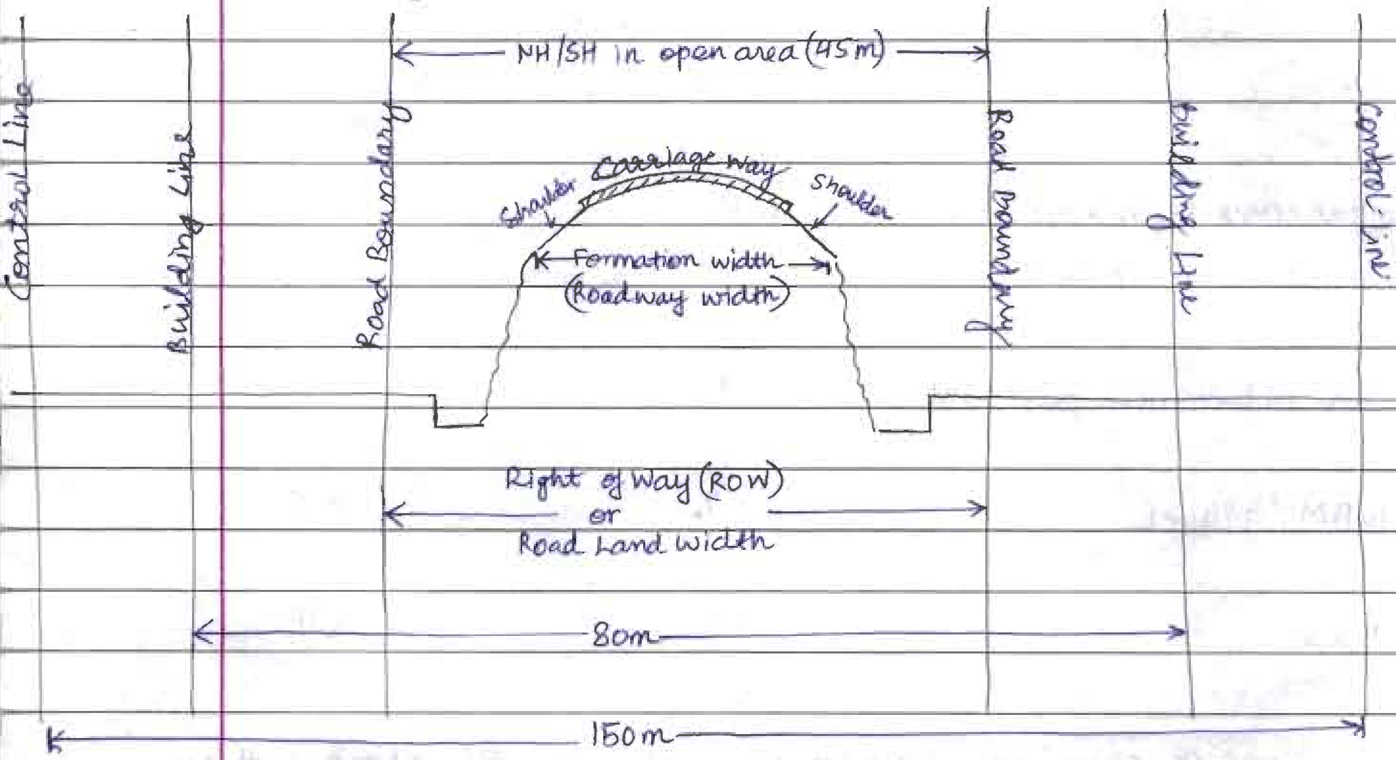
→ Minimum desirable width for rural Highway is 5m and if lane width is restricted, then the value may be reduced to 3m

→ Width of median for bridges should be between 1.2–1.5m



→ transition in median should be b/w 1 in 20 to 1 in 15

→ **Road Margins**



→ Building Line

Represents the road width upto which no building activity is permitted.

→ Control Line

Represents distance upto which nature of building is controlled.

→ Sight Distances

→ Geometric design of highway is done in such a way that from every point on highway the length of view available is sufficient so that the vehicle could be stopped in that visible distance or operations like overtaking could be safely performed.

→ Various sight distances are :

(a) Stopping Sight Distance (SSD)

It is also known as absolute minimum sight distance or non-passing sight distance.

(b) Overtaking sight Distance (OSD)

It is also known as passing sight distance.

(c) Intermediate Sight Distance (ISD)

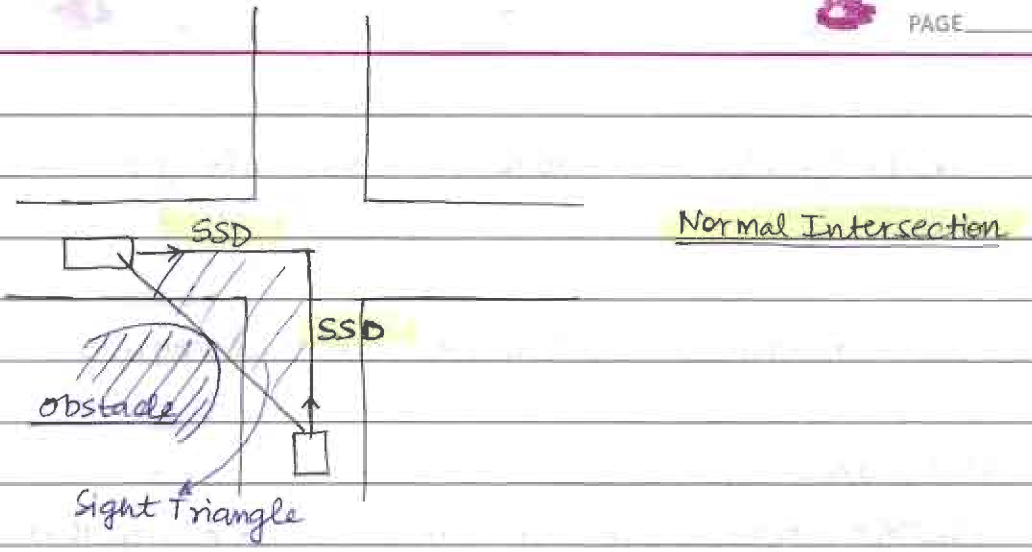
When overtaking sight distance cannot be provided, we provide ISD so as to give some degree ~~to~~ of overtaking opportunity.

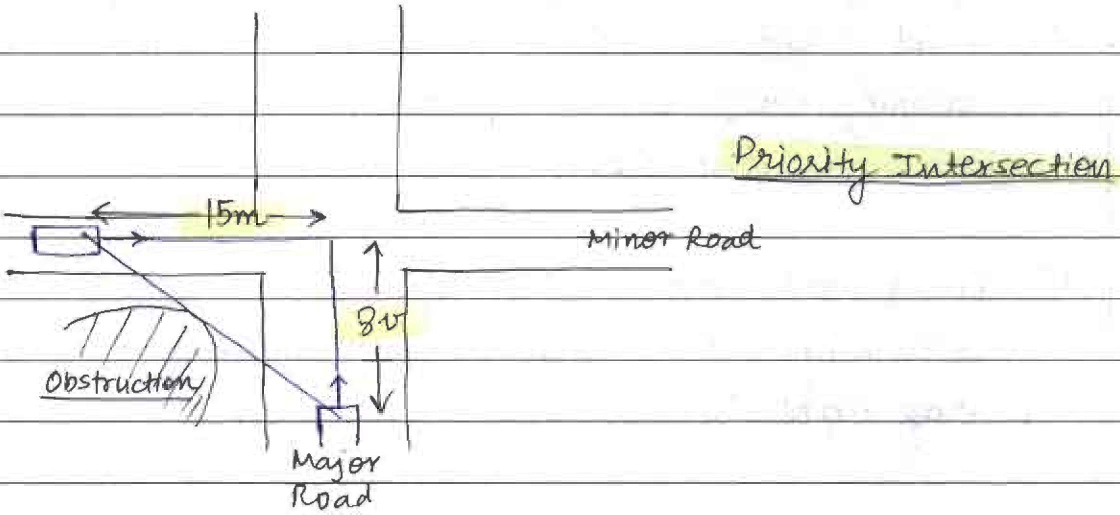
$$\boxed{ISD = 2 \times SSD}$$

(d) Headlight Sight Distance (HSD)

Distance visible to the driver at night under headlight illumination. The minimum value of HSD should be SSD.

(e) Sight Distance at Intersections





→ At priority intersection (major road crosses a minor road) the sight Δ is formed by providing a minimum visibility of 15m along the minor road and a visiblity of 8 seconds travel distance along the major road. (8 v) (where v is in m/s)

1) Stopping Sight Distance

→ It is the minimum sight distance (visibility) that should be visible from all spots of highway such that vehicles travelling at design speed could be safely stopped within that distance.

→ SSD depends on

1) Reaction time of driver (Perception reaction time)

IRC recommends 2.5s as the reaction time for SSD calculations.

2) Speed of vehicle

3) Brake efficiency

IRC assumes a brake eff. of 50%. It has already been incorporated in the longitudinal friction coeff (0.35-0.40) recommended by IRC.

4) Friction coeff of road [Longitudinal]

As per IRC it is taken as 0.35 to 0.4

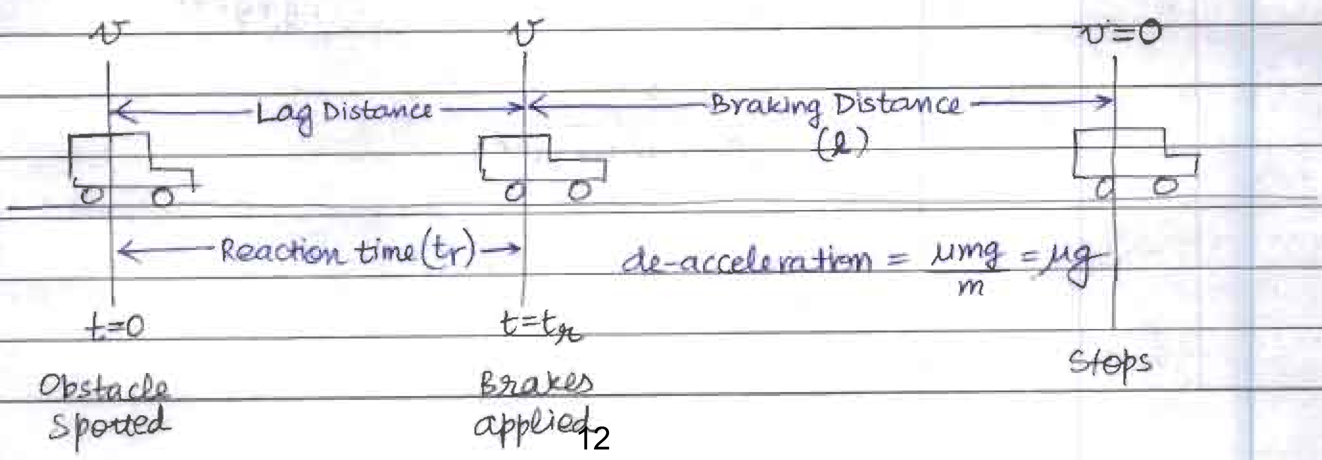
Speed (kmph)	μ [Design]
≤ 30	0.40
60	0.36
≥ 80	0.35

5) Longitudinal gradient of road

Up gradient will lead to a lower value of SSD and down gradient will lead to a higher value of SSD.

→ Calculation of SSD

Case I – When the vehicle is moving on level road i.e. no longitudinal gradient



$$\boxed{\text{Lag Distance} = v t_r}$$

$$v^2 = u^2 + 2as$$

$$0^2 = v^2 - 2\mu g l$$

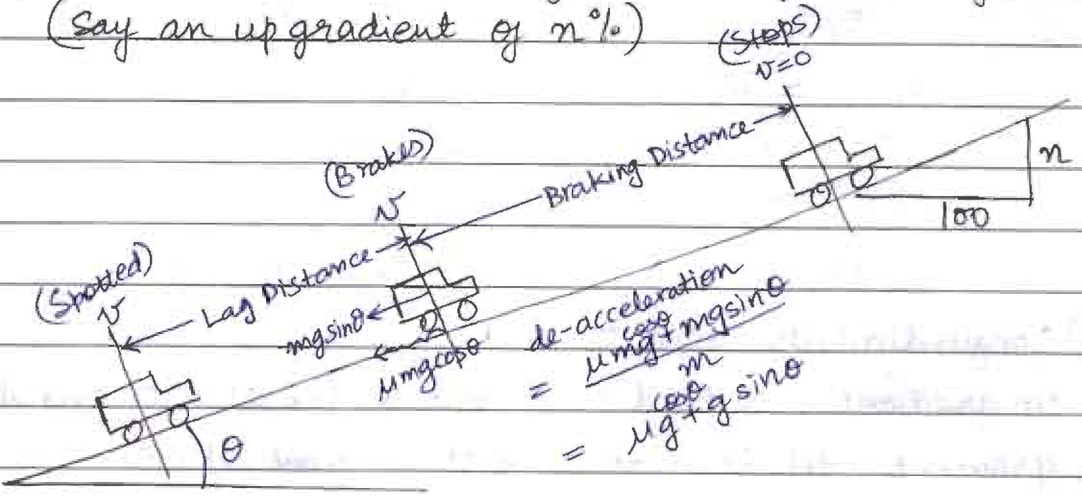
$$\boxed{l = \frac{v^2}{2\mu g}} \rightarrow \text{Braking distance}$$

SSD = Lag Distance + Braking distance

$$\boxed{SSD = v t_r + \frac{v^2}{2\mu g}}$$

$$\boxed{\begin{array}{l} v \rightarrow m/s \\ V \rightarrow kmph \end{array}}$$

Case II – When the vehicle is moving on a longitudinal gradient (Say an upgradient of n%)



de-acceleration
$$= \frac{\mu mg\overset{\cos\theta}{} + mg\sin\theta}{m}$$
$$= \mu g\overset{\cos\theta}{} + g\sin\theta$$

$$\boxed{\text{Lag Distance} = v t_r}$$

$$V^2 = u^2 + 2as$$

$$0^2 = v^2 - 2(\mu g\overset{\cos\theta}{} + g\sin\theta)l \Rightarrow l = \frac{v^2}{2(\mu g\overset{\cos\theta}{} + g\sin\theta)}$$

$$\boxed{l = \frac{v^2}{2g\cos\theta(\mu + \tan\theta)}}$$

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Hydraulic Machine
Handwritten notes by

Kartikay Kaushik

AIR-1 ESE 2021

IES Master classroom Student

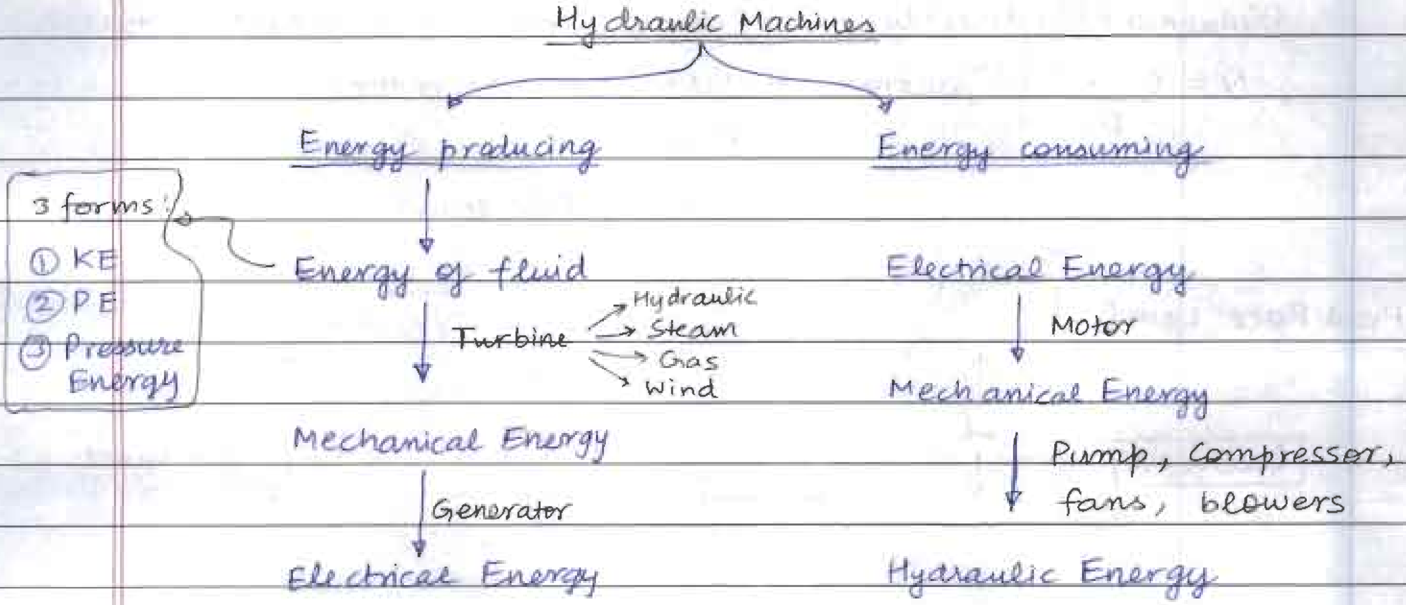
HYDRAULIC MACHINES

CONTENT

Hydraulic Machines

ESE (P) → 6 Ques
ESE (M) → 20-25 Marks

1) Overview of Hydro-electric Projects (HEP's)
2) Hydraulic Turbines { Impulse Turbines
   Reaction Turbines
3) Hydraulic Pumps { Centrifugal pumps
   Reciprocating pumps

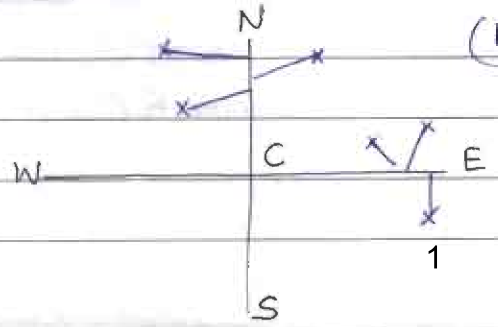


→ Pumps ~~as~~ increase the PE of fluid, compressors (generally used for gases) increase the pressure energy of fluid and fans and blowers increase the KE of fluid.

Chapter 1 - Overview of HEP

⇒ Basics of Electrical

1) Generation
2) Transmission (PGCIL)
3) Distribution (SEBs)



→ Generation plants supply electricity to grids and grids supply it to us.

	Supply	(Load) Demand
f=50Hz	500MW	500MW
f<50Hz	500MW	600MW
f>50Hz	500MW	400MW

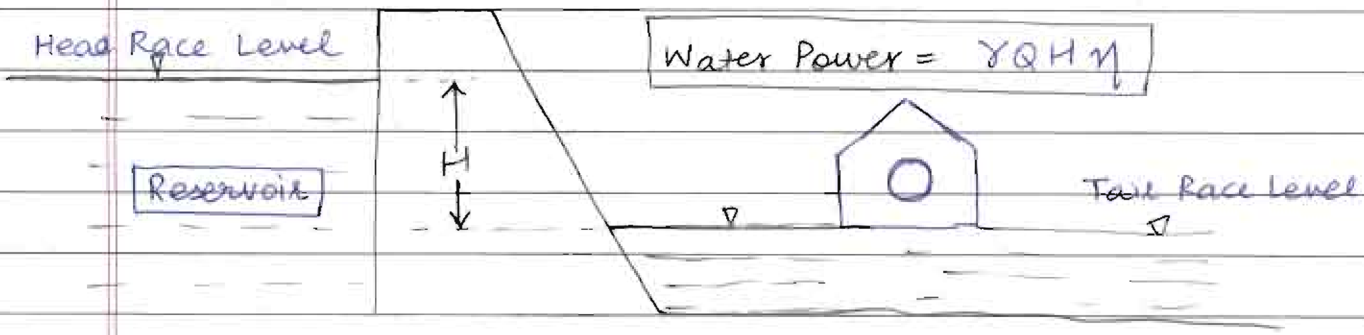
For generation companies,
if Demand is high, price ↑
if Demand is low, price ↓

→ Both of these situations are not desirable as appliances are set to work at 50Hz

→ frequency (f) directly relates to the speed of rotation of turbines.

$$N = \frac{60 \times f}{P}$$ where

N → speed of generator
f → frequency
P → No of Pole pairs.



Water Power = $\gamma Q H \eta$

→ In HEPs, PE of water is utilized to drive a turbine which in turn runs the generator to produce electricity

→ Apart from producing electricity, these projects can also be used for irrigation, drinking water supply, flood moderation, fishing and recreational activities.

→ Such projects are known as Multi Purpose Projects.

⇒ Components of HEP

① Reservoir

→ Water available in the catchment area is stored in reservoir so as to meet requirement of plant throughout the year. Reservoirs can be natural as well as artificial

→ Natural reservoirs are lakes in mountains.

→ Artificial Reservoirs are made by constructing a dam across a river

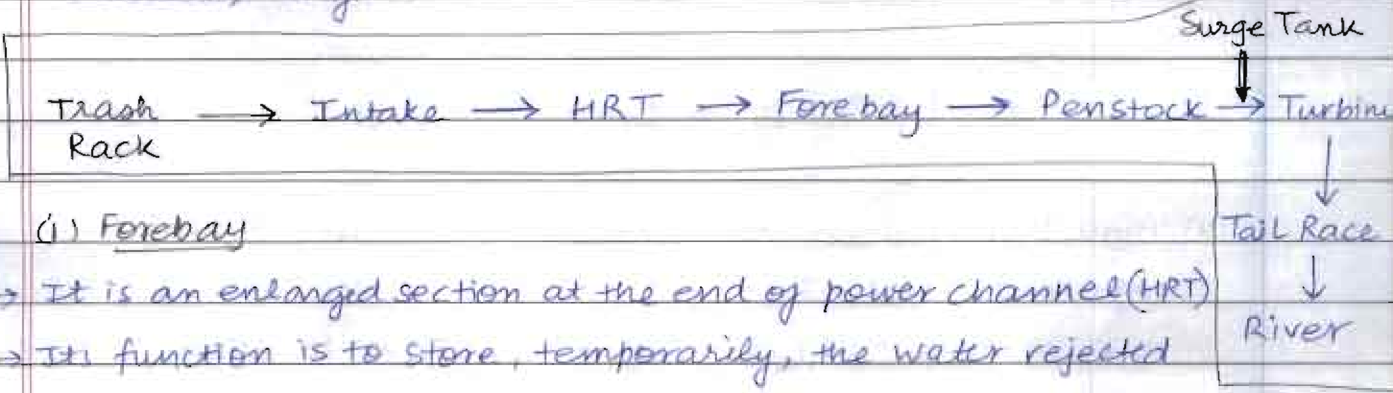
② Trash Rack

It is used to obstruct debris from going into the intake.

③ Waterways

→ It is a passage through which water is carried from the storage reservoir to the power house

→ It consists of Head Race Tunnel (HRT) or Powerchannel, Forebay, Penstock, surge tank



(i) Forebay

→ It is an enlarged section at the end of power channel (HRT)

→ Its function is to store, temporarily, the water rejected by the plant when the load is reduced and to meet the instentaneous increased demand of water due to sudden increase in load.

→ It also helps in absorbing the sudden rise in pressure due to closure of valves when load on turbine decreases. Thus it prevents HRT from water hammer impact.

(ii) Penstock

→ Penstock is a closed conduit for supplying water under pressure from the forebay to the turbine.

→ It is subjected to water hammer pressure due to fluctuation in turbine load and to reduce this a surge tank is provided

(iii) Surge Tank

→ It is a small reservoir fitted at some opening in the penstock to receive the rejected flow when the load on the turbine decreases and thus prevents penstock from water hammer impact

④ Tail Race

→ It is a waterway to carry water discharged by the turbine to a suitable point where it can be safely disposed off or stored for pumping ~~bag~~ back into the original reservoir

NOTE:

1) Fore bay and Surge Tank, both serve same purpose.
2) Surge Tank should be located close to the turbine

→ Classification of HEPs

① Based on availability of head

(a) High Head Plants → Head is more than 250 m
(eg - Tehri) (260m)
(b) Medium Head Plants → Head is b/w 30 m to 250m
(c) Low Head Plants → Head is less than 30m.

→ This classification is not based on any scientific criteria

② Based on Load capacity

(a) Base Load Plant → They supply constant power (Base Load)
eg - Thermal Power Plants, Hydro Power Plants with storage

(b) Peak Load Plants → They supply power during peak hours only
→ Storage type Hydroplant is ideally suited for this purpose as it can be started in few minutes

NOTE: Storage and Pondage

→ Storage and Pondage of water is required for regulation of flow of water so as to make it available in requisite quantity to meet the power demand at a given time.

→ Storage – Storage is impounding of considerable amount of excess runoff during seasons of surplus flow for use in dry seasons. This is accomplished by constructing a dam across a river.

→ Pondage – Pondage is simply a regulating body of water in the form of relatively small pond or reservoir provided at the plant. Pondage is used to regulate the variable water flow to meet power demand. eg – Forebay and Surge Tank

→ Storage and pondage can be obtained from Flow duration curve.

⑤ Based on Function

(a) Run-of-River (R-O-R) plants

→ No storage of water is done and whatever water is available in the river is utilized to run the turbine

→ RoR plants are suitable for perennial rivers only.

→ RoR plants can be with or without pondage.

→ RoR plants without pondage are suitable for Base load applicatio and RoR plants with pondage are suitable for peak load applicatio

→ Plants with pondage is provided with a weir or Barrage to accommodate sufficient storage to take care of load fluctuations.

(b) Storage Plants

→ These plants have storage provided by constructing dams.

→ These plants can meet the peak load demands

(c) Pumped Storage Plants

→ This type of plant is provided when there is a shortage of water

→ These plants generate power during peak hours. During off-peak hours, water is pumped back from tail race channel to the Reservoir.

- → These plants use reversible turbines which functions as both as turbines as well as pump.
- → Such plants convert low value off peak energy into high value on peak energy and hence are economically viable.
- → suitable for peak load applications.

④ Based on source of Energy

(a) River based Power Plant

(b) Tidal Power Plant

- → These plants tap the energy of earth's rotation.
- → There is rise in level of sea water during high tide period and fall during low tide period.
- → Water rises and falls twice a day and hence head on the turbine varies with time cyclically
- → During high tide, when water level along the coast is rising, electricity can be produced.
- → Electricity can also be produced when water is retreating by changing the direction of rotation of turbine
- → Turbines used are Bulb Turbine and Tubular Turbine

Advantages

1) Water → Renewable source
2) Running cost is low
3) Renewable source of energy
4) No GHG emission
5) Quick start and closure
↓
Hence suitable for peak load applications.

Limitations

1) Setup cost is high
2) Long gestation Period
[Due to large scale rehabilitation and clearances from multiple stakeholders like NitI Aayog, MoEFCC, MoWR, MoTA]
3) Far from load centre → high transmission cost
4) ecology is disturbed downstream of the reservoir
5) Rehabilitation and Resettlement issues

⇒ Terminologies in Power generation

① Load Factor

$$= \frac{\text{Average load during a certain period}}{\text{Peak load during that period}}$$

② Utilisation Factor or Plant use Factor

$$= \frac{\text{Maximum Power utilized}}{\text{Maximum Power available (= Installed capacity)}}$$

③ Diversity Factor

$$= \frac{\text{Sum of individual maximum demands}}{\text{Simultaneous maximum demand.}}$$

④ Demand Factor

$$= \frac{\text{Simultaneous maximum demand}}{\text{Sum of individual maximum demand}}$$

$$= \frac{1}{\text{Diversity Factor}}$$

⑤ Primary Power (Firm Power)

→ It is the net amount of power that is available from a plant on a guaranteed basis.

⑥ Secondary Power

→ Excess power available over and above primary power

Q. Load on a Hydel Plant varies from a min of 10000 KW to a max. of 35000 KW. 2 turbogenerators of capacity 22000 KW each have been installed. Calculate

① Total installed capacity of the plant → 44000 KW
② Maximum demand → 35000 KW
③ Load factor → 9/14 → 64.28%
④ Utilization / Plant use factor → 79.54%

Q The peak on a power plant is ~~60000 kW~~ 60 MW. The loads having max^m demands of 30 MW, 20 MW, 10 MW and 14 MW are connected to the power plant. The capacity of the power plant is 80 MW and annual load factor is 0.5

Estimate:

① Average load on the power plant → 30 MW
② Energy supplied per year in kWh → 262800000 kWh
③ Demand factor = 0.811
④ Diversity factor = $\frac{30+20+10+14}{60}$ = 1.233

Chapter-2 Hydraulic Turbine

$$\text{Hydraulic Energy} \xrightarrow{\text{Turbine}} \text{Mechanical Energy} \xrightarrow[\text{Generator}]{\text{Electrical}} \text{Electrical Energy}$$

Hydraulic Energy ↓

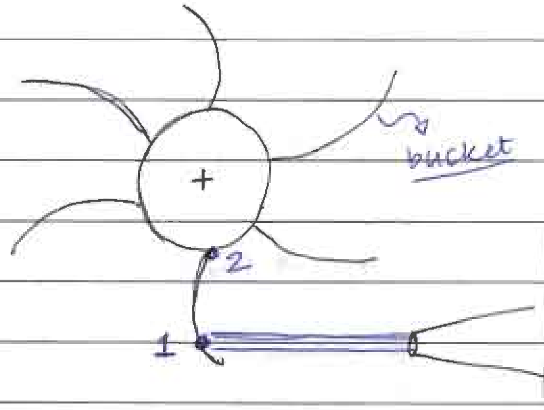
P E —converted→

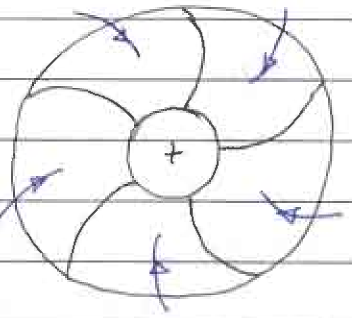
KE → Impulse effect

Pressure Energy → Reaction effect

Impulse effect ↓ **Impulse Turbine**

Reaction effect ↓ **Reaction turbine**





$$\frac{v_1^2}{2g} - \frac{v_2^2}{2g} = RP$$

→ Only KE is used

$$\frac{P_1-P_2}{\gamma} + \frac{v_1^2-v_2^2}{2g} = RP$$

→ Both KE and Pressure energy is used.

→ Hydraulic turbines are the devices which convert hydraulic energy into mechanical energy. This mechanical energy is further converted into electrical energy by a generator

→ Classification of hydraulic turbines

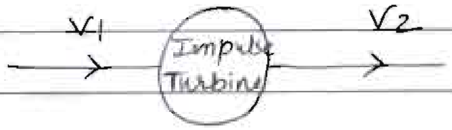
① According to the action of water on moving blade

(a) Impulse Turbine

→ In Impulse Turbine, the energy available at the entrance to the turbine is in the form of Kinetic Energy and water strikes the bucket with KE causing an impact or impulse action

→ Throughout the movement of water through the runner, pressure remains atmospheric and KE of water is extracted in the form of runner power

→ Pelton wheel is the most commonly used impulse turbine



$V_1 > V_2$

$P_1 = P_2 = P_{atm}$

$$\text{Runner Power} \equiv \frac{V_1^2 - V_2^2}{2g}$$

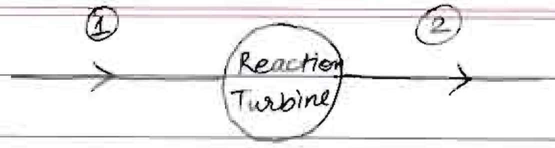
→ ~~In~~ (b) Reaction Turbine

→ In reaction turbines, runner blades are completely submerged in water and energy available at the entrance to turbine is in the form of both Pressure Energy and KE.

→ While flowing through the runner, both KE and pressure energy are extracted in the form of runner power and at exit both KE and pressure are low

→ Flow in reaction turbine is inside an air tight casing

→ Commonly used reaction turbines are Francis turbine, Kaplan turbine and Propeller turbine

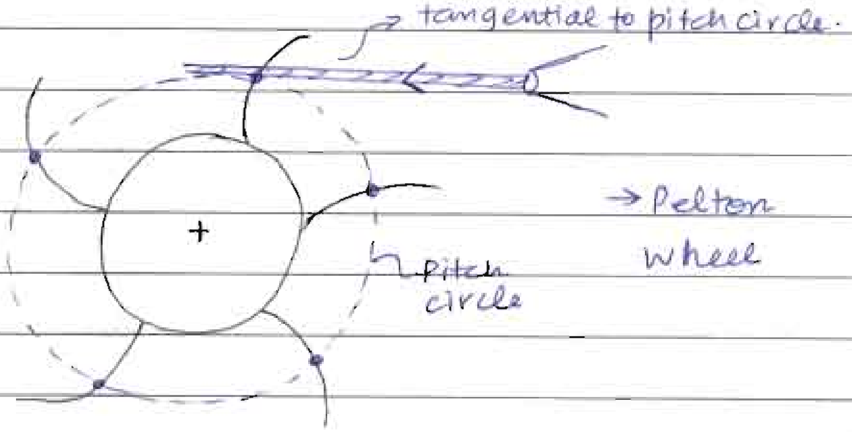


$V_1 >> V_2$ ⇒ RP (Runner Power) $= \frac{(P_1-P_2)}{\gamma} + \frac{V_1^2-V_2^2}{2g}$

$P_1 >> P_2$

② According to the direction of flow of water

(a) Tangential flow Turbine



→ Pelton wheel

→ Water flows in a direction tangential to the path of rotation of runner

(b) Radial flow Turbine

→ Water flows in a radial direction and remains mainly in a plane normal to the axis of rotation of runner.

→ It can be

(i) In ward Radial flow

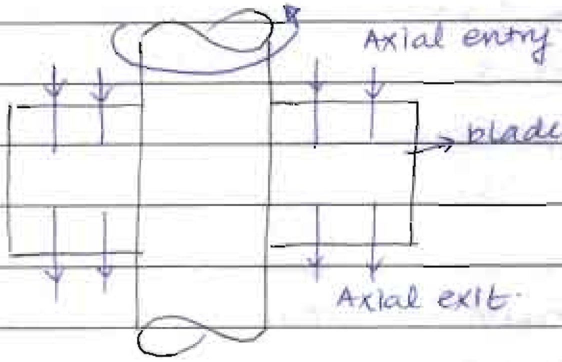
→ Water enters at outer circumference and flows radially inwards towards centre of runner. eg- Old Francis, Thomson turbine

(ii) Outward Radial flow

→ Water enters at centre and flows radially outwards, towards the outer periphery of runner. eg- Fourneyron Turbine

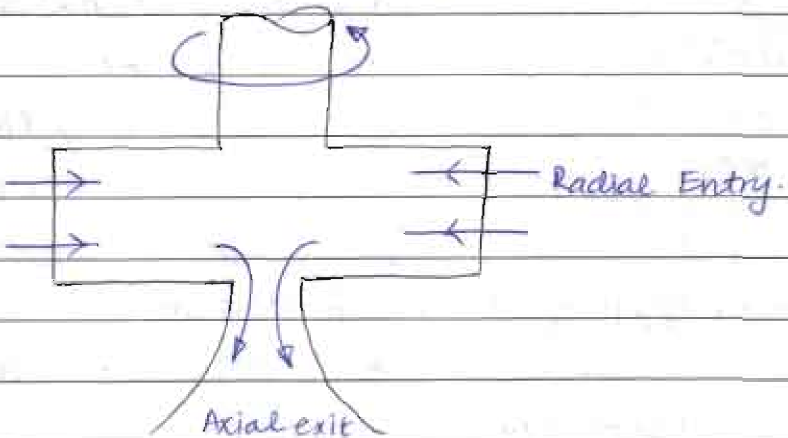
(c) Axial flow Turbine

→ In this turbine, flow of water through the runner is mainly along the direction parallel to the axis of rotation of runner eg- Kaplan turbine, Propeller turbine.



(d) Mixed flow Turbine

→ In this type of turbine, water enters the runner at outer periphery in radial direction and leaves it at centre in the direction parallel to axis of rotation of runner. eg- Modern Francis turbine



③ According to head and discharge

(a) Pelton wheel → Works under high head and hence requires low discharge $[\because P = \gamma Q{\downarrow} H{\uparrow} \eta]$

(b) Francis turbine → Works under medium head and hence requires medium discharge.

(c) Kaplan and Propellor Turbine - Works under low head and hence requires high discharge

④ According to specific speed

→ Specific Speed (N_s) → Speed of a geometrically similar turbine which while working under a head of 1 m produces 1 KW power

$$\boxed{N_s = \frac{N\sqrt{P}}{H^{5/4}}}$$

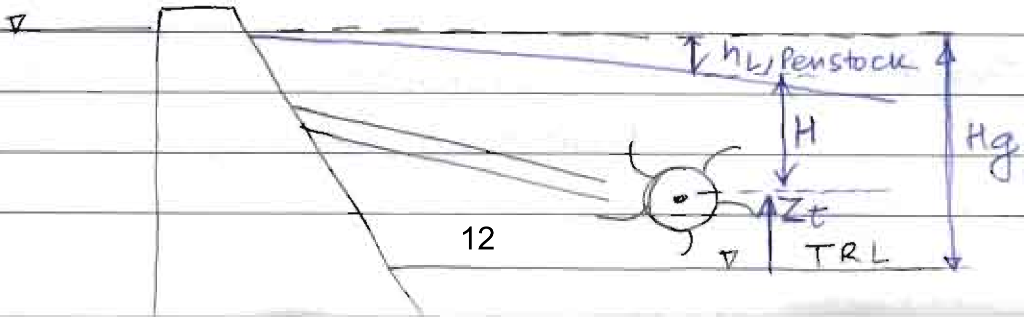
N : speed of runner (in rpm)
P : Power output (in KW)
H : Net Head.

N_s	Type of Turbines
10-35	Pelton wheel with single Jet
>35	Pelton wheel with multiple Jets
60-300	Francis Turbine
300-900	Kaplan Turbine / Propeller
>900	Special type of runners are used

NOTE: Calculation of specific speed is independant of size of turbine and hence this is the most scientific criteria for classification of turbine.

⇒ Head and efficiency of Turbine

① Gross Head (H_g) → It is the difference of Level b/w HRL and TRL



② Net Head

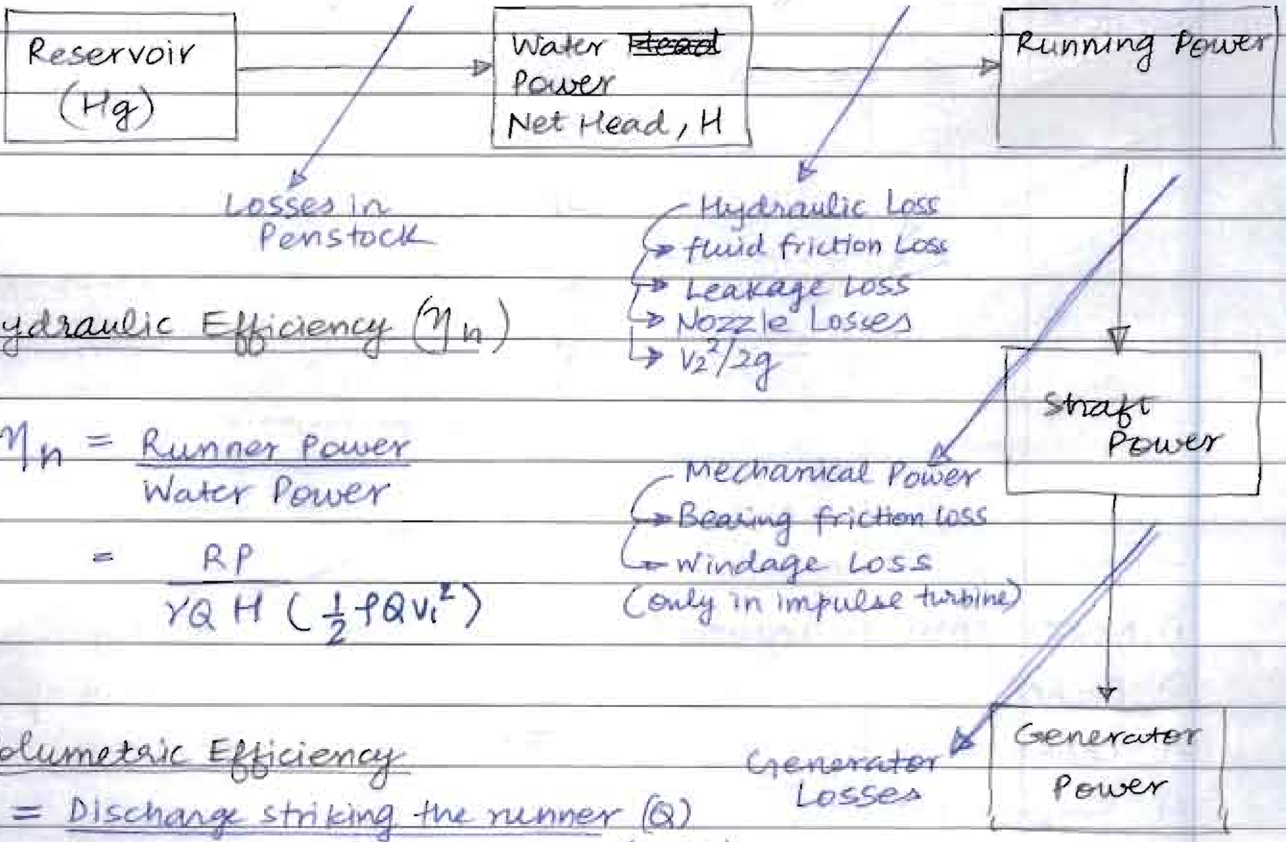
$$\boxed{\text{Net Head} = H_g - h_{L,\text{Penstock}} - Z_t}$$ → Impulse Turbine

Z_t → height of turbine above TRL

$$\boxed{\text{Net head} = H_g - h_{L,\text{Penstock}} - \frac{V_{dt}^2}{2g}}$$ → Reaction Turbine

V_{dt} → Velocity at the exit of draft Tube.

→ Efficiencies of hydraulic Turbine



① Hydraulic Efficiency (η_h)

$$\eta_h = \frac{\text{Runner Power}}{\text{Water Power}}$$

$$= \frac{RP}{\gamma Q H \left(\frac{1}{2}\rho Q V_1^2\right)}$$

② Volumetric Efficiency

$$= \frac{\text{Discharge striking the runner } (Q)}{\text{Discharge supplied to runner } (Q+\Delta Q)}$$

ΔQ → Leakage Losses (generally neglected)

③ Mechanical Efficiency (η_m)

$$\eta_m = \frac{\text{Shaft Power}}{\text{Runner Power}} = \frac{RP - \text{Mechanical Losses}}{WP - \text{Hydraulic Losses}}$$

④ Overall Efficiency (η_o)

$$\text{Overall Efficiency } (\eta_o) = \frac{\text{Shaft Power}}{\text{Water Power}}$$

Shaft Power → Brake horse Power (BHP)

Water Power → Water horse power (WHP)

$$\boxed{\eta_o = \eta_h \times \eta_m}$$ $$\boxed{1\,hp = 745.7\,W}$$

AIR-1 Notes
Pages: 149

HYDOLOGY
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

HYDROLOGY

CONTENT

Hydrology

ESE – Objective (3-5 Ques)
– Conventional (25-45 Marks)
GATE – (2-4 Ques)

1) Introduction
2) Precipitation
3) Abstraktion from ppt. } Test ②
4) Surface Runoff
★★ 5) Hydrograph → Test ②
6) Stream flow Measurement
7) Flood / Flood Routing
8) Ground water

1. INTRODUCTION

→ Hydrology is an earth science involving study of water of earth.

→ Hydrological cycle

→ It is a global sun driven process in which water is transported from oceans to the atmosphere, then to the land and then back to the sea.

→ It is a continuous process with no definite starting point

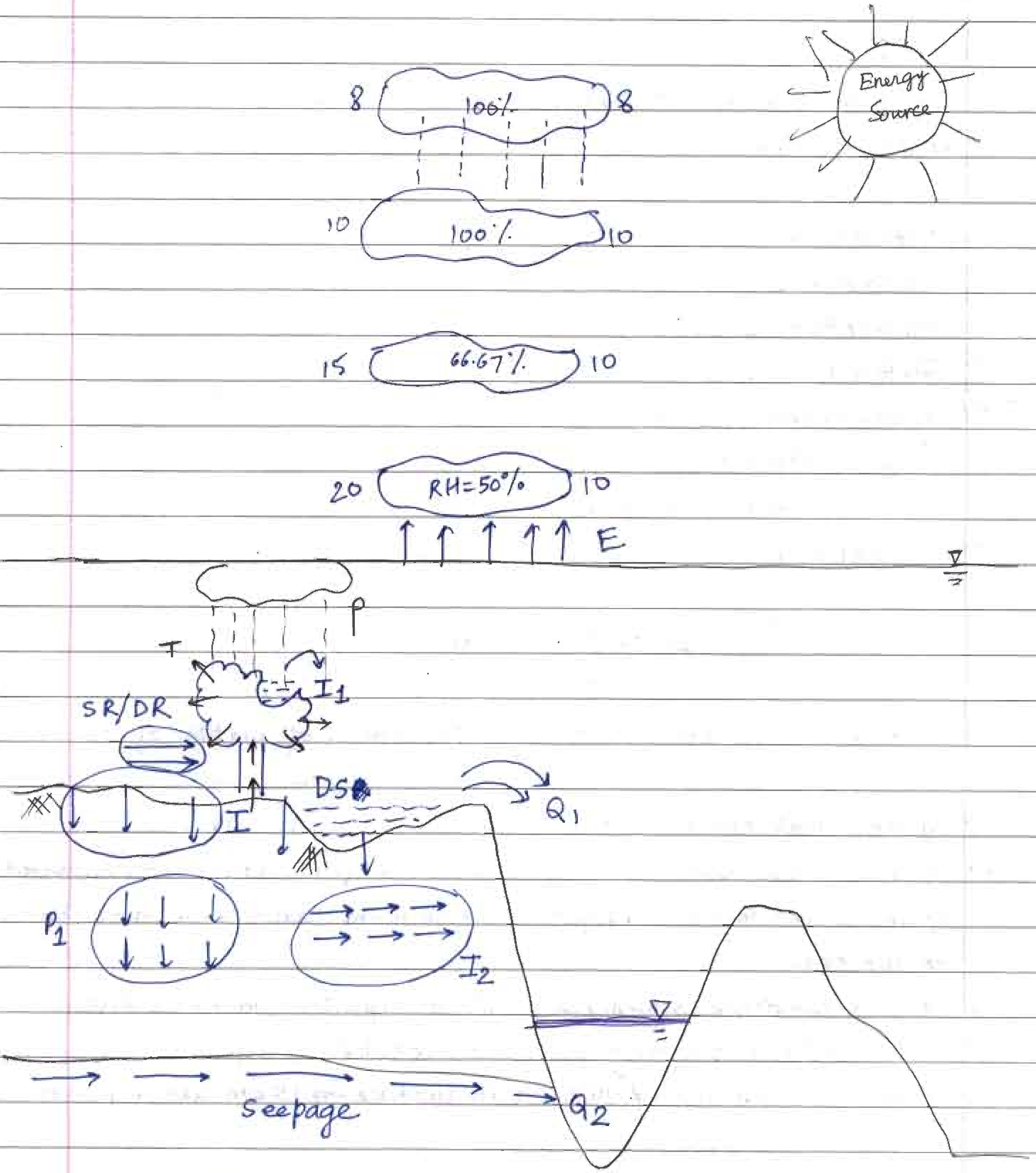
→ A convenient starting point to describe the cycle is taken as ocean

→ Extent → 1 km below the earth surface to 15 km above earth surface.

→ Relative Humidity

$$RH = \frac{\text{Actual vapour Carried}}{\text{Vapour carrying capacity}} \times 100\% \quad (\text{at constant temp.})$$

→ With decrease in temperature, RH increases and vice-versa



→ Due to ~~solid~~ solar radiation falling on ~~earth~~ ocean surface, water surface, water evaporates and mixes with the dry air → moist air. Moist air being lighter than dry air rises and in the

$I_1 \rightarrow$ Interception
$I \rightarrow$ Infiltration

process cools down thereby increasing its RH. RH subsequently reaches 100% (cloud formation). Any further rise in moist air causes condensation (in presence of condensation nuclei) followed by precipitation.

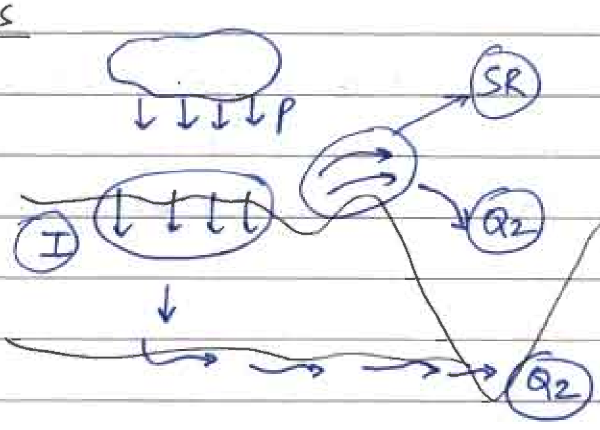
1) Evaporation (E): Change of water from liq to gaseous state.
2) Precipitation (P): Deposition of water on earth surface as rain, snow, hail et
3) Interception (I_1): Short term retention of rain water by vegetation, roof top, pavements etc.
4) Infiltration (I): It is the movement of water into the soil at the surface.
5) Percolation (P_1): Movement of water from one soil zone to a lower soil zone.
6) Transpiration (T): It is the water absorbed from ground and evaporated into the atmosphere through leaves
7) Interflow (I_2): It is the groundwater flowing horizontally above the water table. It is also called sub-surface flow.
8) Depression Storage (DS): Rainwater accumulated in small depressions or ditches above the surface.
9) Surface Runoff (SR): It is the part of rain which reaches the stream outlet soon after the rainfall flowing over the surface. Also, sometimes called Direct Runoff (DR), effective Rainfall or Rainfall excess.

NOTE:
Actually DR is slightly more than SR but for all practical calculations they are treated as same.

10) Q_2: It is the discharge obtained in the stream due to ground water table through seepage. It is also known as Base flow, Dry weather flow. or effluent seepage

11) Q_1 : It is the discharge obtained in the stream due to SR/DR.

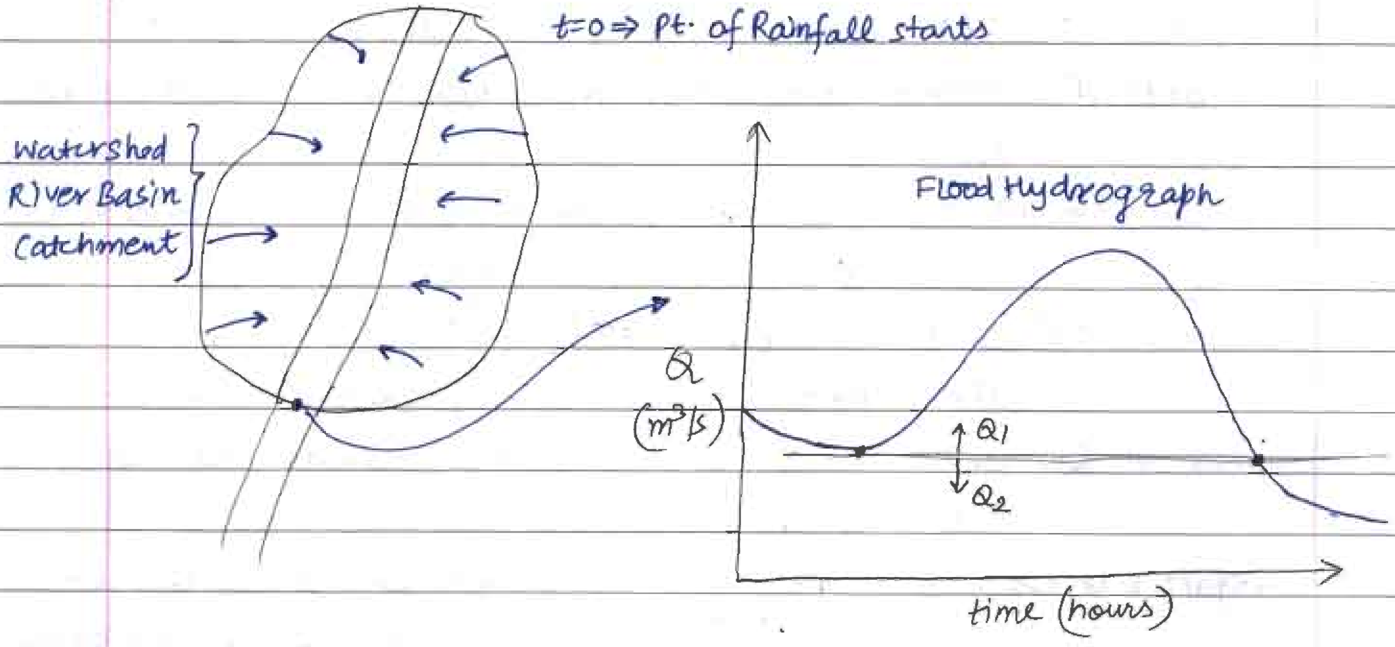
⇒ EXTRAS

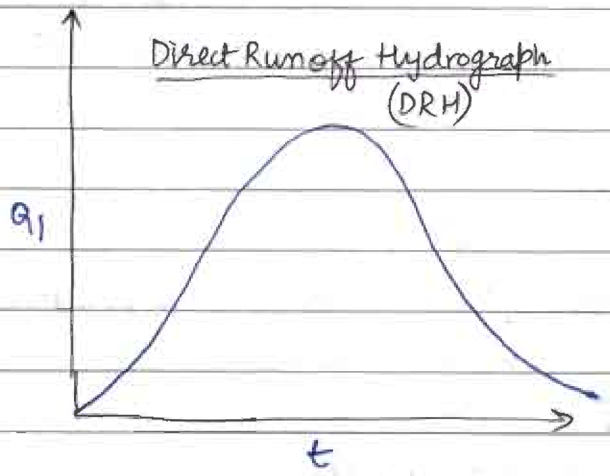


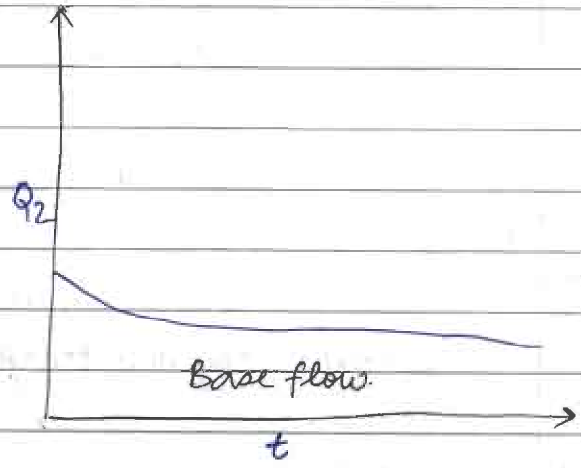
$$\boxed{P = I + SR}$$

Hydrograph: It is a plot of run off (discharge) v/s time.

t=0 ⇒ Pt. of Rainfall starts







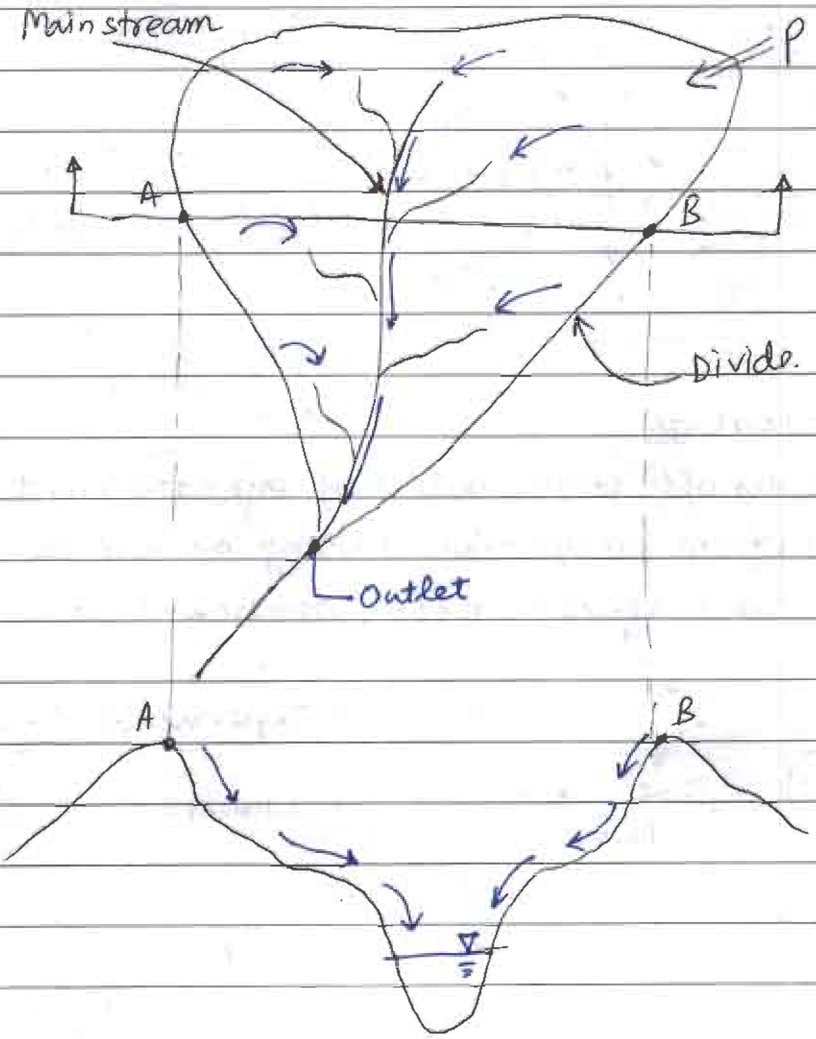
** Area of DRH = Volume of SR/DR/Effective Rainfall/Rainfall excess.

→ Evaporation ~~of~~ from oceans contributes to 90% of atmospheric moisture.

→ In oceans about 9% more water evaporates than falls back as precipitation.

→ Catchment Area: It is an area of land where surface water from rain and melting snow converges to a single point known as catchment outlet where the water joins another water body like lake, river or ocean.

→ catchment area is also known as watershed, river basin or simply basin.



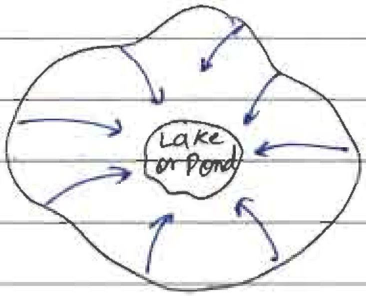
→ Each catchment is separated topographically from adjacent catchment by a geographical barrier such as mountains or hills or ridge

→ The line which divides the SR b/w 2 adjacent catchments is called as topographic divide / Watershed divide / Water divide or simply divide.

→ The divide follows the ridge line crossing the main stream only at the outlet

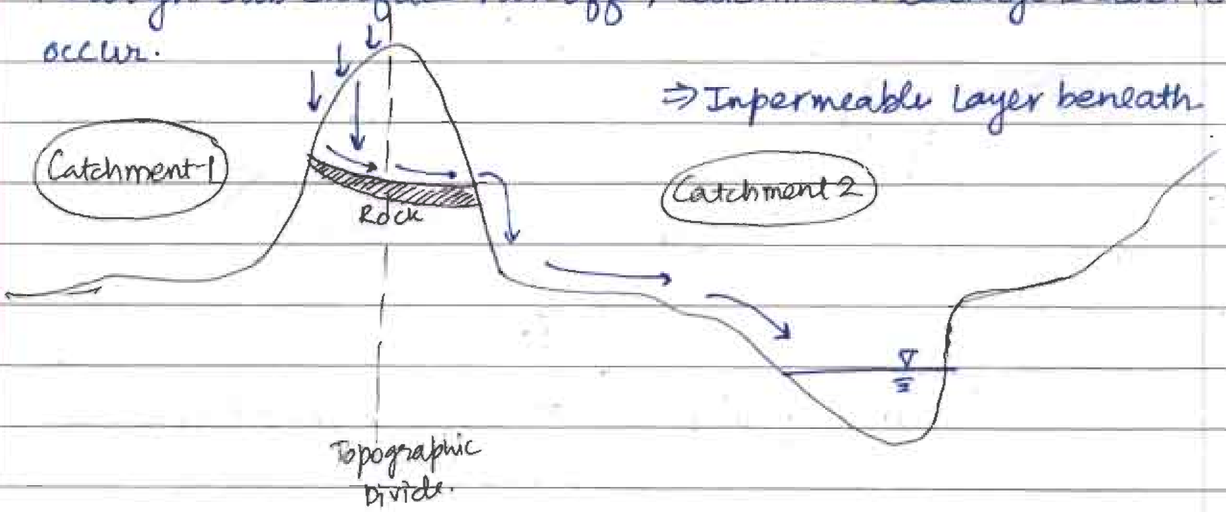
NOTE:

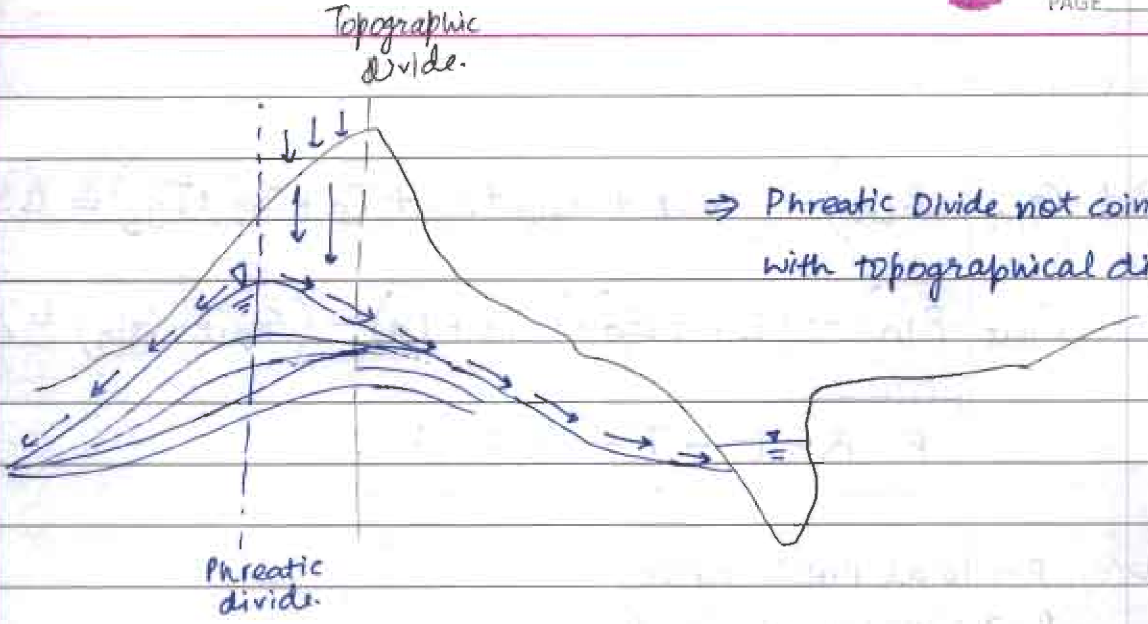
If all water converges to a single point inside the basin it is known as closed catchment



⇒ Catchment Leakage

→ when the runoff at the outlet of one catchment contains contribution from precipitation falling on adjacent catchment through sub-surface run off, catchment leakage is said to occur.





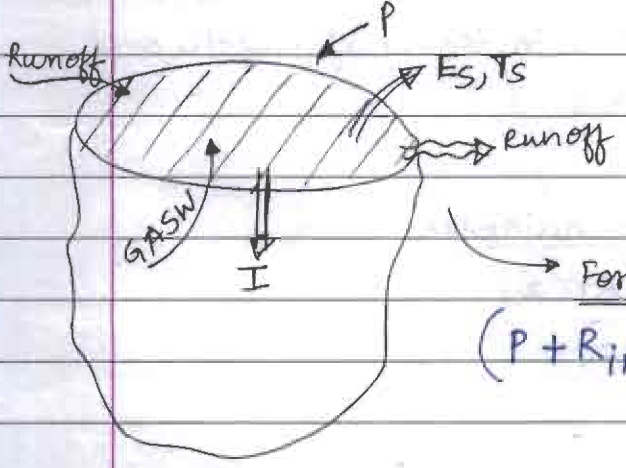
⇒ Phreatic Divide not coinciding with topographical divide.

⇒ Water budget / hydrological budget

→ It is based on law of conservation of mass.

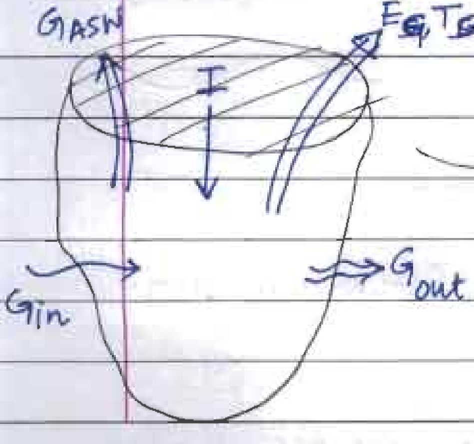
→ It states that:

$$\boxed{\text{Mass inflow} - \text{Mass outflow} = \text{Change in storage } (S_f - S_i)\ (\Delta S)}$$



→ For surface Runoff,

$$(P + R_{in} + G_{ASW}) - (I + E_S + T_S + R_{out}) = \Delta S_{surface}$$



→ For ground water flow

$$(I + G_{in}) - (G_{ASW} + G_{out} + E_G + T_G) = \Delta S_{ground}$$

⇒ Adding both terms, we have,

$$(P + G_{in} + R_{in}) - (R_{out} + G_{out} + E_s + T_s + E_g + T_g) = \Delta S_{Total}$$

$$P - (R_{out} - R_{in}) - (E_s + E_g) - (T_s + T_g) - (G_{out} - G_{in}) = \Delta S$$

$$\boxed{P - R - E - T - G = S}$$

where, P → total Precipitation
R → Net Runoff (out)
E → Total evaporation
T → Total Transpiration
G → Net Groundwater outflow
S → Change in Storage (Final − Initial)

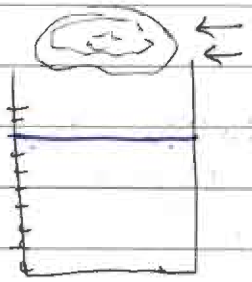
Important Points

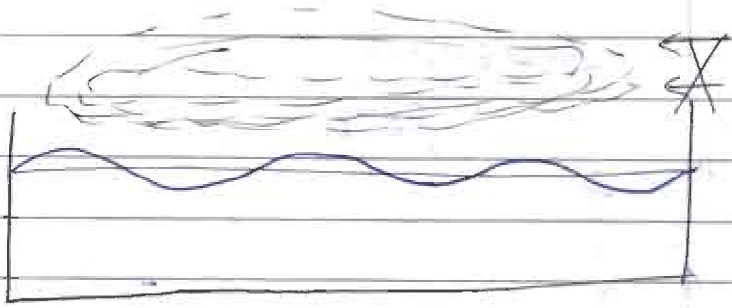
1) Precipitation as Rainfall is expressed in terms of depth over the horizontal projection of the area.

$$\text{Depth of Rainfall} = \frac{\text{Volume of Rainfall}}{\text{Projected Area}}$$

(Same goes for evaporation also)

2)





$$\boxed{\text{Lake Evaporation} = \underset{(<1)}{(\text{Pan coeff})} \times \underbrace{\text{Pan evaporation}}}$$

→ (depth of evaporation per unit time)

Q- A lake has water surface elevation of 103.2 m. above datum. In a month the lake receives an average inflow of 6 cumec and in the same period, the outflow from the lake was 6.5 cumec. In the same month, the lake recieives a rainfall of 145 mm. and the evaporation from lake surface was 6.1 cm. The surface area of the lake is 5000 ha. Calculate the surface elevation of lake at the end of this month.

$$103.2 + \left[\frac{-0.5 \times 86400 \times 30 + 0.145 \times 5000 \times 10^4 - 0.061 \times 5000 \times 10^4}{5000 \times 10^4} \right]$$

$$103.2 + \left[\frac{-0.5 \times 86400 \times 30}{5000 \times 10^4} + (0.145 - 0.061) \right] = 103.258\,m$$

Q- Following observations were made while conducting a water budget for a reservoir for a period of 1 month.

→ Average S.A. = 10 Km²
→ Mean Surface Inflow rate = 10 cumec.
→ Mean " Outflow rate = 15 cumec.
→ Rainfall = 10 cm
→ Fall in Reservoir level = 1.5 m
→ Pan evaporation = 20 cm.
→ Assuming pan coeff. as 0.7, Estimate the average seepage discharge from the reservoir during this month.

$$1.5 = \frac{(5+Q) \times 86400 \times 30}{10 \times 10^6} + \frac{0.7 \times 20 - 10}{100}$$

$$\boxed{Q = 0.6327 \text{ cumec}}$$

2. Precipitation

⇒ Forms of precipitation

1) Rain – Principal mode of ppt. in India (approx. 120cm annualy)
– Denotes water droplets, size ranges from 0.5 to 6.0mm
– On the basis of intensity it is classified as:
(a) light (0 - 2.5 mm/hr)
(b) medium (2.5 – 7.5mm/hr)
(c) heavy (> 7.5 mm/hr)

2) Snow – They are flaky ice crystals having a density of 0.1g/cc

3) Drizzle - Are water droplets less than 0.5 mm with intensity less than 1 mm/hr.

4) Sleet – Frozen rain drops

5) Hail – It consists of large spheres of ice having diameter 5mm to 50 mm.

6) Glaze – When water droplet comes in contact with cold surface it freezes to form an ice coating known as glaze.

⇒ Intensity of rainfall : If x depth of rain falls over a catchment area in time, t, then the average intensity of rainfall, i is given by:

$$\boxed{i = \frac{x}{t}}$$

It is generally expressed in mm/hr or cm/hr.

Q- The intensity of rainfall and time interval of a typical storm is given below. The maximum intensity of rainfall for a 20 minute duration of rainfall in mm/min is ?

time interval (min)	intensity (mm/min)
0 -10	0.7
10 -20	1.1
20-30	2.2
30-40	1.5
40-50	1.2
50-60	1.3
60-70	0.9
70-80	0.4

2.2 → 22 mm
1.5 → 15 mm

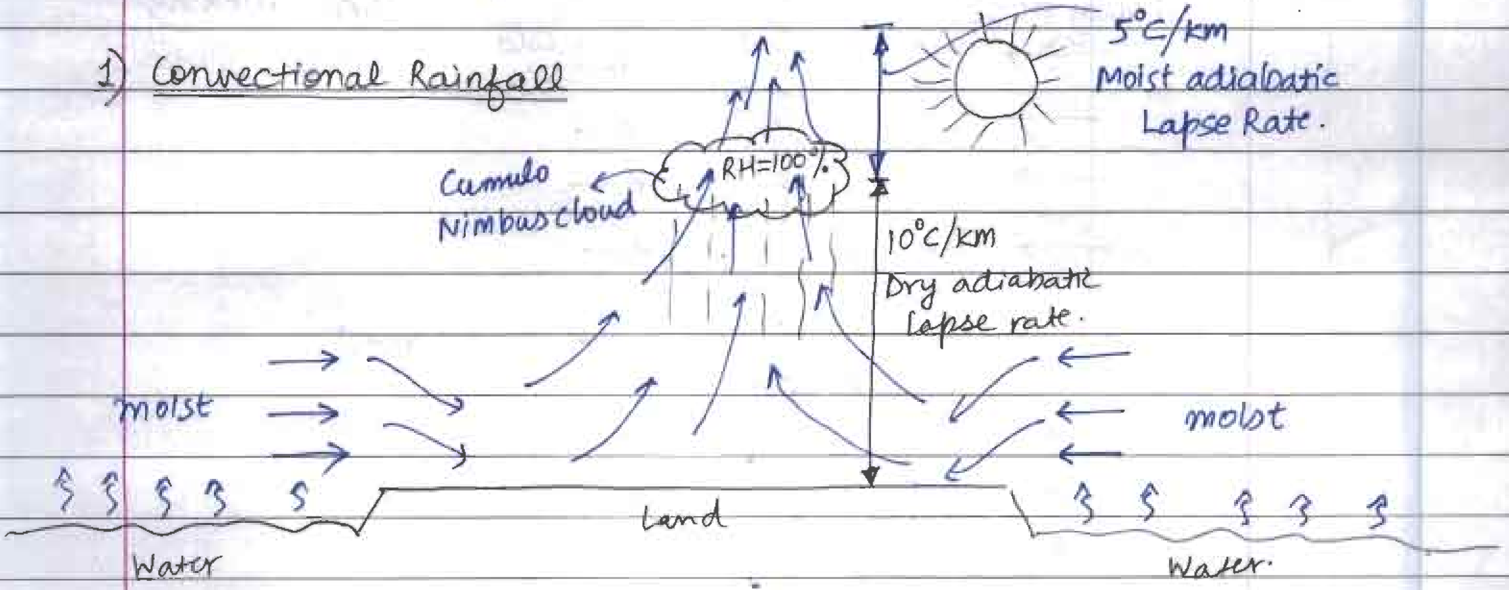
$\Rightarrow$ 37mm in 20min

$\Rightarrow \frac{37}{20} = 1.85$ mm/min.

⇒ Types of Rainfall

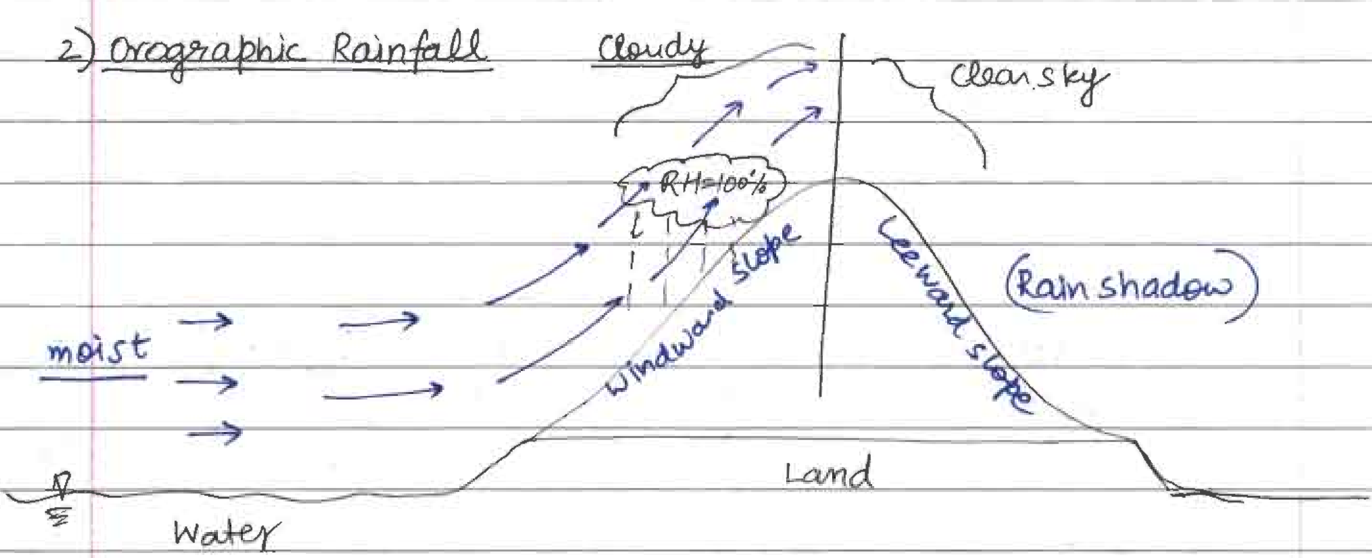
→ Precipitation as Rainfall is classified on the basis of conditions and mechanism of upward movement of moist air.

1) Convectional Rainfall



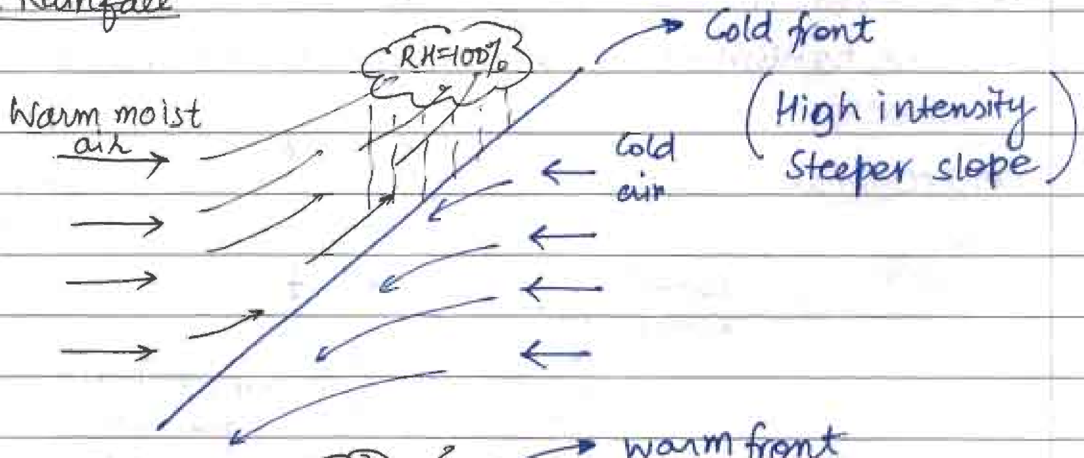
- It occurs due to thermal convection current formed by heating of ground surface.
- Moist adiabatic lapse rate is less than dry adiabatic lapse rate due to release of latent heat of vapourization

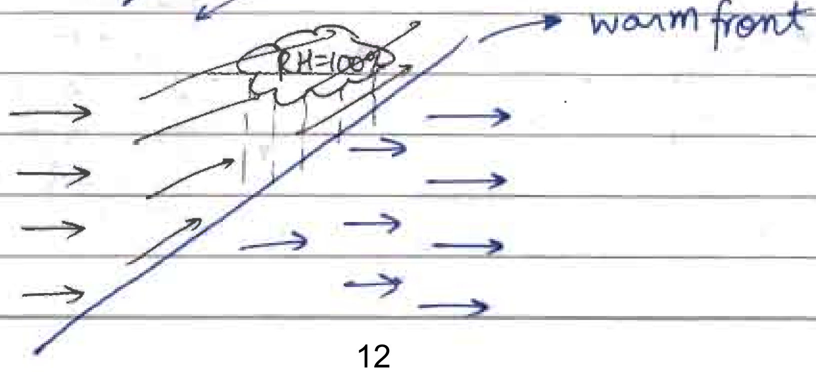
2) Orographic Rainfall



- This ppt. is caused by ascent of air from large water bodies forced by mountain barriers.
- Most of world's pptation including India's occurs through orographic rainfall.

3) Frontal Rainfall





→ This pptation occurs due to conflict between 2 air masses of different temperatures and densities

4) Cyclonic Rainfall

→ This pptation is the result of lifting of air masses due to pressure differences. If low pressure occurs in an area, air will flow in horizontally from all directions causing the air in the low pressure area to lift, resulting in condensation followed by pptation.

→ The air that rushes horizontally changes into a whirling mass due to the rotation of the earth (coriolis effect) and is called cyclone.

Cyclone	Anticyclone
→ Low pressure at the centre	→ High pressure at the centre
→ Counter-cw in Northern hemisphere and cw in Southern hemisphere	→ Cw in northern hemisphere and a.c.w in southern hemisphere.
→ Indicator of Rain.	→ Indicator of good weather
→ Ex- Hurricane, Typhoon	

→ Measurement of Precipitation

→ Precipitation as Rainfall is measured by a device known as rain gauge

→ It is also known as Ombrometer, Pluviometer or hydrometer.

→ Types of Rain gauges

1) Non-Recording Type

→ They do not give a continuous plot (variation) of rainfall against time.

→ Non Recording gauge widely used in India, is Symon's Rain gauge

AIR-1 Notes
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IRRIGATION ENGINEERING
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

IRRIGATION ENGINEERING

CONTENT

24/06/19

Irrigation Engineering

Syllabus

1) Introduction
2) Soil Plant Relationship
3) Water requirement of crops
4) Canal Design
5) Sediment Transport
6) Lining of Canal
7) Reclaimation of water logged and saline soil
8) Design of gravity Dams → GATE
9) Theory of seepage
10) Miscellaneous Topics
    (a) River Draining
    (b) Cross Drainage work
    (c) Diversion Headwork
    (d) Modules
    (e) Canal fall

} GATE (items 2–4)

1. INTRODUCTION

→ Irrigation is artificial application of water to the agriculture field for the purpose of cultivation. i.e. in accordance with crop requirement throughout the crop period for optimum growth of crops.

NOTE:

Crop period is time period from instant of sowing to the instant of harvesting.

⇒ Necessity of Irrigation

1) Inadequate Rainfall
2) Uneven distribution of Rainfall
3) Increasing yield of crops
4) Growing more than one crop in a year.
5) Growing perennial crops like sugarcane.
6) Prevention from drought and famine condition.

⇒ Advantages of Irrigation

(a) Direct advantages

1) Increasing yield of crops
2) Prevention from drought and famine condition
3) Elimination of mixed cropping.

NOTE:

Mixed cropping means growing 2 or more crops simultaneously in the field.

↳ Advantages

↳ Mixed cropping is found economical and necessary when irrigation facilities are lacking i.e if ~~ete~~ weather conditions are not suitable for one of the crop, they may be suitable for other crop and hence farmer will get atleast some yield.

↳ Disadvantages

↳ Diff. crops require diff. types of field preparation, watering pattern, manuring etc. Since it would be difficult to satisfy need of both the crops simultaneously in the field hence, it will result in low yield.

↳ Also at the time of harvesting crops would get intermixed which reduces purity and value of crops in the market.

(b) Indirect Advantages

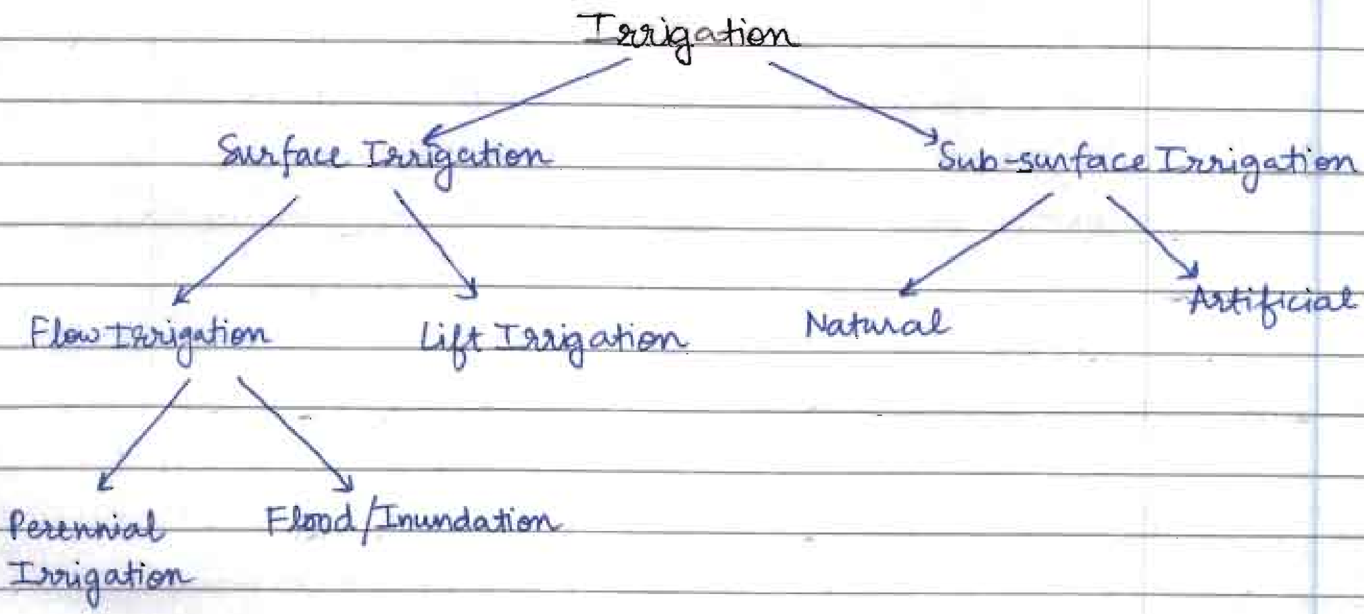
1) Power generation → Ganga Sharda canal system generates 80 MW hydropower.
2) Flood control
3) Transportation → Inland Navigation and Roads
4) Ground water recharge (Percolation)
5) Industrial and domestic water supply
6) Employment generation.

⇒ Disadvantages of Irrigation

1) Water logging
2) Intense irrigation results in cold and damp climate which may cause spreading of disease like dengue and malaria.
3) Ground water pollution due to percolation of water.

NOTE: Bad effect of irrigation can be overcome by economical and scientific use of water.

⇒ Types of Irrigation



⇒ Surface irrigation

→ Surface irrigation is a method in which water is directly applied to the soil surface either by gravity or pumping.

→ It is best suitable for soil with low to moderate infiltration capacities.

→ It is suitable in the area with rolling terrain. (gentle slope)

→ Surface irrigation can be further classified as:

1) Flow Irrigation – If water is available at higher elevation and it is supplied to the lower elevation under the action of gravity, it is called as flow irrigation.

2) Lift Irrigation – If water is lifted up by some mechanical means or some manual means and supplied to the agriculture field it is called as Lift Irrigation.
eg. – Pump, well and Tube well.
Lift Irrigation is costlier than flow Irrigation.

→ Flow Irrigation can be classified as:

1) Perennial Irrigation – If a constant and continuous water is supplied to the agriculture field as per the requirement of crops throughout the crop period it is called as perennial irrigation.

(a) Direct Irrigation – By diverting river run off into a canal with the help of weir or barrage. eg – Ganga canal system.

(b) Storage Irrigation – System of dam and channels
eg – Ram Ganga Dam Project.

2) Flood Irrigation / Inundation – In this system of irrigation a large quantity of water flowing in a river during the flood is allowed to flood or inundate the area which is to be cultivated which causes saturation of the area.

When excess water is drained off under the action of gravity, then cultivation can be practised eg- Sunderbans.

⇒ Sub-surface irrigation

→ In this type of irrigation system, water does not wet the soil surface rather it is directly supplied to the root zone of the plants.

→ It is classified into 2 types:

(a) Natural Sub-Surface Irrigation

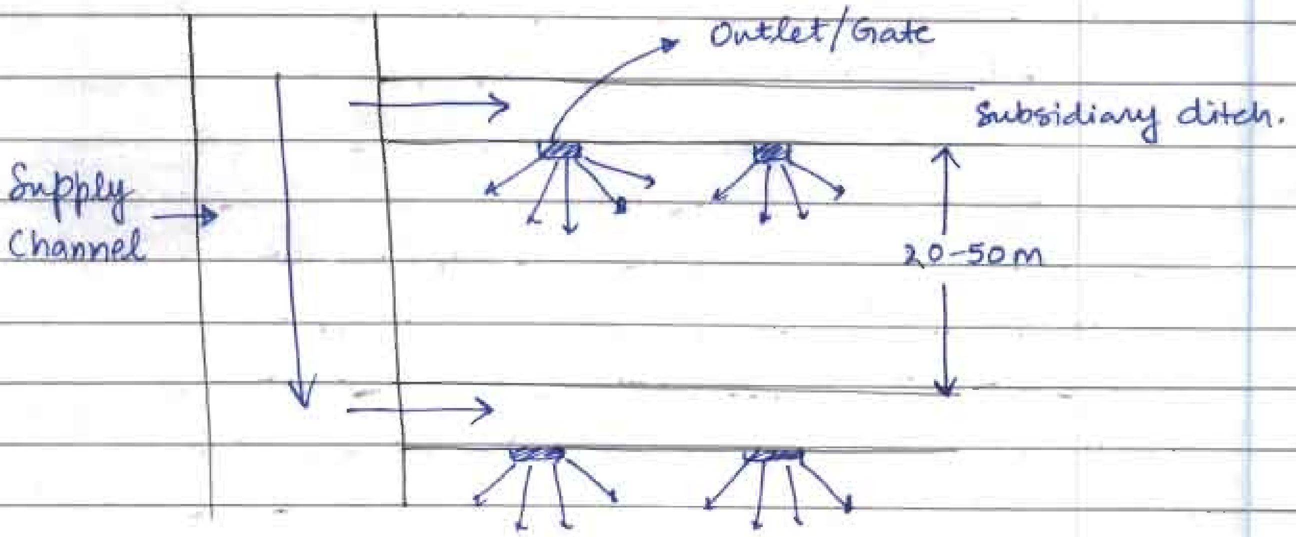
In this system, water seeping through channels and water bodies may irrigate crops grown on lower area by cappilarity.

(b) Artificial Sub-Surface Irrigation

In this system, water is directly supplied to the root zone of plants by a network of perforated pipes, which are laid below the soil surface.

⇒ Techniques of water distribution

1) Free flooding / ordinary Flooding.



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→ In this method ditches are excavated in the field and water from these ditches flows across the field.

→ After water leaves the ditches, no attempt is made to control the flow, hence it is called as wild flooding.

→ Suitable for rolling terrain (gentle slope)

→ Field preparation is low.

→ Water application efficiency is low.

→ Suitable for close growing crop like pasture.

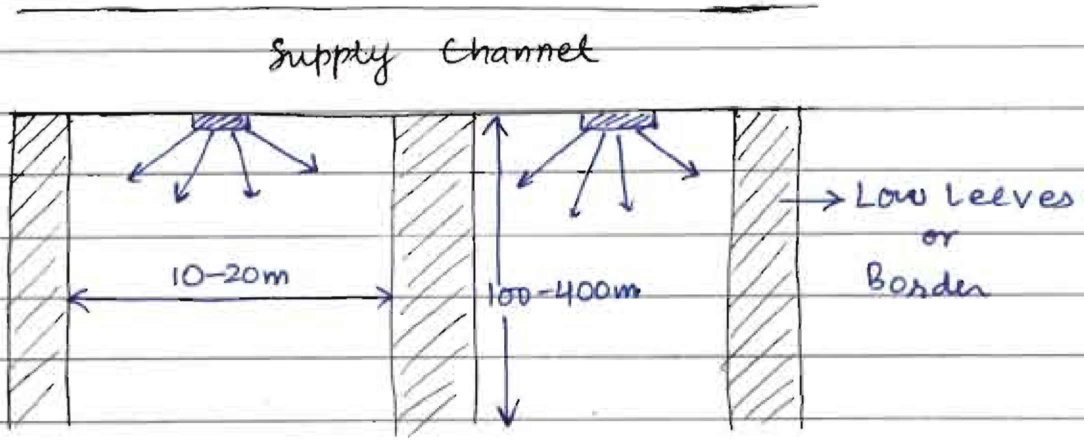
→ Subsidiary Ditch / Lateral Ditch are spaced 20–50 m apart depending on :

(a) Slope

(b) Type of Soil

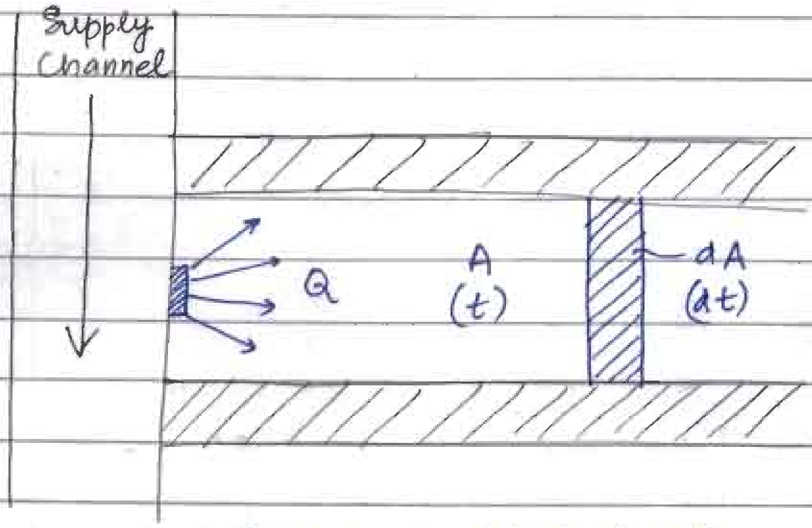
(c) Crop etc.

2. Border Flooding



→ Area is divided into no. of strips separated by low Levees called border.

→ Relation between discharge through supply channel (Q), rate of Infiltration of soil (f), average depth of flow over strips (y), area to be irrigated (A) and time required to irrigate the area (t)



$$Q\,dt = y\,dA + fA\,dt$$

→ Assuming Q, y and f as constant.

$$(Q - fA)\,dt = y\,dA$$

$$\int dt = \int \frac{y}{Q - fA}\,dA$$

$$t = \frac{y}{-f}\left[\ln(Q - fA)\right] + c$$

→ If t = 0 then A → 0.

$$c = \frac{y}{f}\ln Q$$

$$\Rightarrow t = \frac{y}{f}\ln\left(\frac{Q}{Q - fA}\right)$$

$$\Rightarrow \boxed{t = 2.303\,\frac{y}{f}\log\left(\frac{Q}{Q - Af}\right)}$$

⇒ Maximum area that can be irrigated with a particular amount of discharge

if $t \to \infty$ then $A \to A_{max}$

therefore, $Q - A_{max} f = 0$

$$\Rightarrow \boxed{A_{max} = \frac{Q}{f}}$$

→ Size of the strip will depend on discharge (Q), characteristic of soil (f) and slope of the area.

Q- For Border strip method of irrigation, time required to irrigate a strip of 0.04 hectare from a tubewell with a discharge of 0.02 cumec. Infiltration capacity of the soil is 5cm/hr and average depth of flow on the field is 10cm. Also determine maximum area that can be irrigated from this tubewell.

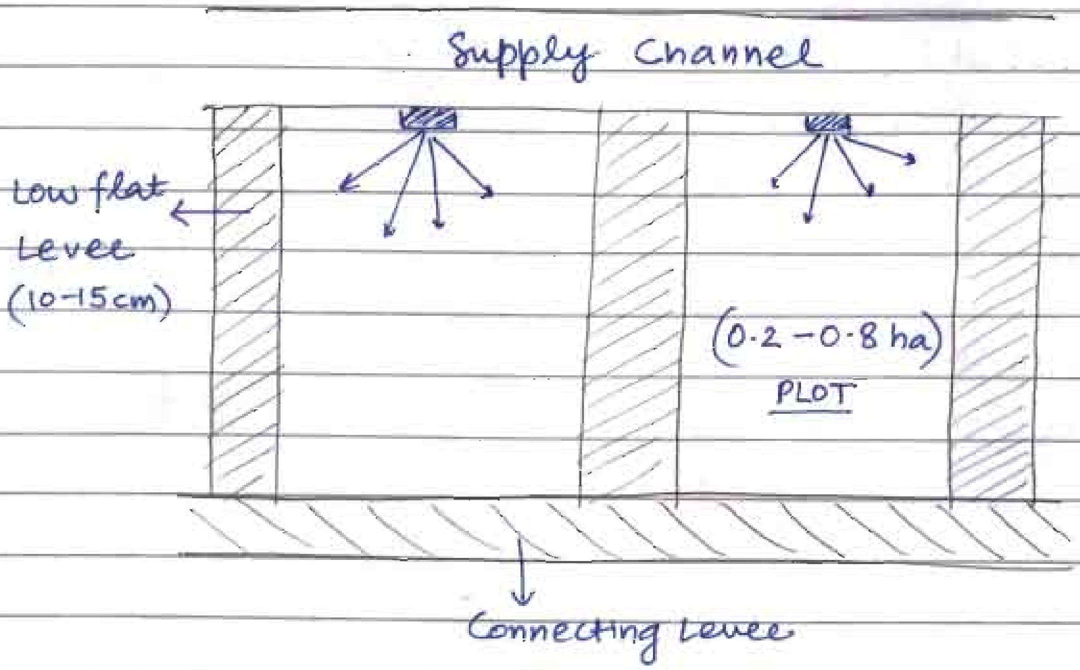
$$t = \frac{2.303y}{f} \log_{10}\left(\frac{Q}{Q-Af}\right)$$

$$t = 2.303 \times \frac{10}{5} \left(\log_{10} \left\{ \frac{0.02}{0.02 - 400 \times \frac{0.05}{3600}} \right\} \right)$$

$$t = 39.05 \text{ mins.}$$

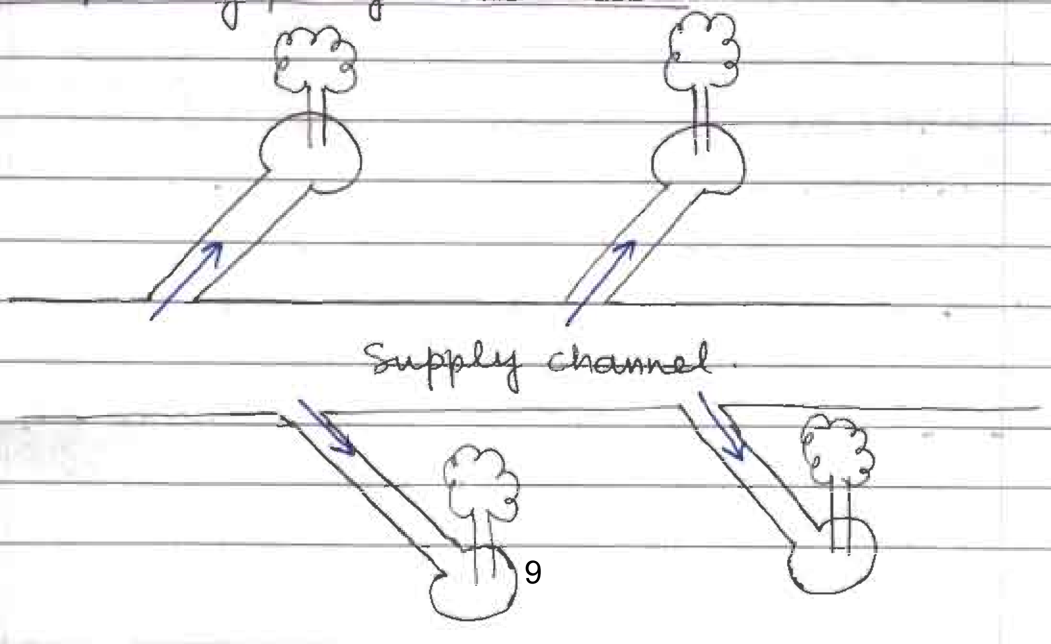
$$A_{max} = \frac{Q}{f} = \frac{0.02 \times 3600}{0.05} = 1440 m^2 = 0.144 ha$$

3) Check Flooding / Method of irrigation by plots (Paddy)



- → In this method, the area to be irrigated is divided into small Plots of area 0.2-0.8 hectares with low flat levees.
- → Each plot has a nearly fair level surface.
- → Irrigation water is applied by filling the plots with water upto desired depth without overtoppling the levees and water is retained there to allow it to infiltrate into the soil.

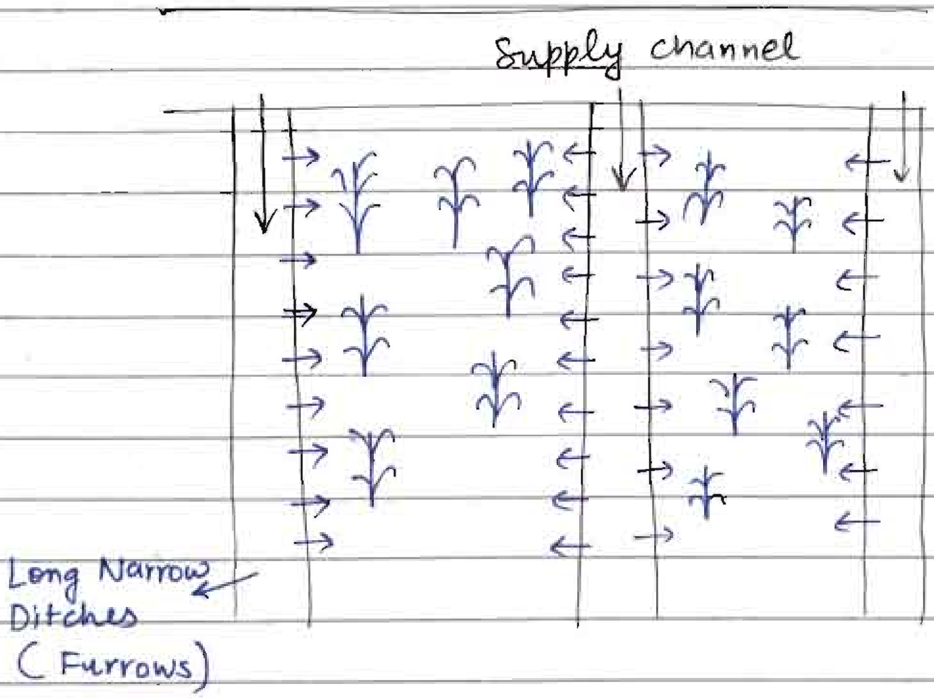
4) Basin flooding / Ring Basin Method



→ This method is a special form of check basin method which is used for irrigation of orchards [enclosure of fruit trees].

→ A separate circular basin is provided for each tree.

5) Furrow Irrigation



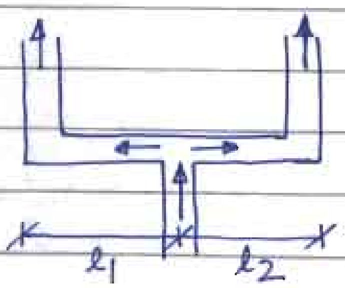
→ In this method water applied to the field to be irrigated by a series of long narrow field channels which are called as furrows, are excavated at regular interval.

→ water entering into these furrows infiltrates into the soil and spreads laterally to irrigate the area between the furrows.

→ In this method, 20-50% area is wetted which results in less evaporation

→ It is suitable for Row crops, cotton, maize, potato, groundnut etc.

6) Sprinkler irrigation



→ In sprinkler irrigation method, water is applied to the land in the form of spray through the network of pipes and pumps.

→ Advantages

(a) It is similar to rain, hence uniform application of water is possible.

(b) It can be used for wide range of topography, soil and crops i.e. irregular topograpuy, steep slope and area in which soil is easily erodable.

(c) No field preparation is required.

(d) Surface runoff and percolation losses are eliminated.

(e) Field application efficiency increases close to 80%.

(f) Fertilizer, insecticide and pesticide can be mixed with water and supplied.

(g) It can be used even when infiltration capacity of soil is high or low.

(h) It can be used even when water table is high.

(i) About 15-20% crop area is increased because no area is lost in ditches and furrows.

→ Disadvantages

(a) Evaporation loss is high.

(b) It causes interference in farming operation due to network system.

(c) Wind may disturb sprinkler pattern which results in non-uniform application of water.

(d) High initial cost.

(e) Requires large electrical power and constant water supply.

(f) Cannot be used for crops requiring large and frequent depth of water. ex- paddy.

(g) Water shall be cleaned from sand and silt because it may cause choking of the system.

7) Drip Irrigation / Trickle Irrigation

→ In this method water is directly and slowly applied to the root zone of the plants by using small diameter plastic pipes with drip nozzles, commonly called as emitters or drippers

→ Water is applied at very low rate (2-10 l/hr) to keep the soil moisture within the desired range of plant growth.

→ Irrigation application efficiency = 90%

→ Evaporation loss, surface run off and percolation loss can be eliminated.

→ Fertilizer can be mixed with water and supplied.

→ Cost of whole system is very high but it is useful ~~for it~~ in the areas where availability of water is less.

→ It is very useful for fruits and vegetables.

⇒ Quality of Irrigation water

1) Sediment

(a) Effect of sediment on quality of irrigation water depends on nature of sediment and characteristic of soil receiving that water.

→ If sediment contains large content of plant nutrients and/or it comes from fertile area then it is quite beneficial particularly for the soil which has low content of plant nutrient and very low water holding capacity.

→ If sediment is not rich in plant nutrients and it is deposited on the surface of fertile area, then it will make area infertile.

2) Concentration of Soluble Salts

→ When salts present in irrigation water are in excess quantity they increase osmotic pressure of soil solution, which causes high soil moisture stress in the root zone and it affects growth of plants and yield of the crops.

→ Bad effect of salts on the plant growth depends on the concentration of salts left in the soil.

→ Concentration of salts in the water may not appear to be harmful initially but with the passage of time the salt concentration in the soil may increase to harmful level as soil solution gets concentrated by evaporation.

→ Salinity concentration of soil solution (C_s) after consumptive use (C_u) is given by:

$$C_s = \frac{C\,Q}{Q - (C_u - R_{eff})} \quad \text{PPM or mg/L}$$

Where, C → concentration of salts in applied water

Q → Quantity of water applied.

C_u → Consumptive use of water i.e. total quantity of water used by crop for its growth.

R_{eff} → effective rainfall that is stored in the root zone

AIR-1 Notes
Pages: 60

Open Channel Flow
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

OPEN CHANNEL FLOW

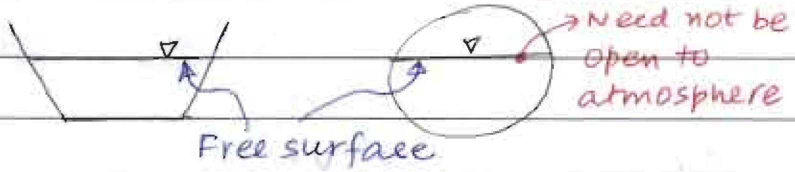
CONTENT

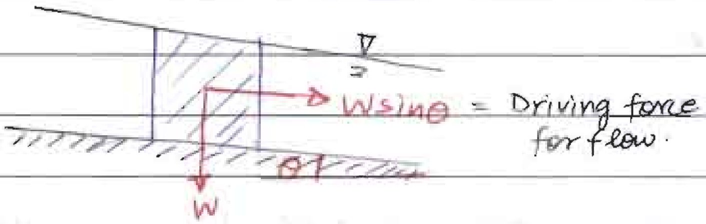
Open Channel Flow

① Introduction
② Uniform Flow
③ Energy-depth Relationship
④ Gradually Varied Flow
⑤ Rapidly Varied Flow
⑥ Surges (X GATE)

Chapter 1 - Introduction

→ Flow having free surface is called open channel flow.
→ open channel flow is due to the gravity effect.





NOTE: On free surface, shear stress is 0.

Type of channel

Prismatic channel	Non-Prismatic Channel	Rigid Boundary Channel	Mobile Boundary Channels
Channel having constant shape, size and bed slope are called prismatic channel. Generally, artificial channels like canals are prismatic	Natural channels are generally Non prismatic canal.	If boundary is non-deformable like- Lined canals or non-erodable unlined canal	They are the ones in which boundary is deformable.

→ In rigid boundary channels, only depth of flow will vary with space and time particularly if it is prismatic.

→ The shape and roughness parameter is not a function of flow parameter

→ In mobile boundary channel, the flow carries significant amount of sediments in suspension and in contact with bed.

→ In OCF, we will study the prismatic channel.

⇒ Type of flow

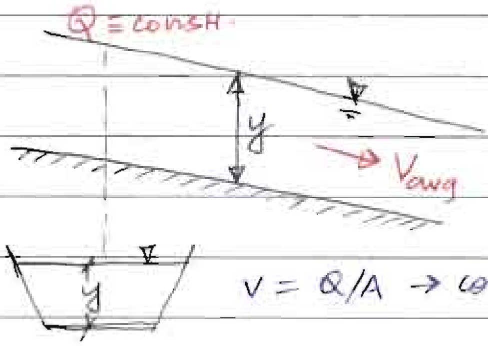
Steady Flow	Unsteady Flow
① Uniform Flow	① GVUF
② Gradually Varied Flow (GVF)	② RVUF
③ Rapidly Varied Flow (RVF)	③ SVUF
④ Spatially Varied Flow (SVF)	

→ If the depth of discharge changes with time, it is unsteady flow otherwise it is steady flow.

→ Steadyness or unsteadyness also depends on observers reference frame.

→ A flow may be unsteady in the inertial frame of reference but may be steady in other frame of reference.

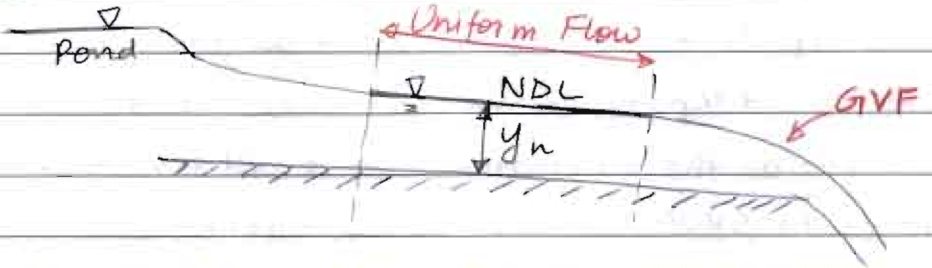
① Uniform Flow



$V = Q/A$ → constant.

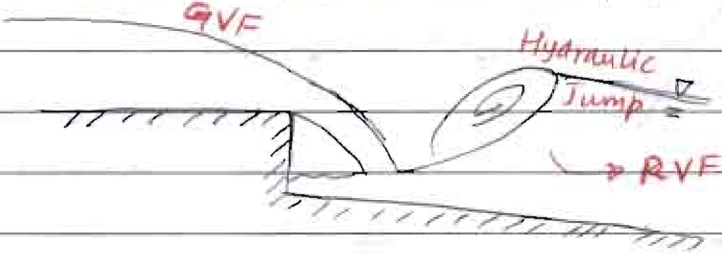
→ If in a prismatic channel, the velocity of flow and depth of flow is constant at various sections, then it is a uniform flow.

→ Depth of flow under Uniform flow is called Normal depth of flow.

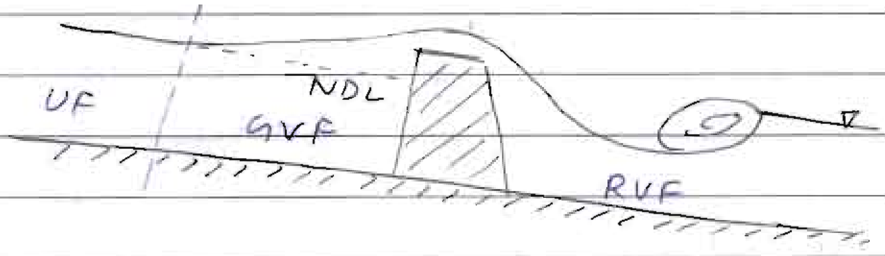


→ Any flow if left undisturbed for some distance, it tries to achieve normal depth of flow.

→ Obstruction to the flow causes the flow to vary



→ If the depth of flow varies gradually along the length of the channel it is called Gradually varied flow. But if the depth of flow varies rapidly varied flow.



→ We know that, if streamlines are straight lines, pressure variation across the depth can be taken as hydrostatic [i.e. piezometric head is constant with depth). Hence, in case of uniform flow, pressure variation across the depth can be taken as hydrostatic.

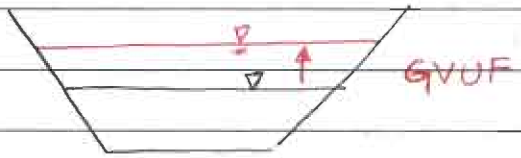
→ In case of GVF, since the streamlines are curved, normal acceleration will exist and pressure distribution truly will not be hydrostatic but since the curvature of streamline is very small in case of GVF, we can take the pressure variation to be hydrostatic, but

→ In case of RVF, since the curvature of streamline is large, pressure distribution across the depth will not be hydrostatic.

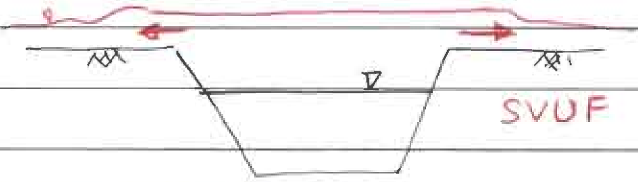
→ Since the GVF profile length is large, friction has significant effect on it but effect of friction on RVF can be neglected.

⇒ SVF – If the flow is added or extracted from the system, the flow will be called spatially varied, like infiltration from runoff. So long as the infiltration rate is not constant, flow will be termed as SVUF but once the infiltration rate becomes constant, flow can be treated as SVF.

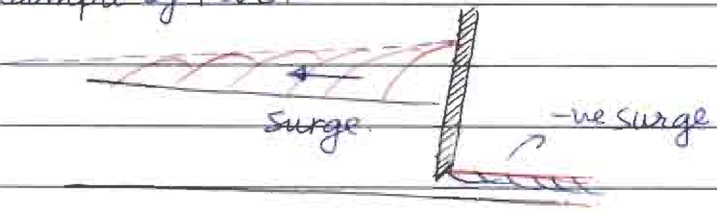
→ Passes of flood wave through a river is an example of GVUF



→ But if the river banks are breached, it is an example of SVUF



→ Surge is an example of RVUF



⇒ Laminar and Turbulent Flow

→ Reynolds no. in OCF, $\boxed{R_e = \frac{VR}{\nu}}$

V → average velocity

R → Hydraulic Radius = $\frac{\text{Area}}{\text{Wetted Perimeter}}$

→ If $R_e < 500$ → Flow in Open channel is laminar.

→ If $R_e > 2000$ → Flow is taken as turbulent.

→ Generally natural channels and canals have turbulent flow.

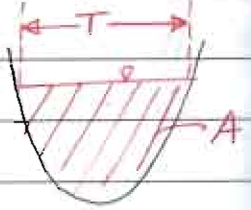
⇒ Critical, Sub-critical and Super critical flow

$$\boxed{F_r = \frac{\overset{\text{average}}{V}}{\sqrt{gD}}}$$

D = hydraulic Depth = $\frac{A}{T}$

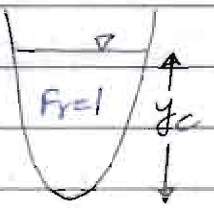
A → Area of flow

T → Top surface width



⇒ $C = \sqrt{gD}$ = celerity → velocity of small gravity wave that occurs in shallow water, generated due to disturbances (small) or obstacles in the channel. It is the velocity of wave wrt water and travels both upstream and downstream

⇒ $V = C$	$F_r = 1$	→ Critical flow
$V > C$	$F_r > 1$	→ Supercritical flow / Torrential / Shooting / Rapid flow
$V < C$	$F_r < 1$	→ Sub-critical flow / Tranquil flow



$F_r = 1 \rightarrow y = y_c$

$F_r < 1 \rightarrow y > y_c$

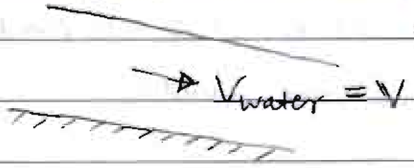
$F_r > 1 \rightarrow y < y_c$

$$F_r = \sqrt{\frac{\text{Inertial Force}}{\text{Gravitational Force}}}$$

⇒ Velocity of wave wrt ground

Velocity of wave wrt water = c [small wave in shallow water]

Velocity of wave wrt ground = $c \pm V_{water}$



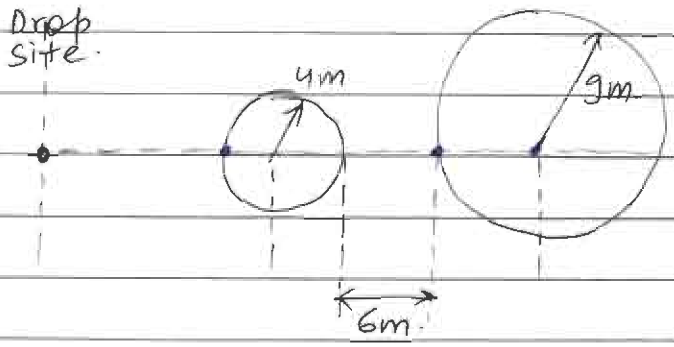
⇒ Upstream travel speed of wave = $c - V$

⇒ Downstream travel speed of wave = $c + V$

⇒ Under sub-critical flow conditions, since $V < C$, the small disturbance wave can travel upstream, but under super critical flow, since $V > C$, a small disturbance wave cannot travel upstream.

⇒ This property can be used for identifying the type of flow in field by throwing a small object, creates a ripple which travels in upstream direction also, the flow is subcritical and if does not travel upwards, the flow is supercritical.

Q- Water flows rapidly in a flat wide channel, 0.4m deep. Pebbles dropped successively in the water at the same spot creates 2 circular ripples as shown in the figure below. Find the speed of water in m/s.



$\frac{V}{\sqrt{gy}} > 1.$ $\quad c = \sqrt{gy} = 1.98$ m/s

$V > C$

$(V-C)(t_2-t_1) = 14$

$(V+C)(t_2-t_1) = 24$

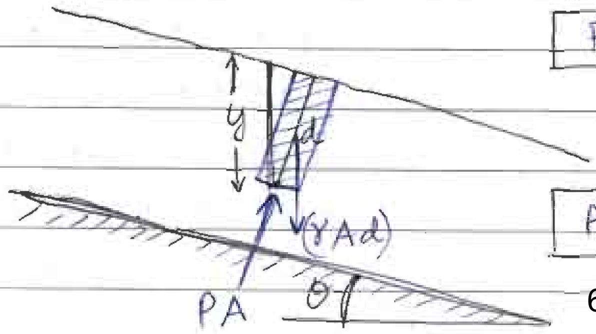
$\frac{V-C}{V+C} = \frac{14}{24} \Rightarrow 24V - 24C = 14V + 14C$

$\Rightarrow V = \frac{38C}{10} = 7.524$ m/s

→ Since disturbance does not travel upstream in super critical flow, it means that the flow upstream of a specified location does not know what is happening on the downstream side. In other words, ~~the~~ to change of flow condition at a section, flow condition must be changed on the upstream side in case of super-critical flow. The super critical flow is said to have u/s control.

→ Sub critical flow is said to have downstream control.

⇒ Pressure Distribution



$PA = (\gamma A d) \cos\theta$

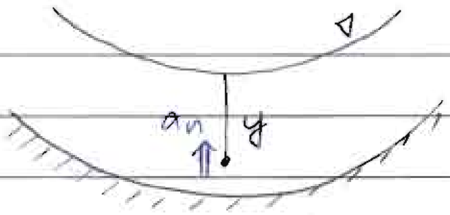
$\boxed{P = \gamma d \cos\theta}$

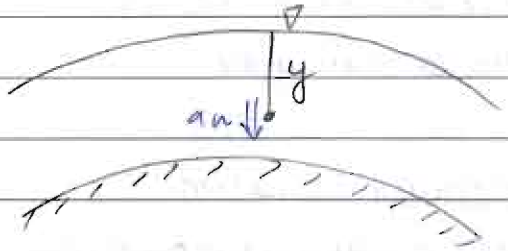
Since, $d = y\cos\theta$

$\boxed{P = \gamma y \cos^2\theta}$

→ Generally for natural channels, $\theta < 6^\circ$ and hence pressure can be taken as γy i.e hydrostatic pressure

→ Generally for large slopes i.e $\theta \geq 6^\circ$, we consider the effect of θ in pressure





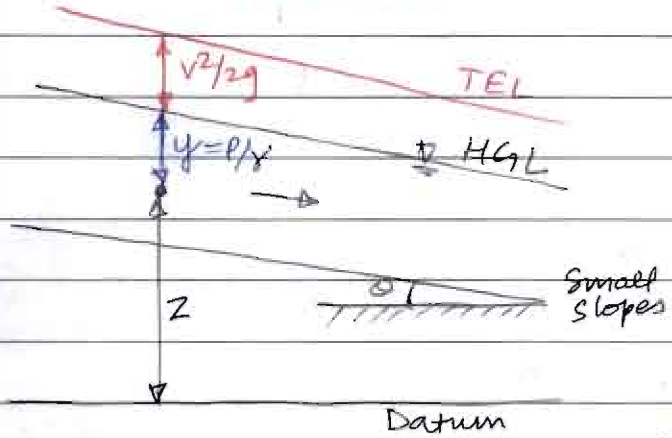
$P = \rho g_{eff} h$

$\boxed{P = \rho(g + a_n)y}$

↳ $P > P_{hydrostatic}$

$\boxed{P = \rho(g - a_n)y}$

↳ $P < P_{hydrostatic}$

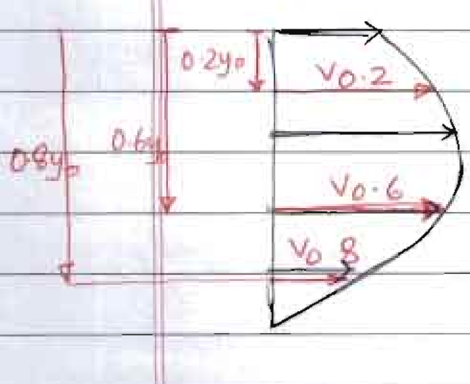


→ Generally for small slopes, HGL coincides with the freesurface

$$\boxed{H_{large\ slope} = y\cos^2\theta + z + \frac{v^2}{2g}}$$

→ For large slopes, HGL lies below the free surface.

NOTE: In OCF, free surface coincides with HGL if the channel slope is small, vertical curvature of the flow lines and acceleration are negligible.

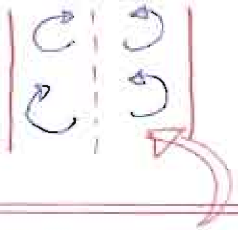


$$\boxed{V_{avg} = V_{0.6} = \frac{V_{0.2} + V_{0.8}}{2}}$$

→ V_{max} occurs slightly below the free surface

→ V_{avg} is taken as K V ~~avg~~ free surface

i.e. $\boxed{V_{avg} \simeq K\, V_{free\ surface}}$ → where K = 0.8 to 0.95

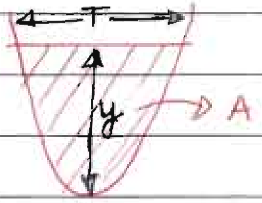


- → The dip in the flow profile is due to secondary currents.
- → Wind effects are negligible
- → if $B > 10y$ [5-10 ~~times~~ of y], the channel is treated as wide channel and in wide channel in the central part, the velocity dip is negligible.

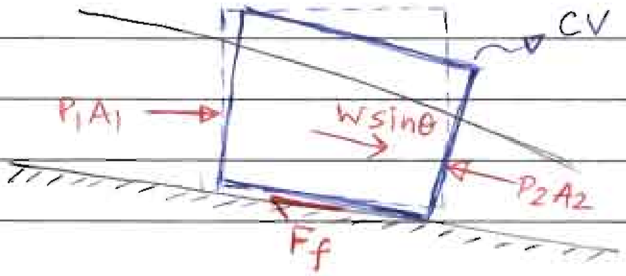
⇒ Continuity Equation

- → For steady incompressible flows, the continuity equation in open channel is taken as $\boxed{Q = \text{constant}}$ i.e. $A_1V_1 = A_2V_2$
- → For unsteady incompressible flows, the continuity equation is taken as:

$$\boxed{\frac{\partial Q}{\partial x} = -T\frac{\partial y}{\partial t}}$$



⇒ Momentum equation in OCF



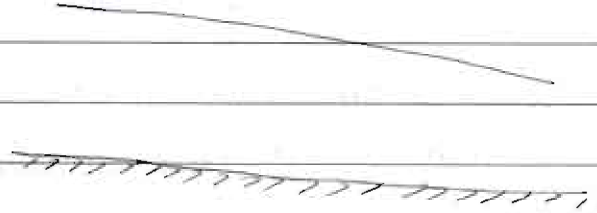
$$P_1A_1 - P_2A_2 + W\sin\theta - F_f = M_2 - M_1 = \overset{\beta_2 \approx 1}{\beta_2}\rho Q V_2 - \overset{\beta_1 \approx 1}{\beta_1}\rho Q V_1$$

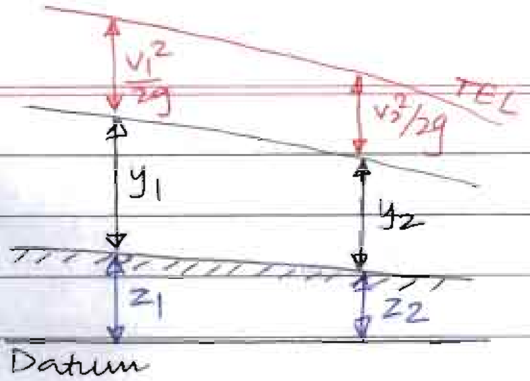
for horizontal and frictionless channel,

$$P_1 - P_2 = M_2 - M_1$$

$$\boxed{\frac{P_1 + M_1}{\gamma} = \frac{P_2 + M_2}{\gamma}} \Rightarrow \boxed{\frac{P+M}{\gamma} = \text{specific force.}}$$

⇒ Energy equation in OCF





$$\frac{P_1}{\gamma}+z_1+\frac{v_1^2}{2g}\alpha_1=\frac{P_2}{\gamma}+z_2+\frac{v_2^2}{2g}\alpha_2+h_L$$

$(\alpha \simeq 1)$

$$\boxed{y_1+z_1+\frac{v_1^2}{2g}=y_2+z_2+\frac{v_2^2}{2g}+h_L}$$

$$\boxed{\text{Specific energy} = \frac{v^2}{2g}+y = E}$$

→ Specific energy can be said to be the distance b/w channel bed and TEL.

NOTE: Critical Flow

→ Under critical state of flow, flow is under unstable state i.e. even a small change in the energy i.e. even a small disturbance can cause significant change in the depth of flow.

→ water surface will appear to be wavy and unsteady.

→ Under critical condition,

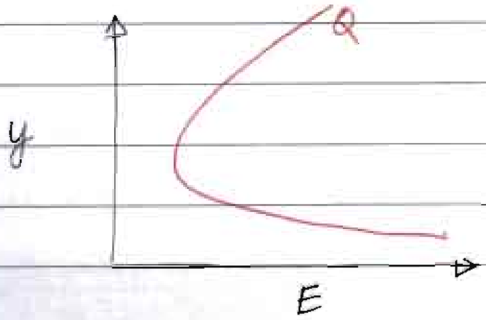
① Specific energy is minimum for a given discharge.
② Discharge is maximum for a given specific energy
③ Specific force is minimum for a given discharge.

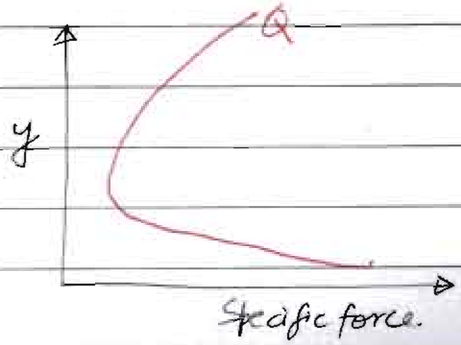
→ Froude No. = 1

✓ → Velocity head = $\frac{1}{2}$ × (hydraulic depth) $\left[\frac{v^2}{gD}=1 \Rightarrow \frac{v^2}{2g}=\frac{D}{2}\right]$

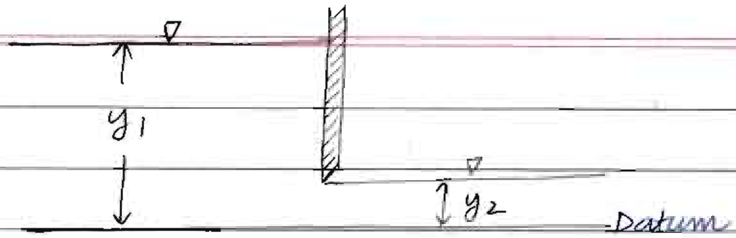
→ Velocity of flow in channel of small slope with uniform velocity distribution equals celerity (c) of small gravity wave in shallow water caused by local disturbances.

→ Slight change in ~~depth~~ energy causes significant change in depth of flow

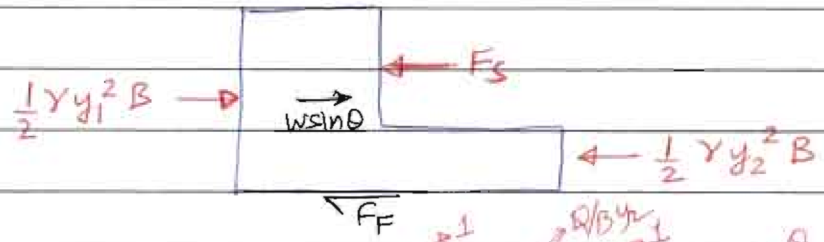




Q-



Find the force exerted by water on the sluice gate assuming negligible losses.



$$\frac{1}{2}\gamma(y_1^2-y_2^2)B - F_s = \overset{1}{\beta_2}\rho Q \overset{Q/By_2}{V_2} - \overset{1}{\beta_1}\rho Q \overset{Q/By_1}{V_1}$$

$$F_s = \frac{B\gamma(y_1^2-y_2^2)}{2} + \frac{\rho Q^2}{B}\left(\frac{1}{y_1}-\frac{1}{y_2}\right)$$

Now, applying energy eqn

$$y_1 + \frac{V_1^2}{2g} = y_2 + \frac{V_2^2}{2g}$$

$$\frac{Q^2}{2gB^2} = \frac{y_1-y_2}{\frac{1}{y_2^2}-\frac{1}{y_1^2}} = \frac{y_1^2 y_2^2}{y_1+y_2}$$

$$F_s = \frac{B\rho g(y_1^2-y_2^2)}{2} + 2\rho g B\left(\frac{y_1^2 y_2^2}{y_1+y_2}\right)\left(\frac{1}{y_1}-\frac{1}{y_2}\right)$$

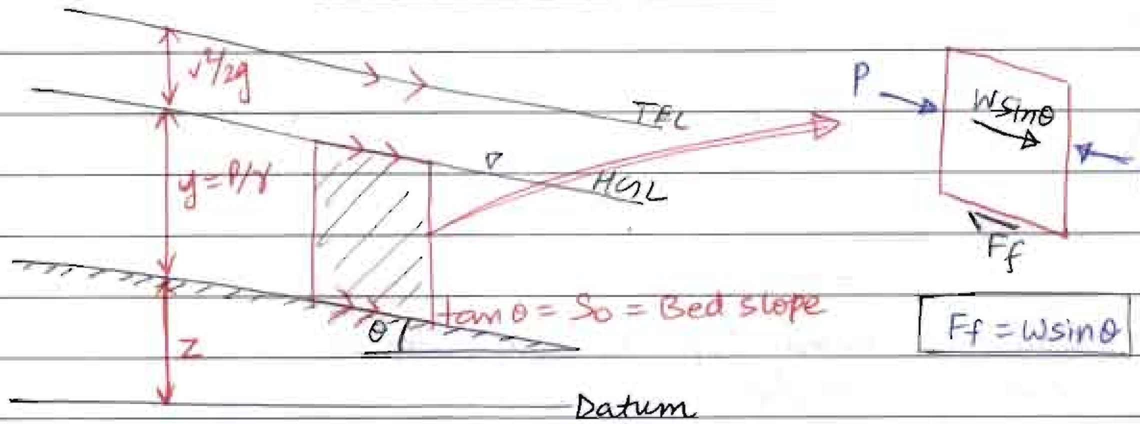
$$\frac{F_s}{B} = \frac{\gamma_w}{2} \quad y_1^2-y_2^2 + 4\frac{y_1^{\cancel{2}} y_2^{\cancel{2}}}{y_1+y_2}\left(\frac{y_2-y_1}{\cancel{y_1 y_2}}\right)$$

$$\frac{F_s}{B} = \frac{\gamma_w}{2}(y_1-y_2)\left[y_1+y_2 - \frac{4y_1y_2}{y_1+y_2}\right]$$

$$\boxed{\frac{F_s}{B} = \frac{\gamma_w}{2}\frac{(y_1-y_2)^3}{y_1+y_2}}$$

NOTE: If we have the discharge given in the above problem then we should not use the formula for force per unit width as given above

Chapter-2 Uniform Flow



- → If the depth of flow, velocity of flow remains constant along the channel length, then the flow is said to be uniform.
- → velocity of flow can vary along the depth but velocity profile at every section will remain same.
- → For establishment of uniform flow certain length is required as transitiony zone. If the length of channel is less than the transitory zone length, uniform flow will not get established.
- → In case of uniform flow since the velocity is not changing, the weight component in the direction of flow must be balanced by the frictional force.
- → The constant depth of flow under uniform flow is called normal depth of flow (y_n). Any flow if left undisturbed for sufficiently long distance, it will try to achieve, the normal depth of flow.
- → Under uniform flow condition, since y and v are constant, the total energy line, the water surface line & bed of the channel will all be parallel, Hence, $\boxed{S_f = S_0}$ (S_f is the energy line slope)

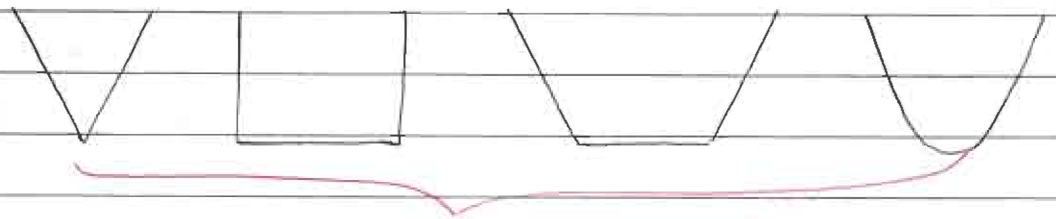
$$\boxed{Q = \frac{1}{n} A R^{2/3} S_f^{1/2} = \frac{1}{n} A R^{2/3} S_0^{1/2}}$$ ⇒ Manning's Equation

$$\boxed{Q = CA\sqrt{RS_f} = CA\sqrt{RS_0}}$$ ⇒ Chezy's Equation.

↳ Since, in uniform flow, $S_f = S_0$.

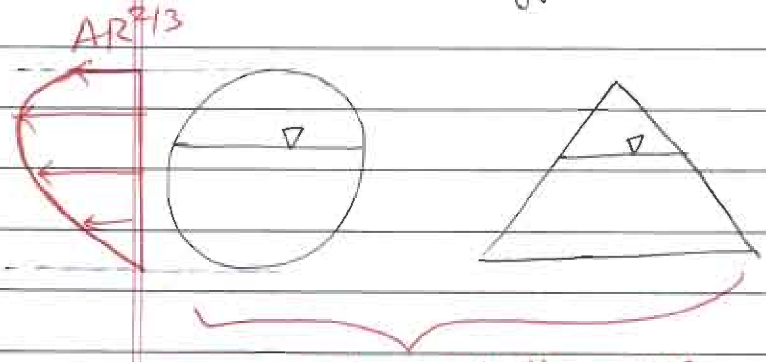
$$\frac{Qn}{\sqrt{S_0}} = R^{2/3}\cancel{S_0^{1/2}}A \Rightarrow \boxed{\frac{Qn}{\sqrt{S_0}} = \overset{f(y)}{AR^{2/3}}}$$

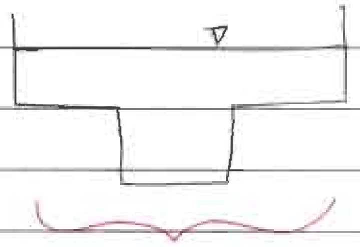
→ Depth of flow obtained from this equation is $y = y_n$ i.e. normal depth of flow.



Only one normal depth of flow for a fixed Q, n, So.

↳ Type 1 channel (Regular channels)





There can be more than one depth for which the flow is uniform, for fixed Q, n, So

↳ Type 2 channel

Irregular Geometry

① Type 1 channel – Top surface width is increasing or remains constant with increasing depth.

② Type 2 channel – Top surface width is decreasing with increasing depth.

NOTE: $AR^{2/3}$ increases with increase in depth of flow for type 1 channels but for Type 2 channels it increases and then decreases.

→ If n and So are known, there is only one discharge possible for uniform flow.

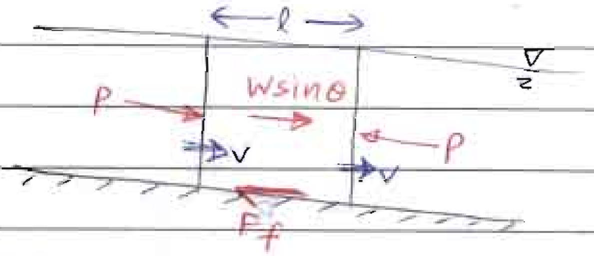
→ Value of chezy's constant is $\boxed{c = \sqrt{\frac{8g}{f}}}$ f → Darcy weischback friction factor.

→ Manning's n can be written as $\boxed{n = (n_b + n_1 + n_2 + n_3 + n_4)\,m}$

n_b → base value for straight, uniform and smooth channel
n_1 → depends on surface irregularity
n_2 → depends on shape and size of X-section
n_3 → depends on obstruction
n_4 → depends on vegetation
m → depends on meandering of channel

→ For lined canals, value of n ranges b/w 0.011 to 0.016
For natural channels, value of n ranges b/w 0.025 to 0.050

→ Momentum equation for uniform flow

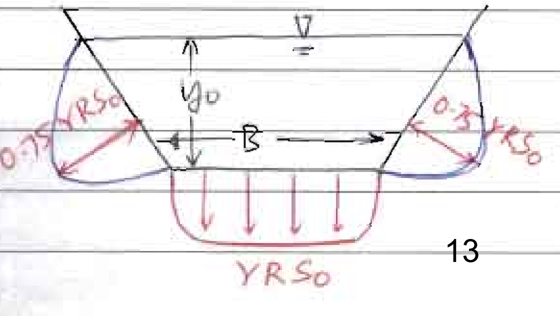


$$P - P + W\sin\theta - F_f = \rho QV - \rho QV$$

$$\boxed{F_f = W\sin\theta}$$

$W = \gamma A l$
$F_f = \tau_{bed} \times P \times l$
As θ is very small, $\sin\theta \simeq \tan\theta = S_0$

So, $\tau_{bed} = \frac{\gamma A \cancel{l} S_0}{P \cancel{l}} = \gamma R S_0 \Rightarrow \boxed{\tau_{bed} = \gamma R S_0}$ → Average shear on the bed.



Valid for $B > 6y_0$

AIR-1 Notes
Pages: 41

PLASTIC ANAYSIS
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

PLASTIC ANALYSIS

→ In the conventional design, a section is assumed to have failed if any point in the section reaches the permissible stress for atmost yield stress (f_y).

→ However, if one point in the cross-section reaches the f_y value the section still has capacity to resist loading before collapse.

→ Thus in plastic analysis, we use the strength beyond the point of first yield i.e. Reserve of strength.

→ Plastic analysis is mostly used for indeterminate structures.

→ In case of determinate structures, beam might fail in deflection criteria before collapse load is reached whereas in case of indeterminate structures, even near collapse loading, deflection may not be significant.

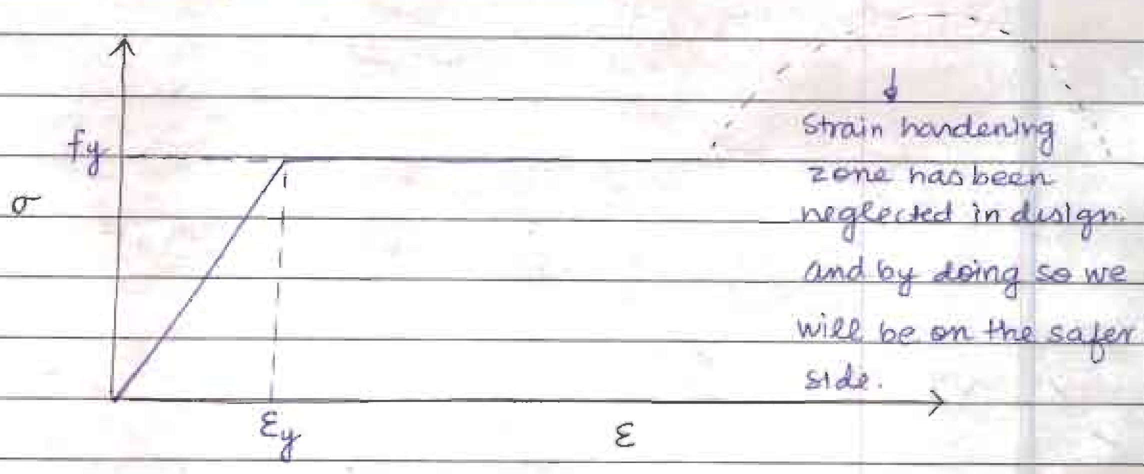
→ Hence, failure mode will be material failure only.

⇒ Assumptions in Plastic Analysis

① Material must possess ductility so that it can be deformed to plastic state.

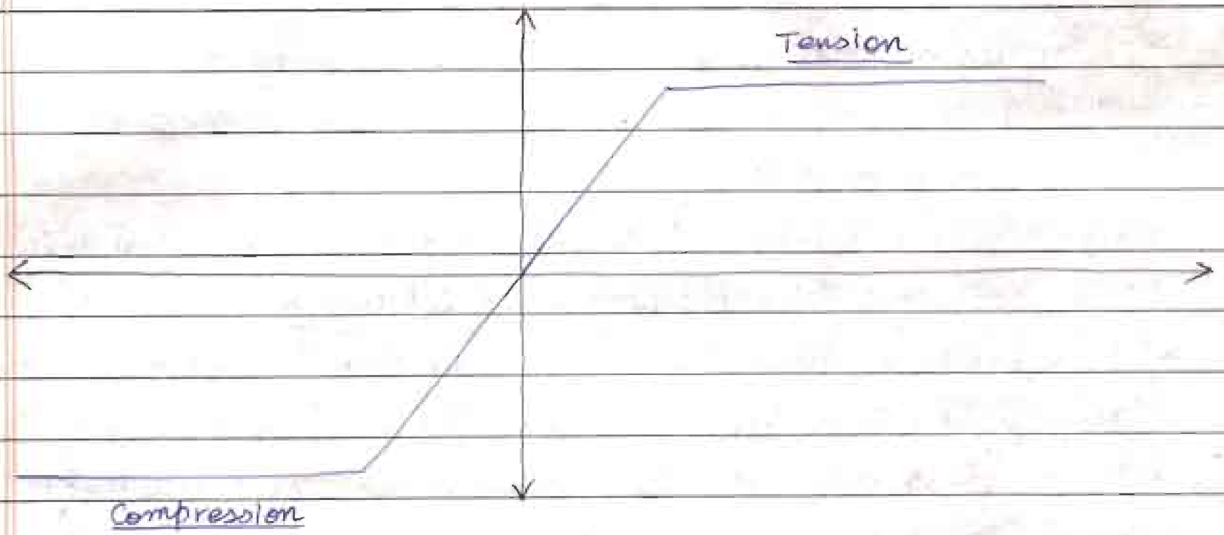
② Strain distribution diagram is linear i.e. plane section before bending remains plane after bending.

③ Stress-strain diagram is idealised elasto-plastic.



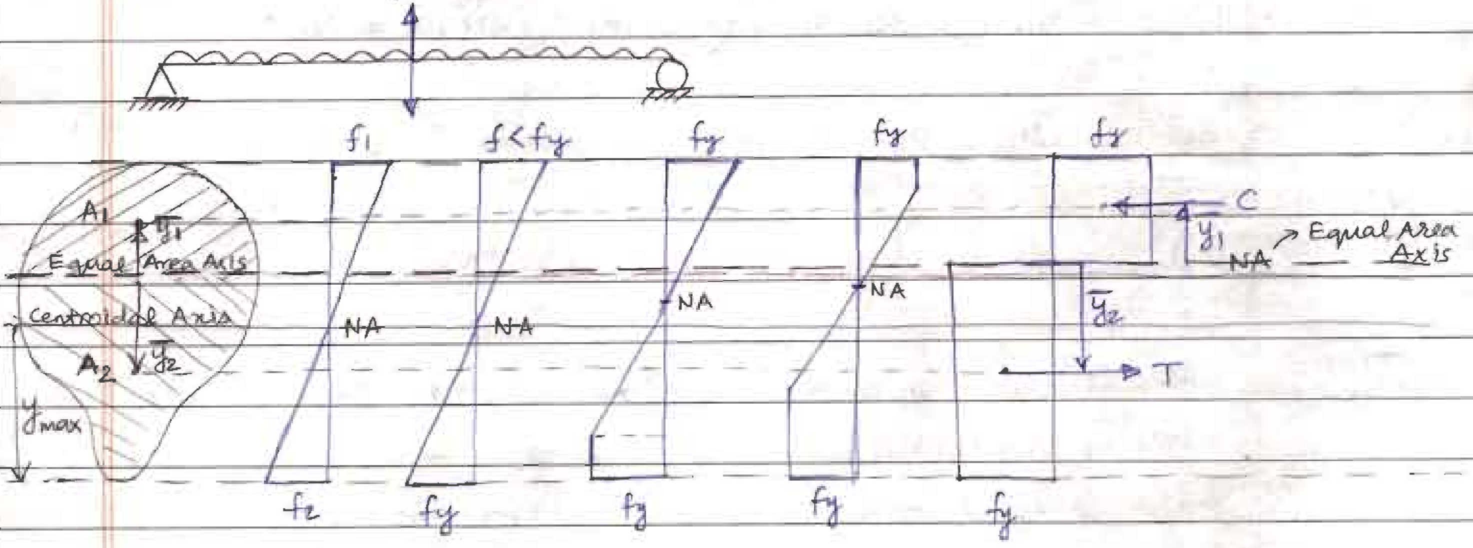
Strain hardening zone has been neglected in design and by doing so we will be on the safer side.

④ Relation between stress and strain is same in tension and compression



⑤ Joints should be sufficiently rigid to transfer the moments.

⇒ Plastic Bending of Beam



$f_2 > f_1$ $\quad M_y = f_y \cdot z_{max}$

$$z_{max} = \frac{I_{CG}}{y_{max}}$$

From force equilibrium, $C = T$

$$f_y A_1 = f_y A_2 \Rightarrow \boxed{A_1 = A_2} = \frac{A}{2}$$

and $M_P = C(\bar{y}_1 + \bar{y}_2) = T(\bar{y}_1 + \bar{y}_2)$

$$= f_y \frac{A}{2}(\bar{y}_1 + \bar{y}_2)$$

So, $$\boxed{M_p = \frac{f_y A}{2}\left(\bar{y}_1+\bar{y}_2\right) = f_y Z_p}$$

$$\boxed{\text{where } Z_p = \frac{A}{2}\left(\bar{y}_1+\bar{y}_2\right)}$$

M_p → Fully Plastic Moment Capacity

Z_p → Plastic Modulus.

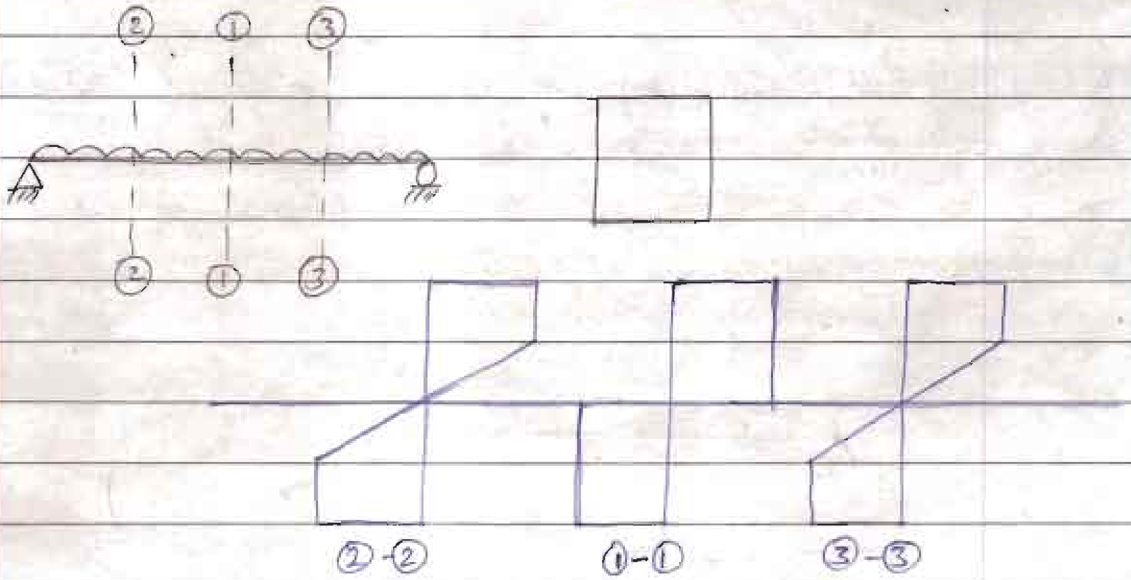
$\bar{y}_1, \bar{y}_2$ → are centre of Gravity of Equal Areas above and below equal area axis.

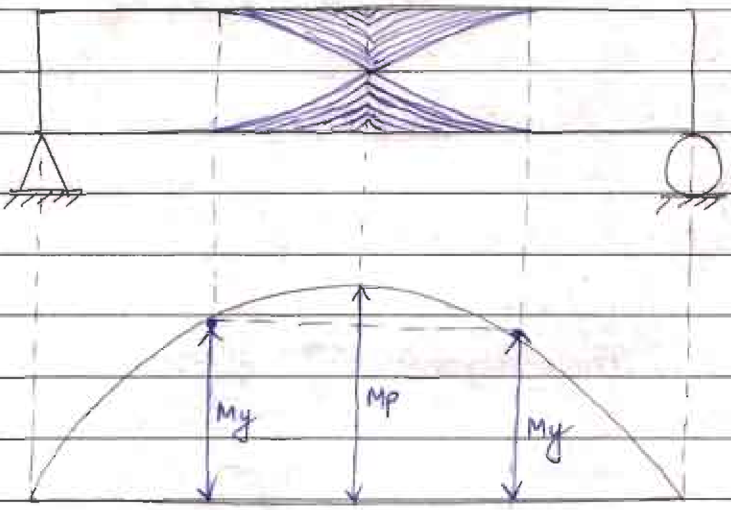
→ Upto elastic bending, NA coincides with centroidal axis whereas under fully plastic bending NA coincides with equal area axis.

→ When BM @ a section becomes M_p, it is said to develop a plastic hinge in which moment capacity $= M_p$

→ Moment capacity of a mechanical hinge $= 0$.

→ Plastic hinge can be thought of as a rusted hinge in which upto BM, M_p, there is a resistance against rotation but the instant, the applied BM becomes M_p, the moment resisting capacity of this section (beyond M_p) becomes equal to 0.





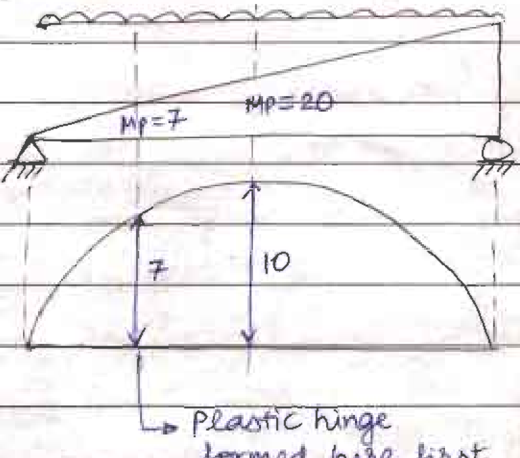
→ Plastic hinge can be defined as a yielded zone due to flexure in a structure in which infinite rotation can take place at a constant resisting Moment, Mp of that section

NOTE:- However, for calculation purpose, plastic hinge will be assumed to be at a single section where the applied BM = Mp.

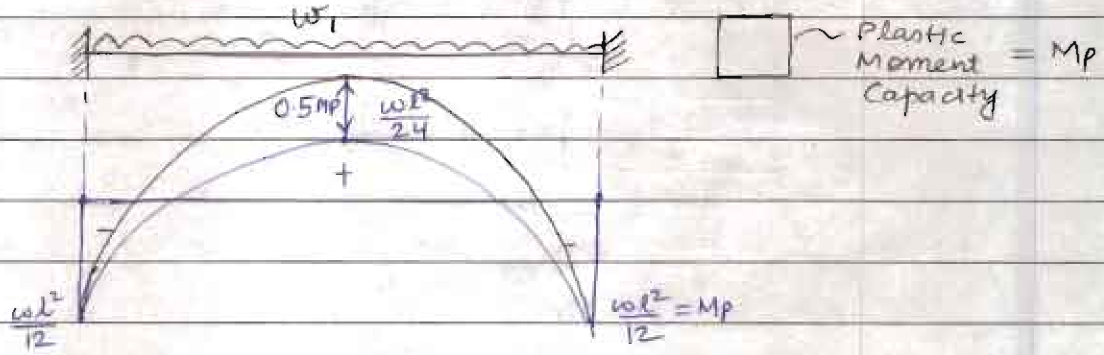
⇒ Important Points

① A section is said to develop plastic hinge when flexural stress at every point of the section becomes equal to fy.

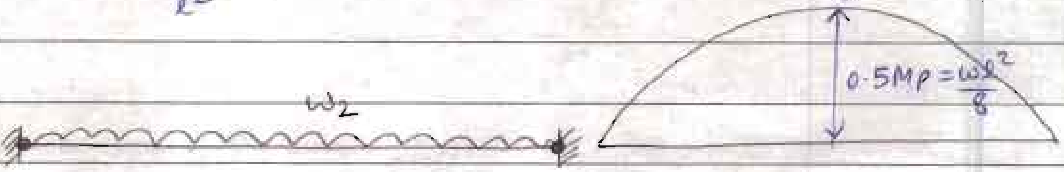
② In the span of a beam, plastic hinge forms first at a section subjected to greatest curvature [Not always greatest BM]



③ Due to formation of plastic hinges one after the other, redistribution of moment takes place and because of this, load carrying capacity of the structure becomes greater than the load at which first plastic hinge forms.



when $w = \frac{12M_P}{l^2}$, the ends become plastic hinge.



when $w_2 = \frac{4M_P}{l^2}$, the mid-span will become a plastic hinge and the beam collapses. So collapse load $= w_1 + w_2 = \frac{16M_P}{l^2}$

④ No of plastic hinges required for complete collapse of the structure $= R+1$, where R is the degree of static indeterminacy of the structure.

NOTE: However, partial collapse of structure due to no of plastic hinges less than R+1.

→ If at collapse,
No. of plastic hinges are:
① $< R+1$ → Partial collapse
② $= R+1$ → complete collapse
③ $> R+1$ → Over complete collapse

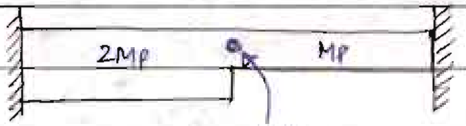
⑤ Length of plastic hinge depends on loading as well as cross section shape.

⑥ Plastic hinge is expected to form at:

(a) At fixed ends.

(b) At location of concentrated load

(c) At section of sudden change in geometry



→ When 2 sections join at ~~at~~ point plastic hinge forms in the section of smaller Mp

(d) At point of zero shear in a span subjected to distributed loading for beams of constant cross section.

⑦ For analysis of collapse, maximum no. of plastic hinges that we have to think of is R+1. If ~~at coll~~ no. of plastic hinges >(R+1) is formed, it will be at a load ≥ the load at which (R+1) hinges are formed.

⇒ Condition for plastic condition

In plastic analysis following must be satisfied:

1) Equilibrium condition [$\Sigma F=0$ and $\Sigma M=0$]

2) Yield condition [At collapse, BM @ any section must not be greater than the fully plastic moment capacity of that section]

3) Mechanism condition [At collapse sufficient no. of plastic hinges must develop, so as to transform a part or whole of the structure into a mechanism leading to collapse.]

→ if all the above 3 conditions are satisfied simultaneously, we get a lowest unique value of collapse load [Uniqueness Theorem]

→ In analysis using plastic method, we have 2 more theorems:

1) Lower Bound Theorem [Static method]

→ It satisfies equilibrium and yield condition.

→ Load determined on the basis of any assumed collapse BMD in which BM at any section is not greater than fully plastic moment capacity of that section will always be ≤ the correct collapse load.

2) Upper Bound Theorem [Kinematic method]

→ It satisfies equilibrium and mechanism condition.

→ Load determined by assuming a mechanism is always greater than or equal to the correct collapse load.

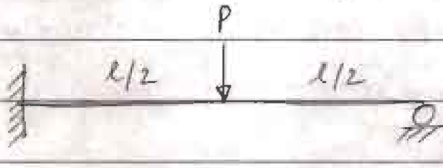
OR

→ Of various possible mechanism, the correct mechanism is one for which loading is minimum.

⇒ Staticmethod of analysis

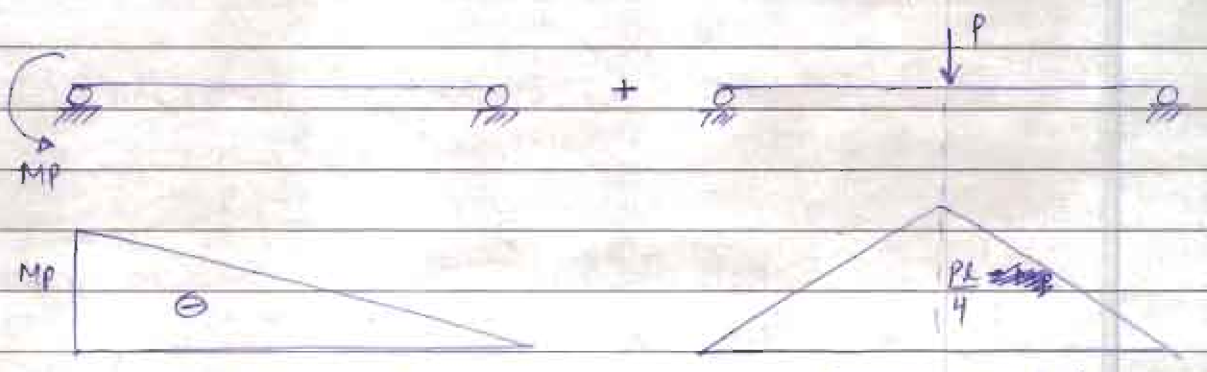
In static method we select moments as unknowns (Redundants) then, redundant BMD and free BMD is drawn. Finally combined BMD is drawn in such a way that a mechanism forms

Q.



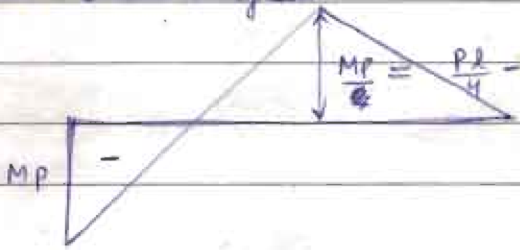
R = 1, So no. of plastic hinges required = 2

Find the collapse load P.



End moment Diagram

Free moment diagram



$\frac{M_P}{[illegible]} = \frac{Pl}{4} - \frac{M_P}{2} \Rightarrow M_p = \frac{2}{3}\frac{Pl}{4} = \frac{Pl}{6}$

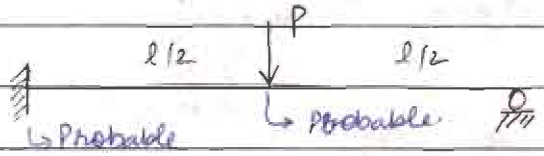
$\Rightarrow \boxed{P = \frac{6M_P}{l}}$

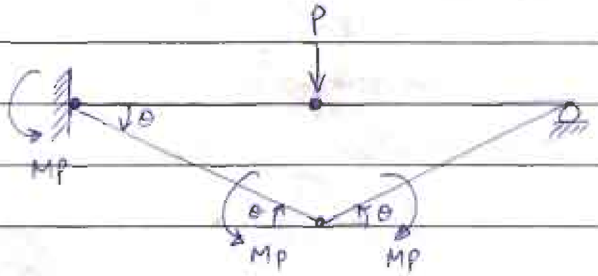
⇒ Kinematic method of analysis

→ Locate the possible places of plastic hinges.

→ Various possible mechanisms are ascertained and the collapse load is calculated working out principle of virtual work.

Q-





From principle of virtual work,

External Virtual Work = Internal virtual work

$$P \frac{l}{2} \phi = 3 M_p \phi$$

$$\boxed{P = \frac{6 M_p}{l}}$$

NOTE: Mp will always be shown opposite to the direction of θ

~~work~~ If the displacement is in the direction of load, the work done is positive otherwise negative.

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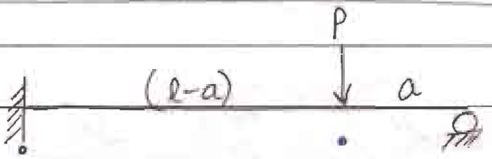
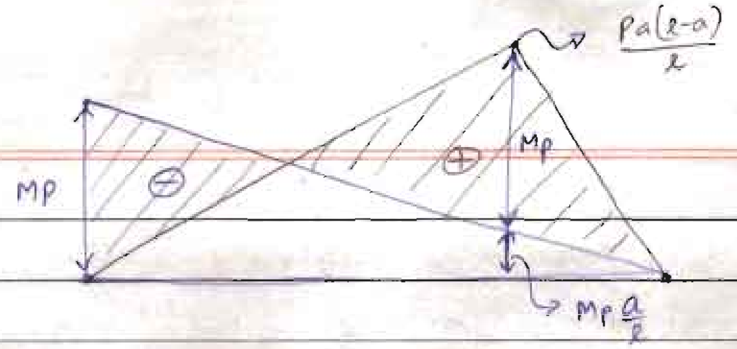


~~Find collapse load P and Mp if~~

Find

(a) Find Mp if P is the collapse load. (Assume Mp unknown)

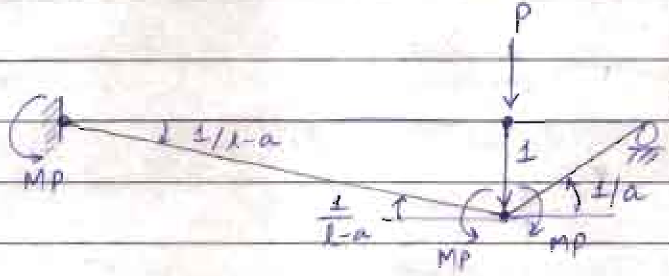
(b) Find the position of load for which collapse load is minimum. (Assuming Mp known)



Static method of Analysis.

So $M_p\left(\frac{a+l}{\cancel{l}}\right) = P\frac{a(l-a)}{\cancel{l}}$

So, $M_p = \frac{Pa(l-a)}{a+l}$



Kinematic method of Analysis

$$\frac{M_p}{a} + \frac{2M_p}{l-a} = P$$

$$\frac{M_p(l+a)}{a(l-a)} = P \Rightarrow \boxed{M_p = \frac{Pa(l-a)}{l+a}}$$

(b) $P = \frac{M_p(a+l)}{a(l-a)}$

For collapse load to be minimum, $\frac{dP}{da} = 0$

$$M_p\left[\frac{1}{a(\cancel{l-a})} + \left(\frac{-(a+l)}{a^{\cancel{2}}(\cancel{l-a})}\right) + \left(\frac{+(a+l)}{\cancel{a}(l-a)^{\cancel{2}}}\right)\right] = 0$$

$$1 = \frac{a+l}{a} - \frac{a+l}{l-a}$$

$$al - a^2 = l^2 \cancel{-a^2} - (\cancel{a^2} + al)$$

$$al = a^2 + l^2 - 2a^2 - al$$

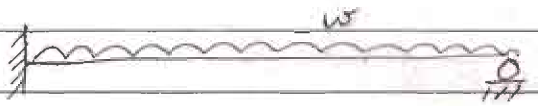
$$a^2 + 2al - l^2 = 0$$

$$a = (\sqrt{2}-1)l = 0.414l.$$

NOTE:

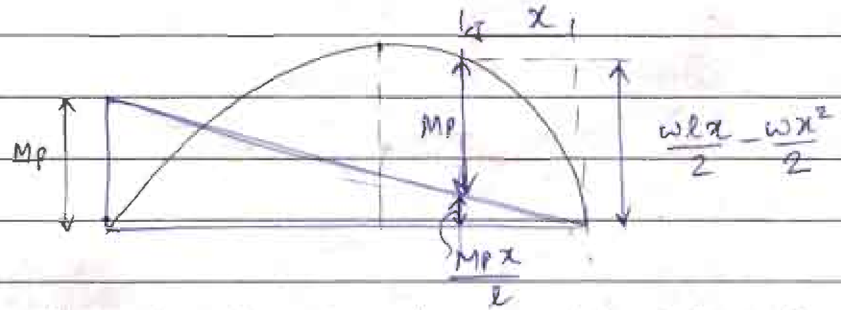
Incase of propped cantilever (of constant cross-section), point load should be placed at a distance of 0.414 l for the collapse load to be minimum.

Q.



Find collapse load, w.

(a)



Zero shear location, is also a critical location.

$$Mp + Mp\frac{x}{l} = \frac{wlx}{2} - \frac{wx^2}{2}$$

$$Mp\left(\frac{x+l}{l}\right) = \frac{wx}{2}(l-x)$$

$$Mp = \frac{w\,l\,x(l-x)}{2(l+x)} \Rightarrow w = \frac{2Mp(l+x)}{lx(l-x)}$$

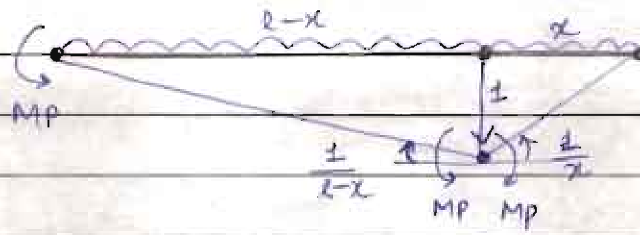
$$\cancel{\frac{dMp}{dx} = 0} \cancel{\Rightarrow}$$

For collapse load to be minimum,

$$\frac{dw}{dx} = 0 \Rightarrow x = (\sqrt{2}-1)\,l = 0.414l$$

Substituting the value of x in eqⁿ ①

$$\Rightarrow \boxed{w_{collapse} = \frac{11.656\,Mp}{l^2}}$$



$$EVW = IVW$$

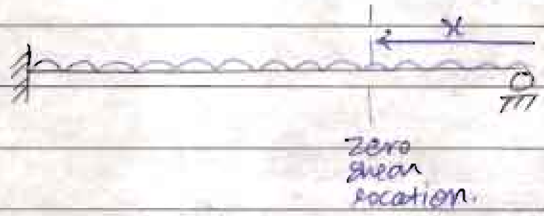
$$w\left[\frac{1}{2}\times 1\times l\right] = \frac{2M_p}{l-x} + \frac{M_p}{x}$$

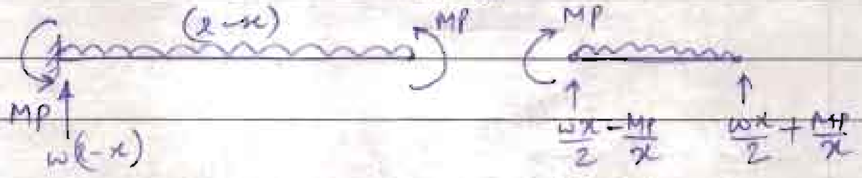
$$\frac{wl}{2} = \frac{M_p(l+x)}{x(l-x)}$$

$$w = \frac{2M_p(l+x)}{lx(l-x)}$$

For minimum collapse load → $\frac{dw}{dx} = 0 \Rightarrow x = (\sqrt{2}-1)l = 0.414l.$

Alternatively,





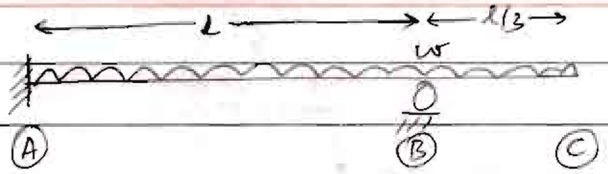
$$2M_p + \frac{w(l-x)^2}{2} = w(l-x)^2 \qquad \frac{wx}{2} - \frac{M_p}{x} = 0 \Rightarrow M_p = \frac{wx^2}{2}$$

$$\cancel{w}x^2 = \frac{\cancel{w}(l-x)^2}{2}$$

$$\sqrt{2}x = l - x \Rightarrow x = \frac{l}{\sqrt{2}+1}\times\frac{\sqrt{2}-1}{\sqrt{2}-1} = (\sqrt{2}-1)l$$

NOTE: In case of ~~UDL~~ propped cantilever with distributed UDL and const cross-section Plastic hinge forms at a distance of 0.414l from the propped end.

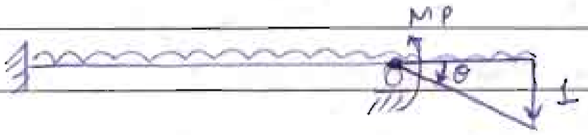
Q-



Find collapse load, w

Collapse mechanism

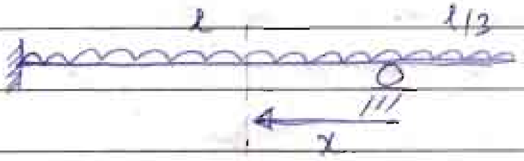
① Partial collapse → Plastic hinge @ B.



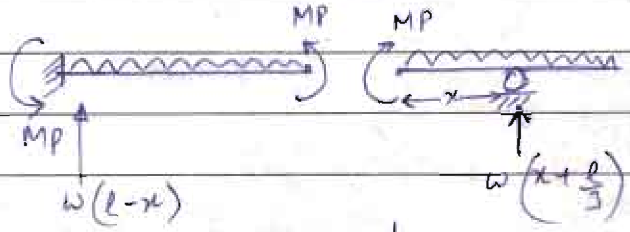
$$M_p\,\theta = w\,\frac{1}{2}\times\frac{l}{3}\times 1$$

$$M_p \times\left(\frac{3}{l}\right) = \frac{wl}{6} \Rightarrow \boxed{w_{collapse} = \frac{18M_p}{l^2}}$$

(ii) Complete collapse of AB



zero shear location



$$2M_p + \frac{w(l-x)^2}{2} = w(l-x)^2$$

$$2M_p = \frac{w(l-x)^2}{2}$$

$$\cancel{w}\left(x^2-\frac{l^2}{9}\right) = \frac{\cancel{w}(l-x)^2}{2}$$

$$2x^2 - \frac{2l^2}{9} = l^2+x^2-2lx$$

$$M_p + \frac{w}{2}\left(x+\frac{l}{3}\right)^2 = w\left(x+\frac{l}{3}\right)x$$

$$M_p = wx\left(x+\frac{l}{3}\right) - \frac{w}{2}\left(x+\frac{l}{3}\right)^2$$

$$= \frac{w}{2}\left[2x-x-\frac{l}{3}\right]\left(x+\frac{l}{3}\right)$$

$$= \frac{w}{2}\left(x^2-\frac{l^2}{9}\right)$$

$x^2 + 2lx - \frac{11l^2}{9} = 0 \Rightarrow \boxed{9x^2 + 18lx - 11l^2 = 0}$

$\Rightarrow \boxed{x = 0.4907 l}$

Now, $w_{collapse} = \frac{2M_p}{x^2 - \frac{l}{9}} = 15.423 \frac{M_p}{l^2}$

⇒ Thus actual collapse load = minimum of both cases

$= 15.423 \frac{M_p}{l^2}$

Q-

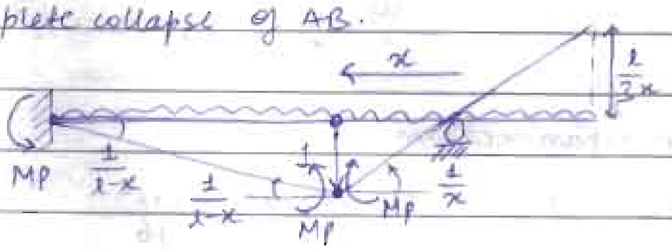
Collapse mechanism

① Partial collapse (Plastic hinge at B)

$$EVW = IVW \Rightarrow \frac{3M_p}{l} = \frac{1}{2} \times 1 \times \frac{l}{3} \times w$$

$$\Rightarrow w = \frac{18 M_p}{l^2}$$

② Complete collapse of AB.



EVW = IVW

$$\frac{1}{2} \times 1 \times l \times w - \frac{1}{2} \times \frac{l}{3} \times \frac{l}{3x} \times w = \frac{2M_p}{l-x} + \frac{M_p}{x}$$

$$\frac{wl}{2} - \frac{wl^2}{18x} = \frac{M_p(l+x)}{x(l-x)} \quad ~~\Rightarrow M_p =~~$$

$$\frac{wl}{2}\left[1 - \frac{l}{9x}\right] = \frac{M_p(l+x)}{x(l-x)} \Rightarrow w = \frac{18 M_p (l+x)}{l(l-x)(9x-l)}$$

For collapse load to be min $\frac{dw}{dx} = 0$

$$\frac{1}{(l-x)(9x-l)} + \frac{(l+x)}{(l-x)^2(9x-l)} - \frac{9(l+x)}{(l-x)(9x-l)^2} = 0$$

$$1 + \frac{l+x}{l-x} - \frac{9(l+x)}{9x-l} = 0$$

$$(l-x)(9x-l) + (l+x)(9x-l) - 9(l+x)(l-x) = 0$$

$$(9x-l)(2l) - 9(l^2 - x^2) = 0 \qquad \boxed{x = 0.49}$$

$$18lx - 2l^2 - 9l^2 + 9x^2 = 0 \qquad \boxed{9x^2 + 18lx - 11l^2 = 0}$$

AIR-1 Notes

Pages: 25

AIRPORT

Handwritten notes by

Kartikay Kaushik

AIR-1 ESE 2021

IES Master classroom Student

AIRPORT

CONTENT

Chapter- Airports

→ ICAO → International Civil Aviation Organization, Montreal, Canada.
→ FAA → Federal Aviation Administration, USA.
→ DGCA → Directorage General of Civil Aviation (Watchdog over AAI)
(Indian govt regulatory body for civil Aviation

⇒ Classification of Airports

1) General- Based on Takeoff and Landing

		Runway Length
CTOL →	Conventional Takeoff & landing.	>1500m
RTOL →	Reduced Takeoff & Landing	1000-1500m
STOL →	Short Takeoff & landing	500-1000m
VTOL →	Vertical Takoff & Landing	25 to 50m²

2) Based on FAA code

Primary airport → Passenger >10000 per year
Non-Primary airport → Passenger <10000 per year

3) Based on ICAO code

(a) Based on Runway length

Code	Basic Runway Length (m)
1	<900
2	[900-1200)
3	[1200-1800)
4	≥1800

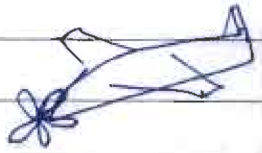
(b) Based on wingspan and distance b/w outside edge of main wheel gear

Code	Wingspan(m)	Dist. b/w -- (m)
A	<15	<4.5
B	[15-24)	[4.5-6)
C	[24-36)	[6-9)
D	[36-52)	[9-14)
E	[52-65)	[9-14)
F	[65-80)	[14-16)

Q-⇒ Classify Aerodrome as per ICAO, which is designed to accomodate Boeing 747 with outer main wheel gear span width of 10·44 m Wingspan = 48 m and requiring Basic runway length of 1830m. D, 4 ⇒ $\boxed{4D}$

⇒ Aircraft characteristics

1) Engine (Piston)



→ Propellor Driven aircraft
→ Operate at low altitude and moderate speed.
→

2) Turbo Prop
→ Refers to propellor driven aircraft powered by turbine engine.

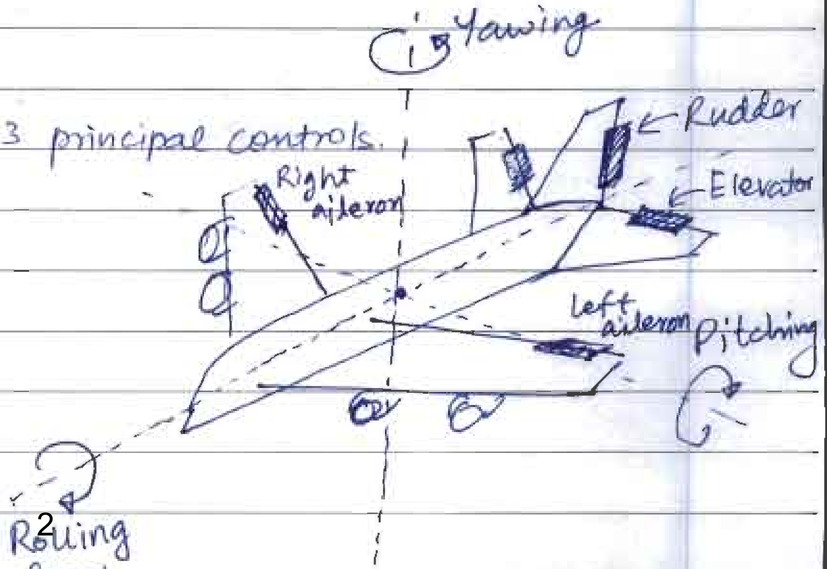
3) Turbofan / Steam jet
→ Refers to those aircraft which are not dependent on propellor for thrust
→ Nearly all commercial aircrafts are lined with turbofan

4) Ramjet
→ No moving part. Must be operated at high speed for fighter planes

⇒ Wing - Purpose of wing is to provide lift. It also carries fuel.

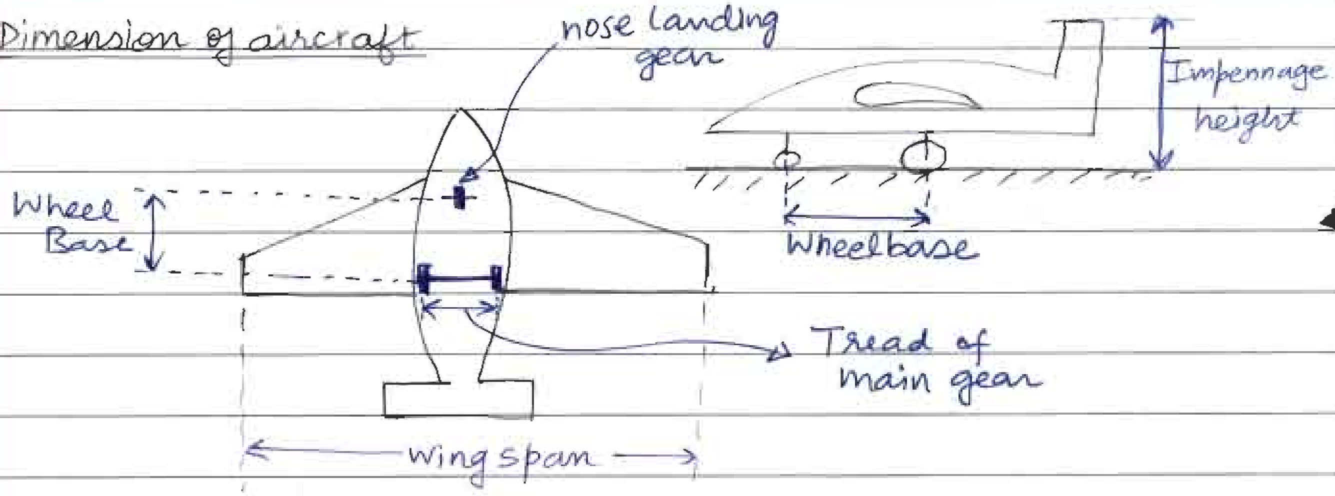
⇒ 3 - control surface
→ Aeroplane is provided with 3 principal controls.

1) Elevator → Pitching
2) Rudder → Yawing
3) Aileron → Rolling



Fuselage - Main body of the aircraft — Carries payload.

⇒ Dimension of aircraft



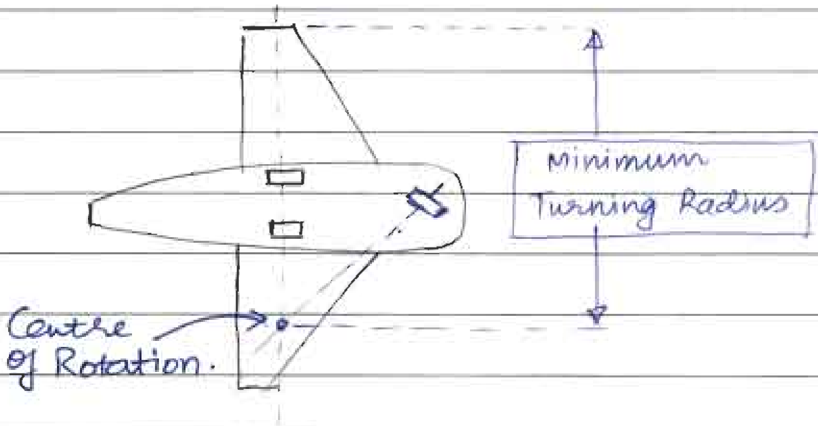
⇒ Minimum Turning Radius

→ For deciding the radius of taxiway, position of aircraft at apron and hangar it is essential to study about minimum turning radius.

→ To determine the minimum turning radius, draw a line through the axis of nose gear when it is at maximum angle of rotation.

→ Intersection point of this line and line drawn through the axis of 2 main gears is called centre of rotation

→ Distance of farther wing tip from the centre of rotation represent minimum turning radius.



⇒ Circling Radius

→ The minimum radius with which the aircraft can take turn in space.

⇒ Jet Blast

→ Aircraft eject hot exhaust gases with high speed

⇒ Fuel Spillage

→ At apron and hangar it is difficult to avoid spillage, hence it is necessary to provide constant supervision and monitoring.

⇒ Noise

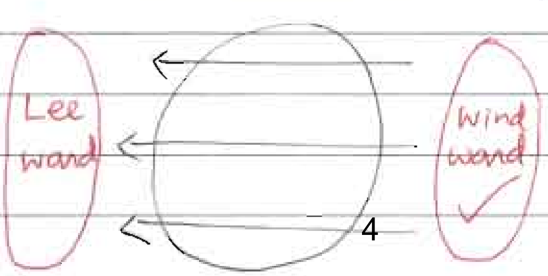
→ Perceiened Noise (Decibal → PNdB

→ upto 1km^2 → 90 PNdB
3km^2 → 80 PNdB.

Chapter- Airport Planning

→ Airport Cite Selection factor

1) Use of airport → Civil/Military
2) Ground accessibility → Site should be accessible to users
3) Regional Plan → The site should fit well into the regional plan
4) Proximity to other Airport
5) Topography → Raised ground, plateau is ideal site for airport due to less obstruction, more uniform wind, natural drainage, better visibility.
6) Wind → Runway is oriented in the direction of wind.
   → The wind data of direction, duration and intensity should be collectord from wind rose diagram over a minimum period of 5 years
   → The site should be located to windward dir^n of setting so that minimum smoke from city is blown over site.



7) Noise → should not be any residential development in the vicinity of airport.

A buffer area may be covered by vegetation b/w airport and heavily populated area to reduce noise level.

8) Future development

9) Drainage and soil characteristics

10) Obstruction and visibility

⇒ Imaginary surfaces

→ Zoning Law - These are the laws made by competent authorities in order to prevent future development in the vicinity of airport and also to prevent activities which will produce smoke and flume.

→ Imaginary surfaces - These are the established surfaces in relation to the airport and to each runway above which no obstruction should project. It depends on type and approach planned for runway, aircraft characteristics.

① Primary surface - Surface which is longitudinally centered on the runway. When the runway is paved, the primary surface extends 200 feet beyond each end of runway. The elevation is same as that of runway.

(40:1)

② Approach surface - It is a surface which is longitudinally centered on the runway center line. It extends outwards and upwards from each end of the ~~runway~~ primary surface

→ Trapezoidal in shape

③ Take off climb surface - Similar to approach surface.

→ Provided at takeoff end of runway.

→ Trapezoidal in shape.

④ Inner horizontal surface (IHS) - It is the surface located in a horizontal plane above an aerodrome and its surrounding.

→ The shape need not be necessarily circular.

→ The radius of outer limit of IHS shall be measured from ARP (Airport Reference Point) and it goes from 2000m to 4000m

→ This surface is 45m above the elevation of ARP.

⑤ Conical Surface - It extends upwards and outwards from the periphery of IHS with a slope of 20:1. The slope of conical surface shall be measured in a vertical plane.

⑥ Transition surface - It is a surface along the side of the ~~straight~~ strip and part of the side of approach surface that slopes at 7:1, upward and outward.

Limit → Upper edge located in the plane of IHS.
→ Slope is measured in vertical plane.

⑦ Outer Horizontal Surface (OHS) - It is a circular, in plane with centre at ARP.

→ Height of OHS is 150m ~~is~~ above ARP

→ OHS extends to 15000 m from ARP.

⑧ Balked Landing Surface - A balked landing for an aircraft means an attempted landing that is abandoned during the final approach stage of the flight

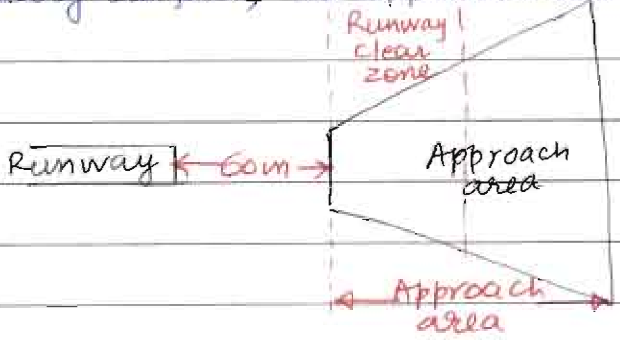
→ This landing surface is an inclined plane originating at a specified distance after the threshhold and extending b/w the inner transition Surface.

⑨ Approach zone: The wide clearance area known as approach zone are required on either side of runway along the direction of landing and takeoff. → It represents the area on ground directly below the Imaginary approach surface

→ Over this area, the aircraft can safely ~~loose~~ lose or gain altitude.

→ The whole area has to be kept free from obstruction.

X → The plane of approach zone is same as approach surface
The only difference b/w the 2 is ~~e~~ while approach surface is an imaginary surface, the approach area indicates actual ground.



⑩ Runway Clear zone / Protection zone – The innermost portion of approach zone which is most critical from obstruction viewpoint is called clear zone.

→ For Instrumental landing → 750m (ILS)
For Non-instrumental landing → 600 m.

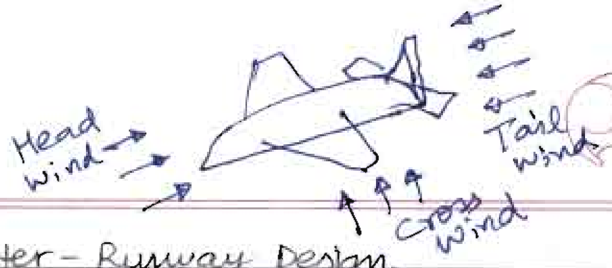
⑪ Turning zone – During the takoff, if engine fails or pilot select to land for any reason, the aircraft will have to take a turn and come in line with runway before landing.

→ The area of airport ~~are~~ other than approach area used for turning operation is known as turning zone.

⑫ OFZ (Obstacle free zone) – The inner approach, ~~turning zone~~ inner transition and balked landing surface together define a volume of airspace known as OFZ.

→ This zone shall be kept free from fixed objects other than navigational aids.

ALS - Approach Ligting System



Chapter - Runway Design

→ Runway is usually oriented in the direction of prevailing wind.

⇒ CW component and wind coverage

→ Limiting value of CW component as per ICAO

→ Design Length Of Runway

Length of reference field (m)	Max. CW component (kmph)
>1500	37
1200-1500	24
<1200	19

⇒ Wind coverage

→ The %age of time in a year during which CW component remains within the permissible limit, is called wind coverage.

→ Runway for mixed air traffic should be planned with wind coverage of 95% and CW component 25 kmph

→ For busy airport, wind coverage may be increased to 98-100%.

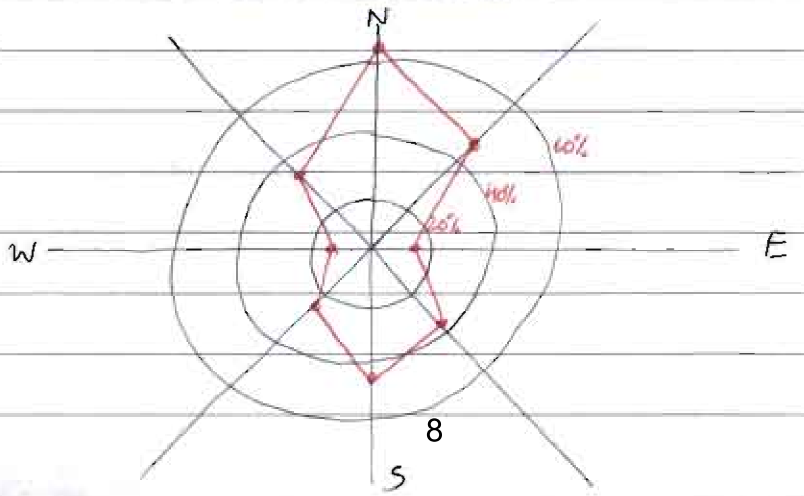
⇒ Wind rose

→ The graphical representation of wind data i.e. direction, duration and intensity is called wind rose.

→ The wind data of atleast 5 years and preferably 10 years should be considered while designing an airport.

→ Wind rose is used to determine the best orientation of runway.

→ Based on True North Orientation.



→ Type 1 <u>showing direction and duration of wind</u>

→ The radial lines indicate wind dirⁿ and each circle represent duration of wind.

→ The best direction of runway is usually along the direction of longest line on wind rose diagram.

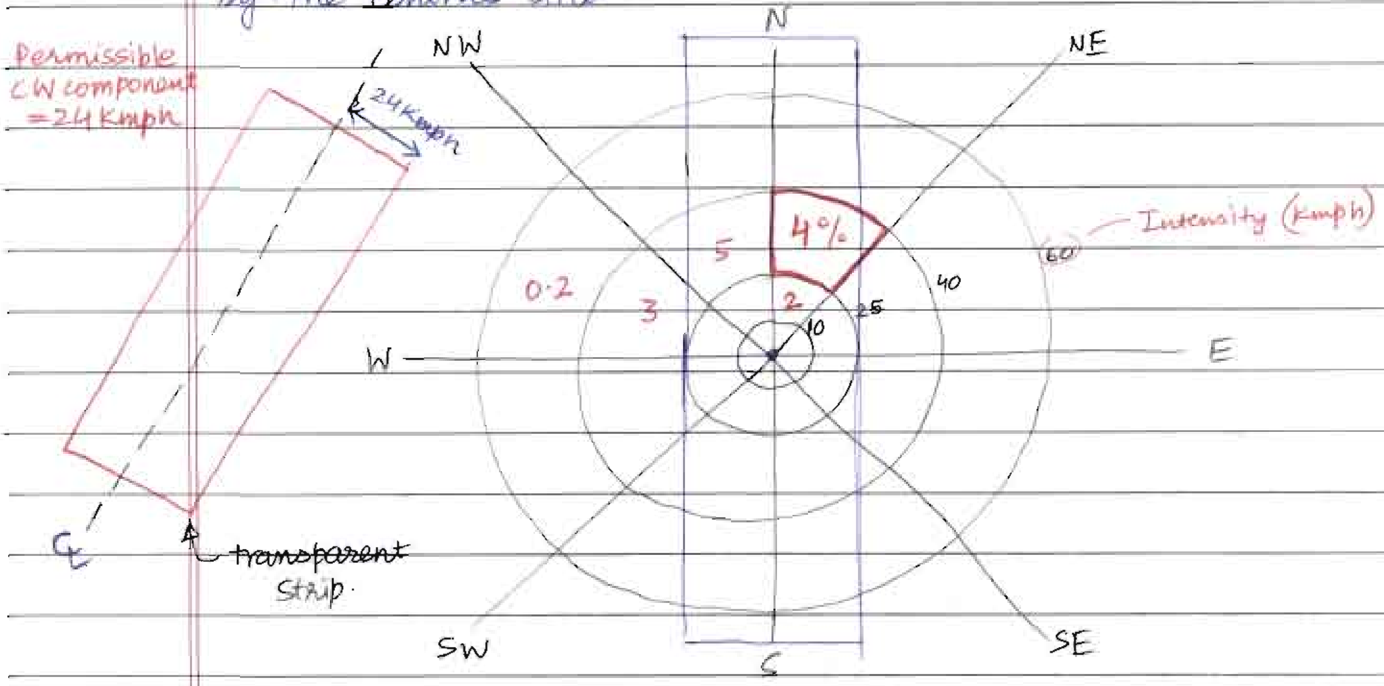
→ Type 2 - <u>showing direction, duration and intensity of wind</u>

→ Each circle represents wind intensity to some scale.

→ The value entered in each segment represents the %age of time in a year during which the wind having a particular intensity blows from respective direction.

→ Wind coverage can be calculated by summing up all the %ages shown in a segment.

→ The runway should be oriented along the direction represented by the <u>central</u> line.



⇒ <u>How to use Wind Rose</u>

→ A transparent template with 3 parallel lines are used to get best orientation through wind rose

→ The middle line of template represents the runway ℄ and distance b/w it and each end of outside line is equal to allowable CW comp.

→ The ℄ of template placed on the centre of wind rose diagram.

→ The values inside the template is summed up to get total %age of time and hence to decide best orientation of runway for maximum %age time by rotating the template in different direction.

→ If single runway is not sufficient to provide the recommended coverage, then 2 or more runways should be planned

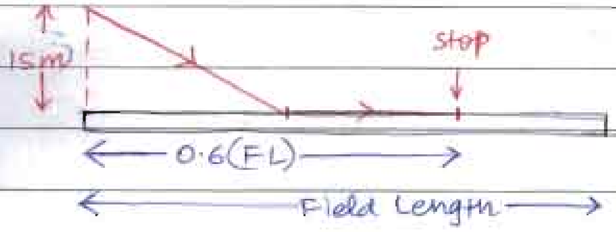
→ Basic runway length

→ It is calculated under the following assumed condition at airport

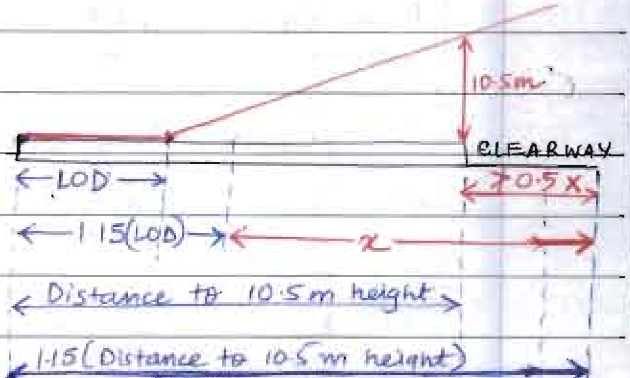
1) → Airport altitude is at sea level.
2) Temperature at airport is standard (15°C)
3) Runway is levelled in longitudinal direction.
4) No wind blowing on runway
5) Aircraft is loaded at it's full loading capacity.
6) Enroute dirn temp ~~a~~ is standard and no wind is blowing.

Combined Correction ≯35%

→ Case I Normal Landing



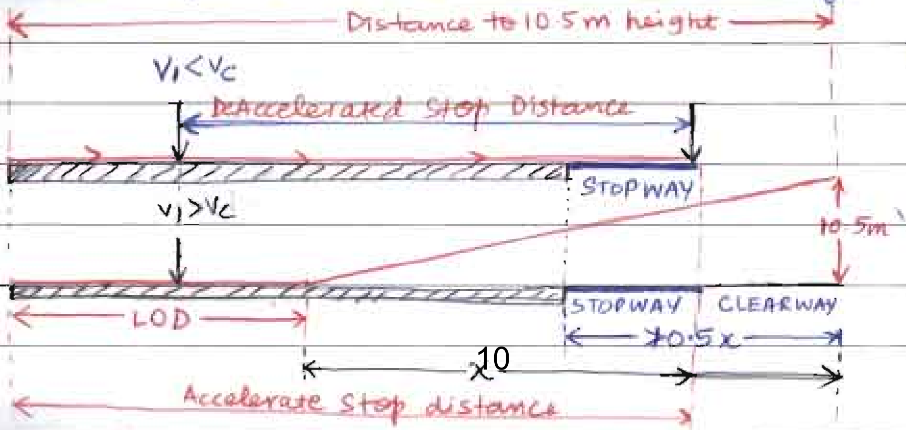
Case II Normal Takeoff



(Take off Distance)

→ Case III Engine failure

① When velocity at failure is less critical velocity



V_1 → engine failure speed.

② When velocity at failure is more than critical velocity

→ The basic runway length is determined by these 3 cases.

Case I Normal Landing - In this case the aircraft should come to stop within 60% of landing distance / Runway Length.

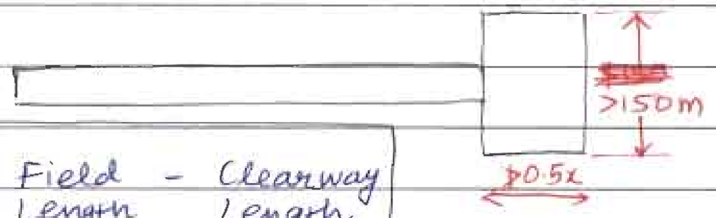
→ Entire landing distance is provided with full strength pavement.

$$\boxed{\text{Field Length} = \text{Landing Distance} = \frac{\text{Stop Distance}}{0.6}}$$

Case II Normal Take off case - In this case, minimum clearway width should be 150 m.

$$\boxed{\begin{aligned}\text{Field Length} &= \text{Take off Distance}\\ &= 1.15 \times (\text{Distance to } 10.5\text{ m height})\end{aligned}}$$

$$\boxed{CL_{max} = 0.5\,[T.O.D. - 1.15 \text{ of } LOD]}$$



$$\boxed{\text{Runway Length} = \text{Field Length} - \text{Clearway Length}}$$

Full strength Pavement = F.L. − CL
or Take off Runway (TOR) length

Q What is the FL and max^m clearway distance for a turbine powered aircraft with following performance.

(a) Normal Take off → LOD = 2133 m

b → Distance to height @ 10.5m = 2438 m.

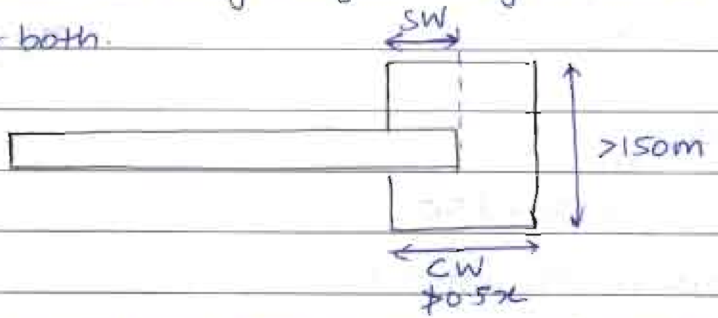
FL = 2803.7 m

CL = 175.375 m

Runway length = 2803.7 − 175.375 = 2628.325 m

Case IV Engine failure case – It describes as the case of 1 engine failure at a critical point during an aircraft take off.

→ In this case, basic runway length may consider either clearway or stopway or both.



→ SW is the area beyond the runway and centrally located in alignment with the centre line of runway.

→ The strength of stopway should be sufficient to carry weight of aircraft without structural damage to aircraft

→ If the engine has failed at speed less than the critical ~~speed~~ engine failure speed, Aircraft decelerates with use of stopway.

→ If engine fails at at speed higher than critical speed then there is no option except to continue to take-off and turn in turning zone and land again.

> NOTE: Critical engine failure speed or decision speed (V_c) is the speed at which engine fails and this is selected by manufacturer

(a) Engine failure takeoff

$$\boxed{F.L. = T.O.D = \text{Distance to } 10.5\,m \text{ height}}$$

$$\boxed{CL_{max} = 0.5\,[TOD - LOD]}$$

$$\boxed{\text{Full strength Length / T.O.R Length} = FL - CL}$$

(b) Engine failure aborted take off

$$FL = \text{Accelerate Stop Distance} = \underset{\text{Pavement}}{\text{Full strength}} + SW$$

Q: Calculate the length of full strength pavement as per specification for a turbine powered aircraft for engine failure ~~takeoff~~.

LOD = 2500 m

Distance to height 10.5 m = 2774 m

FL = 2774 m

CL = 0.5[2774 − 2500] = 137 m

Full strength Pavement = 2774 − 137 = 2637 m

⇒ Correction for Elevation, Temperature & gradient

→ Necessary corrections for BRL are to be applied for elevation, temperature and gradient for actual site of construction.

① Correction for Elevation

According to ICAO, BRL should increase at the rate of 7% for every 300 m rise in elevation above MSL.

② Correction for Temperature

$$\boxed{\text{Airport Reference Temperature (ART)} = T_a + \frac{T_m - T_a}{3}}$$

T_a = monthly mean of average daily temp. of hottest month.

T_m = monthly mean of maximum daily temp.

→ According to ICAO, BRL after having been corrected for elevation, should be further increased by 1% for 1°C rise in ART above the standard atm. temperature at that elevation.

→ Temperature gradient of standard atm temperature from MSL to elevation at which the std. atm temp. is −60°C is 6.5°C / km.

③ Check for total correction [Elevation + Temperature]

→ According to ICAO, if the combined correction exceeds

AIR-1 Notes

Pages: 54

Railway
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

RAILWAY

CONTENT

Railway

Ch-1 Rail, Railway and Rail Joint

→ A mode of transportation

→ IR is second largest in the world. (1st is Russia)

→ IR has 5 training institutes,

1) Indian Railway Institute of CE, Pune.

→ For R&D, IR has it's own unit RDSO, Research, Design and Standards Organisation at Lucknow. It's function is to provide input support to almost all disciplines to R&D wing of IR.

⇒ Classification of Railway Route

→ Done on the basis of importance, traffic carried and the maximum permissible speed of train

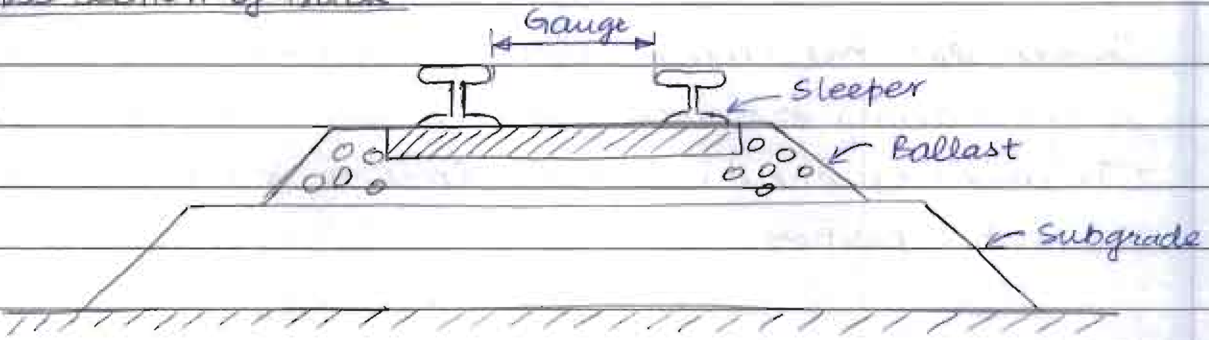
→ B.G. Route

① Group A → Speed upto 160 kmph
② Group B → Speed upo 130 kmph
③ Group C → Suburban railway of Delhi, Chennai, Mumbai, Kolkata.
④ Group D → Speed upto 110 kmph, traffic density < 20GMT
⑤ Group D(special) → speed upto 110 kmph and annual traffic density more than 20 GMT (Gross million Tonne)
⑥ Group E → All other sections and speed < 100 kmph
⑦ Group E(special) → Speed upto 100 kmph and section where traffic density is very high or likely to grow.

→ M.G. Route

① Q > 75 kmph
② R ≤ 75 kmph
③ S < 75 kmph

→ Cross-section of Track



→ The track consists of parallel lines of rail. fitting and fastening, ballast etc To provide hard, smooth and stable passage.

→ Gauge: It is the distance b/w the inner edge of the heads of rail.

→ It is measured 16 mm below the plan of rail running table.

→ In India we have 3+1 type of gauge.

① Broad gauge → 1.676 m

② Metre gauge → 1.000 m

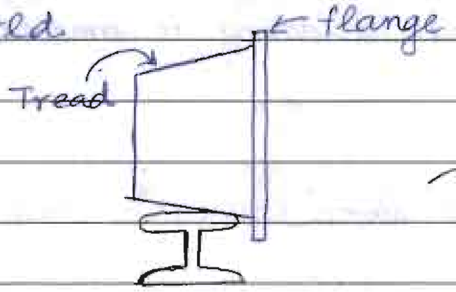
③ Narrow gauge → 762 mm, 610 mm (Darjeeling)

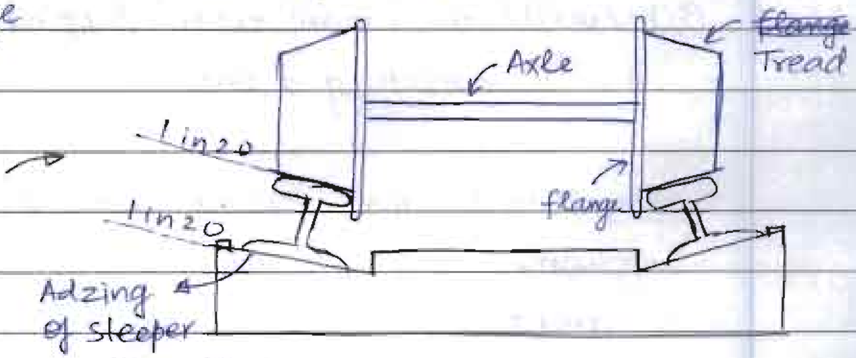
④ Standard gauge → 1.435 m (Used in Metro)

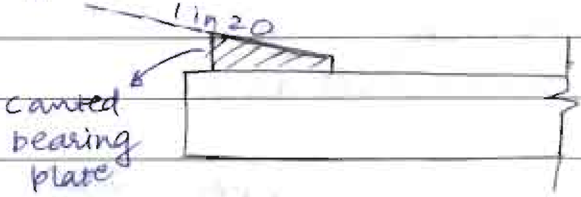
→ In India, apprex 63% BG, 31% MG and 6% NG exist.

→ Whereas, in world 62% Standard gauge and 15% BG exist.

→ Other than these more than 20 type of gauges are there in the world.







→ Coning of wheel - The head of wheels of railway vehicle are not made flat but sloped at 1:20 and this sloping of surface along the circumference forms a part of cone.

→ The coning of wheel is mainly done to maintain the vehicle in central position

→ Behaviour of coned wheel -

① On straight track - Keeps the train in central position. Hence reducing wear and tear of wheel flange. If at any moment the wheel goes out of it's central position, the dia of contact point will become different and there fore, the wheels retreat till they are at central position once again with equal dia.

② On curved track - When train moves on curved track, the distance covered by outer wheel is more than the inner wheel. Centrifugal force shifts the outer wheel outwards, thus causing an increase in diameter. which helps it in moving longer distance compared to inner wheel. Hence more length of outer rail is partly adjusted due to coning.

→ Advantage of coning

① Produces self centering effect

② Reduces wear and tear of wheel flange and rail.

③ Prevents the wheel from slipping / skidding to some extent when negotiating a curve.

→ Adzing of Sleeper - Coning of wheel alone without tilting the rail has some disadvantages like:

(a) Lateral Bending stress on rail due to eccentric loading

(b) High concentration of stress at inner edge of rail and on tread of wheel as well

→ Tilting of rail in 1:20 is done to control above problems.

→ It can be done by either directly making groove on sleeper or with the help of canted Bearing Plate.

→ Now, making groove on sleepers at 1:20 is known as Adzing of sleeper.

Ch-2 Geometric Design

⇒ **Gradient** - Any rise or fall in the track level is known as gradient.

→ Gradient are represented either by 1 in X form or p%

eg - 1 in 200 ⇒ 0.5%

→ Type of Gradient on Railway track

① Ruling Gradient

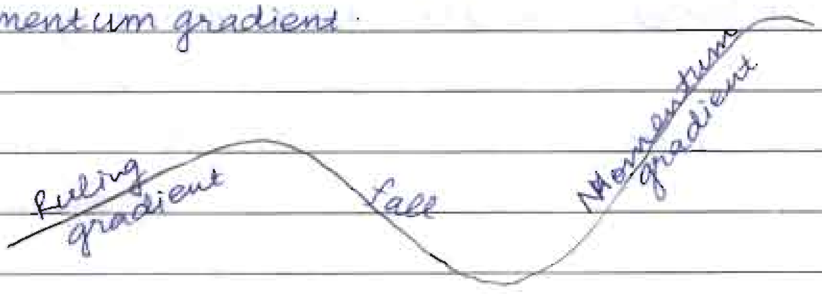
→ In most general case, the maximum gradient allowed is known as Ruling gradient.

→ It is the gradient where there may not be any appreciable loss of speed.

→ In general, for plain areas → 1 in 150 - 1 in 250 → Ruling gradient
for hilly areas → 1 in 100 - 1 in 150 →

② Momentum Gradient

If rising gradient is followed by falling gradient, the train while coming down in a falling gradient acquires sufficient momentum which enables the train to negotiate a steeper gradient than the ruling gradient. This rising gradient is called momentum gradient.



③ Pusher / Helper gradient

→ In hilly areas to reduce the length of railway line, gradient steeper than ruling gradient is provided.

→ In such situation, instead of limiting the train load, the train is run by an assistant or helper engine. Such gradients are called as pusher gradient. [Generally steeper than 1 in 75]

④ ⇒ Gradient in Station yard

→ In station yard, gradient is provided for drainage.

→ It should be sufficiently low so as to:

① To prevent the movement of standing vehicle.

② To prevent additional resistance at the start of vehicle.

→ Maximum → 1 in 400 and minimum → 1 in 1000.

⇒ Grade compensation

→ Due to curvature on the grade, resistance to motion of train increases.

→ In order to avoid resistance beyond allowable limit, the gradients are reduced on the curve.

→ This reduction in gradient is known as grade compensation.

** → For IR,

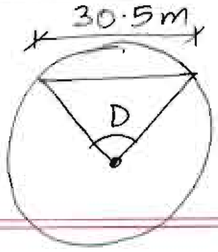
(a) For BG → 0.04 % per degree

(b) For MG → 0.03 % per degree

(c) For NG → 0.02 % per degree

Q → If curve of 4 degree accompanied by ruling gradient of 1 in 150 on BG track, the permissible gradient would be

$\boxed{1 \text{ in } 197.37}$ → permissible / allowable / steepest grade.



⇒ Radius / Degree of curve

→ A curve is defined either by it's radius or by it's degree. The degree (D) of curve is the angle subtended at it's centre by 30·5m (100 feet) chord.

$$\boxed{D = \frac{1750}{R}}$$

→ Maximum Degree of curve or minimum radius:

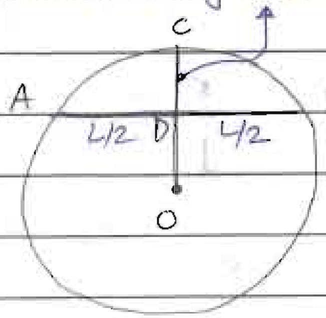
BG → 10° → $R_{min} = 175$ m

MG → 16° → $R_{min} = 109$m

NG → 40° → $R_{min} = 44$ m

⇒ Versine of curve

→ It is used to check the accuracy of curvature. For a chord AB, CD is known as versine of curve.



→ Using property of circle i.e. Intersecting chord theorem.

→ $\frac{L}{2} \times \frac{L}{2} = CD \times (2R - CD)$

→ Assuming $2R - CD \simeq 2R$

So, $\boxed{CD = \frac{L^2}{8R}}$

Q. For 20m chain length and 600 m radius of curve, Degree of curve will be → $\frac{1146}{R} = \frac{1146}{600} = 1 \cdot 91°$

⇒ Super elevation

→ When train negotiates a horizontal curve it is subjected to centrifugal force which pushes the train away from the curve, hence results in increase of pressure on outer rail.

→ To encounter the effect of centrifugal force, the level of outer rail is raised above the inner rail by certain amount known as super elevation

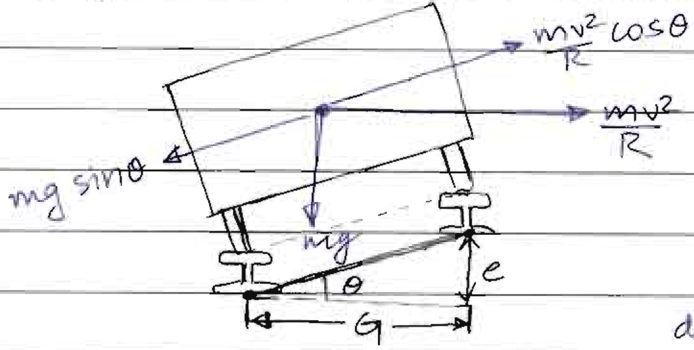
→ Objective of s/e

① To encounter the effect of centrifugal force.

② To provide equal distribution of wheel load on 2 rails

③ To provide smooth and comfortable ride. with safety.

→ Friction force is not considered while deriving s/e.

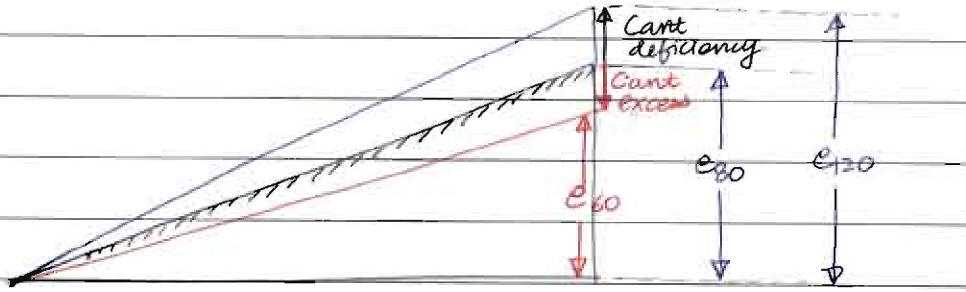


G = { 1750 mm for BG
      1058 mm for MG

↓
dynamic Gauge

$$mg\sin\theta = \frac{mv^2}{R}\cos\theta$$

$$\tan\theta = \frac{v^2}{gR} = \frac{e}{G} \Rightarrow \boxed{e = \frac{G\overset{m/s}{v^2}}{gR} = \frac{G\overset{kmph}{V^2}}{127R}}$$



e_{60}, e_{80}, e_{120} → equilibrium cant provided for 60kmph, 80kmph, 120kmph

e_{80} → Cant provided → Called Actual Cant. (Ca)

→ G: Dynamic gauge is the c/c horizontal distance b/w the ~~gauge~~ rails

→ whereas wheel gauge is defined as the distance b/w inner face of rails

→ Track gauge of BG is 1676 mm

→ Maximum superelevation

→ Maximum value of superelevation in 1/10 to 1/12 of the gauge

Gauge	Group	Under Normal Conditions (mm)	With permission of CE (mm)
BG	A	** 165	185
	B, C	~~140~~ 165	—
	D, E	140	—
MG	Q R S	90	100
NG		65	75

** ~~Ma~~ ⇒ Equilibrium speed and Equilibrium cant

→ Mixed traffic of fast and slow trains moves on the track. Cant provided for slow train will not suit fast train and vice versa. So actual cant provided for an average speed [equilibrium speed] so that all trains with different velocities can be allowed.

→ When load on both the rails is equal then, the cant provided is known as equilibrium cant.

⇒ Equilibrium speed

(a) > 50 kmph

(i) Speed from Martin formula

(ii) $V_{eq} = 0.75 \times V_{max}$

(b) < 50 kmph

(i) Martin formula or super elevation formula

(ii) $V_{eq} = V_{max}$.

} Not much useful. {Not used by IR currently}

**

(c) Weighted average method

$$V_{eq} = \frac{v_1 n_1 + v_2 n_2 + \text{- - - -}}{n_1 + n_2 + \text{- - - -}} = \frac{\Sigma v_i n_i}{\Sigma n_i} = \frac{\Sigma v_i \overset{\text{weight}}{w_i} n_i}{\Sigma w_i n_i}$$

where $n_1, n_2, \ldots$ are no. of trains at a speed of $v_1, v_2, \text{- - -}$

Q. Calculate the equilibrium speed of BG curve of 3° if the speed of several trains running on the line are

No of trains	Speed of train (kmph)
10	60
8	50
3	70

$V_{eq} = 57.62$ kmph

⇒ Cant Deficiency

→ The actual cant is provided on the basis of equilibrium or average speed. For the trains running at higher speed, the actual cant requirement is more than the provided cant for equilibrium speed. This shortage of cant is called cant deficiency

$$\boxed{C_d = C_{th} - C_a}$$

⇒ Limitation of Cant deficiency

Cant deficiency is limited because:

① Higher cant deficiency gives much discomfort

② Extra pressure on outer rail.

⇒ Allowable Cant deficiency

Gauge	Group	Normal C_d (mm)	Remark
BG	A & B	** 75	For BG group of A and B route 100mm Cd is permitted with the approval of CE
	C, D & E	75	
MG		50	
NG		40	

⇒ Cant Excess

→ Cant excess occurs when train travels around a curve at a speed less than the equilibrium speed.

$$\boxed{C_{ex} = C_a - C_{th}}$$

⇒ Maximum Cant Excess → For BG ⇒ 75mm
→ For MG ⇒ 65 mm

NOTE: Book speed of the goods train should be taken into account for working out cant excess.

⇒ Speed of train

→ Safe speed on Railway track should be minimum of the following

(a)→ Safe speed on curve as per Martin's formula (Not in use Nowadays by IR)

(b) Speed calculated as per cant Formula allowing cant deficiency
(c) Maximum speed as per transition length
(d) Maximum specified speed as per Railway Board

⇒ Calculation of speed on curve

~~I/ When speed < 100kmph~~

(a) Martin's formula

(i) When speed < 100 kmph

① On transition curve → $V_{max} = 4.4\sqrt{R-70}$ kmph (BG, MG)
→ $V_{max} = 3.65\sqrt{R-6}$ kmph (NG)
(subjected to max. of 50kmph)

R → Radius (in metres)

② On Non-transition curve

80% of the speed given by ① is allowed for respective gaug

(ii) When speed > 100 kmph

$$V_{max} = 4.58\sqrt{R}$$

NOTE: All the Martin's formulae are not in use by IR

(b) Used by IR

For BG, $V_{max} = 0.27\sqrt{R(C_a + C_d)}$

For MG, $V_{max} = 0.347\sqrt{R(C_a + C_d)}$

For NG, $V_{max} = 3.65\sqrt{R - 6}$

Here, C_a → actual cant in mm

C_d → Cant deficiency in mm

R → Radius of curve in m

Q- S/e provided for 70 kmph locomotive running on 900 m radius curve $= \frac{GV^2}{127R} = 75.022$ mm

Q- What is the maximum speed of train which can run on a curved BG track with radius 650 m and s/e of 5.5 cm.

$$e = \frac{GV^2}{127R} \Rightarrow V = \sqrt{\frac{127 \times 650 \times (55 + 75)}{1750}} = 78.3 \text{ kmph}$$

Q- Minimum velocity of rolling stock permitted to run on BG track with radius 500 m and equilibrium cant 12 cm.

$$V = \sqrt{\frac{127 \times 500 \times (120 - 75)}{1750}} = 40.41 \text{ kmph}$$

Q- What actual cant will be provided in 3° curve of BG railway track for a maximum speed of Rolling Stock 100 kmph.

$$R = \frac{1750}{3} = 583.33 \text{ m.} \Rightarrow 100 = \sqrt{\frac{127 \times 583.33 \times (e + 75)}{1750}}$$

$$\Rightarrow e = 16.12 \text{ cm} < 16.5 \text{ cm}$$

So, OK

→ Determining minimum Radius of curve for given permissible speed (V_m) and book speed (V_g) [Here cant and Radius both are unknown]

① Assume maximum permissible value of C_d and C_{ex} has reached

$$C_a = \frac{G V_m^2}{127 R} - C_{d,max} \rightarrow \text{based on } C_{d,max}$$

$$C_a = \frac{G V_g^2}{127 R} + C_{ex,max} \rightarrow \text{based on } C_{ex,max}$$

Equating both, we get

$$\boxed{R_{min,1} = \frac{13.76 (V_m^2 - V_g^2)}{C_{d,max} + C_{ex,max}}}$$

② considering maximum permissible limit of C_a and C_d are reached

$$C_{a,max} = \frac{G V_m^2}{127 R} - C_{d,max}$$

$$\boxed{R_{min,2} = \frac{13.76 V_m^2}{C_{a,max} + C_{d,max}}}$$

→ Provide $R_{Provided} = \max (R_{min_1}, R_{min_2})$

Q. Determine the minimum radius on BG where max^m permissible speed is 120 kmph. , $V_g = 65$ kmph

$$165 = \frac{13.76 (120)^2}{R_{min}} - 75 \Rightarrow R_{min} = 825.6 \text{ m}$$

$$\frac{13.76 (120)^2}{R_{min}} - 75 = \frac{13.76 (65)^2}{R_{min}} + 75 \Rightarrow R_{min} = 933.4 \text{ m}$$

So, provide $\boxed{R = 933.4 \text{ m}}$

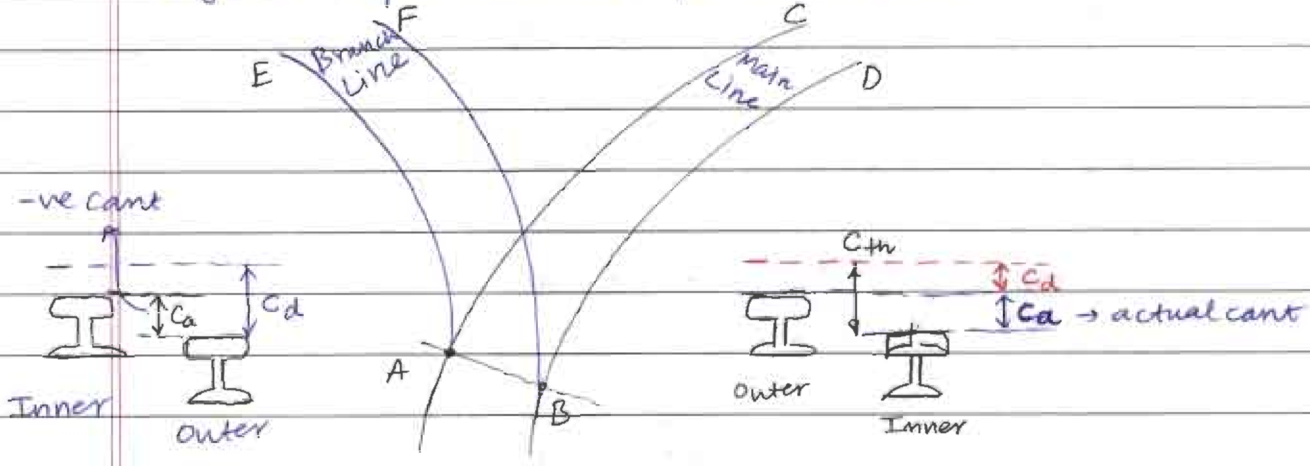
Q. Find the minimum permissible radius on a BG high speed route to permit a maximum speed of 140 kmph

→ $165 = \frac{13.76 V_m^2}{R_{min}} - 75 \Rightarrow R_{min} = 1123.73 \text{ m}$

⇒ Negative ~~Relative~~ superelevation

→ If the level of outer rail in curve is above the level of inner rail, then the s/e is called positive s/e and if the level of outer rail is below the level of inner rail, the s/e is known as negative s/e.

→ When a mainline on curve has a turnout of opposite curvature, leading to a branch line, then the level of outer rail in branch line is kept lower than level of inner rail, this leads to negative super elevation for branch line.



→ Steps to calculate speed on mainline

① → Calculate theoretical cant on branch line by assuming some velocity, $e_{th} = \frac{GV^2}{127R}$

② → By deducting cant deficiency in branch line, calculate the actual cant, $e_a = e_{th} - e_d < 0$

③ → This negative s/e will become actual s/e for main line.

④ → Permissible speed on main line is obtained based on

$$e_{th} = e_a + e_d$$

AIR-1 Notes
Pages: 350

RCC & Prestressed Concrete Structures

Handwritten notes by

Kartikay Kaushik

AIR-1 ESE 2021

IES Master classroom Student

RCC

CONTENT

Design of Concrete and Masonry Structures

[Pre → 15-20 ques.
Conventional → 100 + marks]

1) Footing
2) Column
3) Slab
4) Beam
5) Lintel
6) Water Tank
7) Stair case
8) Retaining wall.

⇒ RCC → IS 456:2000 [with amendment No.4, May 2013]
⇒ Steel → IS 800

1. Introduction

⇒ **Purpose of IS code:**

1) Ensure adequate structural stability by specifying minimum requirements (like minimum reinforcement)
2) Provides simple design tables and charts.
3) Ensure consistency among different designers.
4) Some legal validity.

→ SP-16, SP-24 and SP-34 [SP – Special publication]

SP-16 ↙ Design Tables
SP-24 ↓ explanatory code for IS 456-1978
SP-34 ↳ Reinforcement Detailing.

→ Plane and Reinforced Concrete [PCC and RCC]

PCC ↙ Plain Cement Concrete
RCC ↓ Reinforced Cement Concrete.

→ It is a mixture of Cement, Fine aggregate (sand), coarse aggregate (gravel) and water that results in a solid mass.

→ Sometimes admixtures are also used.

→ A concrete with no reinforcement is called as PCC.

→ PCC is generally used where significant tensile stress does not develop like in the construction of dam, levelling coarse of foundation etc.

→ Concrete is very strong in compression but weak in tension. It's tensile strength is approximately 1/10th of compressive strength.

NOTE: → Portable water shall be used in concrete and pH shall not be less than 6. Sea water shall not be used.

→ For most concrete work, nominal max. size of coarse aggregate is 20 mm.

Nominal size → Expected size
Actual size → Nominal ± tolerance.

→ Reinforced concrete

→ A concrete with reinforcement embedded in it. The embedded reinforcement makes the section capable of resisting higher tension.

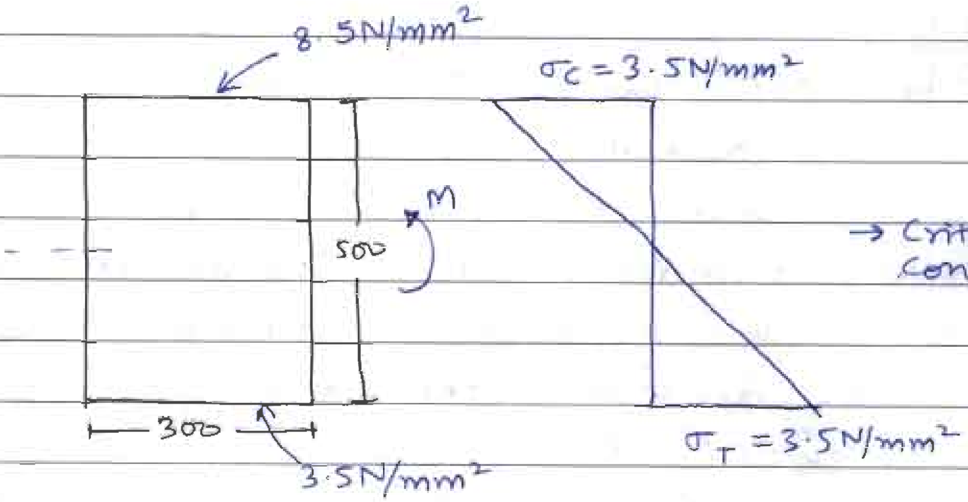
→ All of the tension is assumed to be taken off by the reinforcement (In cracked section analysis). without separating from Concrete.

→ The bond between steel and surrounding concrete ensure strain compatibility i.e. the strain in steel is equal to the strain in surrounding concrete.

→ Reinforcement also impats ductility to the concrete which otherwise is a brittle material.

DPP

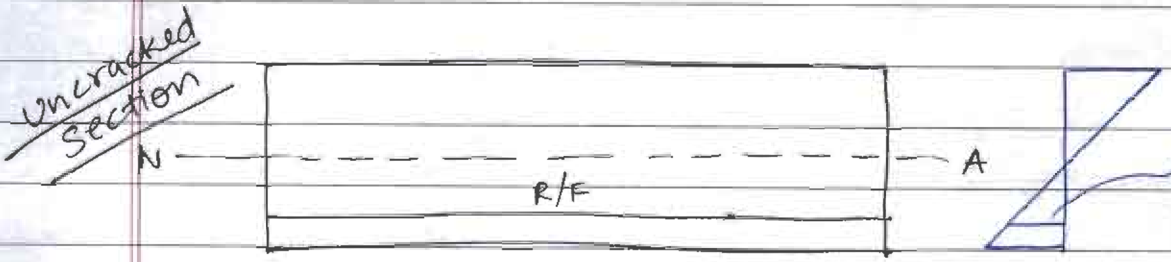
Q-1



→ Critical condition.

$$MOR = 3.5 \times \frac{(300)(500)^3}{12 \times 250} = 43.75\ kNm.$$

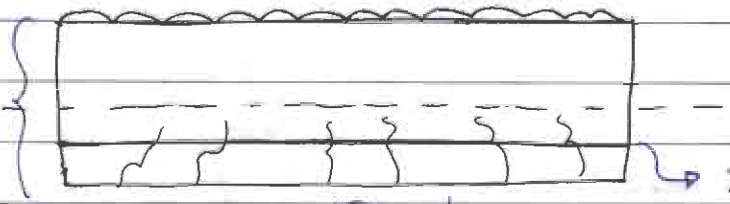
→ MOR of the section (concrete) will be governed from the tension side.



$$f_{st} = \varepsilon_s \cdot E_s$$
$$= \varepsilon_c \cdot E_s$$
$$= \frac{f_c}{E_c}\ E_s$$

$f_c = 0.7\sqrt{f_{ck}}$, $E_c = 5000\sqrt{f_{ck}}$

So, $f_{st} = \frac{0.7}{5000} \times 2\times10^5 = 28\ MPa$ { St → 250
↳ 415
↳ ~~4~~500 }



Section becomes smaller

↳ 250MPa can be utilized

① ↳ gives sufficient warning before collapse [as compared to PCC]

DL on building ↑

→ Ductility means large deflection and this is due to yielding of steel. Ductile members give prior warning before impending collapse.

NOTE: We generally design cracked sections in RCC to use the higher permissible stress of steel.

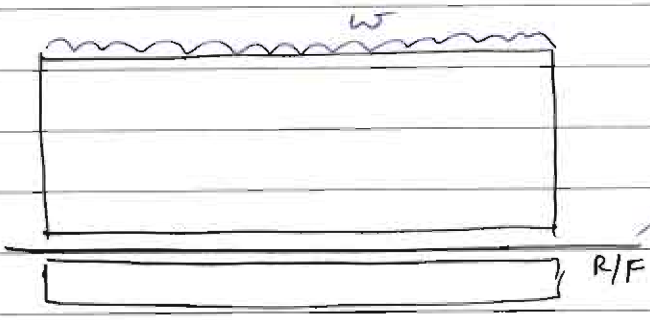
→ Also, the section size required will be less in cracked section compared to uncracked section. However, crack width shall not be high to avoid corrosion of reinforcement.

→ Permissible crack width as per code:

(a) In general → ≤ 0.3 mm

(b) Structure exposed to moisture or in contact with soil or ground water → ≤ 0.2 mm.

(c) Very severe and extreme weather condition → ≤ 0.1 mm.



→ No stress
↓
stress after strain compatibility is ensured

→ <u>Compressive Strength of concrete</u>

→ The most important property of concrete and can be easily tested.

→ Many other properties like tensile strength, bond strength, shear strength, impermeability, durability, Modulus of Elasticity can be inferred from compressive strength.

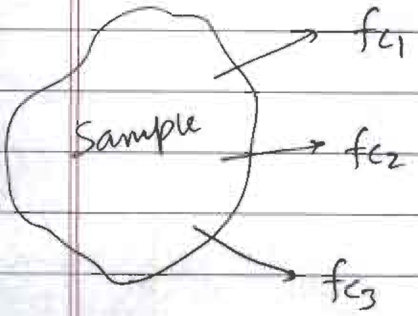
→ Strength of concrete in uniaxial compression is determined by loading the standard test cube [150 mm size] to failure in compression testing mathine.

→ The test specimen is generally tested 28 days after casting and continuous curing.

→ Cube is always tested on sides i.e. faces in touch with mold are in contact with the platen (small plate) of the machine

→ ~~The~~ Three specimen of the sample are taken to report the strength and compressive strength is average of 3 specimen

→ Individual variation shall not be more than ±15% of the average. If the variation is more, the test result of the sample are invalid.



f_{c_i} → specimen strength.

$$\text{Sample strength } (f_{c,avg}) = \frac{f_{c_1} + f_{c_2} + f_{c_3}}{3}$$

$$\frac{f_{c,avg} - f_{c_i}}{f_{c,avg}} \times 100 \leq 15\%$$

$$\boxed{0.85\, f_{sample} \leq f_{specimen} \leq 1.15 \times f_{sample}}$$

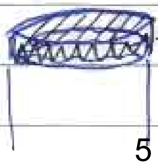
* Why 3 samples → concrete is a non-homogeneous material.

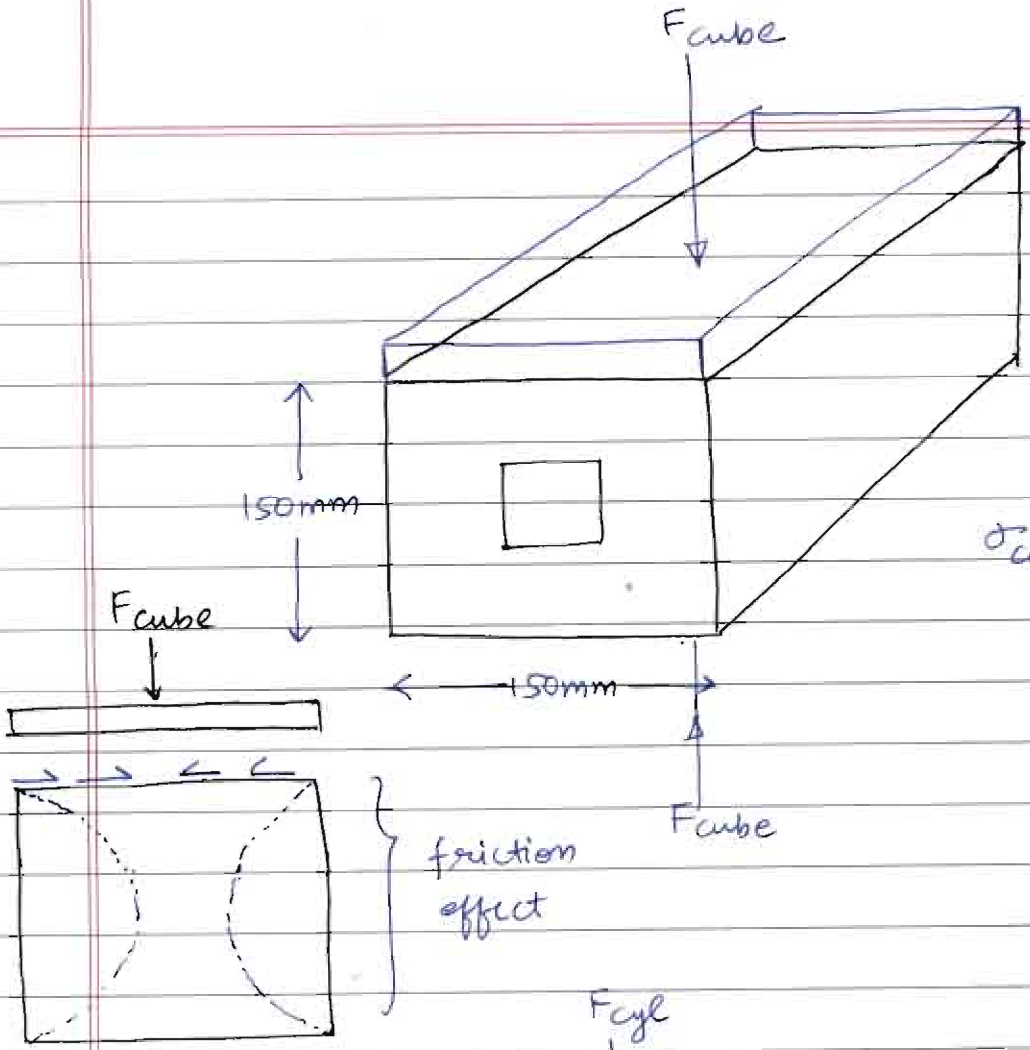
⇒ Comparison of strength of cube and cylinder
IS456 (cube) IS516 (cylinder)

→ Standard cube size → 150mm

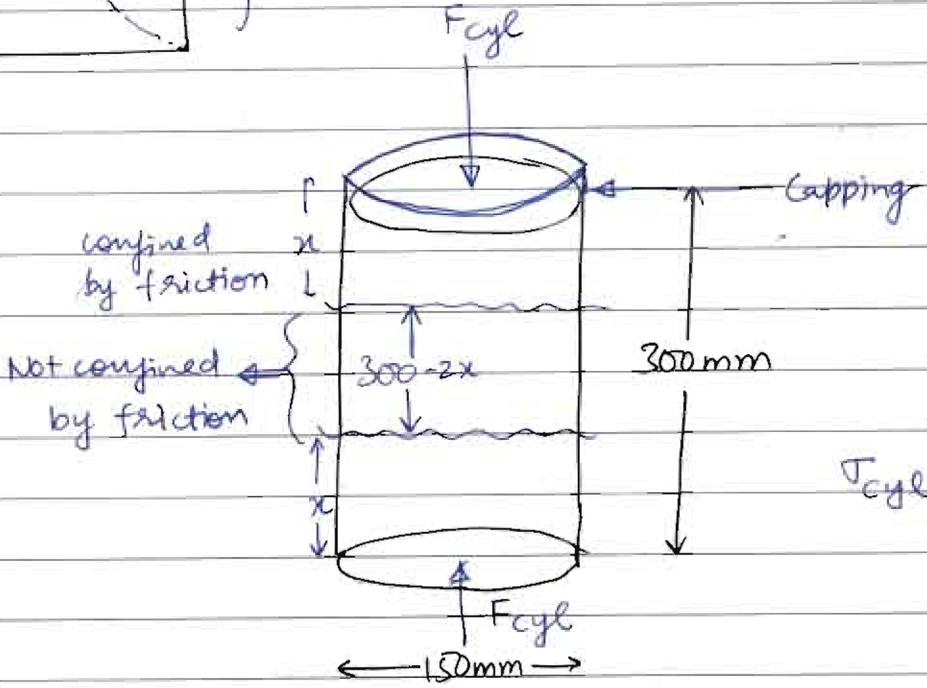
→ Standard cylinder size → 150 mm dia X 300mm height.

→ Cube tested without capping (neat cement paste) and cylinder tested with capping.





$$\sigma_{cube} = \frac{F_{cube}}{(150)^2}$$



$$\sigma_{cyl} = \frac{F_{cyl}}{\frac{\pi}{4}(150)^2}$$

$$\sigma_{cube} > \sigma_{cylinder}$$

$$\sigma_{cylinder} = 0.8 \times \sigma_{cube}$$

→ $\sigma_{cylinder}$ is closer to the practical value as there is generally no confinement practically.

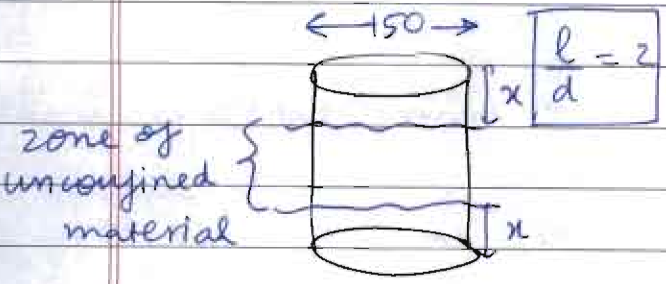
→ The restraining effect of the platens (because of friction) of the testing machine extends over the entire height of a cube. but ~~tests~~ leaves unaffected a part of test cylinder.

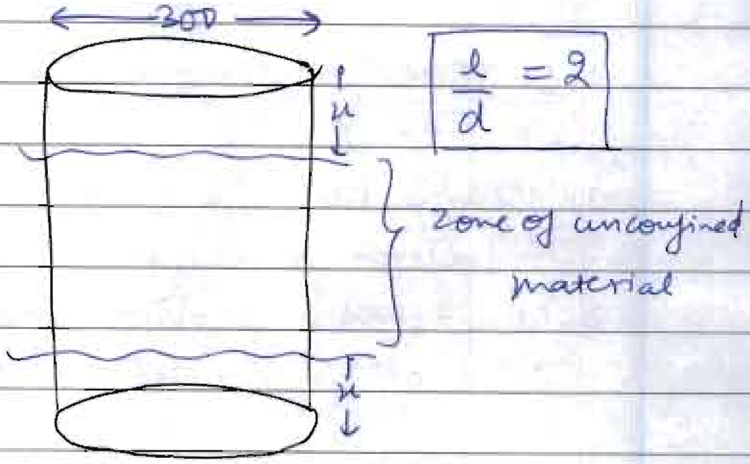
→ Due to restraining effect the strength differs and the cylinder fails at a early stress than the cube. and hence at the verge of failure, $\sigma_{Cube} > \sigma_{Cylinder}$

→ Cylinder strength is closer to the true uniaxial compressive strength of concrete and $f_{cylinder} = 0.8 \, f_{cube}$.

→ IS code uses cube compressive strength.

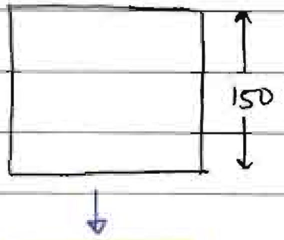
Q:- (ix)

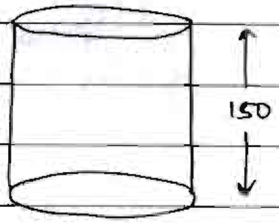




Upto $h \cong 1.7D$ → friction effect is significant.

→





Cube will fail early due to stress concentrations.

→ Grade of concrete

As per IS code:

① Ordinary Concrete → M10, M15, M20 } IS code valid for
② Standard Concrete → M 25 to M 60 55 } these two
③ High-Strength concrete → M 65 to M 100
60

NOTE :→ M30 means characteristic compressive strength of 150 mm size cube at 28 days is 30 N/mm^2.

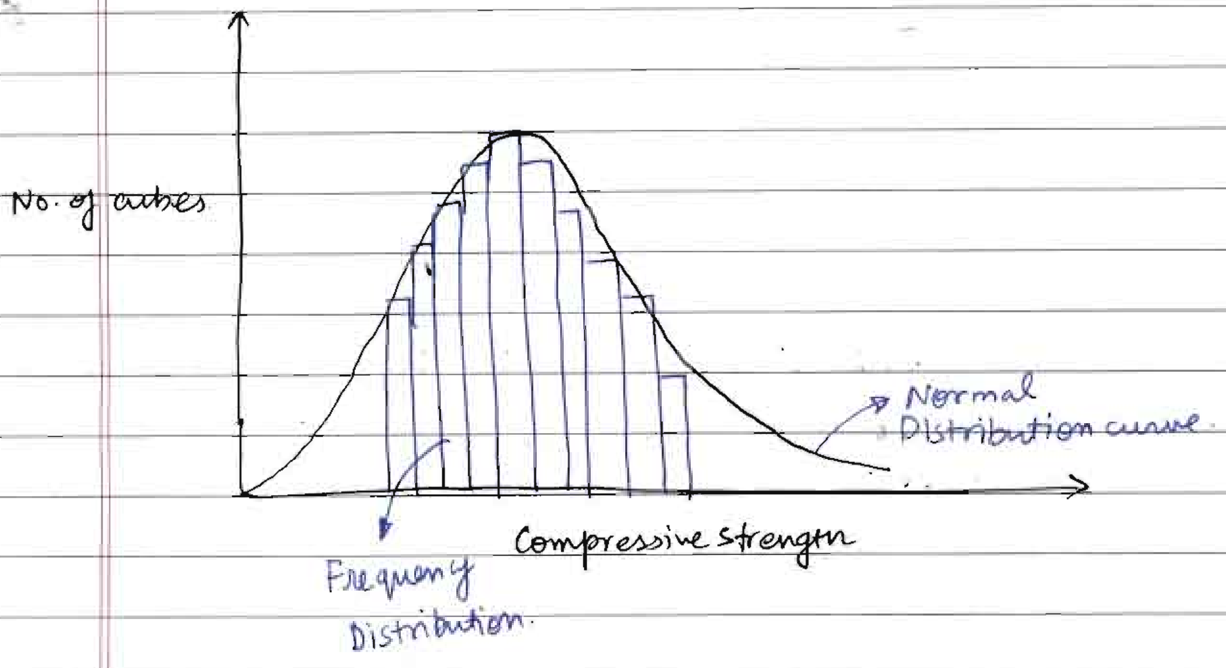
→ IS 456-2000 may not be applicable for concrete grade above M60.

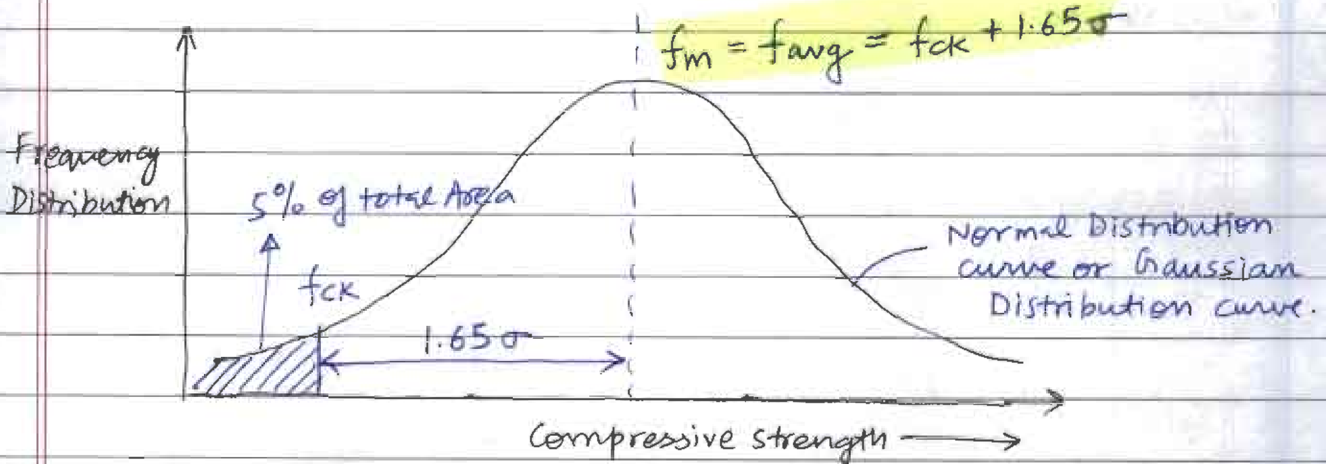
→ M5, M7.5 is known as Lean concrete.

→ Characteristic strength of concrete

→ When a large no. of test result of concrete cube are plotted it follows a normal distribution curve.

→ Characteristic strength is the strength below which not more than 5% of the test result are expected to fall.





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

σ → Standard Deviation.

→ Minimum sample required for standard deviation calculation is 30 and no. of specimen req. = 30X3 = 90.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (f_i - f_m)^2}{N-1}} \qquad N \geqslant 30$$

→ Concrete is designated by characteristic cube strength at 28 days.

NOTE: Cement Hydrates and gains strength over a long period of time and hence strength of concrete increases with time.
→ However, this increase in strength is not considered as per IS 456 : 2000.

X IS 456 - 1978
→ 7 days - 0.7 fck
→ 28 days - fck
→ 6 months - 1.2 fck

Q- The frequency distribution of the compressive strength of 100 samples is as follows. Calculate fck, fm, σ and K where

$$f_m = f_{ck} + K\sigma$$

No. of samples	Compressive strength (N/mm²)
2	10
3	14
9	16
11	18
14	20
15	22
21	24
11	26
9	28
3	30
2	32

→ Let us take $f_{ck} = 15 N/mm^2$.

$$f_m = \frac{\Sigma f_i n_i}{\Sigma n_i} = 22.1 N/mm^2$$

$$\sigma = \sqrt{\frac{\Sigma (f_i - f_m)^2 \cdot n_i}{N-1}} = 4.507$$

$$f_m = f_{ck} + k\sigma$$

$$K = \frac{f_m - f_{ck}}{\sigma} = 1.575$$

⇒ Compressive strength of concrete in structure

→ It is not equal to the strength obtained from the compression test of cube due to many factors like duration of loading, size of member [size effect], multiaxial state of stress and strain gradient.

→ Strength decreases with increase in size however after a certain value, it is almost constant.

→ compressive strength of concrete in structure = 0.85 fcylinder

= 0.85 × 0.8 fcube

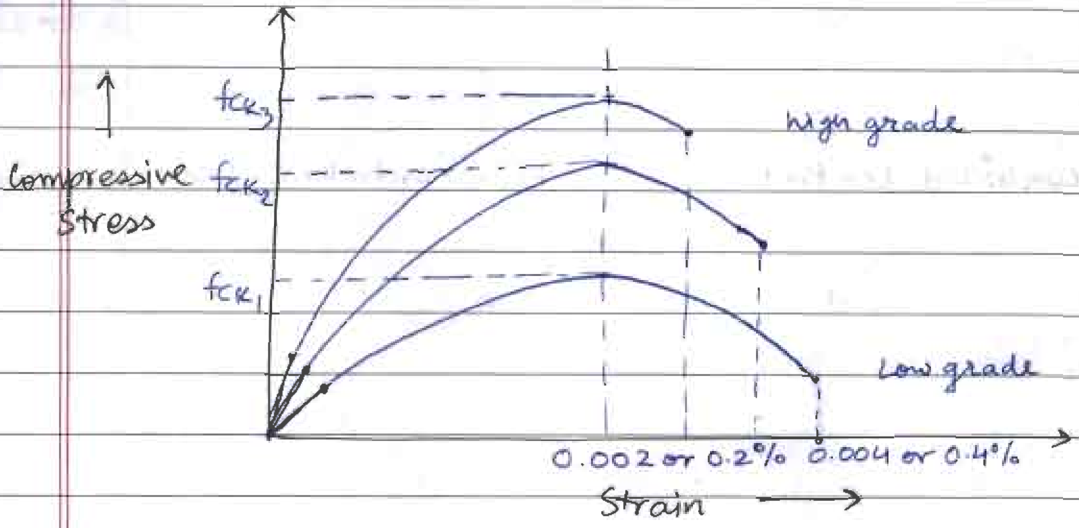
= 0.68 fcube

≃ 0.67 fck [IS code]

✓

→ Due to size effect, actual strength available of concrete in structure = 0.67 fck.

⇒ Stress-Strain curve of concrete in compression



→ Curve is generally linear upto 1/3 to 1/2 of peak stress.

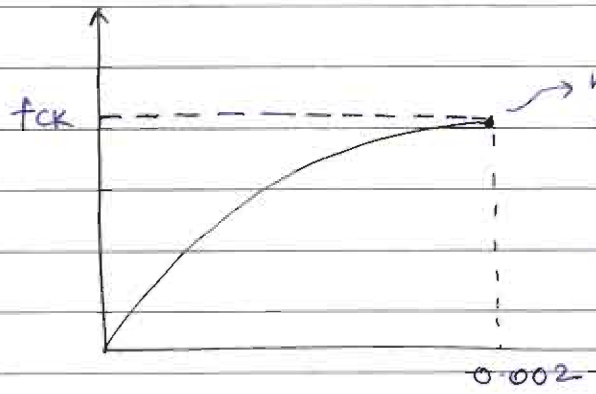
→ maximum compressive stress reaches at a strain of 0.002

→ Stress at 0.002 (0.2%) strain is called compressive strength of concrete.

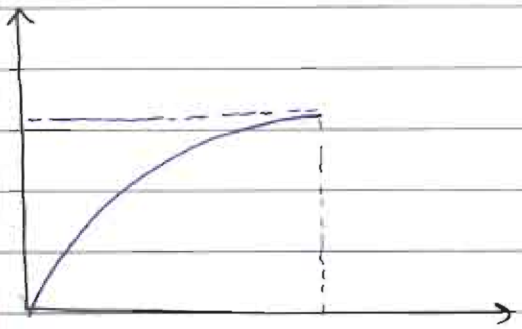
→ The strain at failure is in between 0.003 to 0.005 for usual grade of concrete.

→ The higher the concrete grade, steeper is the initial portion and sharper is the peak of the stress-strain curve i.e not flat at top.

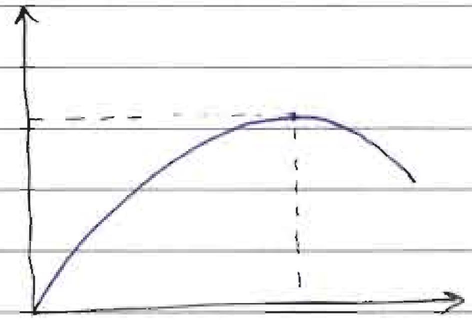
→ Low grade concrete is more ductile than high grade concrete. However, in RCC structure ductility of concrete is not considered.



→ how to obtain the curve beyond this point.
↓
By reducing the stress after the point at which fck is obtained



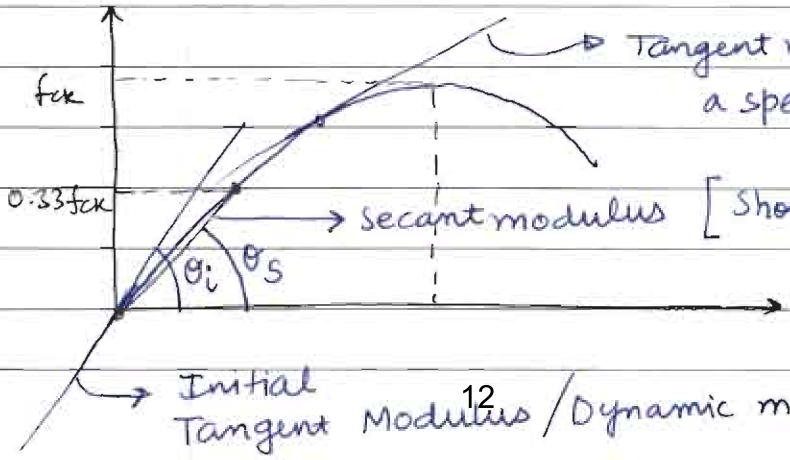
Stress controlled Loading



Strain controlled Loading.

→ To obtain the descending part of the curve, the applied load shall be strain controlled.

⇒ Modulus of Elasticity and poisson's ratio



→ Tangent modulus at a specified stress.

→ secant modulus [Short term static modulus]

→ Initial Tangent Modulus / Dynamic modulus

⇒ 3 types of modulus:

1) Initial Tangent Modus / Dynamic modulus (E_{cd})

→ Slope of tangent at origin of stress-strain curve. (corresponds to a small instaneous strain).

→ Can be used for dynamic load cases (earthquake, wind) or very short period loading like (impact loading in which long term effect of creep and shrinkage can be neglected)

→ Can be obtained by NDT [Electrodynamic method, Resonance frequency method] (NDT → Non ~~Descriptive~~ -Destructive Testing)

2) Secant modulus (E_c)

→ Slope of line drawn from origin to a specified stress level, here it is 0.33 fck.

→ As per IS code, $E_c = 5000\sqrt{f_{ck}}$, where fck - characteristic compressive strength

$$\underset{\text{MPa.}}{\underset{\downarrow}{E_c}} = 5000\sqrt{\underset{\text{MPa}}{\underset{\downarrow}{f_{ck}}}}$$

[± 20% variation permissible]

→ E_c is used to calculate instantaneous elastic deformation for structure analysed using linear static analysis.

→ E_c does not take into account long term effect of creep and shrinkage and hence called as short term static modulus.

3) Tangent Modulus (E_t)

→ Slope at any particular point on the curve.

→ It applies to changes in load from a particular load level.

NOTE:

→ E_c increases with increase in grade of concrete.

→ IS code uses Secant modulus / short term static modulus.

→ Generally dynamic modulus ≥ short term static modulus.

→ Modulus of Elasticity is primarily influenced by the elastic properties of aggregate and to a lesser extent by the conditions of curing, ageing of concrete, the mix propostion

AIR-1 Notes

Pages: 151

Structural Analysis

Handwritten notes by

Kartikay Kaushik

AIR-1 ESE 2021

IES Master classroom Student

Structural Analysis

→ Syllabus

Obj ① Determinacy and Indeterminacy ✓ → Test ②

② Force methods. ✓

③ Displacement methods < Slope Deflection method ✓ → Test ②
Moment Distribution method. → Test ②

Obj ④ Trusses

Obj ⑤ Influence Line Diagram → Test ②

Obj ⑥ Matrix methods

Obj ⑦ Misc (Cables and Arches)

1) Determinacy & Indeterminacy

→ Why do we go for indeterminate structure?

- → Deflections are limited. (greater stiffness)
- → Max BM that develops is smaller as compared to determinate structure i.e. cross-sectional requirement is less → material economy & DL↓
- → More load transfer paths, failure of 1 member will not lead to failure of the entire structure.

→ Disadvantages

- → Support settlement leads to stresses in the members.
- → Stresses indued to temperature changes.
- → Supports have to be more strong.

NOTE: 50% more saving when using indeterminate structures.

→ in structural Analysis, we generally analyse indeterminate structures.

→ If all member forces and support reactions in a str. cannot be found out only by using the eq^ns of static equilibrium, the structure is said to be indeterminate.

→ In the analysis of indeterminate structures, 2 methods are adopted:

1) Force method

2) Displacemethod.

→ In force methods, member forces or support reactions are taken as unknowns and compatibility eqⁿ is written to find out the unknown member forces and support reactions

→ No. of compatibility eqⁿs req = No of unknown member force/ support rxns
= Degree of Static indeterminacy of the structure.

→ In displacement method of analysis, joint displacements are taken as unknown.

NOTE: Joint is the location where 2 members meet and generally we take it as support location, beam column joint, location of discontinuity like internal hinge, sliders.

→ We write the force displacement relationship and use equilibrium equations to find out the joint displacements (unknown). The joint displacements when put back into the force displacement relationship, we get the member forces.

→ The number of eqⁿ equations required
= Number of unknown joint displacements
= Degree of Freedom of the structure
= Degree of kinematic Indeterminacy

⇒ Static Indeterminacy of a Structure (D_s)

D_s → degree of static indeterminacy = [Number of member forces and support reactions] − [No. of equations of static equilibrium]

$\Sigma F_x = 0$
$\Sigma F_y = 0$ 2D
$\Sigma M_z = 0$

$\Sigma M_x = 0$ $\Sigma F_x = 0$
$\Sigma M_y = 0$ $\Sigma F_y = 0$ 3D
$\Sigma M_z = 0$ $\Sigma F_z = 0$

$$D_s = D_{s_i} + D_{s_e}$$

D_{s_i} ↙ internal indeterminacy

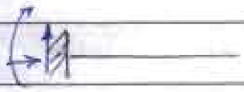
D_{s_e} ↘ external indeterminacy.

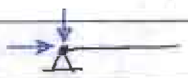
→ D_{s_e} = [Number of support reactions (R)] − [No. of equations of static equilibrium]

→ 2D ⇒ $D_{s_e} = R - 3$

→ 3D ⇒ $D_{s_e} = R - 6$

2D


R = 3

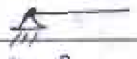

R = 2


R = 1


R = 2

3D


R = 6

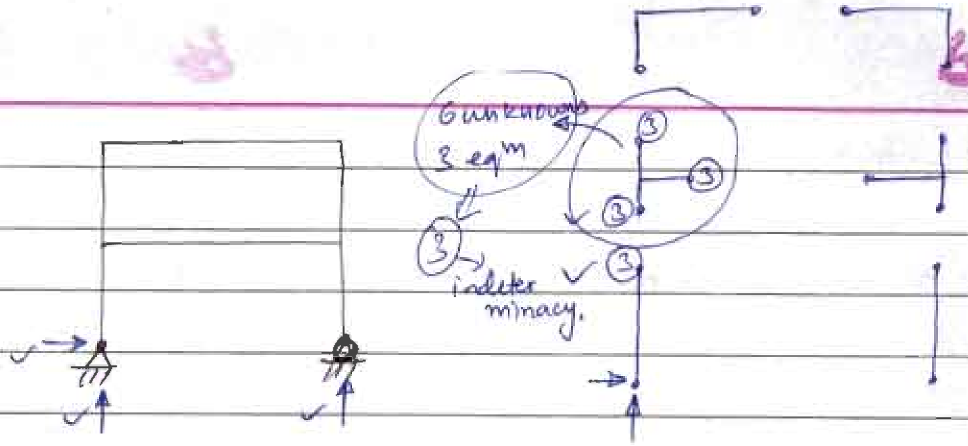

R = 3


R = 1

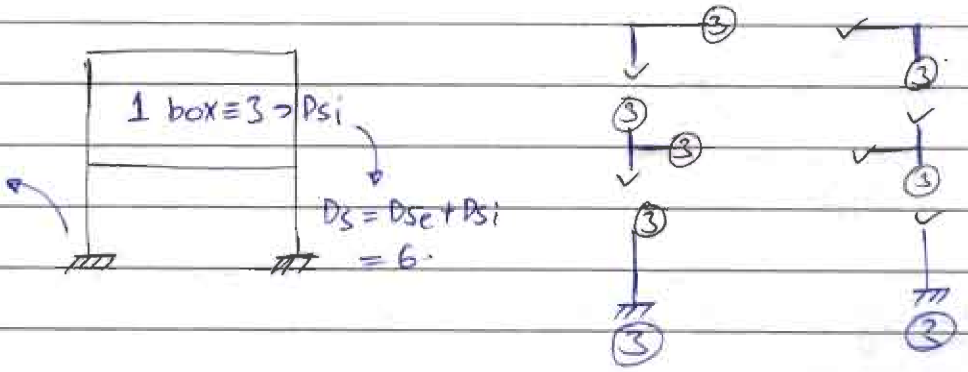

R = 5

NOTE: No. of support reactions at any support = No. of restrained displacements.

$$\boxed{D_{s_i} = D_s - D_{s_e}}$$



→ Even by knowing all of the support rxns if all the member forces cannot be obtained using equilibrium equations then the str. is said to be internally indeterminate.



$D_{se} = R - 3$
$= 6 - 3$
$\boxed{D_{se} = 3}$

$D_S = D_{se} + D_{si}$
$= 6$

Total no. of support rxns = 6

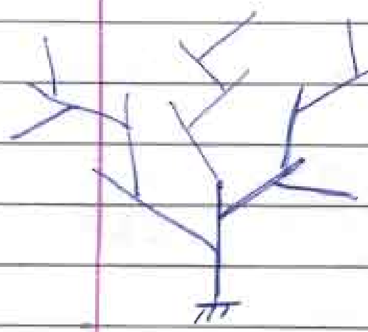
Total no. of member forces = 18

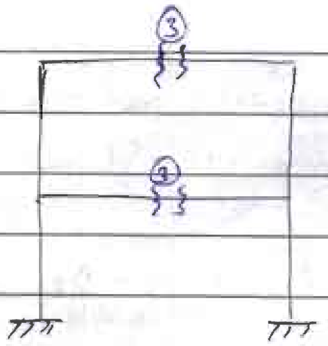
So, $D_S = (18 + 6) - (3 \times 6)$ → No of eqns of static eqns.

$\boxed{D_S = 6}$

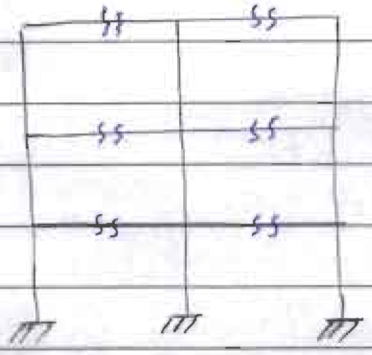
⇒ Static indeterminacy of frames

→ Open tree concept


→ determinate if all forces on ends are known



$D_S = 6$ → 3 x Number of cuts.

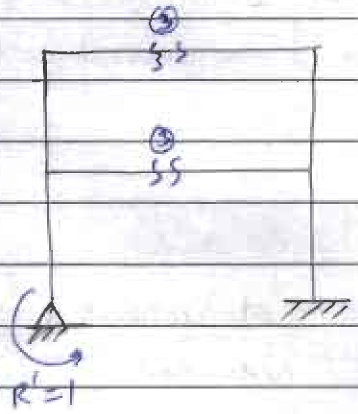


$D_s = 18 \quad \{3 \times 6\}$

→ Frames are rigid jointed structures. All the joints are made rigid by providing extra restraint R' and the structure is cut to make it open tree like structure. Hence $D_s = 3C - R' \quad \{2D\}$

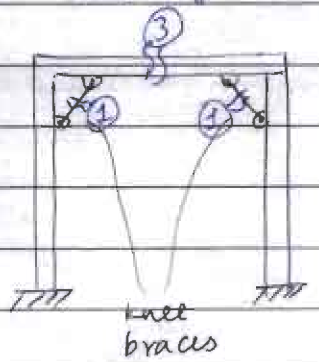
$= 6C - R' \quad \{3D\}$

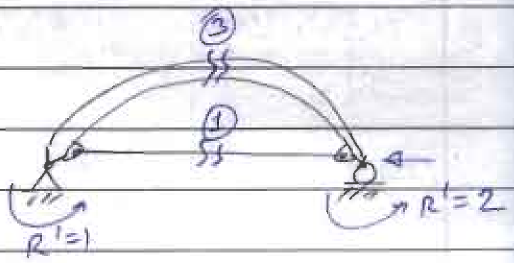
where C is the number of cuts required and R' is the number of restraints required.



$D_s = 6 - 1 = 5.$

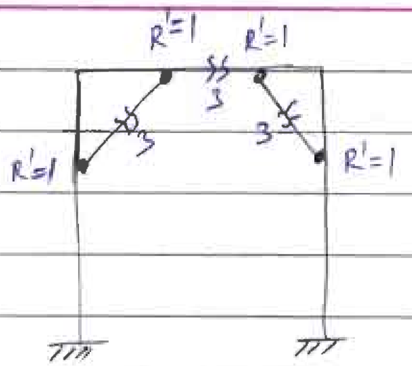
NOTE: If at the cut location unknown forces are less than 3 then in that case for every cut we cannot take 3 unknowns The unknowns should be taken as per the no. of internal forces existing at the cut location.





$D_s = 3 + 1 + 1 = 5$

$D_s = 3 + 1 - 1 - 2 = \underline{1}.$



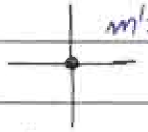
$D_S = 3C - R'$
$= 3 \times 3 - 4 = 5$

→ For open tree following conditions must be met:

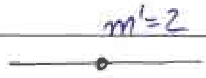
① Each tree should have only 1 root
② There should not be any looped branches
③ None of the members should fall off

→ $R' \left\{ \begin{array}{l} \text{No. of support} \\ \text{restraint req.} \end{array} \right\} = \left[\begin{array}{l} \text{No. of support} \\ \text{rxn if fixed} \end{array} \right] - \left[\begin{array}{l} \text{No. of existing} \\ \text{support reactions} \end{array} \right]$

→ Restraining member or joint



joint hinge

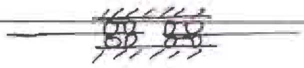


member hinge

$\text{No. of restraint required} = \left\{ \begin{array}{ll} m'-1 & (2D) \\ 3[m'-1] & (3D) \end{array} \right.$

→ m' → number of members meeting at the joint

Shear release
R'=1

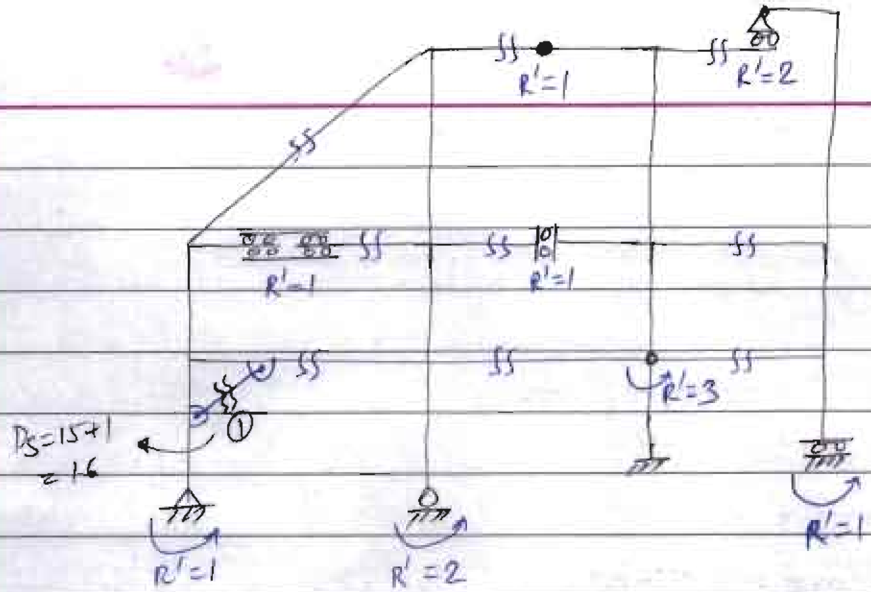


Axial force release
R'=1

Axial force & BM release
R'=2

R'=2

Q-



$D_s = 9 \times 3 - 12 = 15$.

$D_{se} = 8 - 3 = 5$

$D_{si} = 10$

Box concept

No. of boxes = 6

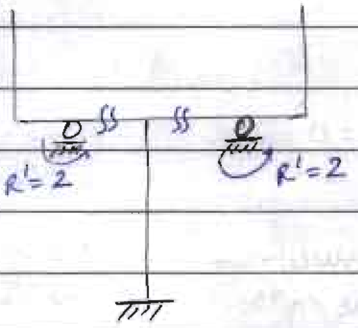
No. of releases = 1+1+1+2+3 = 8

So, $D_{si} = 6 \times 3 - 8 = 10$

$D_{se} = R - 3 = 8 - 3 = 5$

$$\left.\begin{matrix} D_{si} = 6 \times 3 - 8 = 10 \\ D_{se} = R - 3 = 8 - 3 = 5 \end{matrix}\right\} D_s = D_{si} + D_{se} = 15$$

Q-

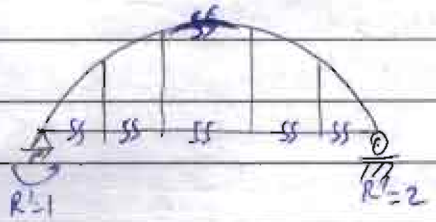


$D_s = 3 \times 2 - 4 = 2$

$D_{se} = 2$

$D_{si} = 0$

Q-

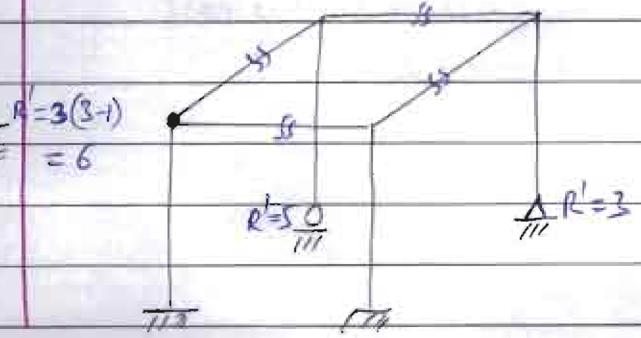


$D_s = 3 \times 6 - 3 = 18 - 3 = 15$

$D_{se} = 0$

$D_{si} = 3 \times 5 = 15$

Q-



$D_s = 6C - R' = 6 \times 4 - 14 = 10$

$D_{se} = (6+6+1+3) - 6 = 10$

$D_{si} = 0$

2D

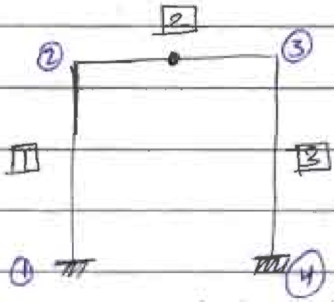
$D_s = 3m + r - \overset{\text{eq}^n\text{ of equilibrium}}{3J} - \text{no. of releases.}$

3D

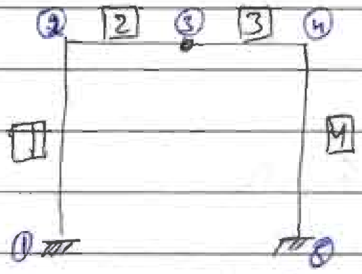
$D_s = 6m + r - 6J - \text{no. of releases.}$

m → no. of members.
r → no. of support reactions.
J → no. of joints.

$D_{s_i} = ??$



$D_s = 3\times3 + 6 - 3\times4 - 1$
$= 15 - 13 = 2$

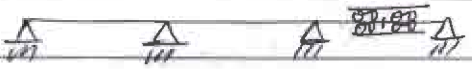


$D_s = 3\times4 + 6 - 3\times5 - 1 = 2$

⇒ Static indeterminacy for beams ($D_{s_i} = 0$)

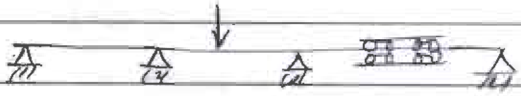
$$\boxed{D_s = \left(\text{No. of support rxns}\right) - \left(\text{No. of equilibrium } \cancel{\text{rxns}}\ \text{eq}^n\text{s}\right) - \left(\text{No. of releases}\right)}$$

→ in case of beams all indeterminacy is taken as external indeterminacy and D_s is calculated as



general loading case

$D_s = 8 - 3 - 1 = 4$



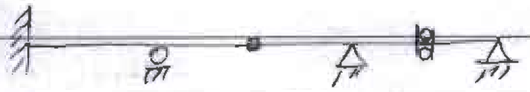
vertical loading case

$D_s = 4 - 2 - 0 = 2$

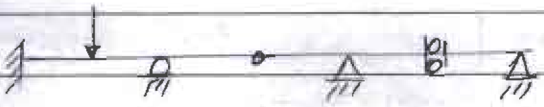
General Loading		vertical loading with all supports at the same level	
	Reaction = 2		R = 1
	R = 1		R = 1
	R = 3		R = 2
	R = 2		R = 1
	R' = 1		R' = 1
	R' = 1		R' = 1
	R' = 2		R' = 1
			R' = 0
Static eq^m = ③		Static eq^m = 2	

Reactions.

Releases

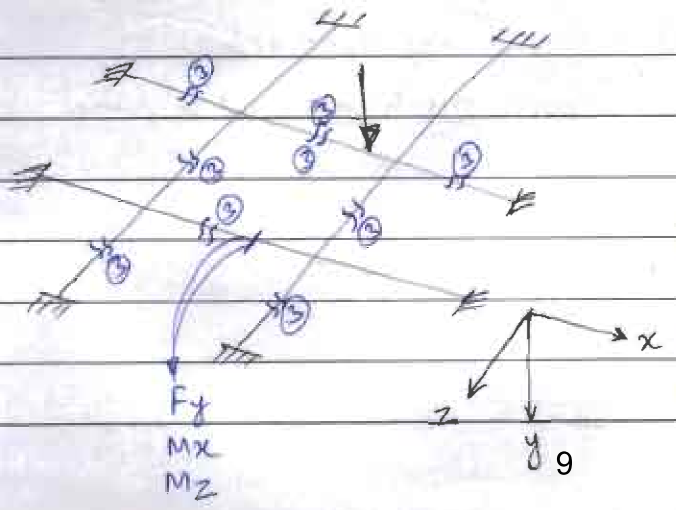


$D_S = (3+1+2+2) - 3 - 2 = 3$



$D_S = (2+1+1+1) - 2 - 2 = 1$

⇒ Static Indeterminacy for Horizontal grid member with vertical loading



$D_S = 3 \times 8 = 24$
↓
C

→ Since at any section we have only 3 internal forces we can treat it as a 2-D structure and hence, $D_S = 3C$, since $R' = 0$ generally

⇒ Stability of structure

→ Stability can be characterized as:

(a) External Stability

(b) Internal Stability

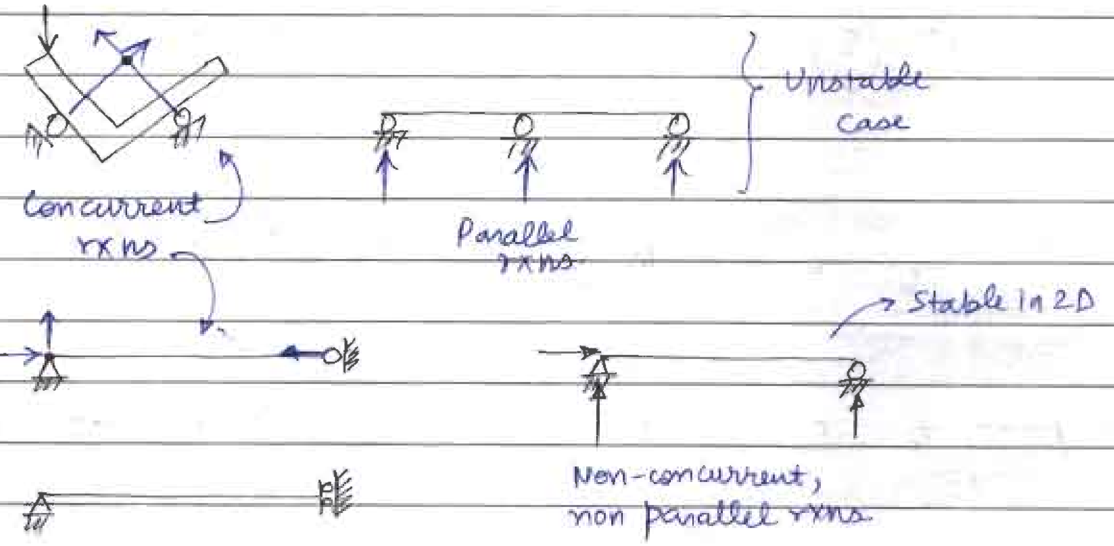
(A) External Stability

→ If the body is sufficiently constrained by external rxns such that rigid body motion of the structure does not take place then the structure is said to be externally stable.

→ The necessary conditions for external stability are:

1) There should be minimum of 3 rxns

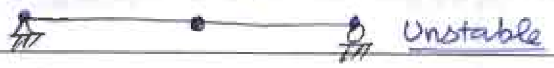
2) The reactions should be neither llel, nor concurrent, nor-coplanar

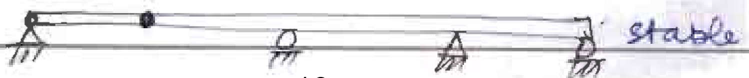


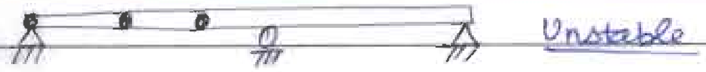
(B) Internal Stability

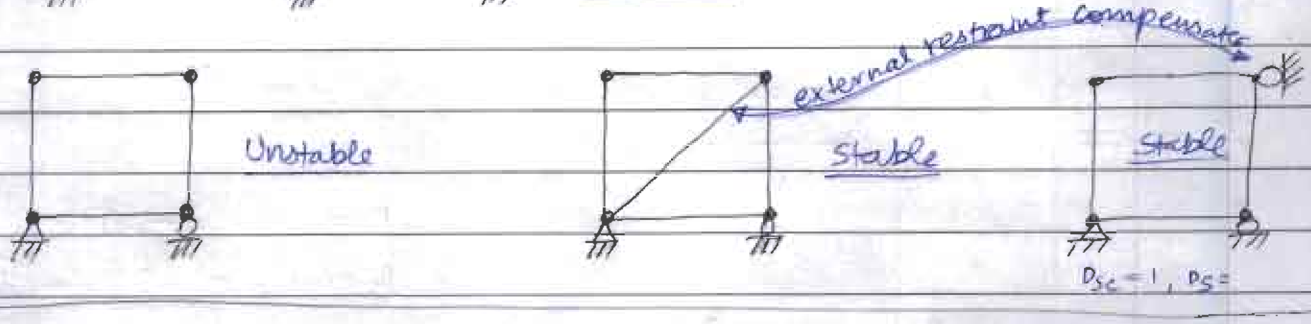
→ When a part of the structure moves appreciably wrt the other then the structure is said to be internally unstable

→ 3 hinges in continuation makes a mechanism and hence it is unstable internally



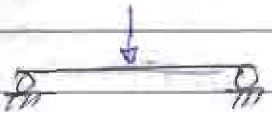






NOTE:

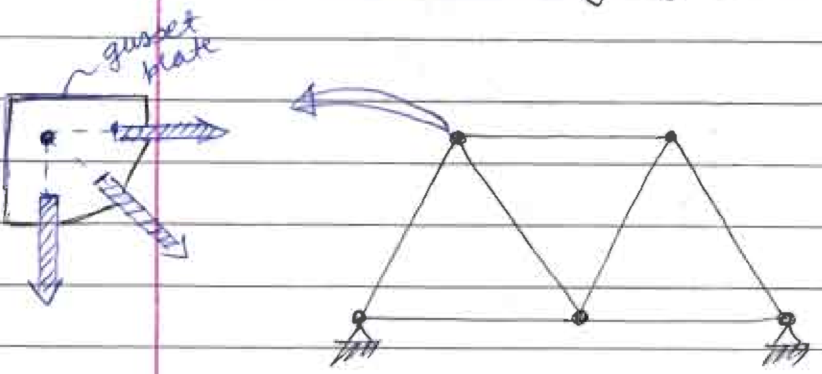
- → Internal Instability could be due to lack of sufficient members or due to large number of internal releases.
- → Negative value of D_{S_e} means structure is externally unstable.
- → Negative value of D_S means structure is overall unstable.
- → Negative value of D_{Si} does not ensure that the structure is unstable internally, because lack of members and large no. of internal releases can be compensated by providing external restraints.
- → In complicated structures it may not be visually possible to comment on the stability of the structure In that case If the structure is analysed by various methods yield the similar results → then the structure is stable otherwise unstable.
- → If a structure is stable under a particular loading but is unstable under general loading condition, then the case of special loading under which it is stable is said to be unstable equilibrium.



→ unstable equilibrium and statically unstable

- → If the no. of rxns is less than 3 then the structure is said to be statically unstable

⇒ Static Indeterminacy of Truss



$D_s = m + r - 2J$ — (2D)

$D_s = m + r - 3J$ — (3D)

- → In case of truss member, every joint is a pin joint and load is acting only on the joint
- → Hence all members are links and thus can have only axial force.
- → In 2D truss, every joint will have only 2 static equilibrium equations as all forces are passing through single point So $\Sigma M = 0$ is of no consequence.

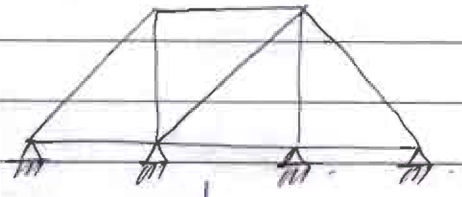
$D_{se} = r - 3 \} \rightarrow 2D$

$\quad\quad\; r - 6 \} \Rightarrow 3D$

$D_{si} = D_s - D_{se}$

NOTE: Simple Truss

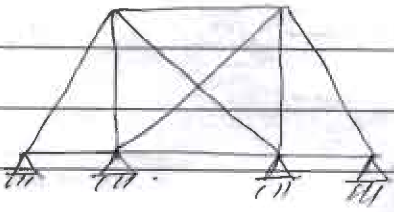
- → If a truss can be completed by adding successively 2 members and 1 joint over a triangular framework then the truss is called Simple Truss
- → Simple truss is always internally determinate and stable
- → $D_s = D_{se}$ for a simple truss.



↓

Simple Truss

$D_s = 4 \times 2 - 3 = 5$

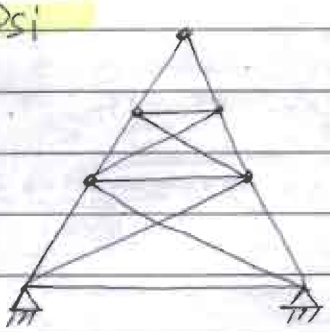


$D_{se} = 5$

$D_{si} = 1$

$D_s = 6$

→ In an otherwise simple truss, the no. of double diagonal panel is $= D_{Si}$

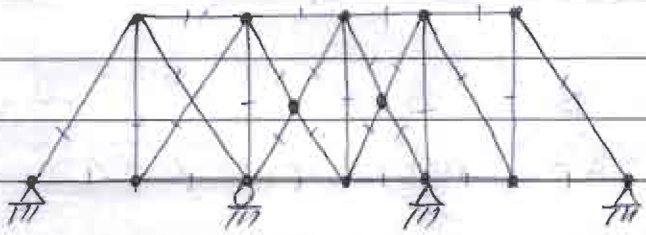


$$D_S = m + r - 2J$$
$$= 13 + 4 - 2 \times 7 = 3$$

or $D_S = \underset{4-3}{D_{Se}} + \underset{2}{D_{Si}}$

$4-3 + 2 = 3$

Q.



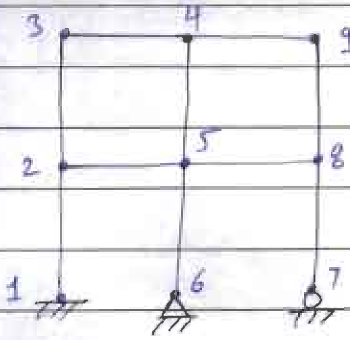
$$D_S = m + r - 2J$$
$$= 28 + 7 - 2 \times 14$$
$$= 35 - 28 = 7$$

⇒ Kinematic Indeterminacy

$$D_K = \begin{bmatrix} \text{Total no. of possible} \\ \text{joint displacements} \end{bmatrix} - \begin{bmatrix} \text{Total no. of} \\ \text{reactions} \end{bmatrix}$$

Type of Joint	Total no. of possible joint Displacements	D_K
1) Rigid jointed plane frame	$\Delta x, \Delta y, \theta_z \Rightarrow 3$ nos.	$3J - r$
2) Rigid jointed space frame	$\Delta x, \Delta y, \Delta z, \theta_x, \theta_y, \theta_z \Rightarrow 6$ nos.	$6J - r$
3) Pin jointed plane frame	$\Delta x, \Delta y \Rightarrow 2$ nos.	$2J - r$
4) Pin jointed space frame	$\Delta x, \Delta y, \Delta z \Rightarrow 3$ nos.	$3J - r$

*



$$D_K = 3 \times 9 - 6 = 21$$

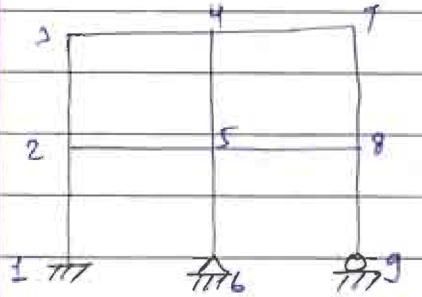
For $\underbrace{J_2, J_3, J_4, J_5, J_9, J_8}$, $\underbrace{\Delta x_i, \Delta y_i, \theta_i} \rightarrow ⑱$

$J_1 \rightarrow 0$
$J_6 \rightarrow 1$
$J_7 \rightarrow 2$ } ③

$18 + 3 = \underline{\underline{21}}$

simply counting is better

If members are inextensible



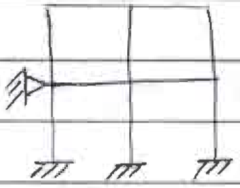
$$\left\{\begin{array}{l}\Delta y_2=0\\ \Delta y_3=0\\ \Delta y_5=0\\ \Delta y_4=0\\ \Delta y_8=0\\ \Delta y_7=0\end{array}\right\} + \begin{array}{l}\Delta x_2=\Delta x_5=\Delta x_8 \rightarrow ① \text{ cut } ②\\ \Delta x_3=\Delta x_4=\Delta x_7 \rightarrow ① \text{ cut } ②\end{array}$$

$D_K = 21-10 = 11.$

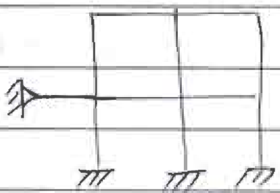
NOTE:

→ In case of inextensibility, D_K in the case of building frame can be taken as $(3J-r-m)$, where m is the no of inextensible members.

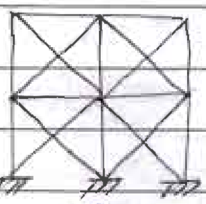
→ This formula is valid only for building frames without lateral bracing.



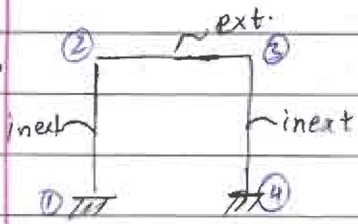
✗ Not a building frame



✓ Building frame.



✗ Not a building frame



$D_K = 3J-r-m$
$= 3\times4-6-2 = 4$

↳ $\Delta x_2, \theta_2, \Delta x_2, \theta_3$.

AIR-1 Notes
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Structural Dynamics
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

STRUCTURAL DYNAMICS

CONTENT

Structural Dynamics

Free and Forced vibrations of single and multi Degree of freedom

→ Vibration is the motion of a particle or a body, displaced from equilibrium position. Vibration in structural system may result from environmental forces like wind, earthquake, waves etc

→ Also rotating machines can create vibrations in a structure

→ **Dynamic Loading**

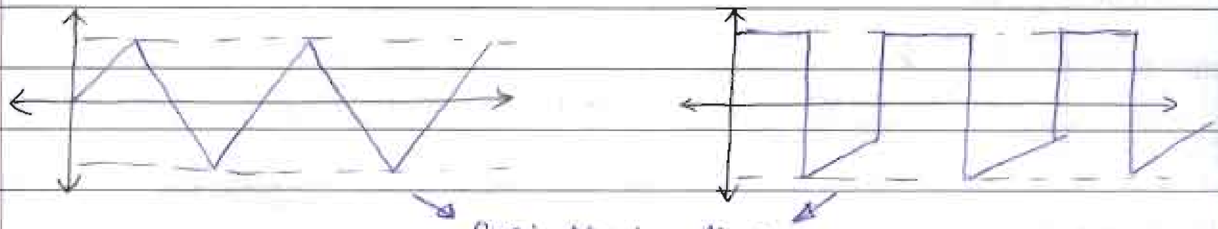
→ A load that varies in magnitude or point of application is called dynamic loading. Dynamic loading can be classified as:

(a) Deterministic (Prescribed) → Machine loading
(b) Stochastic (Random) → Environmental loading

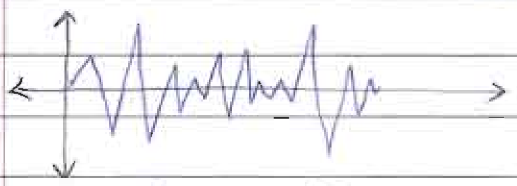
→ Deterministic loading is a known function of time. However, Stochastic loading is not completely known wrt time.

→ Also Dynamic Loading can be classified as:

(a) Periodic Loading (Machine Loading)
(b) Non-Periodic Loading (Environmental Loading)



Periodic Loading



→ Non-Periodic Loading

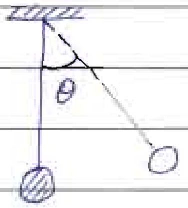
Earthquake

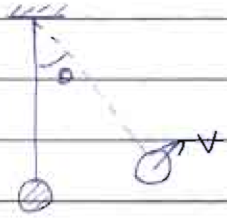
→ Difference b/w Static and Dynamic Analysis

Static	Dynamic
1) Force is constant	1) Force changes wrt time
2) Only one response i.e. displacement	2) Three response i.e. displacement, velocity, acceleration.
3) Only one solution.	3) Infinite no. of solutions
4) Can be solved using static equilibrium	4) Can be solved using dynamic equilibrium or an inertial force + static equilibrium
5) Simple analysis	5) Complex analysis.

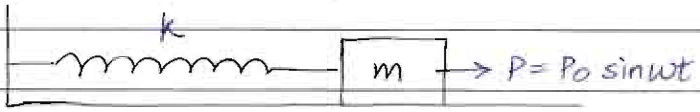
⇒ Causes of dynamic effects

(i) Initial condition

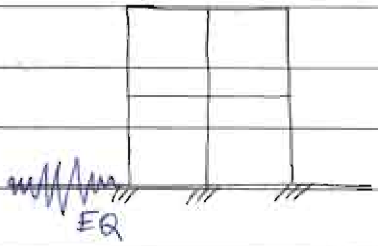




(ii) Applied Force



(iii) Support movement



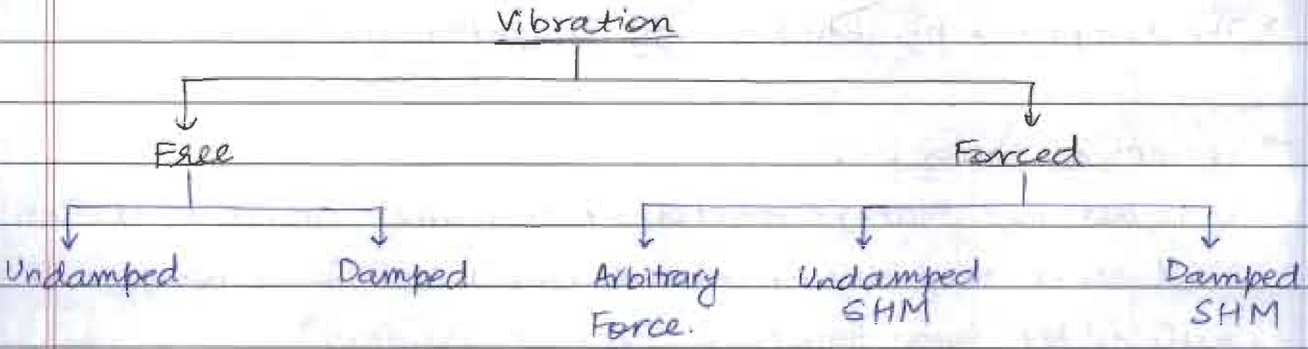
⇒ Type of vibrations

1) Free and Forced
2) Linear and Non-Linear
3) Undamped and Damped
    - Underdamped
    - Critical Damped
    - Over damped.

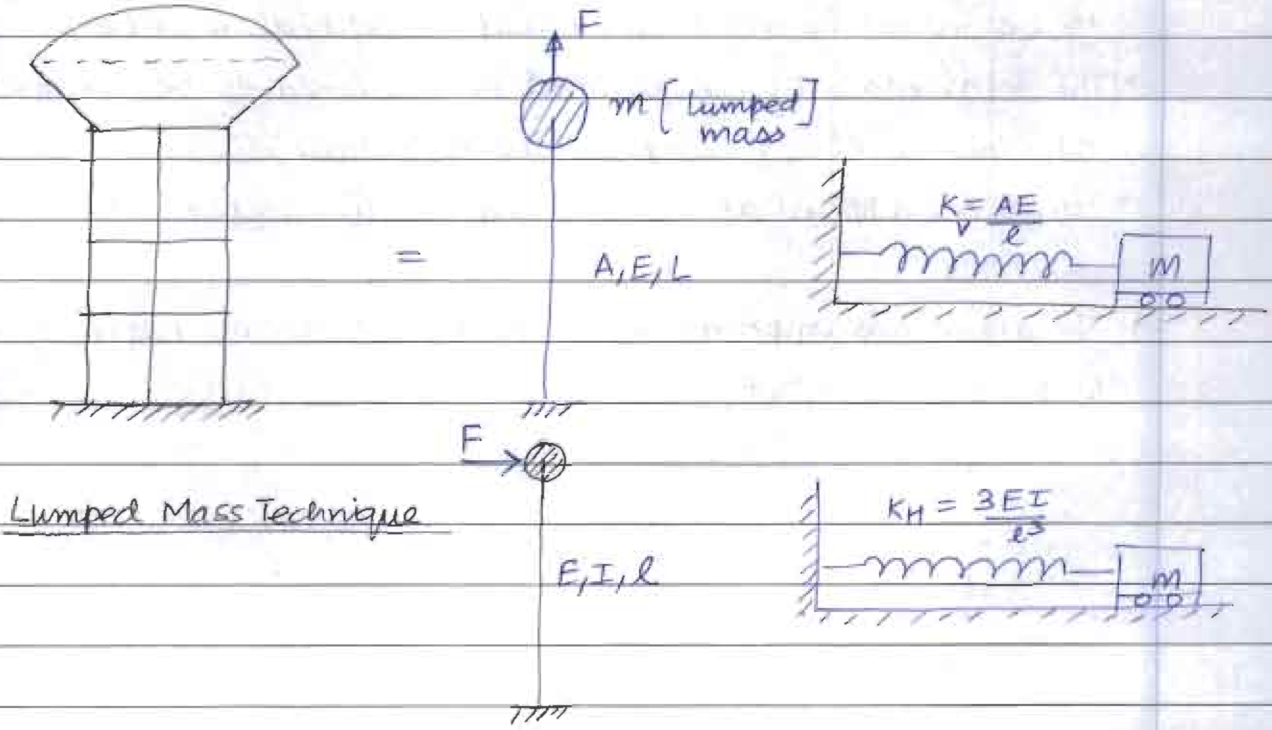
4) Longitudinal, transverse & rotational
5) Deterministic and Random.

> NOTE: We generally consider linear vibrations in structural analysis to take advantage of principal of superposition i.e system behaves linearly.

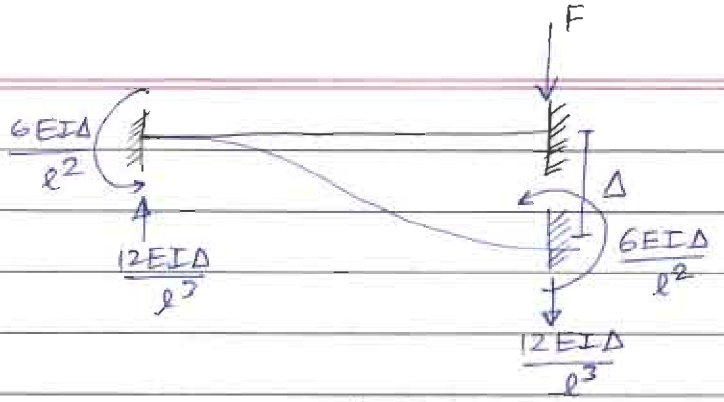
→ The motion that occurs due to initial condition is known as free vibration
→ The motion that occurs due to applied force is called forced vibration



⇒ Analytical model of the dynamic system



Lumped Mass Technique



$F = \frac{12EI\Delta}{l^3} \Rightarrow \boxed{K = \frac{12EI}{l^3}}$

→ The mass represents inertial characteristic + kinetic energy

→ The spring represents stiffness (restoring force) and potential energy.

→ The damping represents energy dissipation mechanism.

→ Concept of shear building

① → It is assumed that no rotation of horizontal member at floor level and hence the structure behaves like a cantilever beam and is deflected by shear force only (earthquake force)

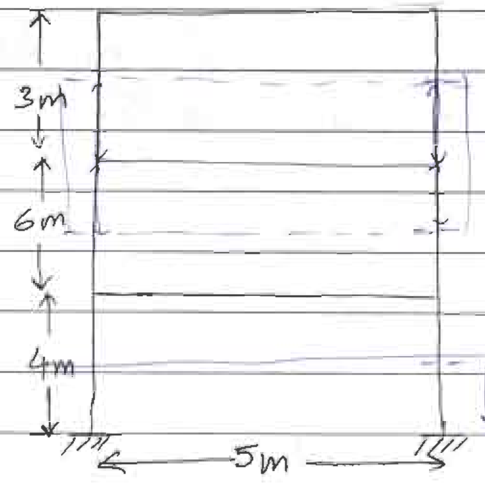
② → Horizontal members i.e. beams and slabs are considered to be infinitely rigid compared to vertical members.

③ → The total mass of the building is assumed to be concentrated at floor levels (Lumped mass technique)

④ → Forces are applied at nodes only i.e. @ lumped mass location.

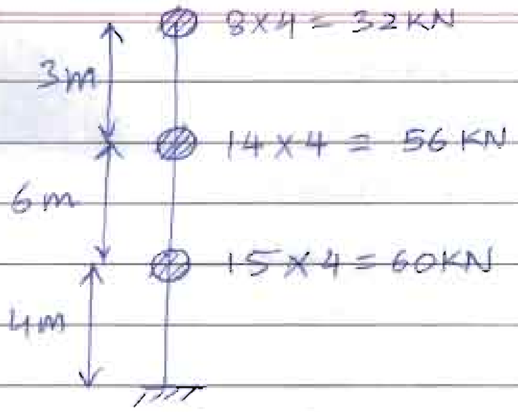
→ The above assumptions ~~to~~ reduce the ∞ no. of degree of freedom to finite no. of DOF

Q.

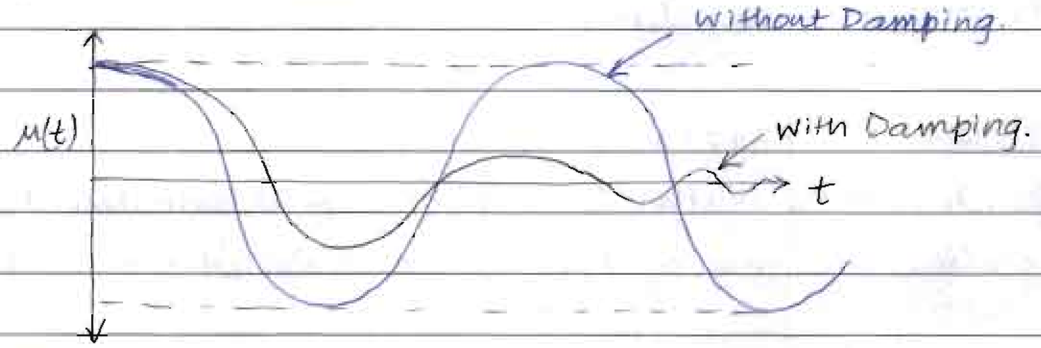


Size of beams and columns = 0.4m × 0.4m
Calculate the lumped masses in the beam column frame.

Weight per unit length = 25 × 0.4 × 0.4
= 4 KN/m



⇒ Damping in dynamic system



→ The amplitude of a vibrating system will not remain constant and it decays with time due to dissipation of vibrating energy and this is called damping.

→ Amplitude means maximum response. It can be amplitude of displacement, velocity or acceleration.

→ Damping in a structural system is due to various mechanisms such as:

① Internal friction of material
② friction at joints
③ Drag effect of medium.

→ It is very difficult to exactly quantify damping of a system based on geometry as it depends on various factors. However, stiffness can be calculated by using material and geometrical properties.

→ Damping is generally obtained from experiments. Following are the main types of damping:

① **Structural Damping** - Internal damping in the structure and is an inherent property of the structure. Includes damping at structural connections and damping due to alternate loading

② Viscous Damping – Due to viscous medium in which the structure is vibrating (eg– Shock absorber of a motorcycle)

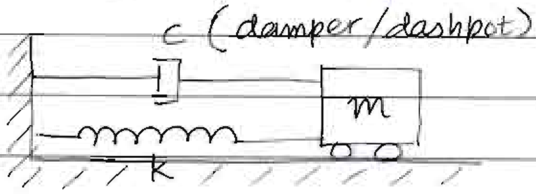
→ For this type of damping, the damping force is directly proportional to the velocity of motion.

→ Generally in structural modelling, we consider all types of damping as viscous damping.

③ Coulumb Damping / Friction Damping

→ Results from the friction b/w sliding surfaces and depend on coeff. of frictn

→ Generally, all types of damping are modelled into viscous damping



$u(t) \rightarrow$ displacement

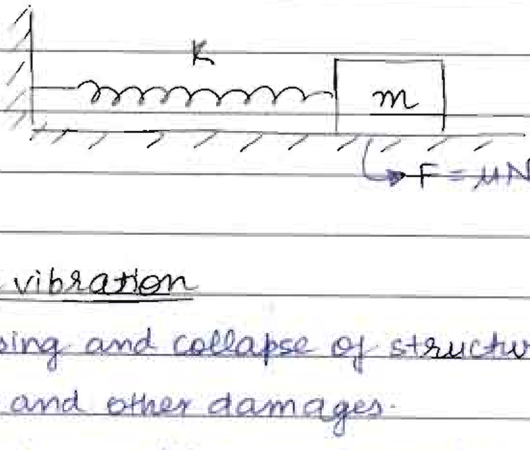
$\dot{u}(t) \rightarrow$ velocity

$\ddot{u}(t) \rightarrow$ acceleration.

$F_d = c\dot{u}$

$F_d \rightarrow$ viscous damping force, $c \rightarrow$ damping coefficient (viscous damping)

$\frac{N-s}{m}$ or $\frac{kg}{s}$



$\hookrightarrow F = \mu N$ (Friction Damping)

→ Effects of vibration

①→ Overstressing and collapse of structure

②→ Cracking and other damages.

③→ Damages to sensitive equipments

④→ Adverse human response.

⑤→ Fatigue fracture.

⇒ Vibrational control in the design of structure

→ Identify, calculate and control the dynamic response

Chapter-2 ⇒ Undamped free vibration of SDOF system

→ Free vibration is initiated by disturbing an elastic system from the static equilibrium position by giving the mass some initial displacement, initial velocity or initial displacement + velocity.

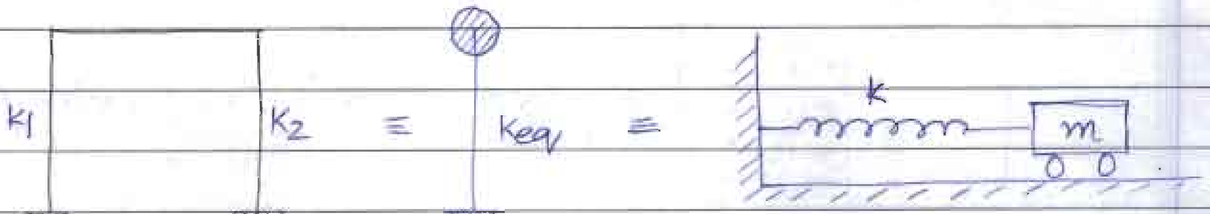
→ No Dynamic Excitation is present i.e. $P(t) = 0$

→ During the vibration, no loss of energy as there is no damping. $(c = 0)$

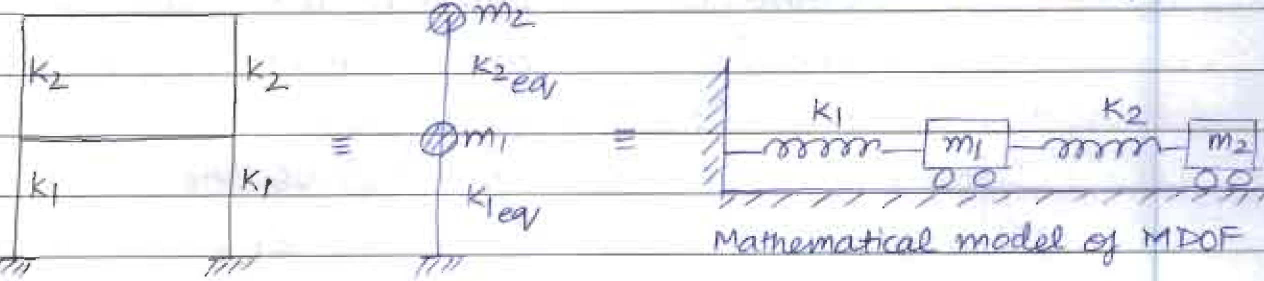
→ Vibration Analysis

① Mathematical Modelling
② Formation of eqⁿ of motion (DE)
③ Solution of eqⁿ of motion
④ Interpretation of results.

⇒ Mathematical Modelling



Mathematical model of SDOF



Mathematical model of MDOF

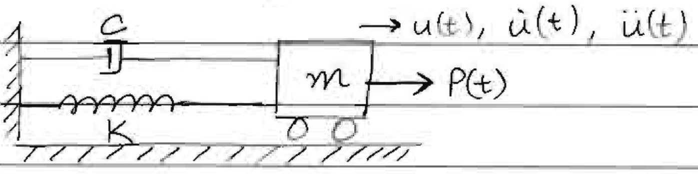
⇒ Formulation of eqⁿ of motion

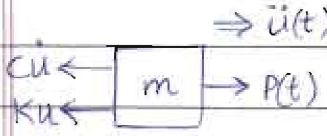
The governing ~~ee~~ DE describing the motion is known as eqⁿ of motion.

Few important methods are:

① Newton's Second Law of motion
② D-Alembert's Principle
③ SHM
④ Energy method.
⑤ Rayleign method.

⇒ Newton's Second Law of motion





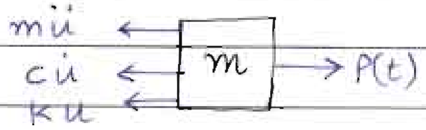
$\Rightarrow P(t) - c\dot{u} - Ku = m\ddot{u}$

$\Rightarrow \boxed{m\ddot{u} + c\dot{u} + Ku = P(t)}$

General eq^n of motion with viscous damping.

⇒ D-Alembert's Principle

→ This principle states that with the inertia force included, a system is in static equilibrium at each instant of time.



$\Rightarrow \boxed{m\ddot{u} + c\dot{u} + Ku = P(t)}$

NOTE: External force P(t), displacement u(t), velocity u̇(t) and acceleration ü(t) are taken to be positive in +ve x-dir^n.

→ Spring force, F_s is opposite to the displacement and Damping Force, F_d is opposite to the velocity.

→ The sign convention considered and eq^n of motion derived is independent of direction of motion

⇒ Solution of eq^n of motion

$$m\ddot{u} + c\dot{u} + Ku = P(t)$$

→ For undamped free vibration,

$m\ddot{u} + Ku = 0$ → Second order LDE with Degree = 1

$\ddot{u} + \frac{K}{m}u = 0$

$D^2u + \frac{K}{m}u = 0 \Rightarrow \left(D^2 + \frac{K}{m}\right)u = 0$

$u \neq 0$ (because of Dynamic vibrations)

⇒ $D^2 + \frac{K}{m} = 0$

⇒ $D = \pm i\sqrt{\frac{K}{m}}$ → $u = c_1 e^{i\sqrt{\frac{K}{m}}t} + c_2 e^{-i\sqrt{\frac{K}{m}}t}$

$$\Rightarrow u = c_1\left[\cos\left(\sqrt{\frac{K}{m}}t\right) + i\sin\left(\sqrt{\frac{K}{m}}t\right)\right] + c_2\left[\cos\left(-\sqrt{\frac{K}{m}}t\right) + i\sin\left(\sqrt{\frac{K}{m}}t\right)\right]$$

$$\Rightarrow u = (c_1+c_2)\cos\left(\sqrt{\frac{K}{m}}t\right) + i(c_1-c_2)\sin\left(\sqrt{\frac{K}{m}}t\right)$$

c_1+c_2 → Real , $i(c_1-c_2)$ → Real

Thus,

$$\boxed{u = A\cos\left(\sqrt{\frac{K}{m}}t\right) + B\sin\left(\sqrt{\frac{K}{m}}t\right)}$$

eq^n of motion for undamped free SDOF

→ Take $\boxed{\omega_n = \sqrt{\frac{K}{m}}}$ and thus, $\boxed{u = A\cos(\omega_n t) + B\sin(\omega_n t)}$

→ $\boxed{\text{Time Period, } T_n = \frac{2\pi}{\omega_n} = 2\pi\sqrt{\frac{m}{K}}}$

→ From the above eq^n it can be said that the state of mass i.e. displacement at 2 instances of time i.e. t_1 and $t_1 + \frac{2\pi}{\omega_n}$ is same. Here $\frac{2\pi}{\omega_n}$ is called as Time Period of function.

$\omega_n \to$ rad/s → circular frequency $\{ K \to N/m \; , \; m \to kg \}$

$T_n = \dfrac{2\pi}{\omega_n}$ → Time Period

$\omega_n = 2\pi f_n$ $\{ f_n \to$ cyclic frequency [cycles per second] $\}$
Hertz (Hz)

$T_n = \dfrac{1}{f_n}$

→ at $t=0$, $u(t) = u(0)$
$\dot{u}(t) = \dot{u}(0)$

$u = A\cos(\omega_n t) + B\sin(\omega_n t)$

⇒ $\boxed{A = u(0)}$

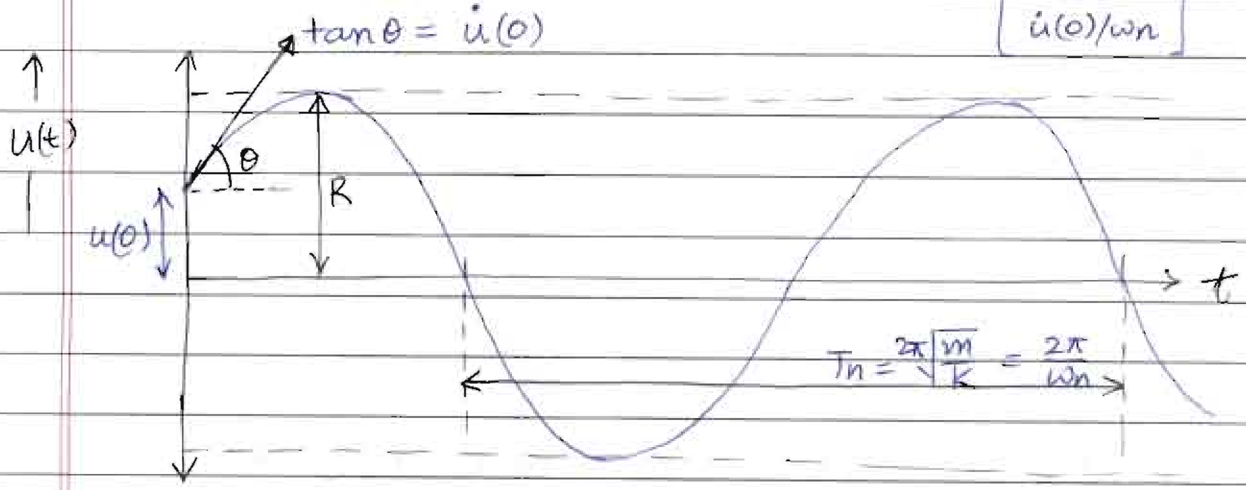
$\dot{u} = -A\omega_n \sin(\omega_n t) + B\omega_n \cos(\omega_n t)$

$\dot{u}(0) = B\omega_n \Rightarrow \boxed{B = \dfrac{\dot{u}(0)}{\omega_n}}$

$$\Rightarrow \boxed{u(t) = u(0)\cos(\omega_n t) + \frac{\dot{u}(0)}{\omega_n}\sin(\omega_n t)}$$

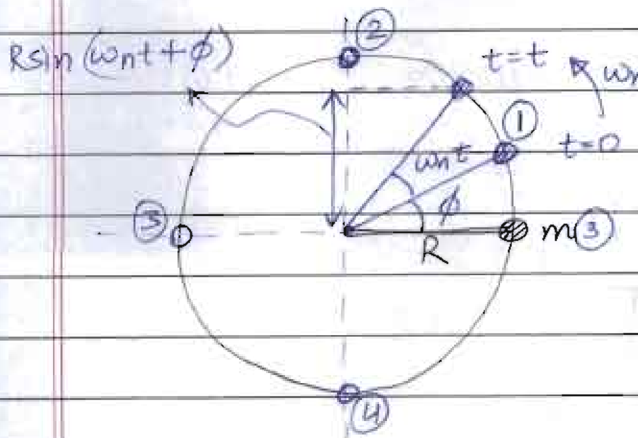
$$\Rightarrow \boxed{u = R\sin(\omega_n t + \phi)} \quad \text{where,} \quad R = \sqrt{[u(0)]^2 + \left[\frac{\dot{u}(0)}{\omega_n}\right]^2}$$

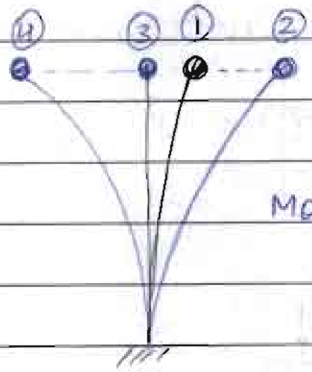
$$\phi = \tan^{-1}\left[\frac{u(0)}{\dot{u}(0)/\omega_n}\right]$$



$$R = \sqrt{[u(0)]^2 + \left[\frac{\dot{u}(0)}{\omega_n}\right]^2}$$

→ Comparison of uniform circular motion and SHM

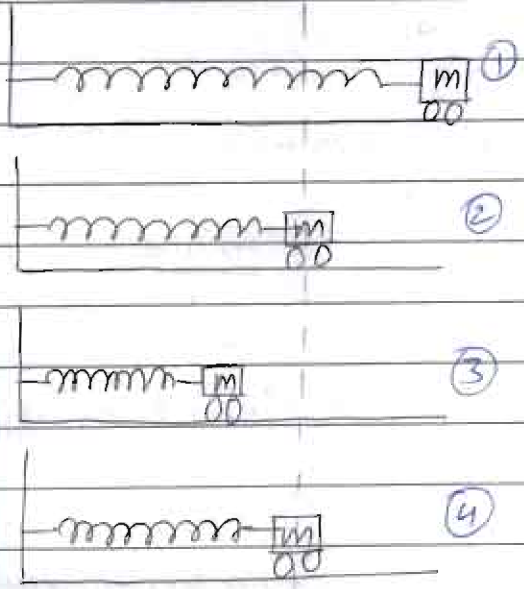


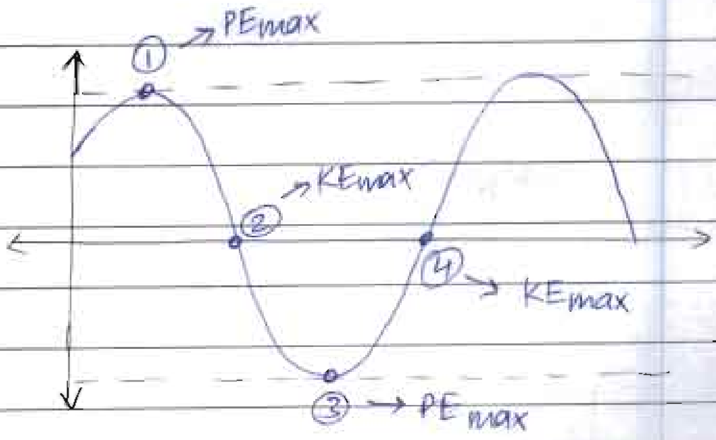


Motion of structure

> NOTE: Characteristic of SHM
>
> → The motion shall be periodic
>
> → When disturbed from equilibrium position a restoring force acts on the body and is directly proportional to the displacement i.e. $F = -Kx$
>
> → ω_n, f_n, T_n are natural properties of the system. This means that irrespective of the initial displacement, velocity given to the system, the natural frequency and time period of the system will remain the same for linear elastic behaviour of the structure in a free vibration.

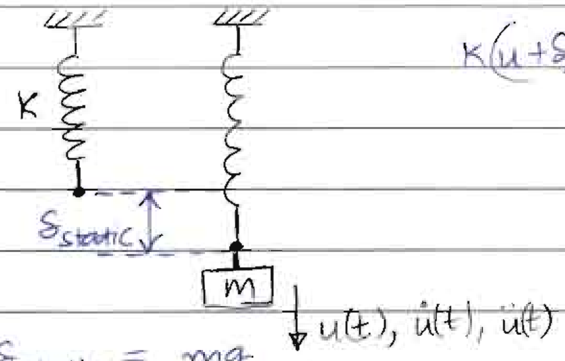
Q: The eqn of free vibration of a system is $\frac{d^2x}{dt^2} + 64\pi^2 x = 0$, it's natural frequency is 4 cps or 4 Hz
(cyclic frequency)

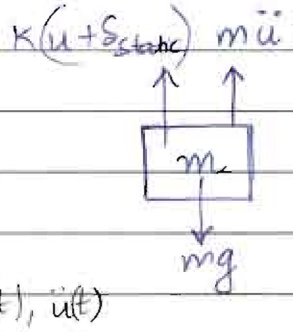




→ At any position of mass, $PE + KE = KE_{max} = PE_{max}$ [For no damping]

→ Influence of gravitational force on equation of motion





$$\delta_{static} = \frac{mg}{K}$$

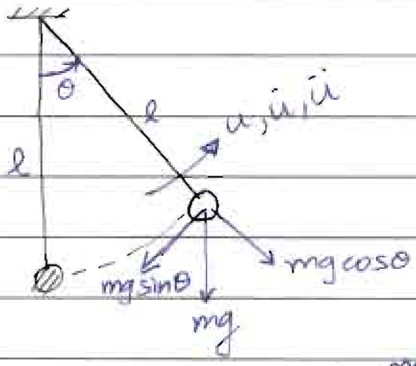
$$\Rightarrow \cancel{mg} = Ku + \cancel{K\delta_{static}} + m\ddot{u} \quad \Rightarrow \quad \boxed{m\ddot{u} + ku = 0}$$

$u(t)$ → displacement from initial position (equilibrium position)

→ The above equation indicates that the equation of motion represented with respect to equilibrium position is not affected by gravitational force

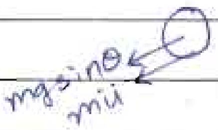
> NOTE: However when gravitational force acts as a destabilising or restoring force, we need to consider the effect of gravity

→ Simple Pendulum



$u = \theta \cdot l$

$\ddot{u} = \ddot{\theta}\, l$



$$\Rightarrow m\ddot{u} + mg\sin\theta = 0 \quad \equiv \quad \cancel{m\ddot{u} + K\theta = 0} \quad \boxed{\cancel{m\ddot{\theta} + \frac{K}{l}\theta \neq 0}}$$

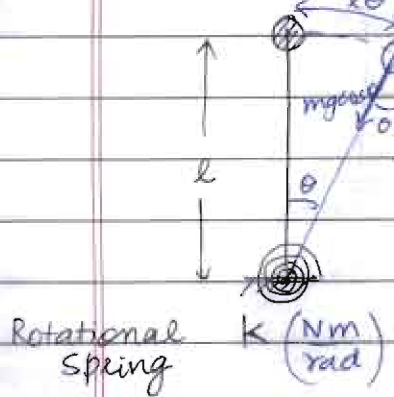
$$\Rightarrow l\ddot{\theta} + g\sin\theta = 0$$

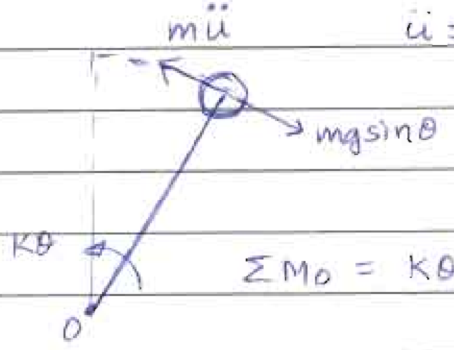
$$\Rightarrow \boxed{l\ddot{\theta} + g\theta = 0}$$ → taking θ as very small

$$\boxed{\omega_n = \sqrt{\frac{g}{l}}}, \quad \boxed{T_n = \frac{2\pi}{\omega_n} = 2\pi\sqrt{\frac{l}{g}}}$$

→ example of gravity as a restoring force

⇒ Gravity as destabilizing force





$\ddot{u} = \ddot{\theta} l$

$\Sigma M_O = K\theta + m\ddot{u}\, l - mg\sin\theta\, l$

So, $m\ddot{u} l + K\theta \mp mg\sin\theta\, l = 0$

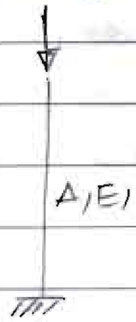
$m l^2 \ddot{\theta} + K\theta \mp mgl\theta = 0$

$$\boxed{m\ddot{\theta} + \left(\frac{K}{l^2} - \frac{mg}{l}\right)\theta = 0}$$

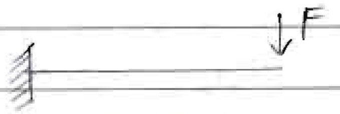
If $\frac{K}{l^2} - \frac{mg}{l} = 0$ ⇒ No vibration.

→ Stiffness of Dynamic system

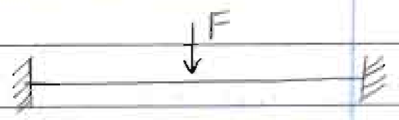
- → The stiffness of structural system can be determined by using standard structural analysis.
- → The stiffness will depend on material and geometrical property.
- → We need to calculate the equivalent stiffness of the structure in order to formulate the eqⁿ of motion.
- → The stiffnesses of commonly used structural elements are:



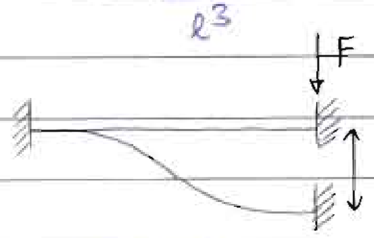
$K = \frac{AE}{L}$



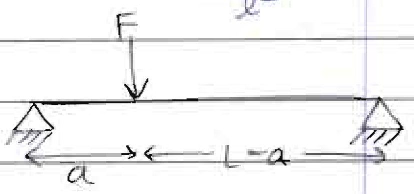
$K = \frac{3EI}{l^3}$



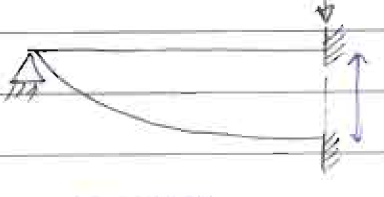
$K = \frac{192EI}{l^3}$



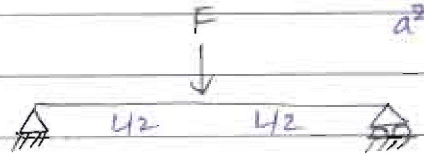
$K = \frac{12EI}{l^3}$



$K = \frac{3EIL}{a^2(L-a)^2}$



$K = \frac{3EI}{l3}$



$K = \frac{48EI}{l^3}$

AIR-1 Notes
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SOIL MECHANICS & FOUNDATION ENGINEERING

Handwritten notes by

Kartikay Kaushik

AIR-1 ESE 2021

IES Master classroom Student

SOIL MECHANICS & FOUNDATION ENGINEERING

CONTENT

Soil Mechanics

→ Soil mechanics is the application of engineering mechanics in problems related to soil when used as a construction material & foundations on which we support our structures. It helps us to interpret the properties, behaviour & performance of various types of soil.

① Origin of soil
② Soil water relationship } Test ①
③ Classification of soil } Test ①
④ Clay mineral and Soil Structure
⑤ Compaction of soil → Test ①
GATE ** ⑥ Permeability
GATE ** ⑦ Effective stress
GATE ** ⑧ Seepage
⑨ Compressibility and Consolidation → Test ①
⑩ Shear strength of soil
Appⁿ ⑪ Vertical stress
Appⁿ ⑫ Earth pressure theory
Appⁿ ⑬ Shallow foundation → Test ① and Deep foundation → Test ②
Appⁿ ⑭ Exploration, expansive soil, stability of slope.

① Origin of Soil

→ Soil is an ~~unconsilat~~ unconsolidated material composed of soil particles produced by the disintegration of rock (gravel / Sand / silt/clay) or decomposition of vegetative matter (Organic Silt / clay).

→ Formation of soil is due to disintegration and transportation of Igneous rock called parent rock or due to the decomposition of vegetative matter.

→ Disintegration of rock is due to weathering which are classified as

(a) Physical weathering → Sand / gravel
(b) Chemical weathering → silt / clay

→ The physical weathering processes can be:

(a) Erosion of rock due to wind, water, glacier.

(b) Expansive force due to freezing water.

(C) Sudden change in temperature.

(d) Organic activity like growth of plant roots in existing cracks, rodents or worms etc.

(e) Unloading and resulting cracking.

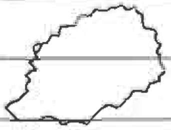
→ Soil formed by physical weathering has same mineralogical relationship and composition as that of parent rock.

→ Particles that are formed are bulky like sand and gravel.

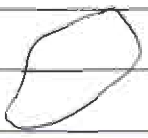
→ The structural arrangement is called single grain structure

→ Single grain structure has no attraction or repulsion b/w the particles

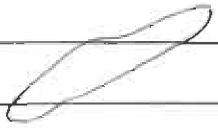
→ Shape of particle formed are angular, rounded, elongated and flat



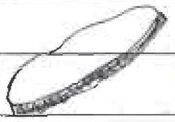
Angular
↳ Roughness more



Rounded
↳ Roughness ~~more~~ less



elongated
(low sphericity)



Flat

→ Quartz, Feldspar and Mica are primary soil minerals formed due to physical weathering.

(b) Chemical Weathering

→ The various chemical processes during chemical weathering are:

① Hydration – Reaction of minerals with H^+ and OH^- of water and these ions replace the existing cation.

② Oxidation – Acid produced during this process causes weathering

③ Carbonation – CO_2 in water dissolves minerals and they are carried away.

④ Desilication – Leaching of silica

NOTE: Leaching means when the water soluble parts are dissolved and washed out, the process is called Leaching.
In this process, mineral composition of the parent rock changes.

→ Chemical weathering process results in the formation of crystalline particles of colloidal size known as clay minerals like kaolinite, Illite and Montmorillonite.

NOTE: If -2 micron sized particles have cohesion b/w them it is called clay particle but if there is no cohesion then it is called clay-sized particle.

→ Most clay mineral particles have plate-like form. having high specific surface [high Surface area per unit volume or mass) with a result that the behavior is affected significantly due to presence of surface forces and hence water can significantly affect the behavior of clay.

⇒ Residual and Transported Soil

→ If the soil is still located at the place of it's origin, it is called residual soil and if it has been transported by wind, water or glacier it is called transported soil.

→ Residual soils have better engineering property and they have angular soil particles.

→ Laterite is an example of Residual soil, Black Cotton Soil

→ The transported soil have smaller grain particles and larger amount of pores.

→ Depending on the transporting agency soils are classified as.

① Alluvial soil → Transported by running water like rivers
② Lacustrine soil → Deposited in still water like lake
③ Marine soil → Deposited in sea water
④ Aeolian soil → Deposited by air, wind.
⑤ Glacial deposits - Transported by ice, glaciers.

→ Names of various types of soils

① Bentonite

It has high %age of clay mineral montmorillonite and it is highly plastic and results from the decomposition of volcanic ash. Highly water absorbent and great swelling and shrinkage tendency.

② Black Cotton soil

It is a residual soil consisting of high %age of Montmorillonite. It has low Bearing capacity and high swelling /shrinkage. It is formed by chemical weathering of Basalt Rock. It is dark in color and is good for growing cotton.

NOTE: Stabilisation of Black cotton soil is done using lime stabilisation and reduces plasticity hence ~~increases~~ makes the soil friable.

③ Loess

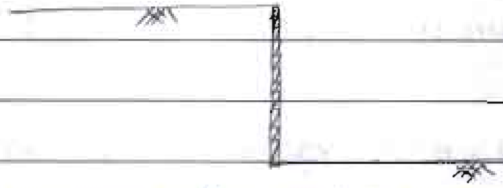
It is a fine grained (silty sized), homogeneous, friable (easily crushable)

NOTE:
< 2 μm → clay } fine grained
2 μm - 75 μm → silt
75 μm - 4.75 mm → sand } coarse-grained
4.75 mm - 80 mm → gravel
80 mm - 300 mm → Cobble
[illegible] >300 mm - Boulder

Aeolian

air borne deposits having uniform grain size and high void ratio.

→ It can stand deep vertical cut because of slight cementation b/w particles due to $CaCO_3$ and Montmorillonite.



→ It has continuous root holes and hence permeability in vertical direction is much greater than that in the horizontal direction.

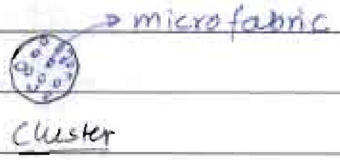
→ It is found in arid and semi-arid region and it is highly porous.

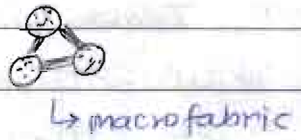
→ It is subjected to collapse when saturated.

→ It has loose meta-stable fabric [arrangement of particles], low density and high compressibility.

→ It has low Bearing capacity.

→ It's macro-fabric is bulky granular.





④ Till

→ It is an unstratified soil made by melting of glaciers.

→ The deposit consists of particles of different sizes ranging from boulder to clay.

→ It can be easily densified by compaction and it is a well graded soil.

→ It has high shear strength. Also known as boulder clay.

⑤ Marl

→ It is a stiff marine calcareous clay of greenish color.

⑥ Varved Clay

→ These are sedimentary deposits consisting of alternate thin layers of clayey silt and silty clayey

NOTE: Clayey Silt
Adjective Noun
Noun represents main component.

- → These clays are results of deposition in glacial lakes due to periods of alternating
- → Shear resistance of varved clay is much smaller along horizontal plane and hydraulic conductivity is much greater in horizontal plane as compared to vertical plane.

⑦ Indurated Clay

- → Induration means clay has become more firm and it does not soften under prolonged wetting.

NOTE: Induration is a term used to describe degree of Lithification
→ Lithification is the conversion of unconsolidated sediments into sedimentary rocks by porosity destruction through compaction and cementation.

⑧ Diatomaceous Earth

- → Diatoms are minute unicellular marine organisms.
- → Diatomaceous earth is a fine light grey soft sedimentary deposit of silicious remains of skeletons of diatoms.

⑨ Lateritic soil

- → Lateritic soils are formed by decomposition of rocks, removal of silica and accumulation of Iron and aluminium Oxides.
- → It is a residual deposit formed from basalt.

→ Presence of Iron oxide imparts reddish color and high specific gravity.

→ Generally it hardens with passage of time.

⑩ Marine Deposit

→ It has low shearing strength, high compressibility and contains organic matter. It is soft and highly plastic.

⑪ Colluvial soil

→ Gravity deposited soil. Also named as Talus. It has irregular and coarse particle.

⑫ Peat

→ It is an organic soil having fibrous particles formed from vegetative matter under conditions of excessive moisture.

→ It is highly compressible and not suitable for foundations.

⑬ Muck

→ Mixture of fine soil particles in highly decomposed organic matter and black in color and extremely soft in consistency.

⑭ Loam

→ Mixture of sand, silt and clay.

⑮ Hard Pan

→ It does not disintegrate when submerged in water and offers great resistance to penetration.

⑯ Tuff

→ It is a fine grained soil composed of particles ejected from volcanoes and deposited by wind and water.

⑰ Dispersive clay (Easily Erodable)

→ It occurs in soil of low and medium plasticity that contains montmorillonite.

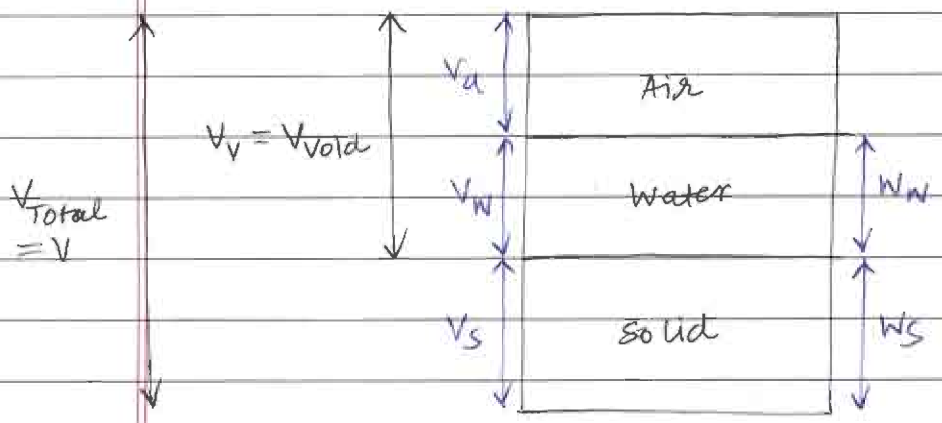
→ It is treated with lime to make it non dispersive.

⑱ Collapsing soil

→ Soil susceptible to large decrease in volume when saturated

② Soil-Water Relationship

⇒ Phase Diagram of soil



→ Soil is generally a 3-phase system but completely saturated soil and completely dry soil are called 2-phase system.

⇒ Basic Definitions

① Water content $w = \frac{W_w}{W_s}$

NOTE: In Environmental Engg,

$$w = \frac{W_w}{W_w + W_s} = \frac{W_w}{W}$$

→ It has no upper limit and for dry soil it is zero.

→ Fine-grained soil have more moisture content than coarse grained soil.

② **Void Ratio** $e = \frac{V_v}{V_s}$

→ It has no upper limit

→ Void ratio of fine grained soil are generally higher than that of coarse grained soil although the size of void is large in case of coarse grained soil

NOTE : $e_{\text{~~clay~~ sand}} \rightarrow 0.5 \text{ to } 0.7$ } generally
$e_{clay} \rightarrow 0.8 \text{ to } 0.9$

③ **Porosity** $n = \frac{V_v}{V}$

→ It's upper limit is 1.

→ If porosity is high density will be less.

④ **Degree of Saturation** $S = \frac{V_w}{V_v}$

→ For dry sole, $S=0$ and for saturated soil, $S=1$

⑤ **%age air void** $n_a = \frac{V_a}{V}$

⑥ **Air content** $a_c = \frac{V_a}{V_v} = 1 - S$

⑦ **Bulk Unit Weight** $\gamma_t = \frac{W_{Total}}{V_{Total}}$

⑧ **Unit weight of solid** $\gamma_s = \frac{W_{solid}}{V_{solid}}$

⑨ Unit wt. of water, $\gamma_w = \frac{W_w}{V_w} = 9.81 \text{ kN/m}^3$

⑩ Dry unit weight, $\gamma_d = \frac{W_s}{V_{Total}}$

→ γ_d is used as a measure of denseness of soil i.e. higher value of γ_d indicated that more solids are packed in the unit volume of soil and hence soil is more compacted.

⑪ Saturated unit weight, $\gamma_{sat} = \frac{\text{Weight of sat. soil}}{\cancel{\text{Weight}}\ \text{Volume of Sat. soil.}}$

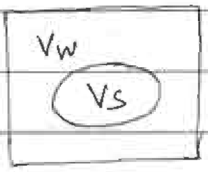
→ Saturated unit wt. will be a function of water content and as water content increases, γ_{sat} decreases.

⑫ Submerged unit weight, $\gamma_{sub} = \gamma_{sat} - \gamma_w$

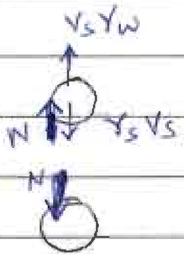
→ When the soil is submerged below ground water table; Buoyant force acts on the particle and hence,

$$\frac{\text{Buoyant weight}}{\text{Volume of soil}} = \gamma_{sub}.$$

→ $\gamma_{sub} \times V$ = Weight (Buoyant) of soil



$$\begin{aligned}
\gamma_{sub} \cdot V &= (\gamma_{sat} - \gamma_w) V \\
&= \gamma_{sat} V - \gamma_w V \\
&= (\gamma_{sat} V_w + \gamma_{sat} V_s) - \gamma_w V_s - \gamma_w V_w \\
&= \cancel{\gamma_w V_w} + \gamma_s V_s - \gamma_w V_s - \cancel{\gamma_w V_w} \\
&= V_s (\gamma_s - \gamma_w)
\end{aligned}$$



So, $N + V_s \gamma_w = \gamma_s V_s$

$\Rightarrow \boxed{N = (\gamma_s - \gamma_w) V_s}$

NOTE:

A saturated soil may not be submerged soil. like a soil saturated with capillary water is not submerged soil. Only soil below the water table is called submerged soil.

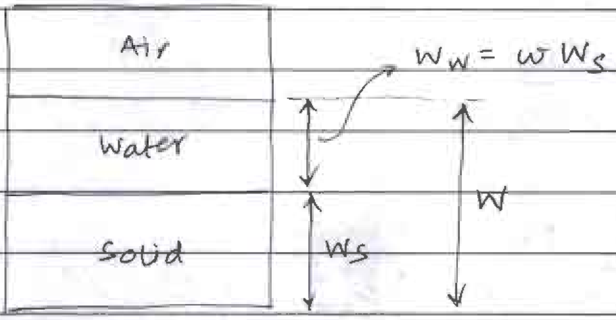
⑬ Specific gravity of solids $G_S = \frac{\gamma_s}{\gamma_w}$

→ Generally for inorganic soils, $G_S \in (2.6, 2.7)$
and for organic soils, $G_S \in (1.5, 2)$

→ Specific gravity of solids is also called absolute specific gravity or grain specific gravity

⑭ Mass specific gravity of soil, $G_m = \frac{\gamma_t}{\gamma_w}$ → bulk unit weight

⇒ Some important Relationship



① $W = W_S + W_W = W_S + w W_S$

$$\Rightarrow \boxed{W_S = \frac{W}{1+w}}$$

② $V_v = e V_s$

So, $V = V_v + V_s = (1+e) V_s \Rightarrow \boxed{V_s = \frac{V}{1+e}}$

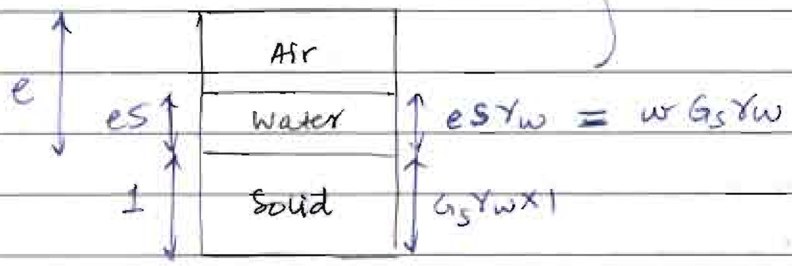
③ $n = \frac{V_v}{V} = \frac{e V_s}{(1+e) V_s} = \boxed{\frac{e}{1+e} = n}$

④ $e = \frac{V_v}{V_s}$ and $n = \frac{e}{1+e}$ $\Rightarrow$ $n + ne = e$

$$\Rightarrow \boxed{e = \frac{n}{1-n}}$$

⑤ $\boxed{eS = wG_s}$

⑥

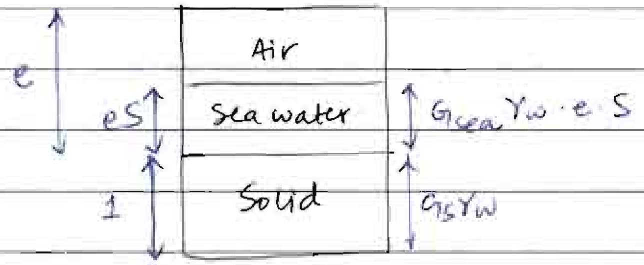


$$\boxed{\gamma_t = \frac{G_s\gamma_w(1+w)}{1+e}}$$

$$\gamma_t = \frac{G_s\gamma_w\left(1+\frac{eS}{G_s}\right)}{1+e}$$

$$\boxed{\gamma_t = \frac{\gamma_w(G_s+eS)}{1+e}}$$

⑦



So, $\boxed{\gamma_t = \frac{\cancel{e}\,\gamma_w(G_s + G_{sea} \cdot eS)}{1+e}}$

⑧ $\boxed{\gamma_{sat} = \frac{\gamma_w(G_s+e)}{1+e}}$

⑨ $$\gamma_{sub} = \gamma_{sat} - \gamma_w$$
$$= \frac{\gamma_w (G_s + e)}{1+e} - \gamma_w$$

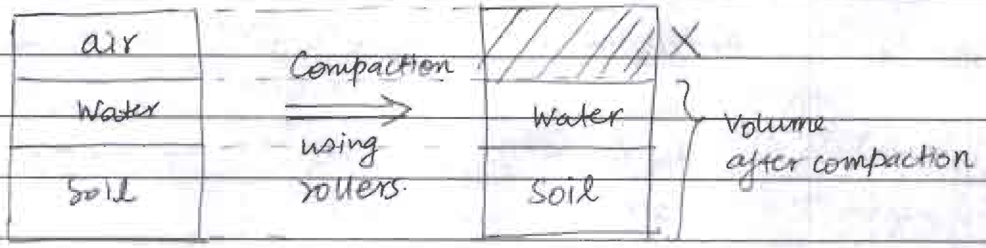
$$\boxed{\gamma_{sub} = \frac{(G_s - 1)\gamma_w}{(1+e)}}$$

⑩ $$\boxed{\gamma_d = \frac{G_s \gamma_w}{1+e} = \frac{\gamma_t}{1+w}}$$

⑪ $$1 - n_a = 1 - \frac{V_a}{V} = \frac{V - V_a}{V} = \frac{V_w + V_s}{V} = \frac{W_w}{\gamma_w V} + \frac{W_s}{V G_s \gamma_w}$$
$$= \frac{W_s}{\gamma_w V}\left[w + \frac{1}{G_s} \right] = \frac{\gamma_d}{\gamma_w}\left(\frac{1 + w G_s}{G_s} \right)$$

$$\Rightarrow \quad \boxed{\gamma_d = \frac{G_s \gamma_w (1 - n_a)}{1 + w G_s}}$$

⑫



$$\boxed{\gamma_d = \frac{G_s \gamma_w}{1 + w G_s}} \rightarrow$$ Zero air void Dry density.

Zero air void dry density is the theoretical maximum dry density at a particular water content. It can never be achieved practically.

Q. The total unit weight of a soil is 16 KN/m^3. The specific gravity of solid particle of soil is 2.67. Water content of the soil is 17%. Assuming $\gamma_w = 9.81$ KN/m^3. Calculate.

AIR-1 Notes
Pages: 268

Strength of Material
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

STRENGTH OF MATERIALS

CONTENT

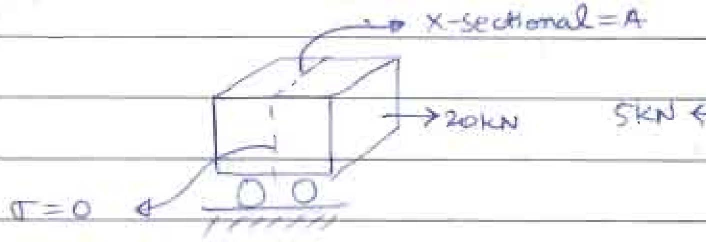
Strength of materials

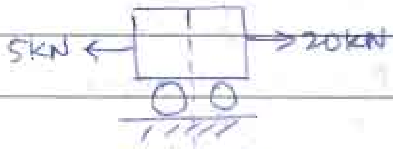
Syllabus:

1) Properties of material and axial stress
2) Bending moment and shear force diagram
3) Bending stress
4) Transverse shear stress
5) Torsional shear stress
6) Transformation of stress and strain
7) Combined stress
8) Thick and Thin shell
9) Spring
10) Column
11) MOI
12) Deflection of Beams

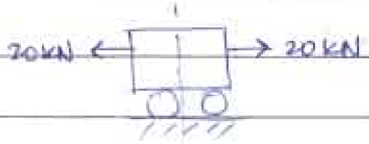
Obj { 8) – 11)

⇒ Properties of materials and axial stress





$\sigma = 5/A$



$\sigma = 20/A$

① Restraining Force

$$\frac{RL}{AE} = L\alpha\Delta T \Rightarrow R = E\alpha\Delta T$$

② Restrained Deformation

→ Stress develops on a body ~~on~~ in account of restraining force or restrained deformation.

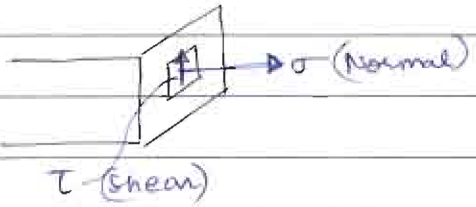
Stress

Normal Stress

→ $\frac{\text{Normal Force}}{\text{Area}}$

Shear Stress

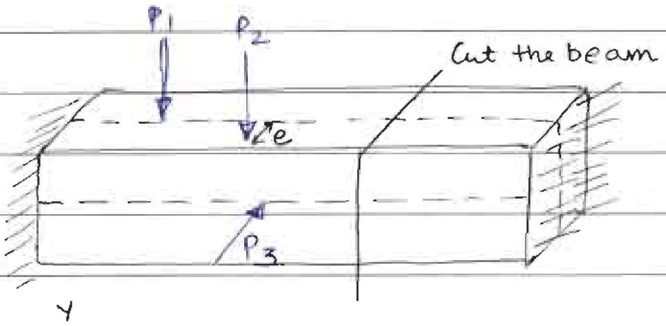
→ $\frac{\text{Force in the plane of section}}{\text{Area}}$

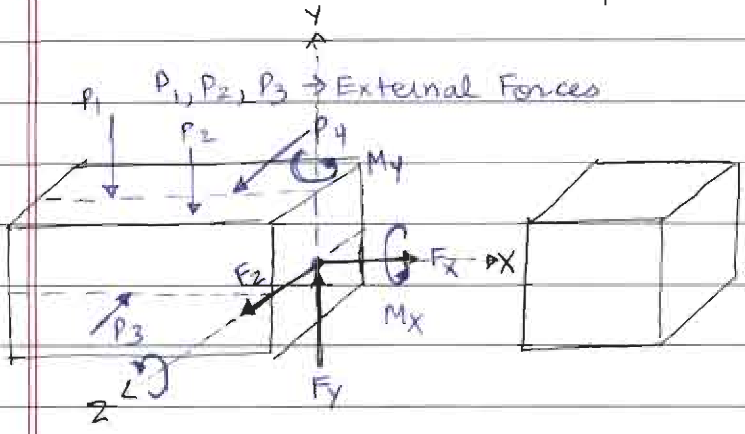


→ Stresses are of 2 types: Normal stress and shear stress.

→ Normal stress is ⊥ar to the section and shear stress is along the section

→ **Internal and External Forces**





P1, P2, P3 → External Forces

Mx, My, Mz, Fx, Fy, Fz are internal Forces } at max there can be 6 I.F. in a plane.

> **NOTE:**
>
> Direction of Moment is given by Right Hand Thumb Rule

→ F_x → Axial Force (⊥ar to the section)

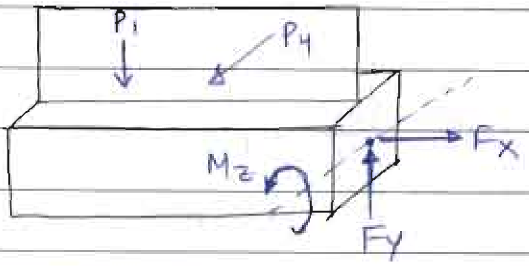
F_y →
F_z → } Shear Force (along the section)

M_x → Torsional Moment [points on section tend to move in the plane itself]

M_y →
M_z → } Bending Moment [points on the section tend to move out of plane]

→ Axial Force → Axial stress → Normal stress
Shear Force → Transverse Shear Stress → Shear Stress
Torsional Moment → Torsional Shear Stress → Shear Stress
Bending Moment → Bending Stress → Normal Stress

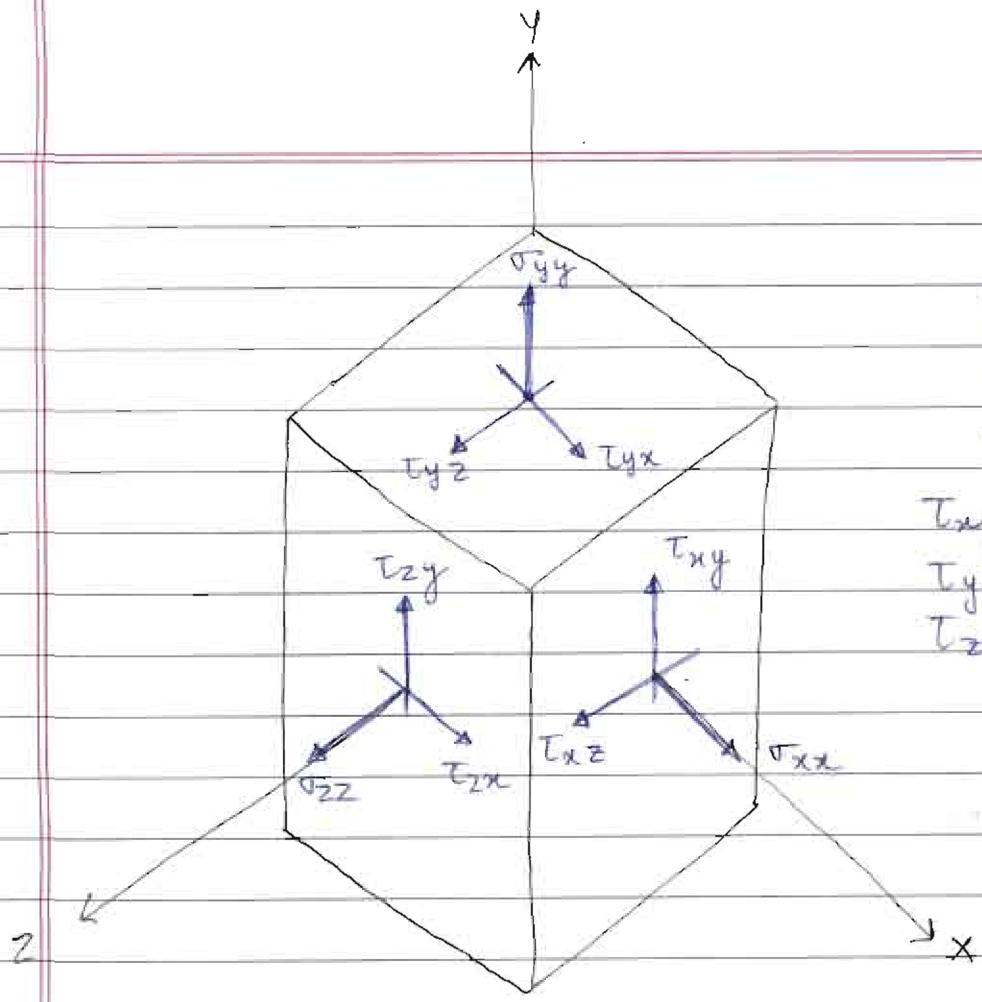
→ <u>2-D case</u> → when loading and structure are in the same plane. [CG plane]



→ When structure and loading are in same plane, it is called a 2-D condition or a planar condition.

→ In 2-D condition, we have 3-internal Forces : Axial force, Shear force and Bending Moment

→ <u>Stresses under general Loading condition</u>



σ_{xx}
σ_{yy}
σ_{zz}
$\tau_{xy} = \tau_{yx}$
$\tau_{yz} = \tau_{zy}$
$\tau_{zx} = \tau_{xz}$

→ Convention → (Stress Symbol)$_{\boxed{}\boxed{}}$

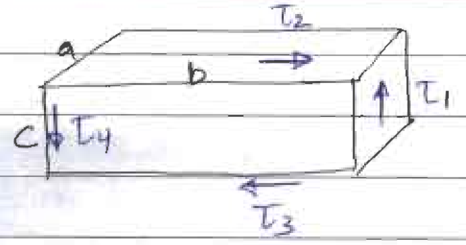
Plane Direction

⊕ x-plane → Outward normal to the plane is in ⊕ x-direction.

→ At any point under general loading condition, number of stress components are 9. $\{\underbrace{\sigma_{xx}, \sigma_{yy}, \sigma_{zz}}_{\text{3-Normal Stress}}, \underbrace{\tau_{xy}, \tau_{xz}, \tau_{yx}, \tau_{yz}, \tau_{zx}, \tau_{zy}}_{\text{6-Shear Stress.}}\}$

→ Statement 1 Shear stresses on opposite faces are equal and opposite in direction [Follows from Force equilibrium]

→ Statement 2 Shear stresses on adjacent $\perp$ar faces are equal and are directed in such a way that either both of them point towards a junction or they point away from a junction. [Follows from moment equilibrium]



$\Sigma F_H = 0$

$\Rightarrow \tau_2(ab) - \tau_3(ab) = 0 \Rightarrow \boxed{\tau_2 = \tau_3}$

$\Sigma F_V = 0$

$\Rightarrow \tau_1(ac) - \tau_4(ac) = 0 \Rightarrow \boxed{\tau_1 = \tau_4}$

$\Sigma M = 0$

$\Rightarrow (\tau_1 ac)b - (\tau_2 ab)c \Rightarrow \boxed{\tau_1 = \tau_2}$

→ Thus at any point under general loading condition, number of distinct stress components is 6. $[\sigma_{xx}, \sigma_{yy}, \sigma_{zz}, \tau_{xy}, \tau_{yz}, \tau_{zx}]$

→ Stress Tensor

$$\begin{array}{c c}
 & \text{Direction} \\
 & \downarrow \\
\begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{bmatrix}_{3\times 3} & \rightarrow \text{Plane.}
\end{array}$$

→ Symmetry of stress tensor is on account of moment equilibrium.

NOTE:

No. of elements of tensor $= 3^n$

$n \rightarrow$ order of tensor

→ Stress is a second ~~of~~ order tensor [Stress, Strain, MOI]

→ Direction is a first order tensor

→ Magnitude is a zero order tensor

→ Transformation of any second order tensor can be done using Mohr's Circle

→ ~~Vector is~~

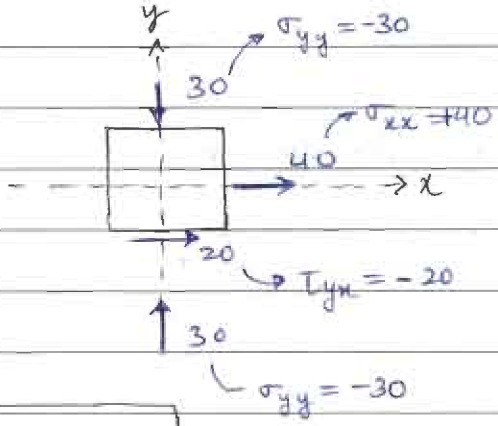
NOTE:

→ Stress is not a vector quantity as it does not follow the Parallelogram law of vector addition, although it has some magnitude and direction.

→ Sign convention for Stresses

σ

Plane	Direction	Sign
⊕	⊕	⊕
⊕	⊖	⊖
⊖	⊖	⊕
⊖	⊕	⊖



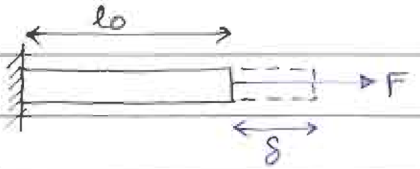
NOTE:

For Normal Stress, we can have:

(a) Tensile Stress → +ve

(b) Compressive Stresses → −ve

→ Normal Strain

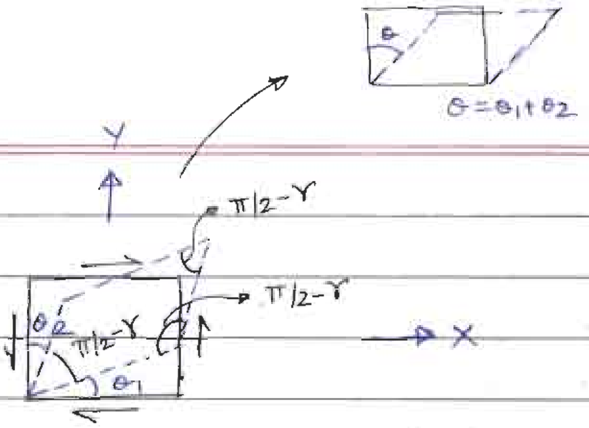


Normal Stress = F / A

$$\text{Average Normal Strain} \Rightarrow \epsilon = \frac{\delta}{l_o} = \frac{\text{Change in length}}{\text{Original length}}$$

Elongation → +ve , Compression → −ve

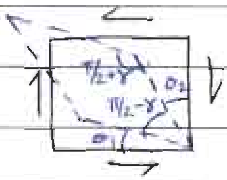
→ Shear strain



→ (Positive)

$\theta_1+\theta_2 \rightarrow$ shear strain (γ)

→



→ (Negative)

→ If angle b/w positive faces decreases, shear strain st rain will be taken positive

→ If angle b/w positive faces increases, shear strain is taken as negative

NOTE:

Positive and negative shear stress produce positive and negative shear strain respectively.

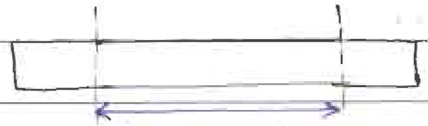
→ Normal strains can be measured using strain gauges or extensometer but stresses cannot be measured, they can only be derived.

→ Hence, Strain is a fundamental quantity not the stress.

→ Stress – Strain curve

→ Stress – Strain curve of a material represents the ~~static~~ characteristic property of a material. [Load deformation curve changes with dimension]

→ Stress-Strain curve for mild steel



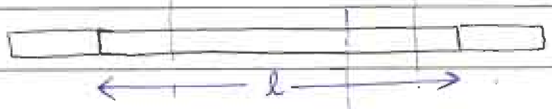
{Universal Testing Machine exerts tensile Force}

Engineering Strain $\varepsilon = \frac{\delta}{l_0}$

$l_0 \rightarrow$ gauge length

$A_0 \rightarrow$ X-sectional Area.

$\sigma = \frac{P}{A_0}$ → engineering stress $\boxed{l_0 = 5.65\sqrt{A_0}}$

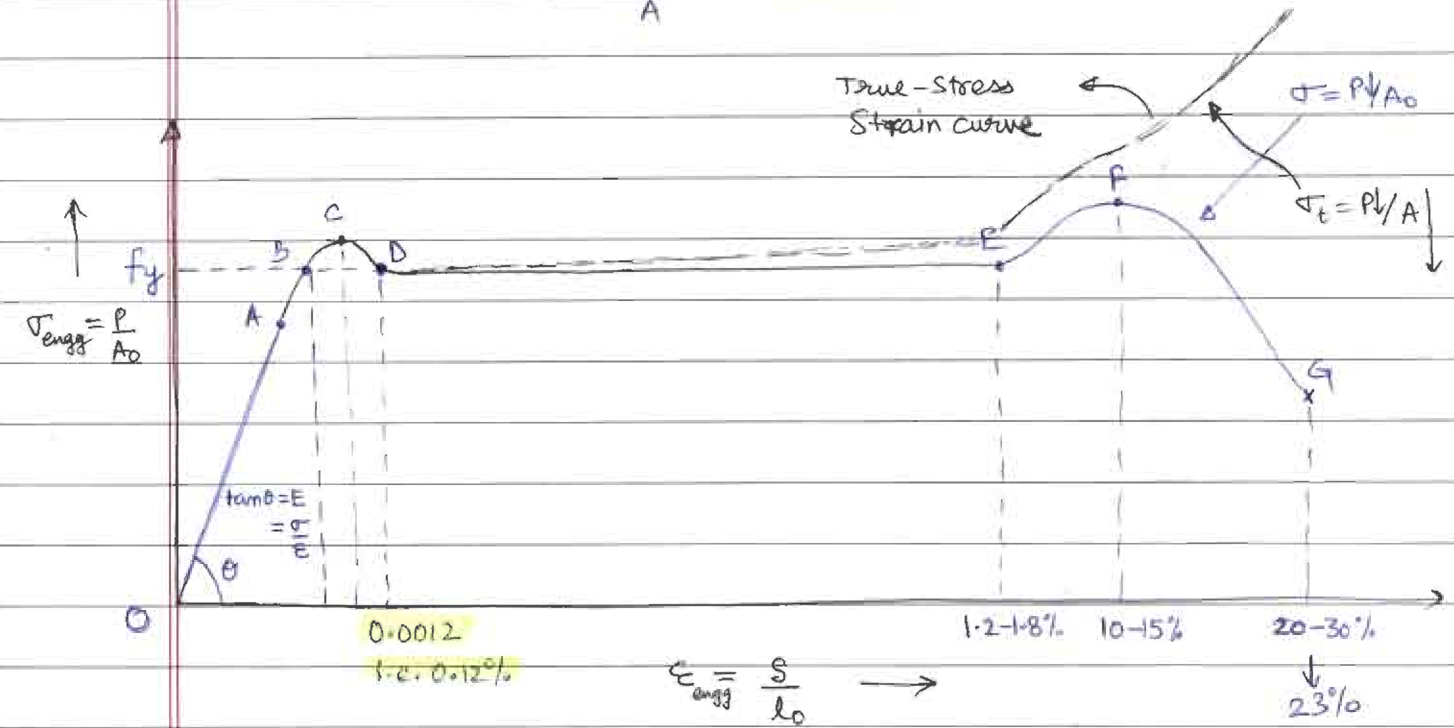


→ at any instant of time.

x sectional area = A

true strain ← $\varepsilon_t = \frac{\delta}{l}$

$\sigma_t = \frac{P}{A}$ → true stress



A → Proportional limit

B → Elastic Limit

C → Upper Yield Point

D → Lower Yield Point

E → Beginning of strain hardening

F → Ultimate stress point

G → Fracture point.

→ Region OA

→ Stress ∝ Strain

i.e. $\frac{\text{Stress}}{\text{Strain}}$ = constant = E [Modulus of Elasticity]

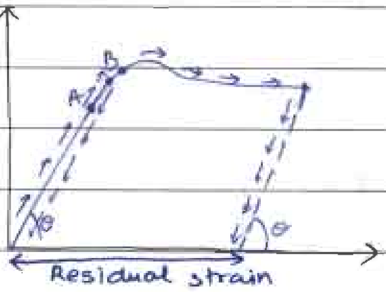
→ Strains are infinitesimal [very small]

→ Volume of the specimen increases in tension.

$lA > l_0A_0$

→ Region AD

→ Strain starts increasing at a greater rate.



→ If material is unloaded before elastic limit B, the original shape and dimension will be regained instantaneously i.e. there is no residual strain i.e. loading and unloading curve is same.

→ Upper yield corresponds to a transient condition

→ Lower yield corresponds to load required to maintain yield.

→ Hence yield strength of material is taken corresponding to lower yield point.

→ Volume of the specimen increases due to tension.

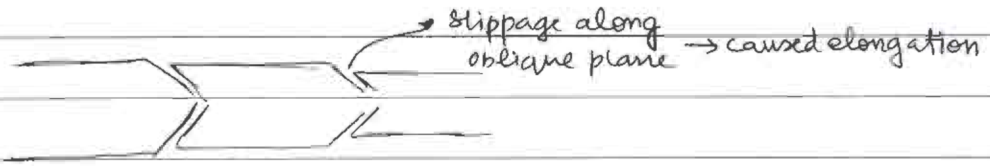
→ Upto D normal stress is primarily responsible for deformation.

NOTE:

In case of solid mechanics, volume changes are thought to be only due to Normal stress

Shear stress creates distortion only [deformation without volume change]

→ **Region DE (Plastic Zone)**



→ Strain increases without significant increase in stress

→ Deformation is caused due to slippage of material on oblique plane, hence, deformation is primarily due to shear stresses, thus volume change is 0.

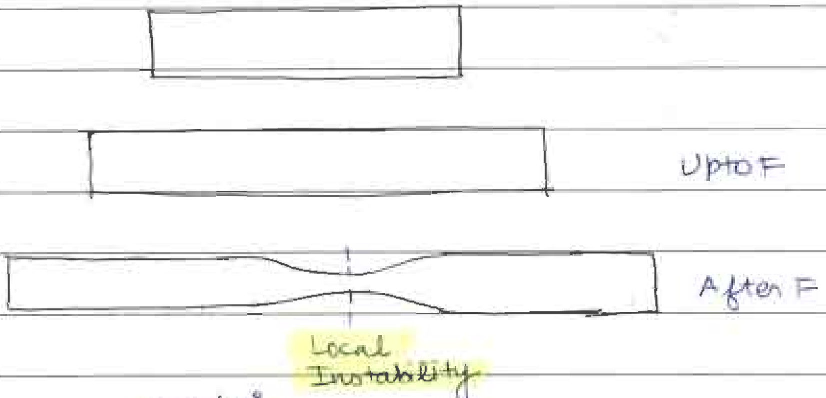
→ Strains are permanent

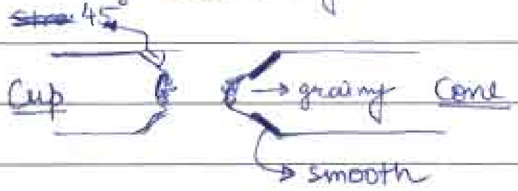
→ **Region EF (Strain Hardening Region)**

→ Beyond point E, material starts offering resistance against deformation

→ This is due to change in crystalline structure of the material

→ **Region FG (Necking Region)**





→ The X-section of the specimen begins to decrease at some localised location due to instability. This is called necking.

→ Ultimate rupture occurs along a cone shaped surface with angle from original surface = 45°

→ This failure is called cup-cone failure and shear is responsible for failure

→ %age reduction in X-sectional area upto the time of fracture is about 50%.

NOTE:

→ In ductile materials, shear is responsible for fracture.

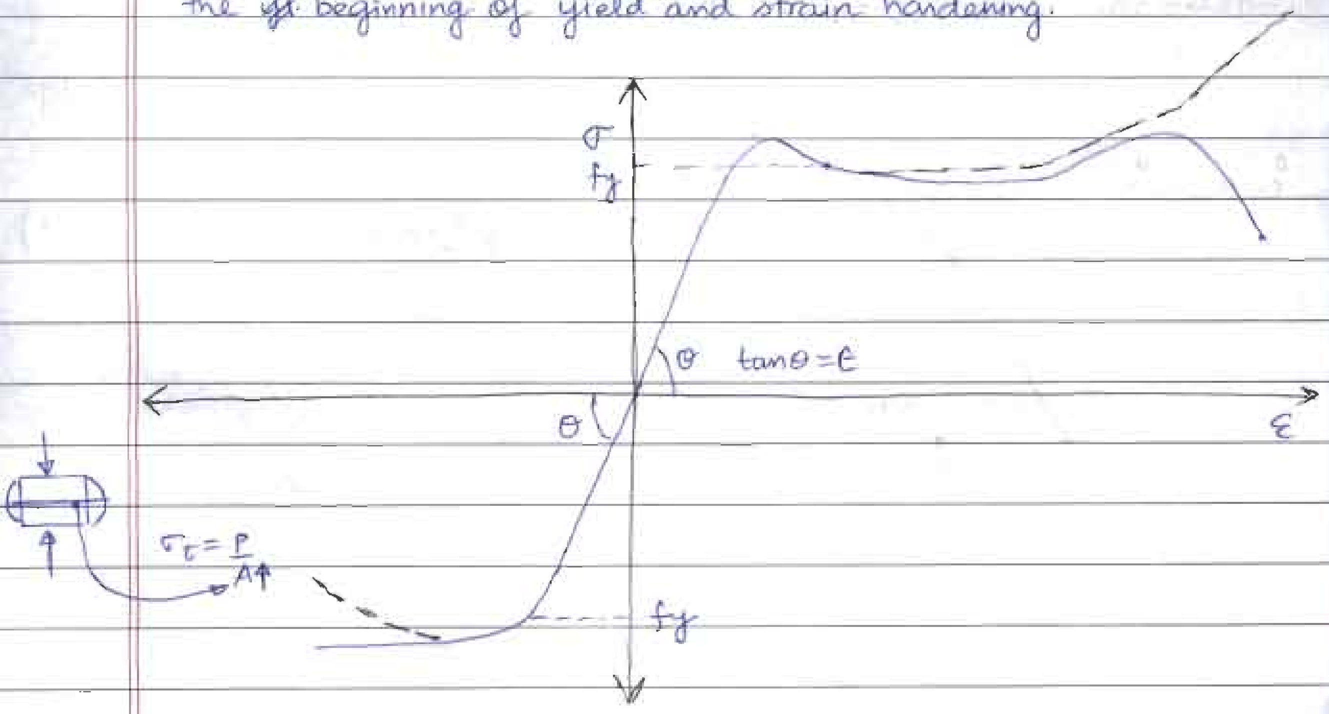
→ Ductile material → when material fails after high inelastic deformation [Rubber is a brittle material].

NOTE: → strain controlled loading.

Normal strain applied is ~~proportional~~ such that the rate of change of ~~shear~~ strain is constant. Near failure, Normal strain will be less to maintain this rate of change of strain.

→ Mild steel in compression

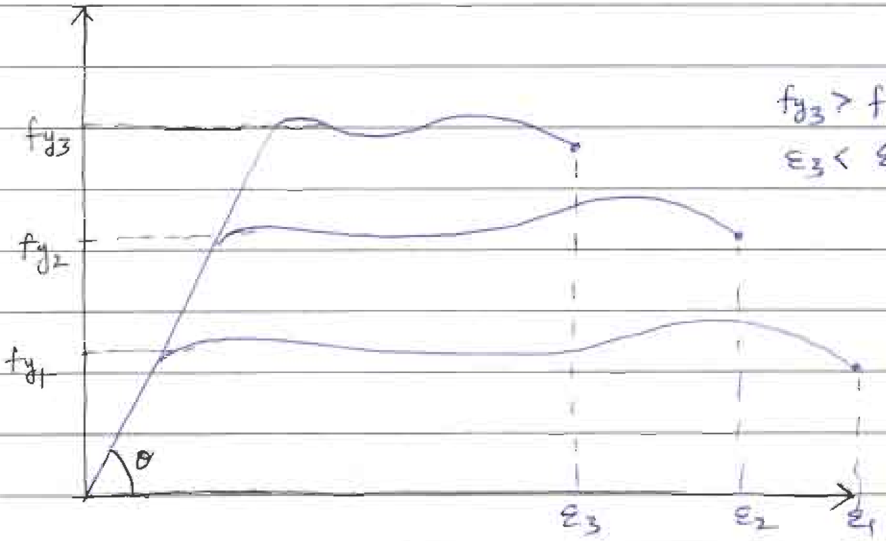
→ The stress strain curve in compression would be essentially same through its initial straight line portion and through the ~~yi~~ beginning of yield and strain hardening.



→ In compression, no necking occurs and modulus of elasticity in tension & compression are same.

→ True stress in compression would be smaller

→ Stress – Strain curve for higher grades of steel



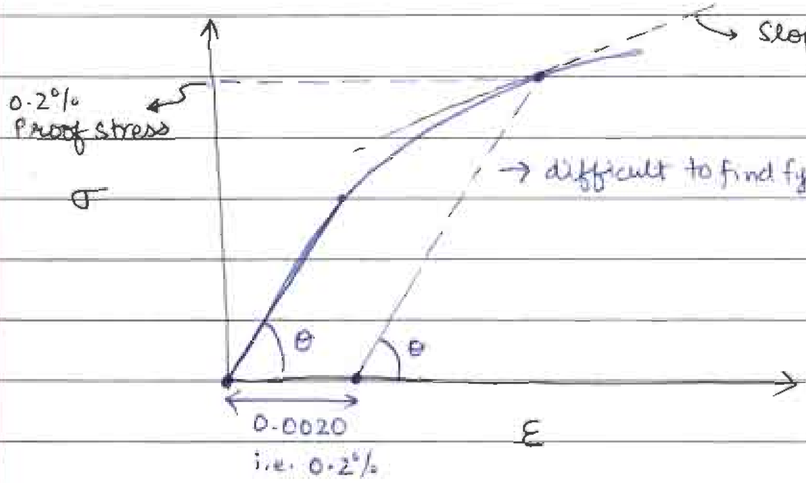
$f_{y3} > f_{y2} > f_{y1}$

$\varepsilon_3 < \varepsilon_2 < \varepsilon_1$

→ Strength, ductility and corrosion resistance can be altered by alloying, heat treatment and using various manufacturing processes.

→ But the modulus of elasticity for various grades are same and as the yield strength increases, ductility reduces.

→ Stress – Strain curve for aluminium and copper



→ Slope is $\frac{1}{1.5}$ times the initial slope.

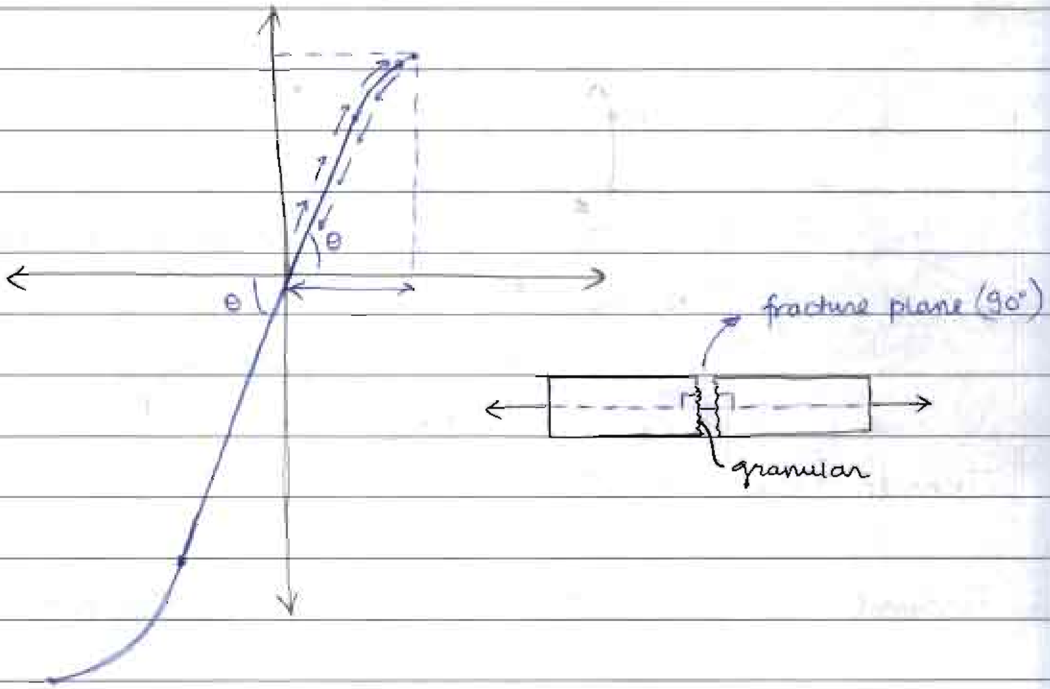
→ difficult to find fy [resolved by offset method]

$\sigma_{permissible} = \frac{f_y}{FOS}$ [ductile material]

$= \frac{f_u}{FOS}$ [Brittle material]

- → In case of aluminium, copper and other materials having no well-defined yield pt, the yield stress for calculation purpose is calculated using offset method, in which we start with 0.0020 (0.2%) strain and move parallel to the initial straight line portion of the stress-strain curve.
- → The point where this line intersects the strain-strain curve corresponds to 0.2% proff stress which is taken as yield stress for calculation purpose.

→ Stress-Strain curve for brittle material {eg cast iron}



- → The linear elastic range in tension is smaller than in compression.
- → Strain at rupture is very small as compared to that in ductile material.
- → Rupture strain is elastic [fracture in elastic range]
- → There is no plastic zone, so ultimate stress = Rupture stress.
- → $\text{permissible stress} = \dfrac{\text{Rupture Stress}}{\text{FOS}}$
- → No necking occurs in this case.
- → Modulus of Elasticity in tension-compression are same

AIR-1 Notes

Pages: 164

Steel Structure
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021

IES Master classroom Student

DESIGN OF STEEL STRUCTURES

CONTENT

23/9/19

Design of Steel Structures

[12-13 Ques in PTE
15-25% in Subjective]

1) Introduction
2) General Design consideration
3) Connection → Bolted / → welded
4) Tension Member
5) Compression Member
6) Beam Design
7) Gantry Girder
8) Plate Girder
9) Industrial building

Code : I.S 800-2007
IS 808 → Structural steel components.

1. Introduction

→ IS codes

(a) IS 800 : 2007 - General construction in steel. (with amendment no. 1, January 2012)
(b) IS 808 : 1989 - Dimensions for steel sections (Steel Table)

→ Steel

→ It is an alloy of iron having carbon content between 0.1 to 1.1%.

→ Based on carbon content, 3 types of steel are:

(a) Low Carbon steel (0.1 to 0.25% Carbon)
(b) Medium Carbon steel (0.2 to 0.60% Carbon)
(c) High Carbon steel (0.6 to 1.1% Carbon)

→ Deoxidizers such as silicon or aluminium is used to control Dissolved Oxygen during the manufacturing process.

→ Lower %age of oxygen content is good for durability of steel and on the basis of oxygen content, we classify steel as

(a) ~~Field~~ Killed Steel [< 30 ppm Oxygen]
(b) Semi-Killed Steel [30 to 150 ppm Oxygen]
(c) Rimmed steel [> 150 ppm oxygen]

→ Structural steel are generally killed or semi-killed Carbon %age in structural steel is generally < 0·25% [Low carbon steel]

→ Mild Steel has a carbon content of nearly 0.1%

→ IS 800 : 2007 can be used for structural Mild steel or high tension structural steel

⇒ Various grades of Steel

Grade		Ultimate Stress (MPa)	Yield Stress (MPa)
E 250 (Fe 410)	A	410	250
	B	410	250
	C	410	250
E 300 (Fe 440)		440	300
E 350 (Fe 490)		490	350
E 410 (Fe 540)		540	410

$E\ 250\ (Fe\ 410)\ A$ → grade of steel

$E\ 250$ ↙ Characteristic Yield Stress

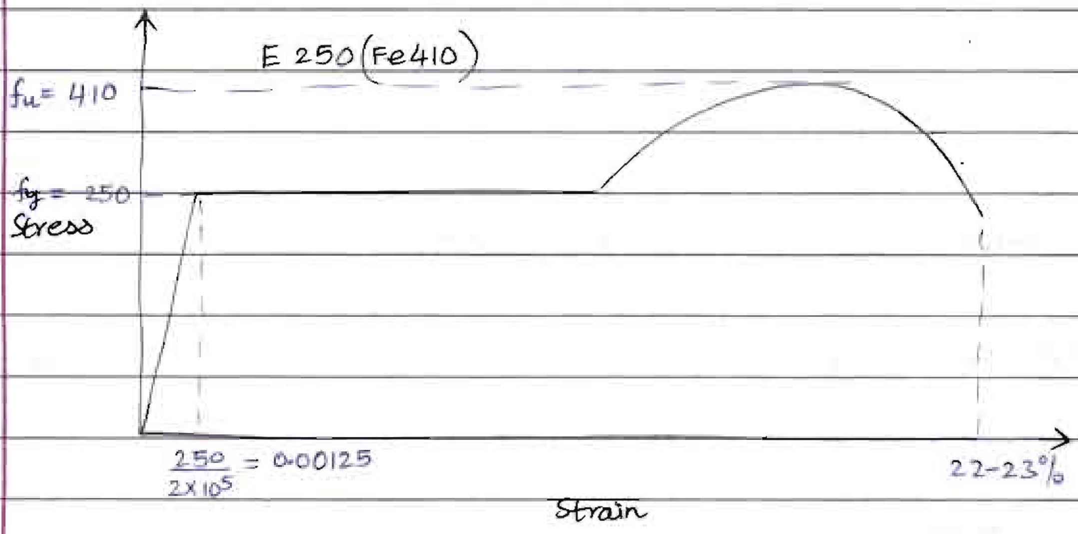
$(Fe\ 410)$ ↘ Characteristic Ultimate Stress

Fe 410 W → denotes higher weldability

NOTE:

1) Structural steel is specified according to characteristic ultimate tensile stress i.e. f_u. It is the ultimate stress below which not more than 5% of the materials are expected to fall

2) R/F bars in RCC are specified according to yield stress.

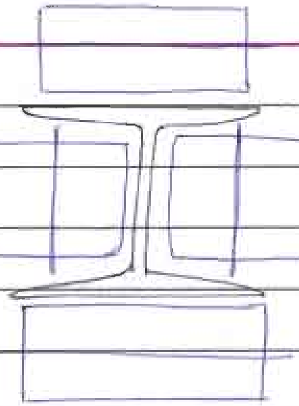


3) Thinner the section, higher is the strength due to higher amount of rolling, cold working, uniform rate of cooling.

Ex- Residual Stress ⇑ →

	t < 20mm	20 < t < 40mm	t > 40mm
E 250 (Fe 410)	$f_y = 250MPa$	$f_y = 240MPa$	$f_y = 230MPa$

→ No. of Rollings ⇓ Grain distribution poor



4) Brittle fracture due to higher tensile stress, lower temperature, thicker material, rapid change of stresses etc.

5) Stainless steel is a low Carbon steel with around 10.5% chromium by weight.

⇒ Grade A is used for non-critical Application i.e. when members are not prone to brittle fracture.

⇒ Grade B is used for critical applications when temperature does not fall below 0°c and when parts are prone to brittle fracture or fluctuations of stresses as in case of bridges.

⇒ Grade C has a guaranteed low temperature upto -40°c and it shall be used for impact loading and higher chances of brittle fracture.

⇒ Physical properties of steel (for all grades)

(a) Density - 7850 kg/m^3

(b) Modulus of Elasticity - 2×10^5 MPa

(c) Poisson's Ratio - 0.3 (Elastic Range)
0.5 (Plastic Range)

(d) Shear Modulus - $G = \frac{E}{2(1+\nu)} = 0.769 \times 10^5$ MPa.

(e) Specific Gravity - 7.85

(f) Coefficient of thermal expansion - 12×10^{-6} /°c

⇒ Advantages of Steel as a Structural material

1) High strength per unit weight
2) High ductility and toughness.
3) Uniformity i.e. very less quality control issues.
4) Environment friendly and high recyclability (≃ 100%)
5) Easy connections and faster construction.
6) Easy repair and modifications.
7) Longer life if properly maintained.

⇒ Disadvantage of steel as a structural material

1) Higher maintenance due to corrosion
2) Fire-proofing cost
3) Prone to buckling due to longer and slender member
4) Fatigue.

⇒ Aluminium

→ Higher strength to unit weight ratio as compared to steel.

→ However, due to lower modulus (≃ 1/3 of steel) bigger sections are required to avoid buckling.

→ greater resistance to corrosion and hence less maintenance.

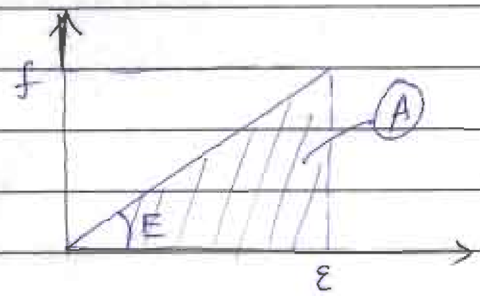
→ Density is approx 1/3 of steel [2700 to 2800 kg/m³]

→ Coefficient of thermal expansion is nearly twice that of steel [23×10^{-6}]

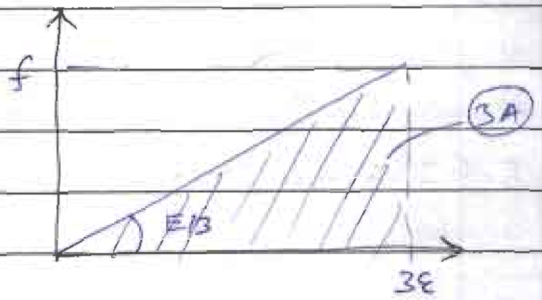
→ less ductile than mild steel.

→ Does not have a well defined yield point and hence yield is assumed as 0.2% proof stress.

→ As it's modulus is 1/3 of steel, It can absorb 3 times the energy at same stress level as ~~a steel~~ compared to a steel member of same dimension provided the stress does not exceed the proportionality limit. Hence it is also used for impact loading provided higher deflection is allowed.



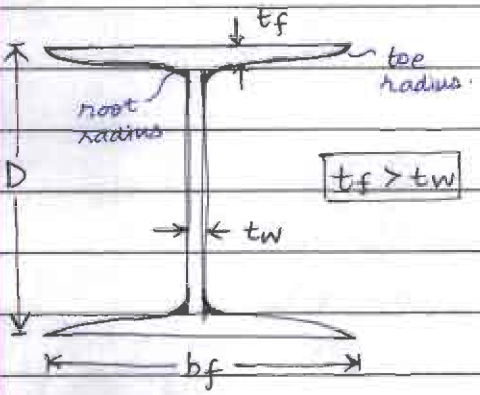
Steel



Aluminium.

→ Design concept is same as steel structure. (IS814)

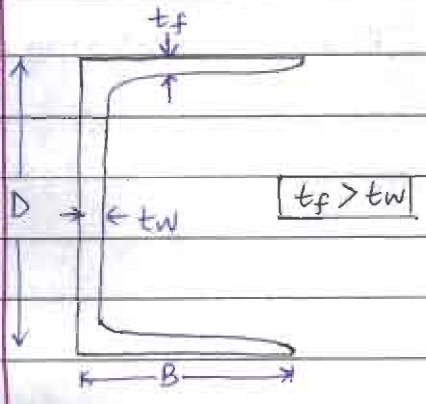
⇒ Standard structural steel sections



ISJB → Indian standard Junior Beam
ISLB → " " Light Beam
ISMB → " " Medium Beam
ISHB → " " Heavy Beam
ISSC → " " Column Section
↳ Type of I-section

Ex- ISMB 300

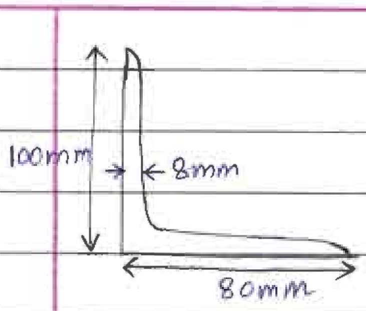
D = 300 mm, B or b_f = 140 mm, t_f = 13.1 mm, t_w = 7.7 mm



ISJC → Junior channel
ISLC → Light channel
ISMC → Medium channel.

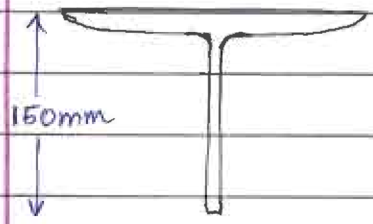
Ex- ISMC 100

D = 100 mm, B = 50 mm, t_f = 7.7 mm, t_w = 5 mm



ISA → Indian Standard equal/unequal angle.

Ex- ISA 100X80X8



ISNT → Indian standard Normal T-section
ISMT → " " Medium T-Section

Ex- ISNT 150@ 223.7 N/m

⇒ ISRO → Round Bars (ISRO 10)
i.e. 10mm dia.

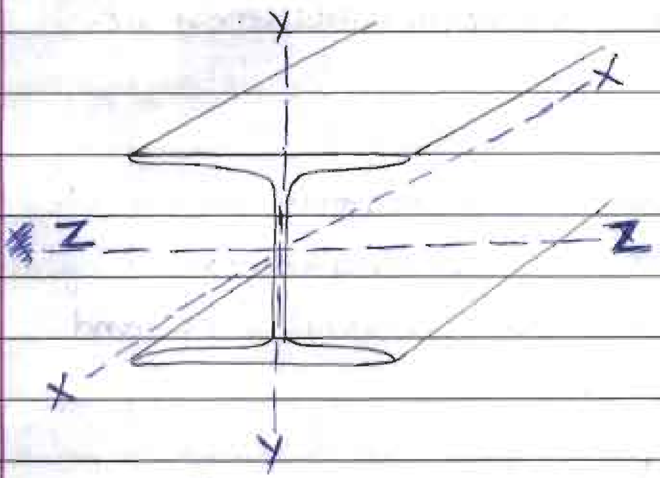
⇒ ISSQ → Square Bars (ISSQ 10 i.e. 10mm side)

⇒ ISPL → Plate (ISPL 2000X1000X8 → Length x width x thickness)

⇒ ISFL → Flat Section (30 ISF 10 → 30mm width and 10mm thickness)

→ These sections can be used either alone (Rolled sections) or in combinations (Built up sections).

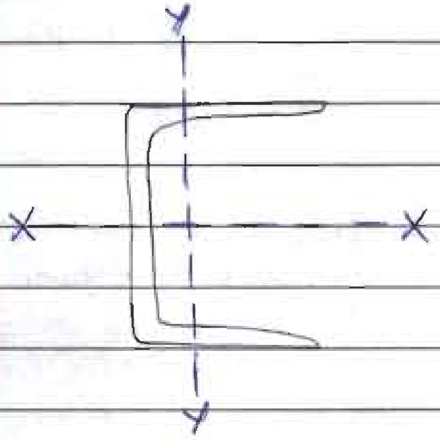
⇒ Convention for member axes

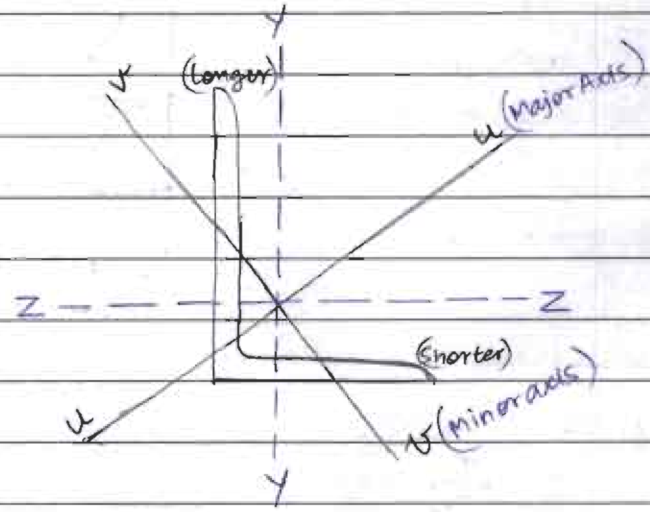


Along the member - X-X

Parallel to flange - Z-Z (Major axis)

Perpendicular to flange - Y-Y (Minor axis)





→ Parallel to smaller leg - ZZ
→ ⊥ar to smaller leg - YY
} for angle sections.

→ In earlier version of IS 800 : 1984, major axis was denoted as X-X

2) General Design Consideration

→ Structure shall fulfill safety, serviceability, economy, aesthetic and environmental criteria.

→ 3 design methods :

(a) Elastic or Working stress method

(b) Plastic / Ultimate Load method

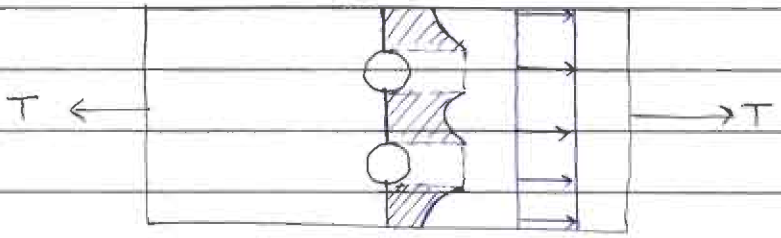
(c) Limit State Method

⇒ WSM (Working Stress Method)

→ It assumes linear elastic response & Safety is ensured by ensuring working stress will be less than permissible stress i.e.

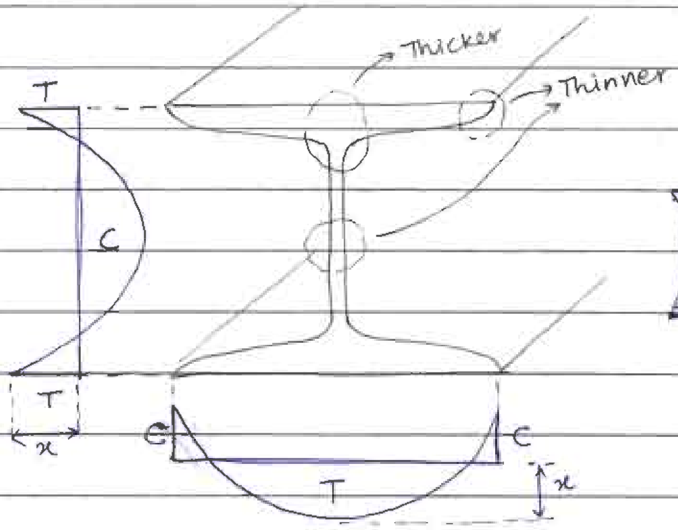
$$\frac{\text{Strength of material}}{\text{FOS}}$$

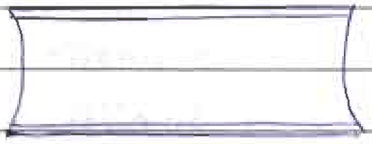
→ However, assumptions of stress being less than permissible stress is not realistic because of stress concentration, long term effect of creep and shrinkage, residual stress and other secondary stresses.



↳ stress concentration due to reduced area of X-section.

NOTE:





Residual stress along the length

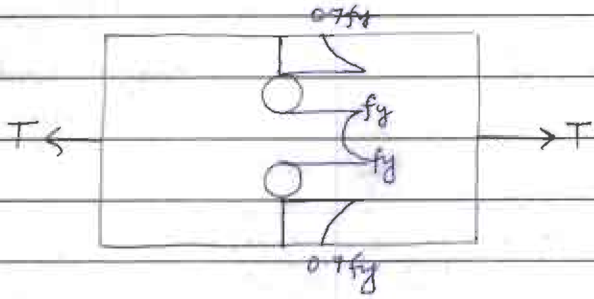
→ Unequal rate of cooling due to different thickness and exposed area and uneven compression by roller will lead to generation of residual stress. The part of section which cools first will have compression because it will resist the shortening of slower cooling part.

→ Also the slower cooling part will have tension.

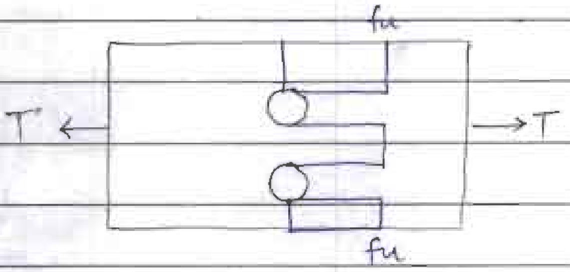
⇒ Does not utilise the reserved strength derived from ductility and redistribution of stress and hence FOS does not give a realistic figure or exact margin of safety.

→ FOS does not have a scientific basis and is based on experience

→ It fails to discriminate b/w different types of loads that are simultaneously acting but having varying degrees of uncertainty.



When working load is acting, ~~momen~~ redistribution of stresses is not available.



At ultimate load, redistribution is significant.

Hence the material ~~to~~ strength is highly underutilized in WSM

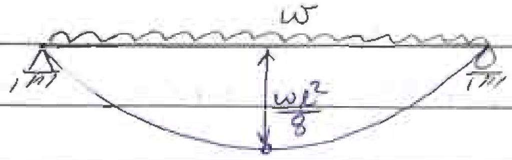
⇒ ULM (Ultimate Load Method)

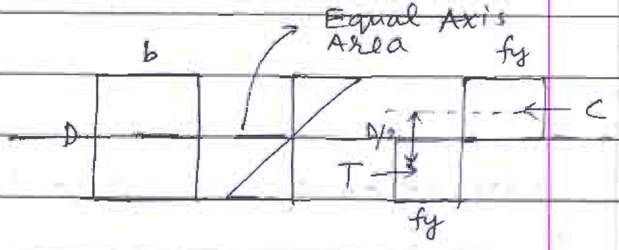
→ Design is done as in the case of plastic analysis in which working load multiplied by load factor is ensured to be less than the collapse load or ultimate load.

→ However, this method does not ensure serviceability criteria like deflection, vibration etc. Also, structure subjected to impact and fatigue loading shall not be designed with plastic theory as it uses full material strength beyond elastic limit.

→ Also safety factor for material is not considered and hence it gives smaller section than WSM.

NOTE: Plastic Analysis





Only one mechanism required for failure

$$\frac{wl^2}{8} = M_p = f_y \frac{bD}{2} \cdot \frac{D}{2}$$

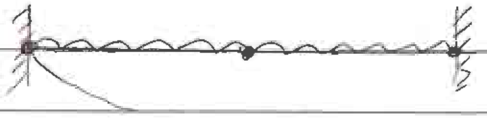
$$M_p = f_y \underbrace{\frac{bD^2}{4}}_{Z_p}$$

Plastic section modulus.

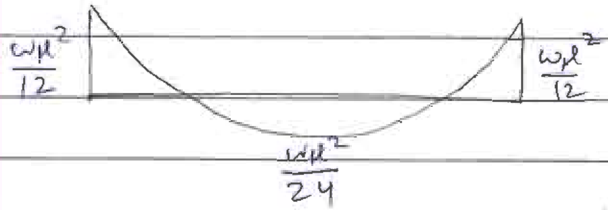
$Z_p = 1.5\ Z_e$

↳ elastic section modulus $= \frac{bd^2}{6}$

In case of SS steel beam ⇒ $\boxed{w_{max} = \frac{8M_p}{l^2}}$



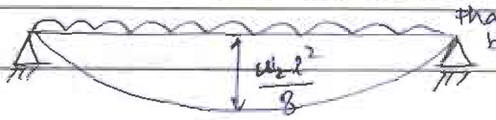
3 hinges required for failure



$\frac{wl^2}{12} = M_p$ → 2 plastic hinge at rigid joints occur.

converted to simply supported

w_2 (additional load that can be applied)



$\frac{w_2 l^2}{8} = \frac{M_p}{2}$ → because $\frac{M_p}{2}$ has been utilized before

So, total load that can be applied $= w_1 + w_2$

$$= \frac{12M_p}{l^2} + \frac{8M_p}{2l^2}$$

$$= \frac{16M_p}{l^2}$$

⇒ LSM (Limit State Method)

→ To avoid all deficiencies of WSM and ULM, LSM was proposed.

→ Partial safety factors are used for both loads and material strength based on acceptable probability of failure derived using reliability analysis. (Level I)

→ Partial safety factors take into account possible overloads and under strength.

Design action (considering partial safety factor for loads) ≤ Design strength (considering partial safety factor for materials)

→ Factored Load / Design Load (F_d) = (Characteristic Load) X γ_f

γ_f → Partial safety factor for loads depending on load combination and limit state being considered.

→ Design strength (f_d) = $\frac{\text{Characteristic Strength}}{\gamma_m}$

γ_m → Partial safety factor for material strength.

→ Characteristic Load is the load which has 95% probability of not being exceeded during the life of the structure.

→ Characteristic strength is the strength below which not more than 5% of the test samples are expected to fall.

⇒ γ_f accounts for (Partial safety factor for loads)

① Possibility of load exceeding characteristic load.

② Possibility of inaccurate assessment of load.

③ Uncertainty in assessment of effect of load. (failure mechanism)

④ Uncertainty in the assessment of limit state being considered.

⇒ γ_m accounts for (partial safety factor for material strength)

① Possibility of strength falling below characteristic strength.
② Reduction in member size due to faulty construction.
③ Reduction in strength due to fabrication and tolerances.
④ Uncertainty in theoretical assumptions.
⑤ Uncertainty in the calculation of strength of member.

→ Limit states are the states beyond which the structure becomes unfit for use.

→ The limit states are classified as:

① Limit State of strength / Ultimate Limit strength.
② Limit State of serviceability.

⇒ Limit state considered by IS code

① Limit State of Strength

(a) Strength including yielding, buckling and transformation into a mechanism (plastic hinge formation)
(b) Stability against overturning and sway
(c) failure due to excessive deformation or rupture
(d) fracture due to fatigue.
(e) Brittle fracture.

② Limit State of serviceability

(a) Deformation and deflection (can cause damage to non structural components and finishes but not to structural component)

AIR-1 Notes
Pages: 176

Surveying
Handwritten notes by

Kartikay Kaushik
AIR-1 ESE 2021
IES Master classroom Student

SURVEYING

CONTENT

Surveying [3-4 marks - 7-8Q - 50-60M]

GATE Objective Conventional

Chapters

1. Fundamentals of Surveying
2. Linear Measurement
3. Compass Surveying ✓
4. Theodolite
5. Traversing
6. Levelling ✓
7. Tacheometry ✓
8. Trigonometric Levelling ✓
9. Measurement of Area Volume. ✓
10. Photogrammetry ✓
11. Curve ✓
12. Field Astronomy
13. Theory of Errors.
14. Plane Table Surveying
15. Contour

1. Fundamental of Surveying

→ Surveying is the art of determining relative position of points on, above and below the earth surface, and presenting it graphically or numerically.

→ Objective of Surveying

1. To determine relative position of points
2. To layout or markout the proposed structure on the ground
3. To determine relative quantities like Area and Volume.

→ Methods of Presentation

AB = 10 km } Numerical representation

A ——10km—— B } Graphical representation. { Plan or Map }

→ 1) Numerical Representation (AB = 10 Km)

2) Graphical Representation (A ——10km—— B)

→ Graphical representation is done in the form of Plan or map:

(i) Plan — Large Scale
(ii) Map — Small Scale.

NOTE:

→ vertical distance on a map can be presented with the help of contour or spot level.

→ Contour is an imaginary line joining the points of same elevation on the earth surface (Natural contour : Water surface)

→ Spot levels are height of individual points.

→ Contour is preferred over spot levels because it gives better visualisation over spot levels

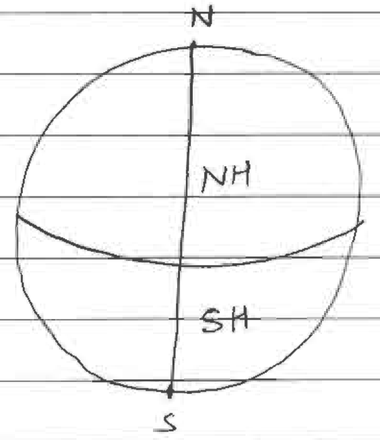
→ Basic definition

1) → Shape of Earth

(a) Oblate Spheroid : Slightly flat at poles.
Polar Axis is 43.5 km smaller than equatorial axis.

(b) Ellipsoid : Equatorial section is elliptical in nature

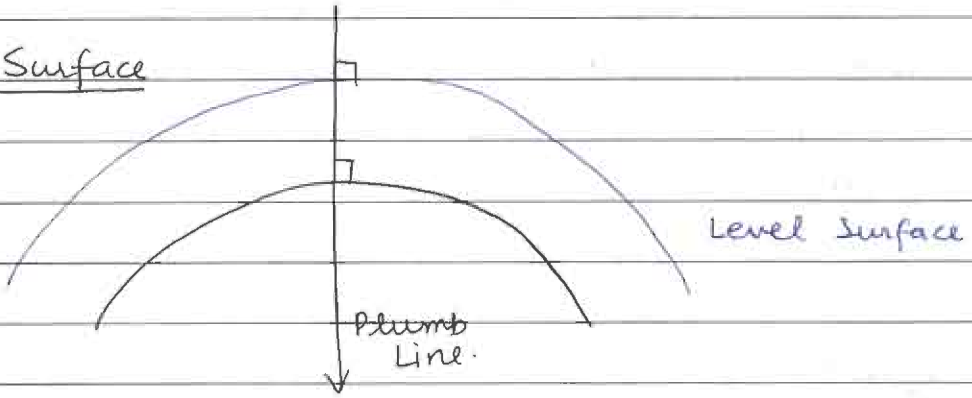
(c) Ovalloid : Southern Hemisphere is slightly larger than Northern Hemisphere.



→ We can observe that no geometrical figure completely defines the shape of earth, hence a new name is given to the shape of earth i.e. GEOID

NOTE:
For calculation purpose, we'll assume earth to be spherical in nature.

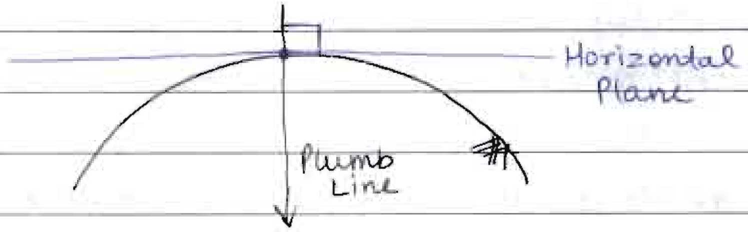
2) → Level Surface



→ Level Surface is a curved surface llel to the spherical ~~flat~~ surface of earth and hence every point on it is equidistant from the centre of the earth.

→ Every element on level surface is perpendicular to plumb line.

3)- Horizontal Plane

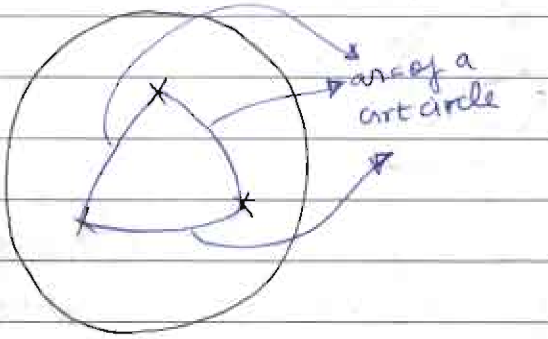


→It is a tangential plane to the earth surface which is also perpendicular to plumb line.

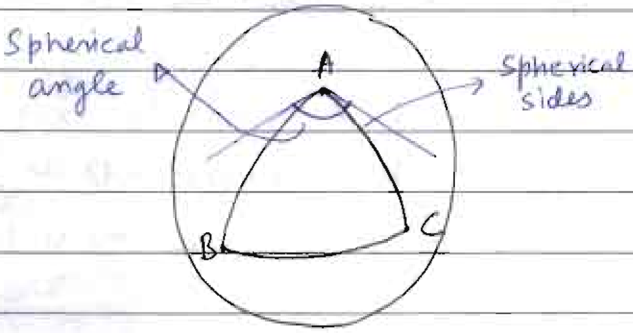
4)- Great circle

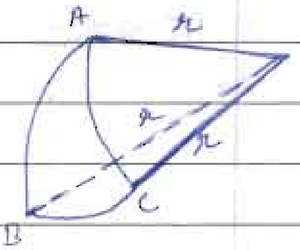
→It is a imaginary circle passing through the centre of the earth.
→A great circle divides earth surface into 2 equal parts.

5) Spherical Triangle



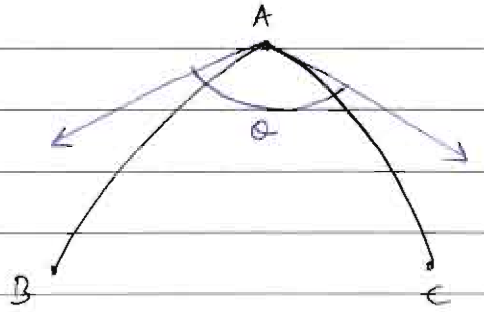
A spherical Δ is a Δ which is formed on the surface of a sphere by intersection of 3-arcs of different great circles.

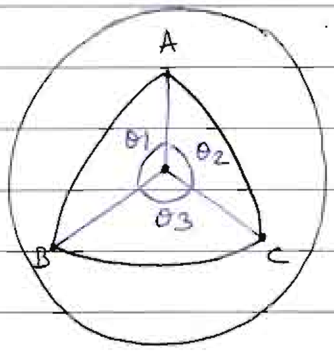




→ The arc enclosing spherical Δ are called as spherical sides and the angles in which these arc intersect are called as spherical angle.

→ Spherical angle is defined as angle between the tangent to the great circles at the point of intersection of 2 spherical sides





$\widehat{AB} = R\widehat{\theta_1}$

$\widehat{BC} = R\,\theta_3$

$\widehat{CA} = R\,\theta_2$

↓

We can neglect R and compare on basis of θ.

→ Length of a side of a spherical Δ is defined as the angle subtended by that side at the centre of the sphere.

→ **Properties of Spherical Δ**

1. Each side of a spherical Δ must be less than equal to π.
2. Each angle of a spherical Δ must be less than π.
3. Sum of 3 sides must be between (0 to 2π).
4. Sum of 3 angles of a spherical Δ must be between [π to 3π).

NOTE:

$$\begin{array}{rl} & 182^\circ\ 57'\ 39'' \rightarrow \text{Sum of spherical Angles} \\ - & 180^\circ\ 0'\ 0'' \\ \hline & 2^\circ\ 57'\ 39'' \rightarrow \text{Spherical Excess} \end{array}$$

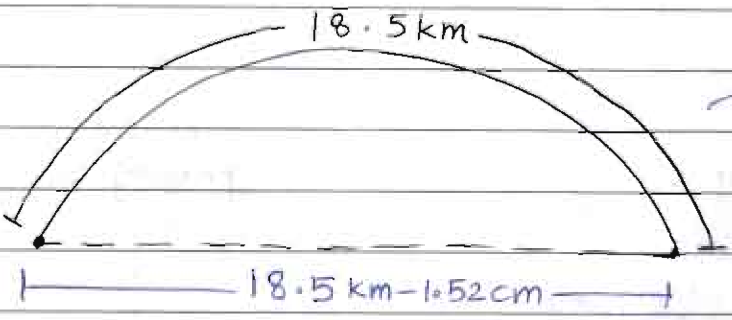
Amount by which sum of angles of a spherical Δ exceed by 180° is called as Spherical Excess.

5. Surface Area of a spherical Δ must be less than $2\pi R^2$
6. Greater angle is opposite to greater side.

→ Classification of Surveying

→ Surveying can be classified into various means eg- instrument used, purpose, place of survey etc. But mainly is surveying is classified into 2 types:

1) Geodetic surveying
2) Plane Surveying.



→ curved area can be assumed to be plane as long as it is small.

$$\text{Geodetic Survey} \geq 195.5\ \text{km}^2 > \text{Plane survey}$$

$$\Downarrow$$

$$\text{S.E.} \Rightarrow 1''$$

Geodetic Survey	Plane survey
1. Geodetic survey is done for large area and we consider earth's surface as curved.	1. Plane Surveying is done for small area and earth surface is considered as flat surface i.e. curvature of earth is neglected.
2. Area greater than equal to 195.5 km^2	2. Area less than 195.5 km^2
3. It is done by SOI - Survey of India to establish control points throughout the Country.	3. It is done for local survey.
4. It uses spherical trigonometry	4. It uses plane trigonometry.

NOTE:

→ In Plane surveying plotted measurements are projected on a horizontal plane.

→ For Area = 195.5 km^2, spherical Excess = 1''

→ Classification of surveying based on purpose of survey

1. Topographical Survey

These survey are used to obtain maps which show details of natural and man-made features on the earth surface including elevation information.

Scale: 1:25,000 to 1:10,00,000

2. Engineering survey

These surveys are used for engineering works, eg - dams, sewer, railway, roads etc.

Building work: 1:50 to 1:200

Bridges and other civil engg works: 1:500 to 1:2500

Highway: 1:1250 to 1:50000

3) Cadastral Survey

These are used to represent property boundaries.

1:1000 to 1:5000

4) Hydrographic Survey

These survey are done on or near the water body such as lake, river, bay etc.

5) Astronomic Survey

With the help of astronomic survey we can determine latitude, longitude and Local Mean time of any place

6) Geological Survey

It is used to obtain information about different strata of earth surface.

→ Classification based on Instrument

1) Chain Surveying

→ It is simplest type of surveying in which only linear measurements are done with the help of chain or tape.

→ No angular measurement is done.

2) Compass surveying

→ In compass surveying, directions and horizontal angles are measured with the help of compass and distances are measured with the help of chain or tape.

NOTE:
Trough compass is the only non-circular compass.

- 1 vernier division is slightly smaller than 1 division of main scale.

$$n v = (n-1) s$$

$$LC = s - v$$

$$= s - \left(\frac{n-1}{n}\right) s$$

$$\boxed{L.C. = \frac{s}{n}}$$

s → L.C. of main scale

n → no. of division on vernier scale.

→ **Retrograde Vernier**

- n divisions on vernier scale are equal to (n+1) divisions on main scale
- 1 vernier division is slightly larger than 1 division of main scale.
- vernier division and main scale division increase in opposite direction, whereas in direct vernier both increase in same direction

$$n v = (n+1) s$$

$$L.C. = v - s$$

$$\boxed{L.C. = \frac{(n+1)}{n} s - s = \frac{s}{n}}$$

Q → The main plate of a Theodolite is divided into 1080 equal parts and 60th division of vernier scale coincides with 59th division of main scale. Determine L.C. of theodolite.

$$L.C. = s - v \qquad\qquad 60 v = 59 s$$

$$= \cancel{\frac{360°}{1080}} s - \frac{59}{60} s \qquad\qquad v = \frac{59}{60} s$$

$$= \frac{s}{60} = \frac{\overset{6}{\cancel{360}}°}{1080 \times \cancel{60}} = \frac{\cancel{6} \times 6\cancel{0} \times 60''}{\underset{3}{\cancel{108}\cancel{0}}} = 20''$$

→ Special Types of Vernier

1) Double Vernier

→ If graduations of main scale increases in one direction only we have a single vernier whereas when main scale is graduated in both the directions a double vernier is used. eg.- Theodolite.

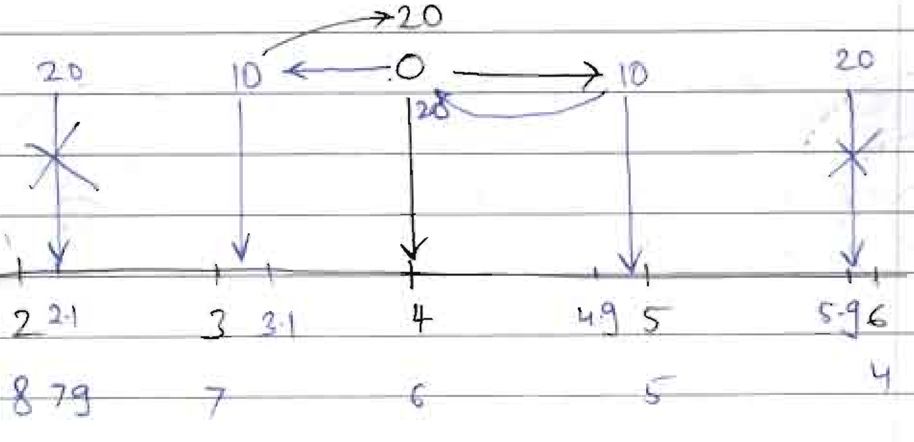
→ Double vernier consists of 2 direct verniers extentending in both the direction with index mark in the centre.

2) Double Folded Vernier

→ A double folded vernier is a special type of double vernier whose total length is exactly half of combined length of corresponding double vernier

→ A double folded vernier is used when it is required to ~~we~~ reduce the length of vernier scale eg - sextant to measure vertical angles of elevation or depression.

→ In double folded vernier the vernier is read from index mark (0 mark) towards either of the extreme division and then from other extreme division towards centre in the same direction



→ **Extended Vernier**

→ When divisions of main scale are verey close and it becomes very difficult to determine exact graduation where coincidence occurs, If vernier of normal length is used.

→ Hence, extended vernier is very useful when available length of vernier scale is small and it is required to have small least count without making vernier divisions very close

→ In extended vernier, n divisions of vernier scale are equal to (2n-1) divisions of main scale.

$$n v = (2n-1) s$$

$$v = \frac{(2n-1)}{n} S.$$

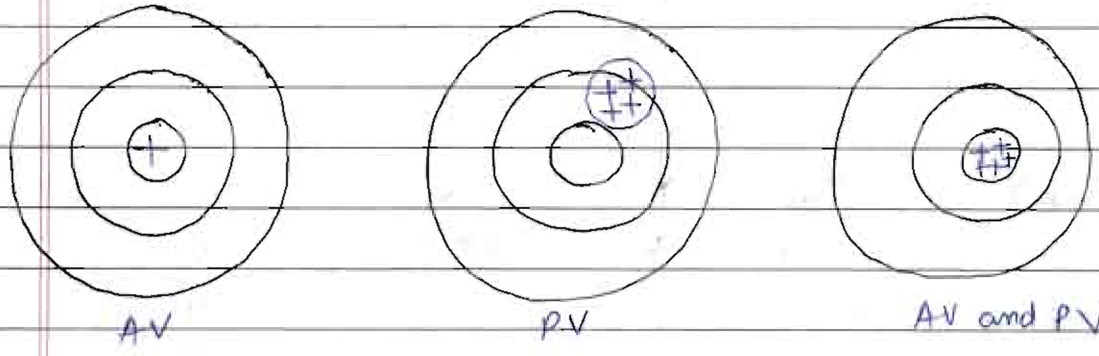
$$L.C. = 2S - v$$

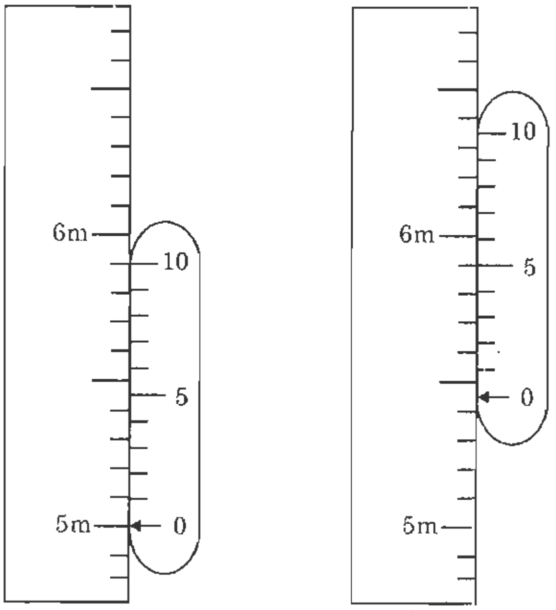
$$= 2S - \frac{(2n-1)S}{n} = \frac{S}{n}$$

** NOTE:

Extended Vernier is used in an instrument called Abney Level used to find vertical angles

→ **Precision and Accuracy**

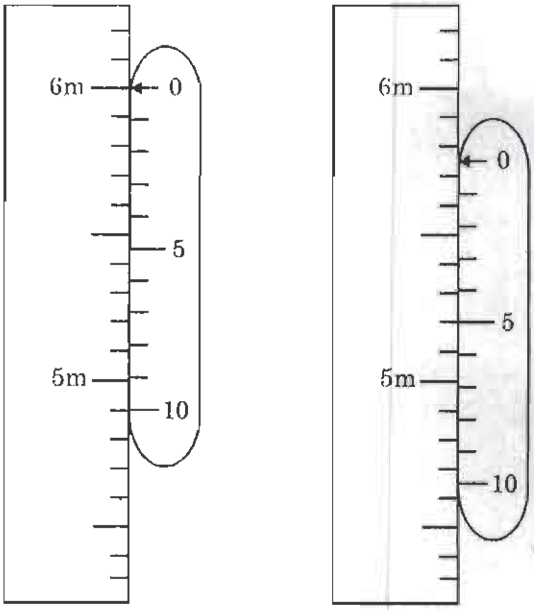




5.00m
(a)

5.$\overset{4}{\cancel{3}}$5m
(b)

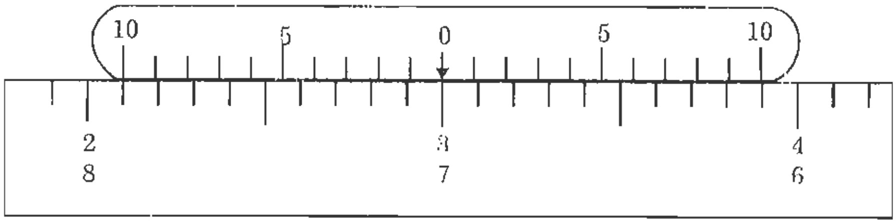
Direct Vernier



6.00m
(a)

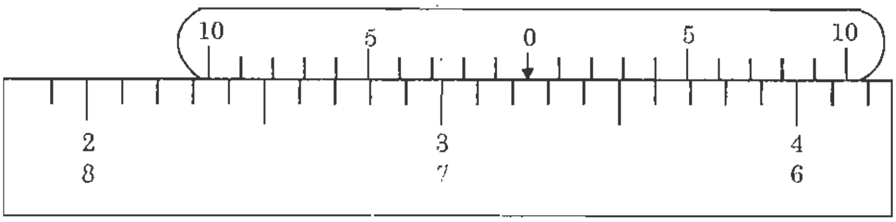
5.75m
(b)

Retrograde Vernier



3.00 →

7.00 ←

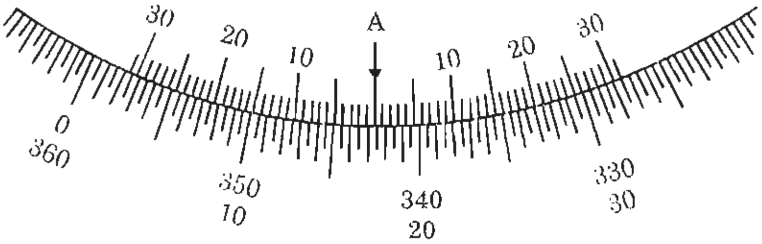


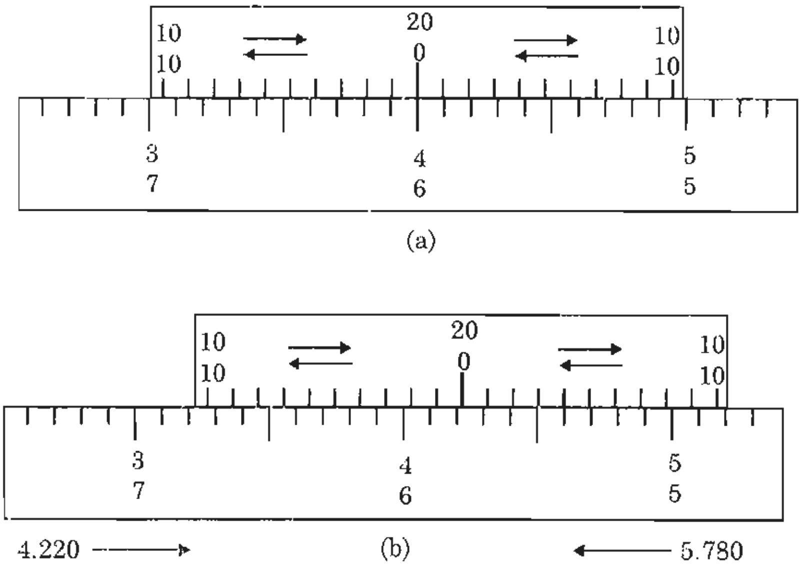
3.24 → UMS

6.76 ← LMS

Double Vernier

①

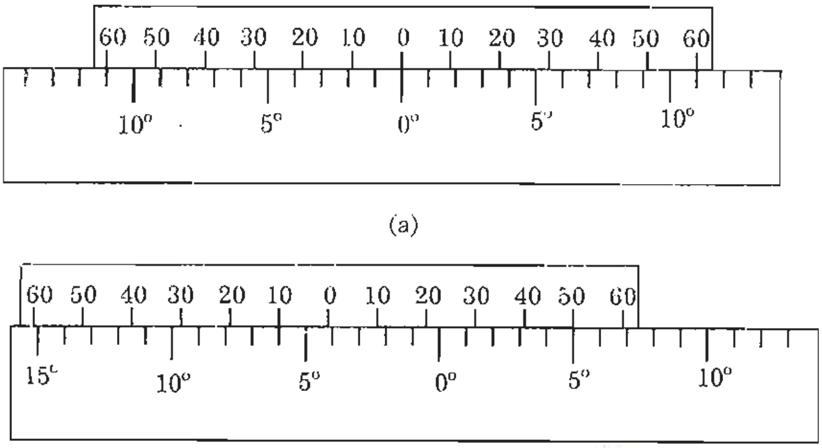




(a)

(b)

Double Folded Vernier



(a)

(b) 4°10'

Extended Vernier

②