CIVIL ENGINEERING

ESE TOPICWISE

CONVENTIONAL SOLVED PAPER-I

1995-2025

IES MASTER PUBLICATION

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PREFACE

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It is not mere hard work that helps a student succeed in an examination like ESE that witnesses lakhs of aspirants competing neck to neck to move one step closer to their dream job. It is hard work along with smart work that allows an ESE aspirant to fulfil his dream.

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IES Master feels immense pride in bringing out this book with utmost care to build upon the exam preparedness of a student up to the UPSC standards. The credit for flawless preparation of this book goes to the entire team of IES Master Publication. Teachers, students, and professional engineers are welcome to share their suggestions to make this book more valuable.

MR. KANCHAN KUMAR THAKUR

DIRECTOR—IES MASTER

CONTENT

(ii) Maximum shear stress (τ_{max}) $= \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4 \times \tau_{xy}^2}$

$$= \frac{1}{2}\sqrt{(120 + 90)^2 + 4 \times 84.85^2}$$

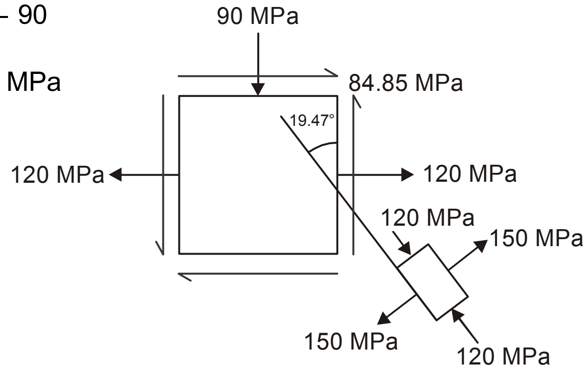
$$= 135 \text{ MPa}$$

(iii) Other principal stress

$$\sigma_1 + \sigma_2 = \sigma_x + \sigma_y$$

$$150 + \sigma_2 = 120 - 90$$

$$\sigma_2 = -120 \text{ MPa}$$



Again we know,

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

$$\Rightarrow \quad \tan 2\theta_P = \frac{2 \times 84.85}{120 - (-90)}$$

$$\theta_P = 19.47°$$

So, inclination of minor principal stress with 120 MPa is ($19.47° + 90 = 109.47°$) in anti-clockwise direction

Q-18: ***What combination of Principal stresses will give the same factor of safety for failure by yielding according to the maximum shear stress theory and distortion energy theory. Consider only a two dimensional case.***

[10 Marks, ESE-2019]

Sol: Let the major and minor principal stresses are (σ_1) and (σ_2) respectively. As 2-dimensional condition is assumed, so $\sigma_3 = 0$.

Here two cases arise:

Case-I: The two principal stresses are unlike stresses.

Case-II: The two principal stresses are like stresses.

Case-I:

Maximum shear stress theory:

$$\text{Maximum of } \left[\left|\frac{\sigma_1 - \sigma_2}{2}\right|, \left|\frac{\sigma_1}{2}\right|, \left|\frac{\sigma_2}{2}\right|\right] = \frac{\left(\frac{f_y}{FOS}\right)}{2}$$

$$\Rightarrow \quad \left(\frac{\sigma_1 - \sigma_2}{2}\right) = \frac{\left(\frac{f_y}{FOS}\right)}{2} \quad \text{...(i)}$$

Maximum distortion energy theory:

$$\frac{1}{12G}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right] = \frac{\left(\frac{f_y}{FOS}\right)^2}{6G} \quad \text{...(ii)}$$

Putting, $\left(f_y/FOS\right)$ value from Eq. (i) to Eq. (ii), we get

$$\frac{1}{12}\left[(\sigma_1-\sigma_2)^2+(\sigma_2)^2+(\sigma_1)^2\right] = \frac{(\sigma_1-\sigma_2)^2}{6}$$

$$\Rightarrow \quad (\sigma_1-\sigma_2)^2+\sigma_1^2+\sigma_2^2 = 2(\sigma_1-\sigma_2)^2$$

$$(\sigma_1-\sigma_2)^2-\sigma_1^2-\sigma_2^2 = 0$$

$$\Rightarrow \quad \boxed{2\sigma_1\sigma_2=0}$$

∵ The product of principal stresses is zero, which means either σ_1 or σ_2 or both are zero.

Therefore, it can not result, in a two dimensional stress condition. Hence, Case II will exist.

Case-II:

Maximum shear stress theory:

$$\text{Maximum of}\left[\frac{|\sigma_1-\sigma_2|}{2},\frac{|\sigma_1|}{2},\frac{|\sigma_2|}{2}\right] = \frac{\left(\frac{f_y}{FOS}\right)}{2}$$

$$\Rightarrow \quad \left(\frac{\sigma_1}{2}\right) = \frac{\left(\frac{f_y}{FOS}\right)}{2} \qquad \ldots\text{(iii)}$$

Putting, value of $\left(\frac{f_y}{FOS}\right)$ from Eq. (iii) to Eq. (ii), we have

$$\frac{1}{12}\left[(\sigma_1-\sigma_2)^2+(\sigma_2)^2+(\sigma_1)^2\right] = \frac{(\sigma_1)^2}{6G}$$

$$\Rightarrow \quad (\sigma_1-\sigma_2)^2+(\sigma_1)^2+(\sigma_2)^2 = 2(\sigma_1)^2$$

$$\Rightarrow \quad 2\sigma_2^2-2\sigma_1\sigma_2 = 0$$

$$\Rightarrow \quad \boxed{\sigma_2 = \sigma_1}$$

Hence, both stress should be equal and like stresses

Q-19: ***A bar of length 1.2 m, diameter 40 mm is subjected to an axial tensile load of 130 kN and a twisting moment of 600 N.m. If the same material yielded at an axial stress of 200 N/mm², determine the safety factor associated with the bar, considering***

(i) Principal stress failure theory

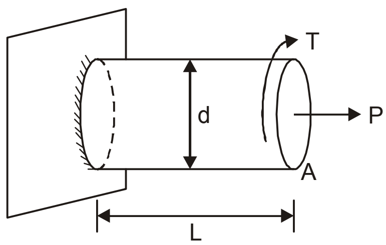
(ii) Maximum shear stress theory

(iii) Distortional strain energy theory

Take E = 200 GPa and μ = 0.25

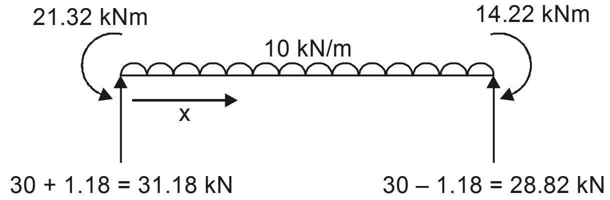
[20 Marks, ESE-2020]

Sol:

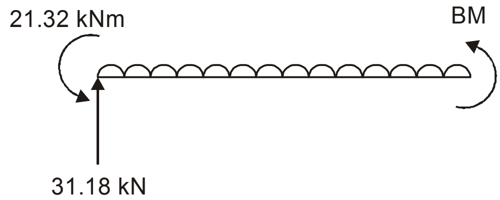


For maximum positive BM in member BC

$$SF\ (V) = 0$$



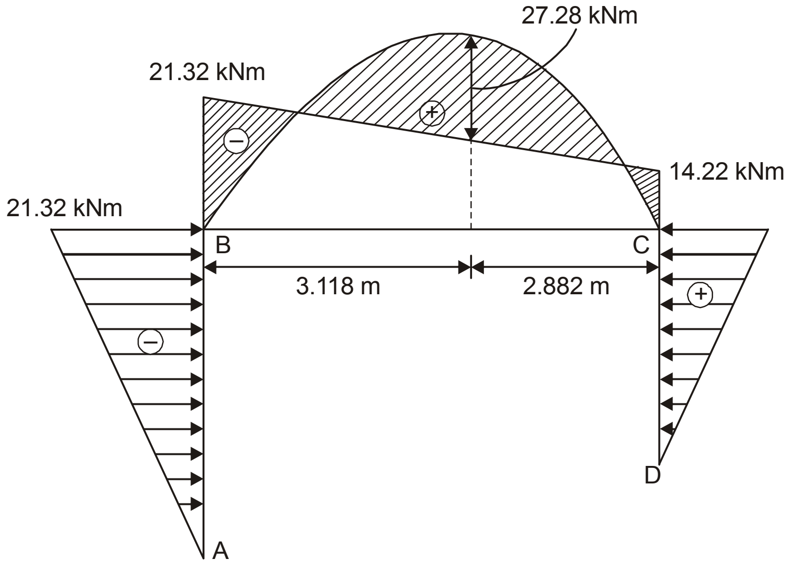
For S.F. = 0



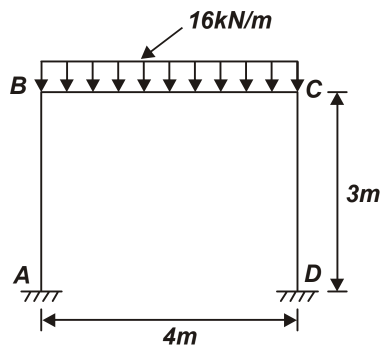
$$10x - 31.18 = 0$$

$$\boxed{x = 3.118\ m}$$

$$(BM)_{max} = 31.18 \times 3.118 - \frac{10 \times 3.118^2}{2} - 21.32 = 27.28\ kNm$$

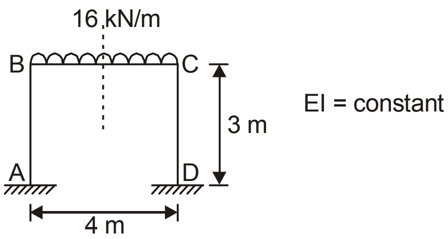


Q-18: ***Analyze the portal frame shown in the figure below by moment distribution method. The frame is fixed at A and D, and has rigid joints at B and C. Draw the bending moment diagram and sketch the deflected shape of the structure. Take EI as constant:***

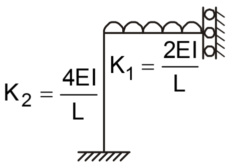


[20 Marks, ESE-2023]

Sol:



As the frame is symmetrical, concept of symmetrical approach will be used.



Joint	Member	Stiffness factor	D.F.
B	BA	$\frac{4EI}{3}$	$\frac{8}{11}$
	BC	$\frac{2EI}{4}$	$\frac{3}{11}$

Fixed end moments

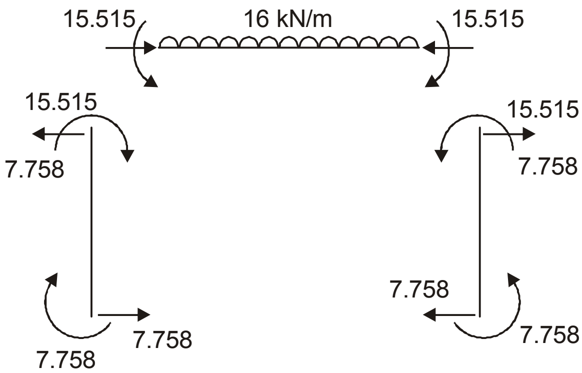
$$M_{FBA} = M_{FAB} = M_{FCD} = M_{FDC} = 0$$

$$M_{FBC} = -M_{FCB} = -\frac{wL^2}{12} = -\frac{16\times 4^2}{12}$$

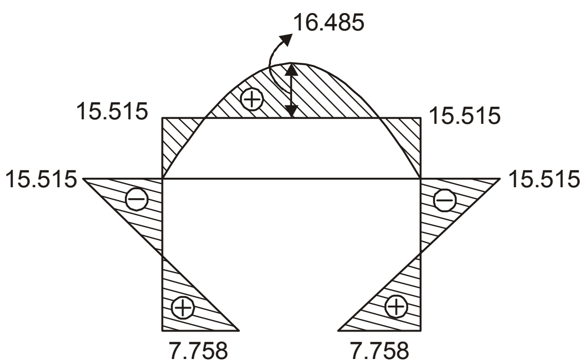
$$= -\frac{64}{3} \text{ kN-m} = -21.33 \text{ kN-m}$$

A	B (8/11)	B (3/11)	C′
0	0	–21.333	
	15.515	5.818	
7.758			
7.758	15.515	–15.515	

The free body diagram will be as shown below.



$$H_A = H_B = \frac{15.515 + 7.758}{3} = 7.758 \text{ kN}$$



$$I_{xx} = 2I_{xx,one}$$

$$I_{yy} = 2I_{yy,\,one} + 2A\left(C_{yy} + \frac{t_g}{2}\right)^2$$

$\Rightarrow$ $$I_{xx} < I_{yy}$$

$\Rightarrow$ $$I_{min} = I_{xx}$$

$\Rightarrow$ $$r_{min} = \sqrt{\frac{2I_{xx,one}}{2A}} = \sqrt{\frac{I_{xx,one}}{A}}$$

$$= \sqrt{\frac{226000}{684}} = 18.177$$

$\Rightarrow$ $$\tau = \frac{1800}{18.177} = 99.025$$

From the given table, $$f_{cd} = 92.6 + \frac{105 - 92.6}{100 - 90}(100 - 99.025)$$

$$= 93.81 \text{ N/mm}^2$$

$\Rightarrow$ $$\text{Factored load} = f_{cd} \times 2A = 93.81 \times 2 \times 684 = 128.33 \text{ kN}$$

Q-8: ***In a roof truss, a diagonal consists of an ISA 60 mm × 60 mm × 8 mm (ISA 6060 @ 0.07 kN/m) and it is connected to gusset plate by one leg only by 18 mm diameter rivets in one chain line along the length of the member. Determine tensile strength of the member, if yield stress for steel is 250 MPa.***

[12 Marks, ESE-2019]

Sol: We will follow the recommendation of IS 800 : 1984 since the necessary data for analysis is not given like the location of connection of bolt, $f_{u.}$

Diameter of rivet hole = 18 + 1.5 = 19.5 mm

Net effective area provided. $A_{eff} = A_1 + KA_2$

where, A_1 = Net sectional area of the connected leg

A_2 = Area of the outstanding leg.

If angle connected by one leg only

$$K = \frac{3A_1}{3A_1 + A_2}$$

Here, $$A_1 = \left(60 - \frac{8}{2} - 19.5\right) \times 8 = 292 \text{ mm}^2$$

$$A_2 = \left(60 - \frac{8}{2}\right) \times 8 = 448 \text{ mm}^2$$

$$K = \frac{3 \times 292}{3 \times 292 + 448} = 0.6616$$

$$A_{eff} = 292 + 0.6616 \times 448 = 588.41 \text{ mm}^2$$

Allowable tensile stress, $(f_a) = 0.6 \times f_y = 0.6 \times 250 = 150 \text{ N/mm}^2$

So, Tensile strength $= f_a \times A_{eff} = 150 \times 588.41$

$$= 88.261 \text{ kN}$$

(Assuming two leg shear R/f of Fe500 grade)

$$0.87 \times 415 \times \left(2 \times \frac{\pi}{4} \times 6^2\right) \times \frac{850}{Sv} = (0.804 - 0.53) \times 300 \times 850$$

$$Sv = 248.4 \text{ mm}$$

From minimum shear R/f criteria

$$\frac{A_{sv}}{bSv} \geq \frac{0.4}{0.87f_y}$$

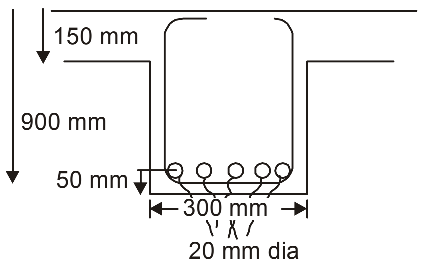
$$Sv \leq 170 \text{ mm}$$

Sv $\not>$

(i) 0.75 d

(ii) 300 mm OK

Provide shear stirrups 6mm ϕ @170mm



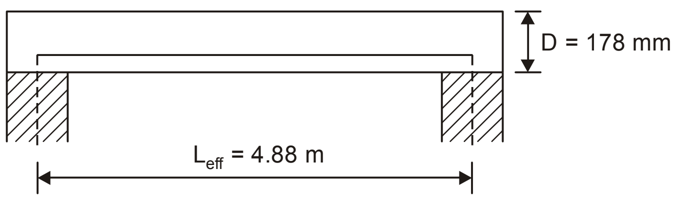
Q-13: ***A simply supported one way slab 178 mm thick having an effective span of 4.88 m is reinforced with 12 mm diameter rebars at 125 mm centre to centre. The nominal concrete cover to the main reinforcement is 20 mm. The slab is subjected to a live load of 4 kN/m² and surface finish of 1.2 kN/m². Use M25 concrete and Fe500 grade steel. Compute only the short-term deflection and deflection due to shrinkage. Shrinkage strain is 0.0003. Density of concrete is 25 kN/m³.***

$$E_C = 5000\sqrt{f_{ck}}, E_s = 2 \times 10^5 \text{ MPa}$$

$$P_t = \frac{100A_{st}}{bd}; P_c = \frac{100A_{sc}}{bd}.$$

[20 Marks, ESE-2022]

Sol:



Reinforcement = 12@125 mm

Nominal cover = 20 mm

Live load = 4 kN/m^2

Surface finish = 1.2 kN/m^2

Q-48: A batch of concrete consists of the following ingredients:

Ingredients	Batch Mass (kg)	Specific heat cal/gm/°C	Initial Temperature (°C)
Cement	86	0.27	44
Sand	320	0.25	26.0
Coarse Aggregate	1498	0.23	4.2
Water	35	1.00	1.8
Free Moisture in Sand (3%)	9.0	1.00	26.0
Free Moisture in Coarse Aggregate (1%)	14.5	1.00	4.2
Ice	X	0.50	–4.0

If the desired placement temperature is 11°C and concrete gains 4°C after cooling has occurred, find the quantity of ice to be added for the given set of materials. [10 Marks, ESE-2024]

Sol:

Placement temperature = 11°C

Temperature gain after cooling = 4°C

Temperature at which concrete should be placed = 11 – 4 = 7°C

Using heat balanced equation between weighted, specific heat, Initial temperatuer of each ingredient, amount of ice to be added and final temperature of concrete.

$W_C C_C(t_c - t) + W_S C_S(t_s - t) + W_A C_A(t_A - t) + W_{SM}(t_s - t) + W_{AM}(t_A - t) + (W_w - W_i)(t_w - t) = W_i(t - 0.5\, t_i + 80)$

where,

W_C = Mass of cement, kg,

W_S = Mass of sand, kg,

W_A = Mass of coarse aggregates, kg,

W_{SM} = Mass of free moisture in sand, kg,

W_{AM} = Mass of free moisture in coarse aggregate, kg,

W_W = Mass of mixing water that is added (including ice but not including moisture on aggregates), kg,

W_i = Mass of ice, kg,

C_C = Specific heat of cement; cal/g/°C,

C_S = Specific heat of sand, cal/g/°C,

C_A = Specific heat of coarse aggregates, cal/g/°C,

t_C = Initial temperature of cement, °C,

t_S = Initial temperature of sand, °C,

t_A = Initial temperature of coarse aggregates, °C,

t_W = Initial temperature of water, °C,

t_i = Initial temperature of ice, °C, and

t = Final temperature of concrete, °C.

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CONTENT

Q-8: ***Water (bulk modulus of elasticity = 2.2 × 10³ MPa) is flowing with a velocity of 2 m/s through an elastic pipe (modulus of elasticity = 2.1 × 10⁵ MPa) of diameter = 500 mm, thickness = 5 mm and length = 2 km. If a valve provided at the end of the pipe is closed in 2 s, what will be the rise in pressure due to the resulting water hammer?*** ***[8 Marks, IES-2016]***

Sol:

$$K = 2.2 \times 10^3 \text{ MPa.}$$
$$V = 2 \text{ m/s.}$$
$$E = 2.1 \times 10^5 \text{ MPa}$$
$$D = 0.5 \text{ m.}$$
$$t = 0.005 \text{ m.}$$
$$l = 2 \times 10^3 \text{ m.}$$
$$T = 2 \text{ s.}$$

Velocity of wave,

$$C = \sqrt{\frac{K}{\rho}} \times \frac{1}{\sqrt{1+\frac{KD}{Et}}}$$

$$C = \sqrt{\frac{2.2\times10^3\times10^6}{1000}} \times \frac{1}{\sqrt{1+\frac{2.2\times10^3\times10^6\times0.5}{2.1\times10^5\times10^6\times0.005}}} \text{ m/s}$$

$$C = 1483.24 \times 0.699$$
$$C = 1036.54 \text{ m/s}$$

Critical time of closure

$$T_c = \frac{2l}{c} = \frac{2\times2\times10^3}{1036.54}$$
$$T_c = 3.86 \text{ s.}$$
$$T\ (= 2\text{ s}) < T_c\ (= 3.86\text{ s}).$$

⇒ Rise in pressure $= \rho CV \text{ N/m}^2$

$$\Delta P = 1000 \times 2 \times 1036.54 \text{ N/m}^2$$
$$\Delta P = 2073.08 \text{ kN/m}^2$$
$$\boxed{\Delta P = 2.07\times10^6 \text{ N/m}^2}$$

Q-9: ***What is the purpose of intake structure? What factors should be considered in locating an intake structure and what are the main considerations in the design of an intake structure?*** ***[8 Marks, IES-2016]***

Sol: A intake structure is constructed to withdraw water from surface sources such as lake or river at the entrance of the conduit.

Following factors should be considered in locating an intake structure:

(1) Intake must be located in purer zone of sources. Therefore it should be located at upstream of the point of discharge of sewage in the river.

(2) Intake should never be located near navigation channels so that water should not get polluted due to discharge from ships & boats.

(3) Intake should be located in deep water, away from shore line so as to draw water even drawing drier period of year.

$$447 = 205\,N_{\phi'} + 2c'\sqrt{N_{\phi'}} \qquad \text{... (4)}$$

By solving equations (3) and (4) we get

$$N_{\phi'} = 2.125 \text{ and } c'\sqrt{N_{\phi'}} = 5.6875$$

$$\Rightarrow \quad \frac{1+\sin\phi'}{1-\sin\phi'} = 2.125 \text{ and } c'\times\sqrt{2.125} = 5.6875$$

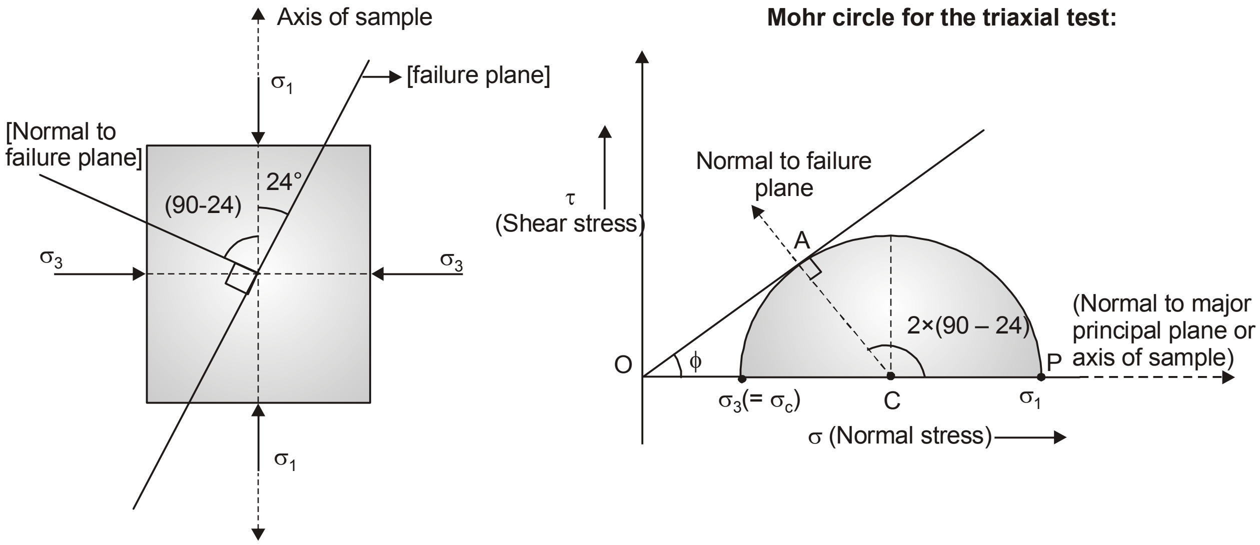
$$\Rightarrow \quad \sin\phi' = \frac{2.125-1}{2.125+1} \text{ and } c' = 3.902 \text{ kN/m}^2$$

$$\Rightarrow \quad \phi' = 21.1° \text{ and } c' = 3.902$$

Q-11: *A specimen of fine dry sand, when subjected to triaxial compression test, failed at a deviator stress of 400 kN/m². It failed with a pronounced failure plane with an angle of 24° to the axis of the sample. Compute the lateral pressure to which the specimen would have been subjected.*

[5 Marks, IES-2012]

Sol:



Specimen is of fine dry sand, thus c = 0 and failure envelope (OA) passes through origin.

It is given in the question that deviator stress = 400 kN/m²

$$\Rightarrow \quad \sigma_1 - \sigma_3 = 400 \text{ kN/m}^2 \qquad \text{... (i)}$$

In ΔOAC,

Exterior angle ACP = sum of interior and opposite angles ($\angle AOC + \angle OAC$)

$$\Rightarrow \quad 2 \times (90 - 24) = \phi + 90°$$

$$\Rightarrow \quad \phi = 42°$$

$$\sin\phi = \frac{AC}{OC}$$

$$\Rightarrow \quad \sin\phi = \frac{\frac{(\sigma_1-\sigma_3)}{2}}{\frac{(\sigma_1+\sigma_3)}{2}}, \quad [\because \text{ Stress OC corresponds to } \frac{\sigma_1+\sigma_3}{2}]$$

$$\Rightarrow \quad \frac{400}{\sigma_1+\sigma_3} = \sin(42°)$$

$$\Rightarrow \quad \sigma_1 + \sigma_3 = 597.791 \text{ kN/m}^2 \qquad \text{... (ii)}$$

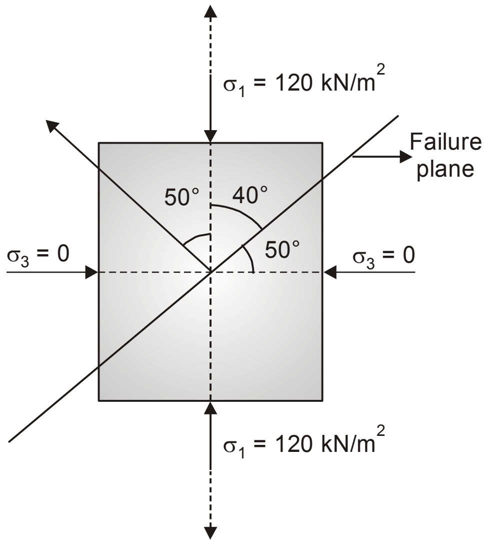
Solving equations (i) & (ii), we get

$$\sigma_3 = 98.895 \text{ kN/m}^2$$

Thus, the lateral pressure to which the specimen is subjected = 98.895 kN/m^2.

Q-12: When an unconfined compression test was conducted on a cylindrical soil sample, it failed under an axial stress of 120 kN/m^2. The failure plane makes an angle of 50º with the horizontan. Determine the cohesion and the angle of internal friction of the soil. [4 Marks, IES-2014]

Sol:



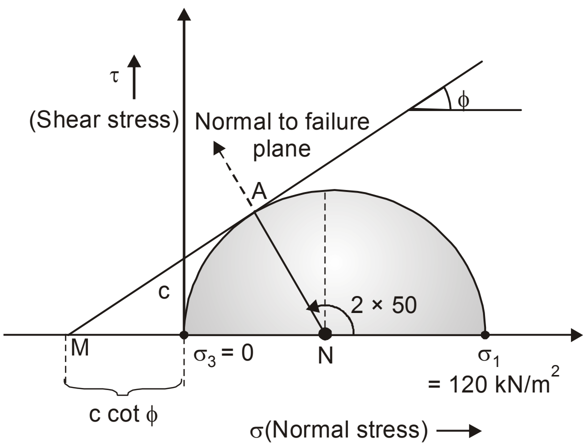


Fig. (a)

In Δ AMN,

$$\angle NAM + \angle AMN = 2 \times 50$$

$$\Rightarrow \quad 90 + \phi = 100$$

$$\Rightarrow \quad \phi = 10°$$

$\therefore$ Angle of internal friction of soil, $\phi = 10°$

In Δ AMN,

$$\sin\phi = \frac{AN}{MN} = \frac{\frac{(\sigma_1 - \sigma_3)}{2}}{c\cot\phi + \frac{(\sigma_1 + \sigma_2)}{2}} = \frac{\frac{\sigma_1}{2}}{c\cot\phi + \frac{\sigma_1}{2}}$$

$$\Rightarrow \quad \sin 10 = \frac{\frac{120}{2}}{c\cot 10° + \frac{120}{2}}$$

$$\Rightarrow \quad c\cos 10° + 60\sin 10 = 60$$

$$\Rightarrow \quad c = 50.346 \text{ kN/m}^2$$

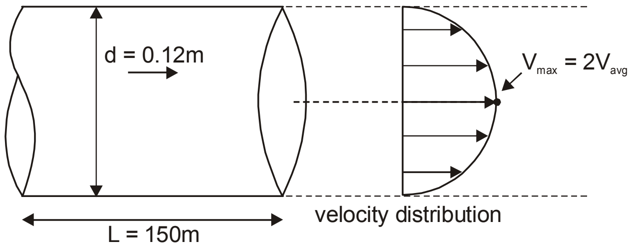
$\therefore$ Cohesion of soil, $c = 50.346 \text{ kN/m}^2$

Q-13: Determine the axial stress at failure for a dry dense sand in triaxial loading if $\sigma_3 = 300 kN/m^2$. A previous test had given $\sigma_3 = 150 kN/m^2$; $\sigma_1 = 735 kN/m^2$ at failure. [4 Marks, IES-2014]

Q-3: An oil having viscosity 0.08 Ns/m² specific weight 8829 N/m³, density 900 kg/m³ flows at the rate of 5.4 × 10⁻³ m³/s through a horizontal circular pipe of 0.12 m diameter and length 150 m. Find
(1) pressure difference in 150 m length in kN/m²
(2) wall shear stress in N/m² and
(3) average and maximum velocity. ***[4 Marks, IES-2010]***

Sol: Given,

Dynamic viscosity, (μ) = 0.08 N-s/m²
Specific weight, (γ) = 8829 N/m³
Density, (ρ) = 900 kg/m³
Discharge, (Q) = 5.4×10^{-3} m³/sec
Diameter of pipe, (d) = 0.12 m
Length of pipe (L) = 150 m



Check for the type of flow :

$$V_{avg} = \frac{Q}{A} = \frac{5.4\times10^{-3}}{\frac{\pi}{4}\times(0.12)^2} = 0.4775\ ms^{-1}$$

$$R_e = \frac{\rho V_{avg} d}{\mu} = \frac{900\times0.4775\times0.12}{0.08} = 644.625$$

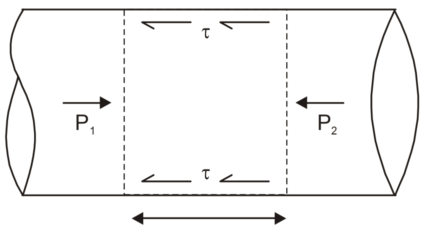
$\because R_e < 2000, \therefore$ Flow is laminar

(i) Pressure difference (in KPa)

$$\text{Pressure difference } (P_1 - P_2) = \frac{32\mu V_{avg} L}{D^2} = \frac{32\times0.08\times0.4775\times150}{(0.12)^2}$$
$$= 12733.33 \text{ Pa}$$

$\therefore$ Pressure difference = 12.733 kPa

(ii) Wall shear stress (in N/m²)



In uniform-steady state condition, net force on the element will be zero.

$$P_1\left(\frac{\pi d^2}{4}\right) - P_2\left(\frac{\pi d^2}{4}\right) = \tau(\pi dL)$$

$$\Rightarrow \quad (P_1 - P_2)\frac{\pi d^2}{4} = \tau(\pi dL)$$

$$\Rightarrow \quad 12.733\times1000\times\pi\times\frac{(0.12)^2}{4} = \tau\pi\times0.12\times150$$

$\Rightarrow$ τ = 2.547 N/m^2

$\therefore$ Wall shear stress = 2.547 N/m^2

(iii) Average and maximum velocity

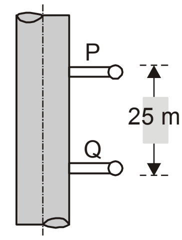
Average velocity, V_{avg} = 0.4775 ms^{-1}

For a laminar flow in a circular pipe, we know that

$$V_{max} = 2\,V_{avg} = 2 \times 0.4775 = 0.955\ ms^{-1}$$

$\therefore$ Maximum velocity, V_{max} = 0.955 ms^{-1}

Q-4: ***A 30 mm diameter vertical pipe conveys oil of dynamic viscosity of 1 poise and mass density of 0.85 gm/cc. The pressure measured at two points P and Q located 25 m apart are 1882 cm and 4706 cm. If the flow is laminar, determine the direction of the flow and the discharge.***



[8 Marks, IES-2014]

Sol: Given,

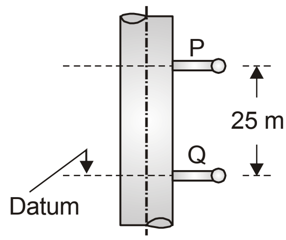
Diameter of pipe, (D) = 30 mm = 0.03 m

Dynamic viscosity of oil, (μ) = 1 poise = 0.1 N-s/m^2

Mass density, (ρ) = 0.85 gm/cc = 850 kg/m^3

Pressure head at, P = 18.82 m

Pressure head at, Q = 47.06 m



Flow takes from point of higher total energy head to the point of lower total energy head. Velocity head at both points P and Q will be same. Therefore, flow will take place from point of higher piezometric head to point of lower piezometric head.

$$\frac{P_Q}{\gamma} + Z_P = 18.82 + 25 = 43.82\ m$$

$$\frac{P_Q}{\gamma} + Z_Q = 47.06 + 0 = 47.06\ m$$

$\because$ $\left(\frac{P_Q}{\gamma} + Z_Q\right) > \left(\frac{P_P}{\gamma} + Z_P\right)$, therefore flow will be upward, i.e. from Q to P.

Applying energy equation between P and Q,

$$\frac{P_Q}{\gamma} + Z_Q + \frac{V_Q^2}{2g} = \frac{P_P}{\gamma} + Z_P + \frac{V_P^2}{2g} + h_f$$

$$47.06 + (0) = 18.82 + 25 + h_f \qquad [\because V_Q = V_P]$$

$\Rightarrow$ h_f = 3.24 m

We know that head loss in laminar flow is given as,

$$h_f = \frac{32\,\mu VL}{\gamma D^2} = \frac{128\,\mu QL}{\pi\gamma D^4}$$

$$\Rightarrow \quad \frac{128\mu QL}{\pi\gamma D^4} = 3.24$$

$$\Rightarrow \quad \frac{128 \times 0.1 \times Q \times 25}{\pi \times 850 \times 9.81 \times (0.03)^4} = 3.24$$

$\Rightarrow$ Q = 2.148 × 10^{-4} m^3/sec

$\therefore$ Discharge in the pipe = 0.2148 l/sec.

Q-6: ***Determine the correct magnetic bearings of the lines of closed traverse having the following bearings as observed:***

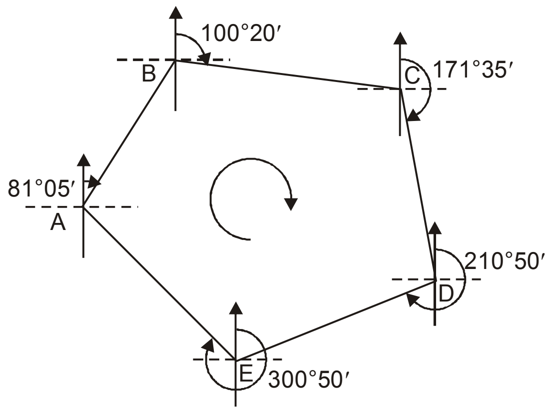
Line	***AB***	***BC***	***CD***	***DE***	***EA***
FB	***81°05'***	***100°20'***	***171°35'***	***210°50'***	***300°50'***
BB	***260°20'***	***282°35'***	***351°45'***	***30°05'***	***121°10'***

[20 Marks, IES-2020]

Sol:

Line	**FB**	**BC**
AB	81° 05′	260° 20′
BC	100° 20′	282 35′
CD	171° 35′	351° 45′
DE	210° 50′	30° 05′
EA	300° 50	121° 10′

We find that there is no line whose F.B and B.B differ exactly by180°.



Calculation of interior angle

$\angle A$ = BB of EA – FB of AB

= $121°10' - 81°05' = 40°5'$

$\angle B$ = BB of BA – FB of BC

= $260°20' - 100°20' = 160°$

$\angle C$ = BB of BC – FB of CD

= $282°35' - 171°35' = 111°$

$\angle D$ = BB of CD – FB of DE

= $351°45' - 210°50' = 140°55'$

$\angle E$ = BB of DE – FB of EA

= $30° 5' - 300°50' = -270°45' + 360°$

= $89°15'$

Sum of interior angle = $541°15'$

Theoretical sum = (2N – 4)90° = 540°

Error = $541°15' - 540 = 1°15'$

$$\text{Correction per angle} = \frac{-1°15'}{5} = -0°15'$$

Hence, corrected interior angle

$\angle A$ = $39°50'$

$\angle B$ = $159°45'$

$\angle C$ = $110°45'$

$\angle D$ = $140°\ 40'$

$\angle E$ = $89°$

The F.B and B.B of line CD differ by $180°10'$, the difference being only $10'$. Hence FB of CD is obtained by adding half the difference.

Hence corrected FB of CD = $171°35' + 5'$

= $171°40'$

and corrected BB of CD = $171°40' + 180°$

= $351°40'$

So, corrected back bearing of BC

CB = $\angle C + \text{FB of CD} = 110°45' + 171°40'$

= $282°25'$

FB of BC = $282°25' - 180° = 102°25'$

Again BA = $\angle B + BC = 159°45' + 102°25'$

= $262°10'$

FB of AB = $262°10' - 180° = 82°10'$

Again BB of EA = $\angle A + \text{FB of AB}$

= $39°50' + 82°10'$

= $122°$

So, FB of EA = $122° + 180° = 302°$

Again BB of DE = $\angle E + \text{FB of EA}$

= $89° + 302°$

= $31°$

So, FB of DE = $180° + 31° = 211°$

Again BB of CD = $\angle D + \text{FB of DE}$

= $140°40' + 211° = 351°40'$

So, corrected FB and BB are

Line	FB	BC
AB	$82°\ 10'$	$262°\ 10'$
BC	$102°\ 25'$	$282\ 25'$
CD	$171°\ 40'$	$351°\ 40'$
DE	$211°$	$31°$
EA	$302°$	$122°$