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ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-5: Production Engineering and Material Science
Strength of Materials and Mechanics-1
Fluid Mechanics and Turbo Machinery-2

Name : Rohit Kumar

Roll No : M E 1 9 M B 0 L B 6 7 6

Test Centres

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Student's Signature

Rohit

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE	
Question No.	Marks Obtained
Section-A	
Q.1	45
Q.2	43
Q.3	—
Q.4	26
Section-B	
Q.5	24
Q.6	—
Q.7	—
Q.8	40
Total Marks Obtained	178

Signature of Evaluator: SM

Cross Checked by: [illegible]

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Section A : Production Engineering and Material Science

a) Iodine has an orthorhombic unit cell for which the *a*, *b* and *c* lattice parameters are 0.479 nm, 0.725 nm and 0.978 nm, respectively.

(i) If the atomic packing factor and atomic radius are 0.547 and 0.177 nm, respectively. Determine the number of atoms in each unit cell.

(ii) What will be the density of Iodine, if atomic weight of Iodine is 126.9 g/mol?

[12 marks]

$$APF = \frac{\text{No of atom} \times \text{Volume of one atom}}{\text{Volume of atomic cell}}$$

$$0.547 = \frac{n \times \frac{4}{3} \times \pi \times 0.177^3}{0.479 \times 0.725 \times 0.978}$$

$$n = 7.998$$

$$\Rightarrow \boxed{n \simeq 8} \quad \text{Ans}$$

10^{-9}

(ii) $$\text{Density} = \frac{\text{No of atom} \times \text{wt. of an atom}}{6.023 \times 10^{23} \times \text{vol of unit cell}}$$

$$= \frac{8 \times 126.9 \times 10^{21}}{6.023 \times 10^{23} \times 0.479 \times 0.725 \times 0.978}$$

$$\boxed{\rho_{Iodine} = 4.9628 \text{ g/cm}^3}$$

(12)

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Q.1 (b) A 20 mm deep slot is to be cut through a workpiece of 150 mm length with the help of HSS side and face cutter whose diameter is 120 mm and has 10 teeth. The cutting speed is 40 m/min and feed is 0.20 mm per teeth. Calculate the time required to machine the slot.

[12 marks]

Necessary approach $= \sqrt{d(D-d)}$

$= \sqrt{20(120-20)}$

$= 44.72$ mm.

Length to be machined $= 150 + 44.72$

$= 194.72$ mm.

Milling feed is given by $= f_t Z N$

where Z is no of teeth

~~$f_m = 0.20$~~

$V = \frac{\pi D N}{1000} \Rightarrow 40 = \frac{\pi \times 120 \times N}{1000}$

⇒ N = 106.103 rpm.

f_m = 0.2 × 10 × 106.103.
= 212.206 mm/min.

Maching time, $t_m = \frac{194.72}{212.206}$

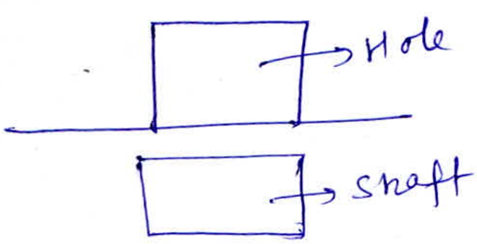
t_m = 0.9175 min

or t_m = 55.055 sec

(12)

(c) Design general type GO and NO GO gauges for components having $25H_8f_9$ fit. The basic size falls in the diameter range of 18 – 30 mm. The fundamental deviation for '*f*' shaft = $(-5.5D^{0.41})$ microns. Take gauge tolerance as 10% of work tolerance. Sketch the gauges with important values. The multipliers for 8 and 9 grades are 25 and 40 respectively.

[12 marks]



Mean Dia = $\sqrt{D_1 D_2}$ = 23.238 mm.

$i = 0.001D + 0.45\sqrt[3]{D}$.
$= 0.001 \times 23.238 + 0.45 \times \sqrt[3]{23.238}$
= 1.307 μm.

Tolerance on hole = 25 i = 32.684 μm.
Tolerance on shaft = 40 i = 52.295 μm.

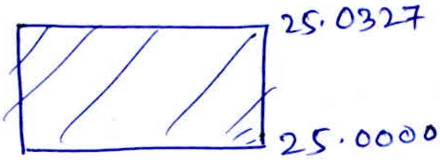
Fundamental deviation of shaft = $-5.5 \times 23.238^{0.41}$
= −19.976 μm.

∴ UL of Hole = 25.0327 mm
LL of Hole = 25 mm.

U·L of shaft = 24.980 mm
L·L of shaft = 24.927 mm.

∴ ~~GO GUAGE → for~~

For hole → (Plug guage is designed).



Guage tolerance = $\frac{10}{100} \times 32.684$.

= 3.2684 μm.

Dimension of GO-Guage = $25.0327 - \frac{3.2684}{1000}$

= 25.029 mm.

Dimension of NO GO Guage.

= $25.000 + \frac{3.2684}{1000}$.

= 25.00326 mm.

Incomplete

For shaft gauges ? ?

09

d) What do you understand by fatigue? What are different stages of fatigue failure? What are factors which are necessary for fatigue failure?

[12 marks]

Fatigue → Time dependent failure of an material is termed as fatigue.

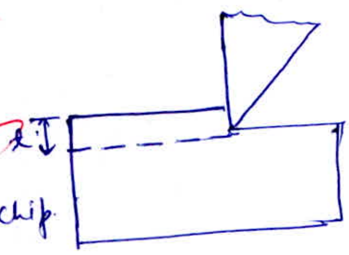
Q.1 (e) While machining steel with zero rake angle, prove the following expression:

$$\frac{\tau_s}{p_c} = \frac{r(1-\mu r)}{1+r^2}$$

where τ_s is shear strength of material, p_c is specific cutting power and r is chip thickness ratio $\left(\frac{t_1}{t_2}\right)$.

[12 marks]

$P_c = \frac{F_c}{bt} = \frac{F_c}{fd}$ — (1)



where t = thickness of uncut chip.
b = width
f = feed of cut
d = depth of cut.

and $\tau_s = \frac{F_s}{A_s}$

Area of shear is given by $\frac{bt}{\sin\phi}$

$\tau_s = \frac{F_s \sin\phi}{bt}$ — (2)

∴ using (1) and (2)

$\frac{\tau_s}{P_c} = \frac{F_s \sin\phi}{bt} \times \frac{bt}{F_c}$

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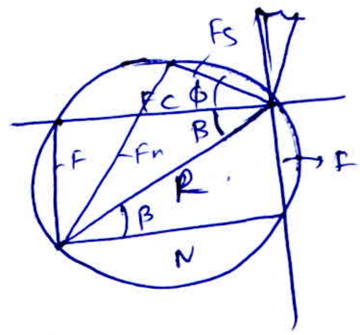
$\Rightarrow \frac{\tau_s}{P_c} = \frac{F_s \sin\phi}{F_c}$



From Merchant circle

$F_s = R\cos(\beta+\phi)$

an $F_c = R\cos\beta$.

Putting F_s & F_c in above eqn.

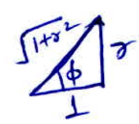
$\Rightarrow \frac{\tau_s}{P_c} = \frac{\cos(\beta+\phi)\sin\phi}{\cos\beta}$

Using Merchant analysis

$\Rightarrow \frac{\tau_s}{P_c} = \frac{(\cos\beta\cos\phi - \sin\beta\sin\phi)\sin\phi}{\cos\beta}$

$\frac{\tau_s}{P_c} = (\cos\phi - \tan\beta\sin\phi)\sin\phi$.

For zero rake angle $\tan\phi = r$



$\cos\phi = \frac{1}{\sqrt{1+r^2}}$

$\sin\phi = \frac{r}{\sqrt{1+r^2}}$

Using value of $\sin\phi$ and $\cos\phi$ and $\mu = \tan\beta$

$\frac{\tau_s}{P_c} = \frac{r}{1+r^2} - \mu\frac{r^2}{1+r^2}$

$$\Rightarrow \boxed{\frac{\tau_s}{P_c} = \frac{r(1-\mu r)}{1+r^2}}$$

Proved

12

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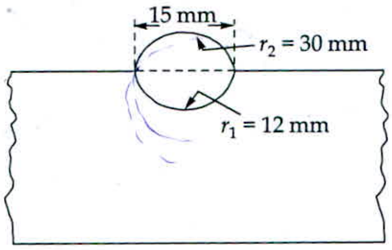
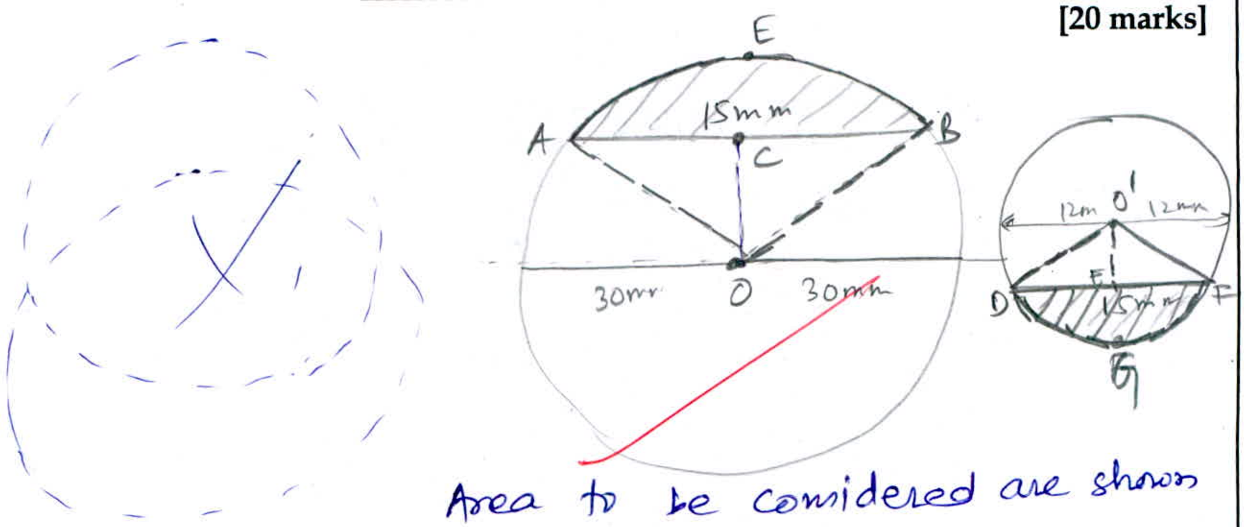
Q.2 (a) The cross-section of weld bead is shown in figure. The profile of the bead and the fusion zone are taken circular for convenience. Bead width and radii of curvature of circular profiles are shown in figure. What is percentage dilution?



[20 marks]



Area to be considered are shown by shaded line.

Area (AEB) represents reinforcement.

ad Area (DEF) represents penetration.

In Δ AOC

~~∠AOC~~ $OC = \sqrt{30^2 - 7.5^2} = 29.047$ mm

$\angle AOC = \tan^{-1}\left(\frac{AC}{OC}\right) = 14.4775^\circ$

$\angle AOB = 2\angle AOC = 28.955^\circ$

Area of shaded portion = Area of sector (OAEB) − Area of Δ AOB

$= \pi \times 30^2 \times \frac{28.955}{360} - \frac{1}{2} \times 15 \times 29.047$

$= 9.5597\ mm^2$

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In $\Delta O'DF$

$O'E = \sqrt{12^2 - 7.5^2} = 9.3675$ mm.

$\angle DOE = \tan^{-1}\left(\frac{7.5}{9.3675}\right)$

$\angle DOE = 38.682^\circ$

$\therefore \angle DO'F = 2 \times \angle DOE = 77.364^\circ$

Area of shaded portion (ie DEF).

Area of sector (ODGF) − Area of $\Delta O'DF$

$= \pi \times 12^2 \times \frac{77.364}{360} - \frac{1}{2} \times 15 \times 9.3675$

$= 26.9622\ mm^2$.

~~% dilution = $\frac{A_R}{A_R + A_R}$~~

$\%\ \text{dilution} = \frac{A_p}{A_p + A_R} \times 100$

$= \frac{26.9622}{26.9622 + 9.5597} \times 100$

$= 0.7382 \times 100$

$\therefore$ **% dilution = 73.82%** Ans.

20

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(b) What are linear defects in crystal? Describe different types of linear defects.

[20 marks]

~~There are four types of linear defects in crystal.~~

~~(i) Grain Boundary~~

~~(ii) Twin Boundary~~

~~(iii) Low angle tilt boundary.~~

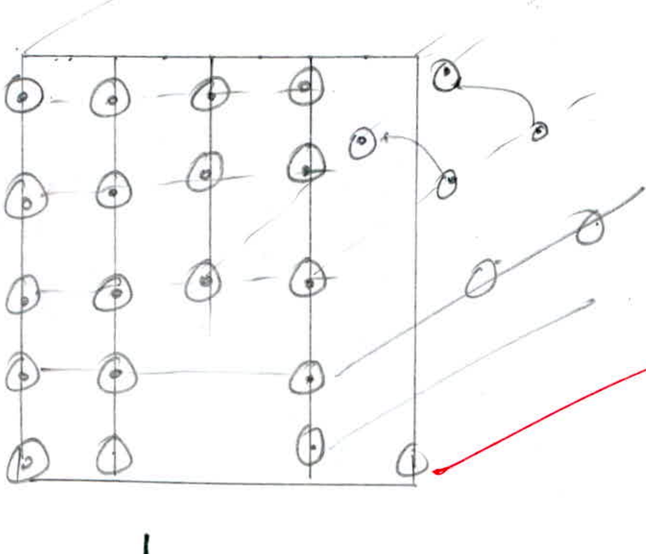
There are two types of linear defect in crystal.

(i) Edge dislocation

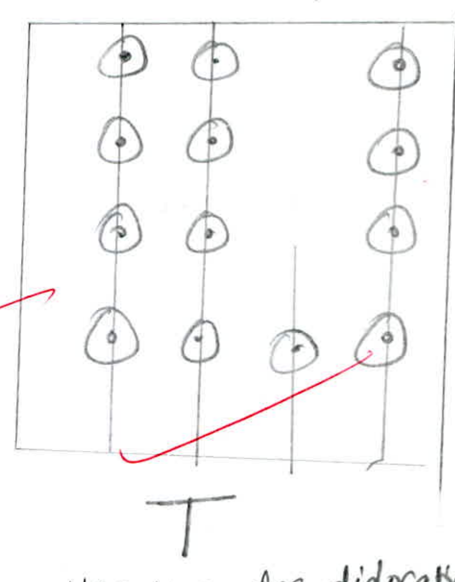
(ii) Screw dislocation.

Did not explain.

Edge dislocation → It is the boundary between slipped and unslipped portion of crystal lattice.



Positive edge dislocation



Negative edge dislocation

→ Berger vector which represents the magnitude and direction of dislocation is perpendicular to the dislocation line

→ It represents the bulk ~~movemen~~ mass movement.

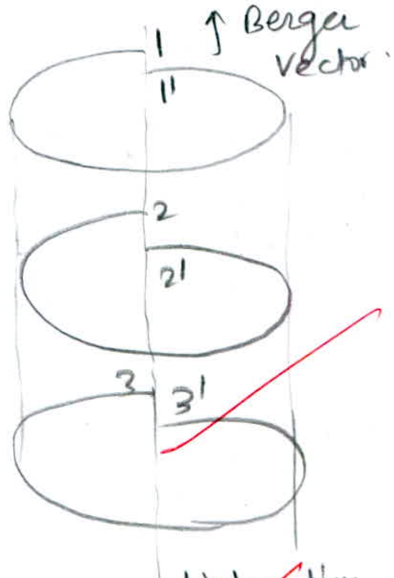
There are two types of motion of ~~atoms~~ parallel

(i) Climb motion → It represent the movement of atom in a plane perpendicular to the dislocation line. It is multiplanar movement and it generally occur at higher temperature in screw dislocation

(ii) Glide motion → It represents the movement of atom in same plane. It contributes in the bulk motion at lower temperature

Easier the movement of dislocation, more the ductility of material.

Screw dislocation → When a shear stress is applied in polycrystalline material, different plane slips in helical manner resulting in screw dislocation.



screw dislocation

→ For screw dislocation, Burger vector is perpendicular to the dislocation. parallel

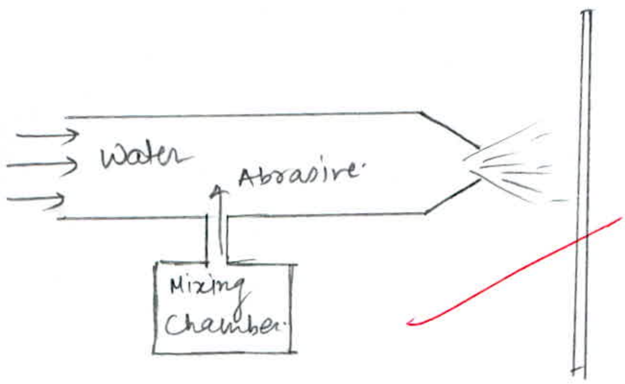
→ It contributes the bulk motion of atoms at higher temperature.

add few things about mixed dislocations

07

(c) Explain the principle of abrasive water-jet machining using suitable schematic diagram. Write the advantages and applications of AWJM.

[20 marks]



→ make proper diagram refer solution

Principle of Abrasive water jet machining.

In abrasive water jet machining, the removal of material takes place due to erosive action of abrasive particle.

Abrasive is carried by high speed water jet and when this high speed jet strikes the workpiece, abrasive particle removes the material by ~~abr~~ erosion.

Abrasive particle generally used is SiC, Al_2O_3.

It is used for ~~maching~~ machining of non conducting material which can't be machined using EDM or ECM.

Nozzle which carries the high speed water jet is generally made of tungesten carbide or Sapphire.

Material removal rate depends of nozzle tip off distance and ratio of abrasive particle to water. As nozzle tip off distance increases MRR increases, then stabilises after that decreases

Advantages of water jet Machining :-

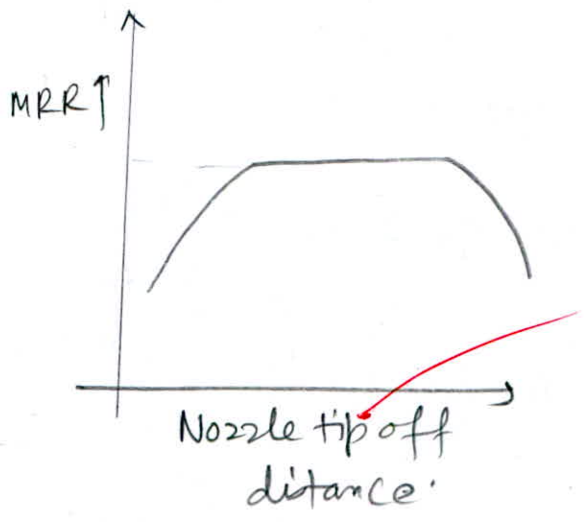
(i) Simple construction, cheap.

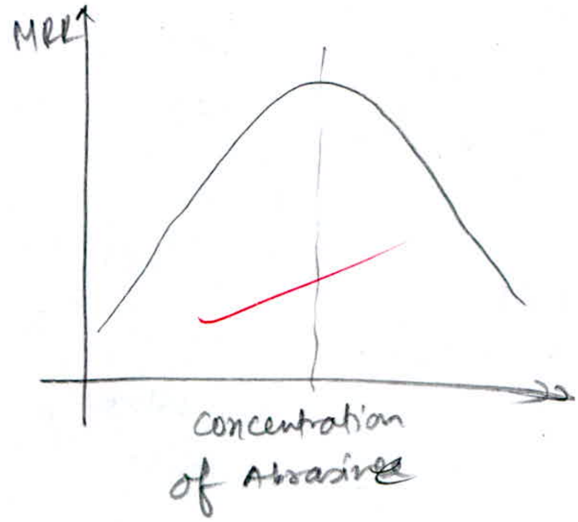
(ii) Non conducting material can be machined easily

(iii) Brittle material like glass and ceramics can be easily machined.

iv) No HAZ v) No tool wear

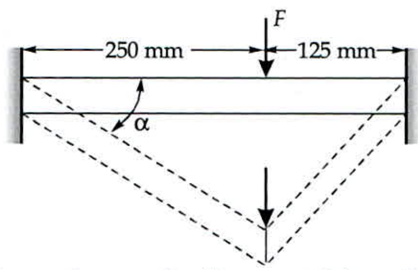
Application → Deburring of glass
Cutting of ceramics, tungsten, glass.





16

(a) A 375 mm long sheet with a cross-sectional area of 5×10^{-4} m^2 is stretched with a force, F, until $\alpha = 20°$. The material has a true stress-true strain relationship as, $\sigma = (700 \text{ MPa})\epsilon^{0.3}$. Calculate:



(i) The total workdone, ignoring end effects and bending.

(ii) What is α_{max} before necking begins?

[20 marks]

Q.3 (b) Sketch the setup for spot welding and also explain about spot welding in detail. Show the pressure v/s time graph for different phases. Explain how melting efficiency is calculated? Write down major drawbacks of spot welding process and also write down process parameters for spot welding.

[20 marks]

Q.3 (c) For the lead-tin alloy 40 wt% Sn and 60 wt% Pb at 150°C. Assume that 10 wt% Sn is fully soluble in Pb at 150°C and 2 wt% Pb is fully soluble in Sn at 150°C. At 150°C densities of Pb and Sn are 11.23 g/cm^3 and 7.24 g/cm^3 respectively. Calculate the relative amount of α and β phase present in terms of (i) mass fraction and (ii) volume fraction. Also draw Pb-Sn phase diagram.

[20 marks]

(ii) Nitriding → It involves diffusing of Nitrogen atom into the component by circulating NH_3. Since the nitride are very hard, it doesn't require further heat treatment. It is generally used with Aluminium, Vanadium, Chromium which forms very hard nitride surface when reacts with nitrogen.

(iii) Cyaniding → Component to be hardened is kept in molten bath of cyanide such as Sodium cyanide. This leads to diffusion of both Carbon and nitrogen atom. This method is quicker than above two.

mention the temperature range

(iv) Flame hardening → In this method, material to be hardened is heated with gas torch and then water is applied to the heat surface so that it is hardened up to the depth at which heat has penetrated. It is used for lathe bed and crankshaft.

(v) Induction Hardening → This is the quickest method of hardening and is generally used for medium carbon steel. When the component is kept near the transformer, a secondary current is induced into it due to which it gets heated. This method is used for hardening of connecting rods.

+ (camshaft)

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4 (c) During turning a steel rod of 180 mm diameter by a carbide tool of geometry 0°, –12°, 7°, 5°, 30°, 60°, 0 (mm) at a speed of 600 rpm, feed of 0.32 mm/rev and 4 mm depth of cut, the following observations were made:

Tangential component of the cutting force, $F_z = 1000$ N

Radial component of the cutting force, $F_y = 200$ N

Chip thickness (after cut), $t_2 = 0.8$ mm

For the above machining conditions, determine:

(i) Friction force, *F* and normal force, N acting at the chip-tool interface.

(ii) Yield shear strength of the work material under this machining condition.

(iii) Cutting power consumption in kW.

[20 marks]

Given

Rake angle $\alpha = -12°$.

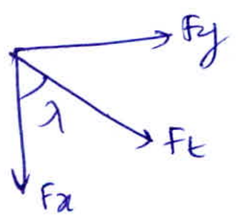
speed, $N = 600$ rpm

feed, $f = 0.32$ mm/rev.

depth of cut, $d = 4$ mm.

From the nomenclature, $\lambda = 60°$

where λ is principal cutting edge.



Thurst force F_t is given by

$$F_t = \frac{F_y}{\sin\lambda}$$

$$\Rightarrow F_t = \frac{200}{\sin 60°} = 230.94 \text{ N}.$$

cos 30°

as cutting force, $F_c = 1000$ N.

(F → Friction force)

(i.) $F = F_c \sin\alpha + F_T \cos\alpha$

$= 1000 \sin(-12°) + 230.94 \cos(-12°)$

$= 17.98$ N.

$N = F_c \cos\alpha - F_T \sin\alpha$.

$= 1000 \cos(-12) - 230.94 \sin(-12)$

$= 1026.1627$ N.

(ii) Chip thickness ⇒ $t = f\sin\lambda$

$= 0.277$ mm

$r = \frac{t}{t_c} = 0.3464$.

shear angle, ϕ is given by

$\tan\phi = \frac{r\cos\alpha}{1-r\sin\alpha} = \frac{0.3464\cos(-12°)}{1-0.3464\sin(-12°)}$

$\boxed{\phi = 17.54°}$

Shear force F_s is given by $F_s = F_C\cos\phi - F_T\sin\phi$

$F_s = 1000\cos(17.54) - 230.94\sin(17.54)$.

$F_s = 883.91$ N.

Yield shear strength, τ_s

$\tau_s = \frac{F_s}{A_s} = \frac{F_s\sin\phi}{bt} = \frac{883.91\sin 17.54}{0.32\times4}$

[Using $bt = fd$]

$\boxed{\tau_s = 208.113\ N/mm^2}$

(iii) Cutting speed $V = \frac{\pi DN}{60} = \frac{\pi\times0.18\times600}{60}$

$V = 5.654$ m/s.

Cutting power $= F_C\cdot V$.

$= 1000\times5.654$.

$= 5654.866$ W

$\therefore$ $\boxed{P = 5.654\ kW}$ Ans.

07

(Procedure is correct)

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Section B : SOM & Mechanics - 1, Fluid Mechanics and Turbo Machinery - 2

(a) The velocity field of a flow is described by $\vec{V} = (4x)\vec{i} + (5y+3)\vec{j} + (3t^2)\vec{k}$. What is the pathline of a particle at a location (1 m, 2 m, 4 m) at time $t = 1$s?

[12 marks]

we know that

Velocity $= \frac{d\vec{s}}{dt}$ (where s is position vector).

for x direction ⇒ $u_x = \frac{\partial x}{\partial t}$

$4x = \frac{dx}{dt}$ ⇒ $dt = \frac{dx}{4x}$

integrating the above eqn.

⇒ $\int_0^t dt = \frac{1}{4} \ln x + c$

⇒ $t = \frac{1}{4} \ln x + c$

at $t = 1$, and $x = 1$.

$c = 1$.

⇒ $\ln x = 4(t-1)$

⇒ $x = e^{4(t-1)}$

For y-direction $v = \frac{\partial y}{\partial t}$

⇒ $(5y+3) = \frac{\partial y}{\partial t}$ → integrating eqn.

⇒ $t = \ln(5y+3) + c$

at $t = 1$ sec and $y = 2$.

⇒ $1 = \ln(10+3) + c$

⇒ $c = -1.565$ ⇒ $t + 1.565 = \ln 5y + 3$

$y = (e^{t+1.565} - 3)\frac{1}{5}$ ⇒ $\boxed{y = \frac{1}{5}(4.78e^{t} - 3)}$

In z-direction

$\frac{\partial z}{\partial t} = 3t^2$

⇒ $z = t^3 + c$

⇒ At $z = 4m$ at $t = 1 sec$

$4 = 1 + c$ ⇒ $c = 3$

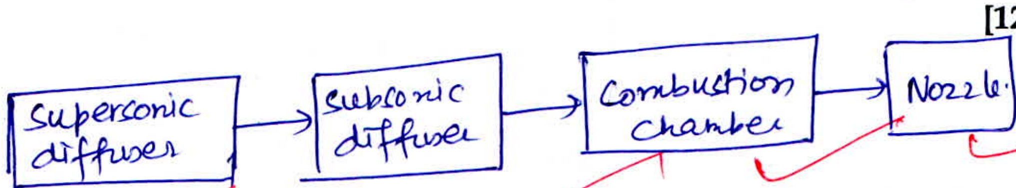
$\boxed{z = t^3 + 3}$

$\therefore (x, y, z) = [e^{4(t-1)}, \frac{1}{5}(4.78e^{t} - 3), t^3 + 3]$.

(6) eliminate t and write in x, y, z.

Q.5 (b) With the aid of a neat diagram, explain the working principle of a Ramjet engine. Also write its advantages.

[12 marks]



Ramjet Engine

construction and working → It consist of supersonic diffuser and subsonic diffuser in which kinetic energy of air gets converted into static pressure or ram air. The rammed air is passed into combustion chamber where due to combustion temperature and pressure of air increases. When this air is expanded in nozzle it creates a thrust.

It is similar to turboengine but without a turbine and compressor. It doesn't need a compressor for compressing the air

It creates thrust from the forward motion of engine only. It cannot start of its own.

Advantage:-

① It does not containe moving parts ~~like~~ like compressor and turbine so it is cheap.

② It is lighter in construction.

③ At higher Mach no of 2-3 it is economical.

Disadvantage:-

① Fuel consumption at lower Mach no is very high.

② It can't start of its own from static condition.

(69)

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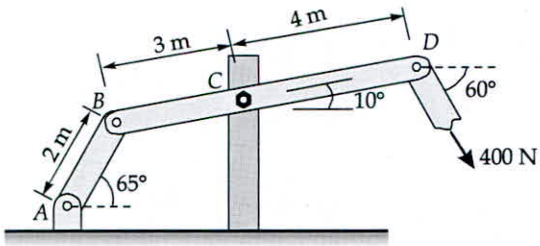
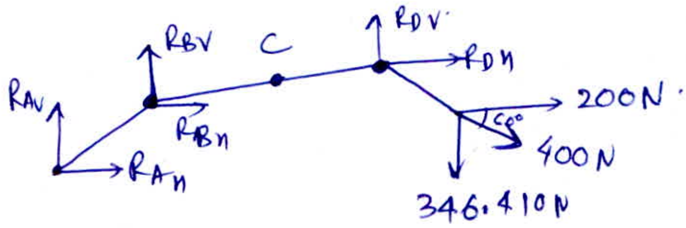
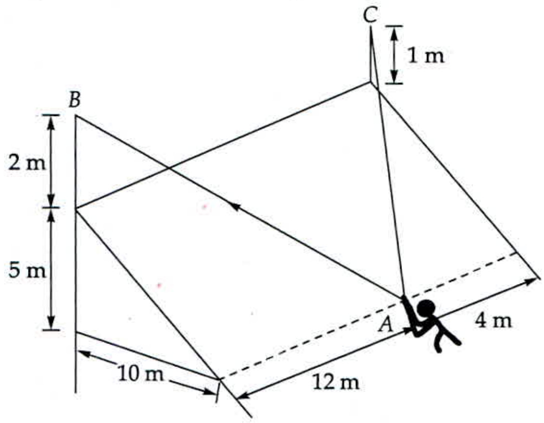
Q.5 (c) Member BD is hinged to a fixed support with the help of a bolt of diameter 2 cm. Member BD is 10 cm wide and 5 cm thick. Determine the shear stress in the bolt and bearing stress at *C* in member *BD*.



[12 marks]



(d) In trying to move across a slippery icy surface, a 75 kg man uses two ropes, *AB* and *AC*. Knowing that the force exerted on the man by the icy surface is perpendicular to the icy surface, determine the tension in each rope.



[12 marks]

Q.5 (e) (i) Allowable stress is determined from ultimate strength after considering factor of safety. State the rationale behind considering factor of safety.

(ii) The principal strains at a point loaded biaxially in a strained material are $\epsilon_1 = +500 \times 10^{-6}$, $\epsilon_2 = +300 \times 10^{-6}$. If $E = 200$ kN/mm², $\nu = 0.3$, what are principal stresses?

[6 + 6 marks]

(ii) Principal stress is given by

~~$\sigma_1 = \frac{E}{1+\mu}$~~ $\quad \boxed{\sigma_1 = \frac{E}{1-\mu^2}(\epsilon_1 + \mu\epsilon_2)}$

Using above eqn.

$$\sigma_1 = \frac{200 \times 10^3 \times 10^{-6}}{1-0.3^2}(500 + 0.3 \times 300)$$

$$\boxed{\sigma_1 = 129.67 \text{ MPa}}$$

$$\sigma_2 = \frac{E}{1-\mu^2}(\epsilon_2 + \mu\epsilon_1)$$

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$$\sigma_2 = \frac{200\times10^3\times10^{-6}}{1-0.3^2}(300+0.3\times500).$$

$$\boxed{\sigma_2 = 98.9\text{ MPa}}$$

6

) Factor of safety is considered because whatever equation we derive in strength of Material is developed under certain assumptions like.

(a) Material is considered as homogenous and isotropic

(b) stress concentration is neglected.

(c) self weight is neglected.

(d) Member is considered to be prismatic

(e) Load is considered to be static.

However in actual practice, these conditions are not satisfied, so we have to take a factor of safety to account for these.

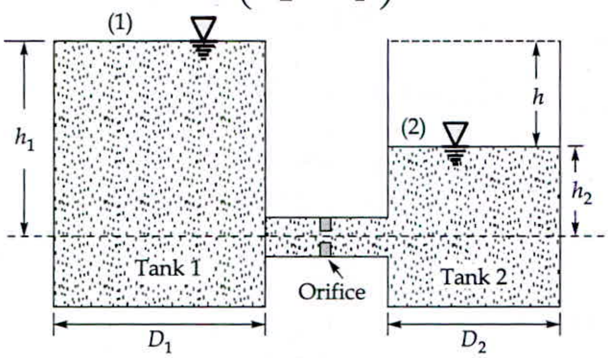
3

6+3 = 09

8

Q.6 (a) A system that consists of two interconnected cylindrical tanks with diameter D_1 and diameter D_2 is to be used to determine the discharge coefficient of a short diameter (D_0) orifice. At the beginning ($t = 0$ second), the fluid heights in the tanks are (h_1) and (h_2) as shown in figure. If it takes 't_f' second for the fluid levels in the two tanks to equalize and the flow to stop, then show that the discharge coefficient (C_d) of the orifice is:

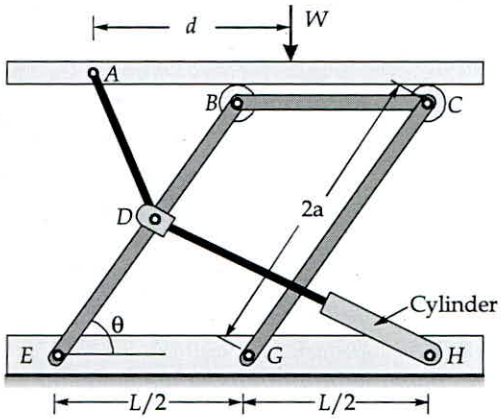
$$C_d = \frac{2\sqrt{(h_1 - h_2)}}{\left(\frac{D_0^2}{D_2^2} + \frac{D_0^2}{D_1^2}\right) \times t_f \times \sqrt{2g}}$$



Assume that the fluid is incompressible, and losses other than that associated with flow through the orifice are negligible.

[20 marks]

(b) A hydraulic lift table is used to raise a 1000 kg crate. Member *EB* and *GC* are equal. Cylinder apply force in the direction *DH*. *D* is at mid point of *EB*. Determine the force exerted by the cylinder in raising the crate for $\theta = 60°$, $a = 0.7$ m, $L = 3.2$ m and $d = 1$ m.



[20 marks]

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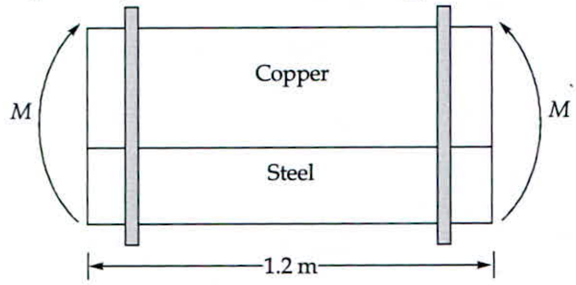
(c) A helicopter gas turbine requires an overall compressor pressure ratio of 12 : 1. This is to be obtained using a two-spool layout consisting of a four stage axial compressor followed by a single stage centrifugal compressor. The polytropic efficiency of the axial compressor is 92% and that of the centrifugal compressor is 83%. The axial compressor is having a stage temperature rise of 32 K, using a 50 percent reaction design with a stator outlet angle of 25°. If mean diameter of each stage is 25.0 cm and each stage is identical, calculate the required rotational speed. Assume a work done factor of 0.85 and a constant axial velocity of 160 m/s.

Assuming an axial velocity at the eye of the impeller, an impeller diameter of 35.0 cm, a slip factor of 0.92 and power input factor of 1.04, calculate the rotational speed required for the centrifugal compressor. Ambient conditions are 1.01 bar and 288 K. Take $c_p = 1.005$ kJ/kgK and $\gamma = 1.4$.

[20 marks]

Q.7 (a) Two beams are clamped together as shown in figure:



Both are of equal length and both have 5 cm width. Height of copper beam is 10 cm and that of steel beam is 6 cm. What could maximum moment that can be allowed without any failure of $E_{Cu} = 120$ GPa, $(\sigma_{allowable})_{Cu} = 150$ MPa, $E_{St} = 200$ GPa and $(\sigma_{allowable})_{St} = 250$ MPa?

[20 marks]

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Q.7 (b) **(i)** For a multi-stage steam turbine having same stage efficiency for all stages. Prove that, $\eta_{internal} = R.F. \times \eta_{stage}$

(ii) A 20 stage 50% reaction turbine develops a diagram power of 14 MW. The total isentropic enthalpy drop is 900 kJ/kg. The stage efficiency is 76% and the reheat factor is 1.05. The exit angle of blades is 20° and the blade velocity ratio is 0.7.

Calculate:

(p) Flow rate of steam required (in kg per hour) if all the stages develop equal work.

(q) Blade velocity

[10 + 10 marks]

Q.7 (c) Air enters a 10 m long section of a rectangular duct cross section 15 cm × 20 cm made of commercial steel at 1 atm and 35°C at an average velocity of 7 m/s. Disregarding the entrance effects. Determine the fan power needed to overcome the pressure losses in this section of the duct. Assume the flow is steady and incompressible. Consider the air properties at 1 atm and 35°C.

Density, $\rho = 1.145\ \text{kg/m}^3$

Dynamic viscosity, $\mu = 1.895 \times 10^{-5}\ \text{kg/m-s}$

kinematic viscosity, $\nu = 1.655 \times 10^{-5}\ \text{m}^2/\text{s}$

The roughness of commercial steel surfaces, $\varepsilon = 0.000045$ m.

For the friction factor, the governing equation is Colebrook equation:

$$\frac{1}{\sqrt{f}} = -2.0\log_{10}\left(\frac{\frac{\varepsilon}{D_h}}{3.7} + \frac{2.51}{\text{Re}\sqrt{f}}\right)$$

where, ε = Roughness of surface, D_h = Hydraulic diameter, Re = Reynolds number, f = Friction factor, $\frac{\varepsilon}{D_f}$ = Relative roughness

[20 marks]

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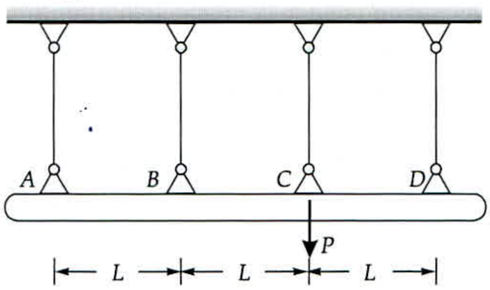
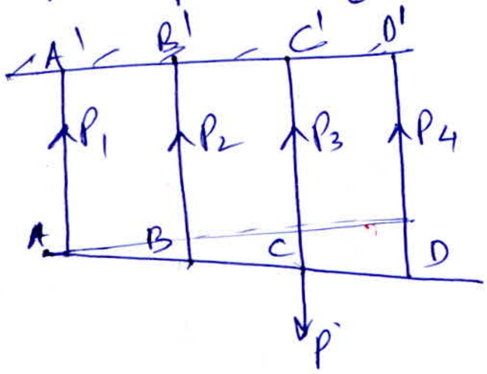
a) The rigid rod *ABCD* is hinged with the help of 4 wires of equal length and cross-section area. Determine tension in each wire if force *P* is applied at C in downward direction. All the wires have same Young's modulus.



[20 marks]

Final position of rod will be.



let the forces in wire A, B, C, D be P_1, P_2, P_3, P_4 respectively.

$$P_1 + P_2 + P_3 + P_4 = P \quad \text{— ①}$$

(From static eqm. condition)

Applying moment balance at D.

$$P_1 \times 3L + P_2 \times 2L = P \times L \Rightarrow 3P_1 + 2P_2 = P \quad \text{— ②}$$

$+P_3 \times L$

Now applying compatibility eqn.

$$\frac{\Delta_4 - \Delta_1}{3L} = \frac{\Delta_3 - \Delta_1}{2L}$$

[where $\Delta_1, \Delta_2, \Delta_3, \Delta_4$ are elongation of rod 1, 2, 3, 4 respectively].

$$\Rightarrow 2\Delta_4 - 2\Delta_1 = 3\Delta_3 - 3\Delta_1$$

$$\Rightarrow 2\Delta_4 - 3\Delta_3 = -\Delta_1$$

[Using $\Delta = \frac{PL}{AE}$].

$$\Rightarrow 2P_4 - 3P_3 = -P_1 \quad \text{— ③}$$

Also

$$\frac{\Delta_2 - \Delta_1}{L} = \frac{\Delta_3 - \Delta_1}{2L}$$

[Using similar Δ]

$$\Rightarrow 2\Delta_2 - 2\Delta_1 = \Delta_3 - \Delta_1$$

$$\Rightarrow 2P_2 - P_3 = P_1 \quad \text{— ④}$$

From ③ & ④

$$2P_4 - 3P_3 = -2P_2 + P_3$$

$$\Rightarrow 2P_4 + 2P_2 = 4P_3$$

$$\Rightarrow P_4 + P_2 = 2P_3$$

All (4) eq^ns are

$P_1 + P_2 + P_3 + P_4 = P$ — (1)

$3P_1 + 2P_2 = P$ — (2)

$2P_4 - 3P_3 = -P_1$ — (3)

$2P_2 - P_3 = P_1$ — (4)

$2P_4 + 2P_2 = 4P_3$

$P_4 + P_2 = 2P_3$ — (5)

Using (5) in (1)

$P_1 + P_3 + 2P_3 = P \Rightarrow P_1 + 3P_3 = P$

$P_1 + P_3 = 2P_2$

$2P_3 = P - 2P_2$

$P_1 + P_4 = P/2$

$P_4 = \frac{P}{2} - P_1$

$P_3 + P_2 = P/2$

$P_2 = \left[P - 3P_1\right]\frac{1}{2}$

$\Rightarrow P_3 = P - 4P_1$

$P_1 + \frac{P}{2} - \frac{3P_1}{2} + P - 4P_1 + \frac{P}{2} - P_1 = P$

$\Rightarrow \left(P_1 - \frac{3P_1}{2} - 4P_1 - P_1\right)$

5

Solving $2P = \frac{11}{2}P_1$

$\Rightarrow P_1 = \frac{4P}{11}$ Ans

$P_2 = \frac{P - \frac{3 \times 4P}{11}}{2} = -\frac{1}{22}P$

$P_3 = P - \frac{16P}{11} \Rightarrow P_3 = -\frac{5}{11}P$

$P_4 = \frac{3}{22}P$ Ans

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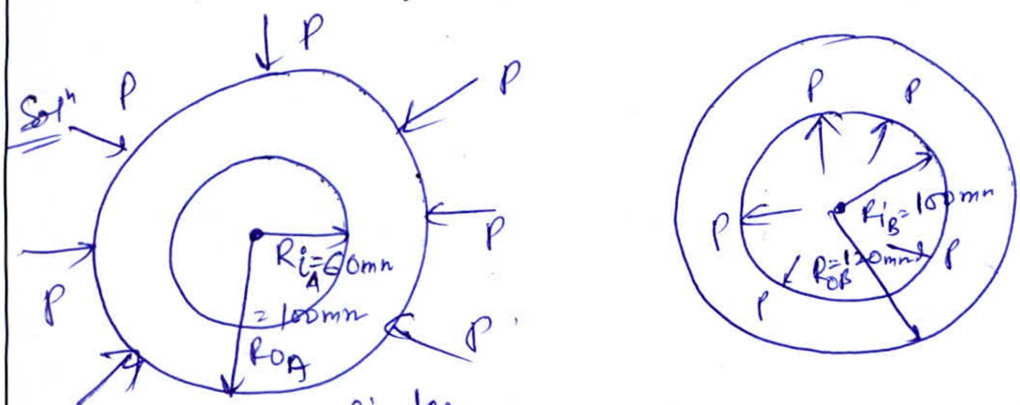
b) A compound cylinder is formed by shrinking one cylinder onto the other, the final dimensions become inner diameter of 12 cm, external diameter of 24 cm and junction diameter of 20 cm. After shrinking of outer cylinder over inner cylinder the radial pressure at common surface is 20 N/mm². Calculate the necessary difference in diameters of the two cylinders at the common surface. Take E = 200 GPa, ν = 0.3 for inner cylinder and E = 100 GPa and ν = 0.32 for outer cylinder. What is the minimum temperature through which the outer cylinder should be heated before it can be slipped on?
$\alpha = 11 \times 10^{-6}/°C$ for outer cylinder,

[20 marks]

Sol^n



Inner cylinder

Let the inner cylinder be A and outer ~~cylinder be B~~

Due to shrinkage → At inner cylinder.

Hoop pressure at outer surface of A.

$$\sigma_{h_A} = \frac{-P(R_o^2 + R_i^2)}{R_o^2 - R_i^2}$$

Radial stress at outer surface of A = $-P$ (compressive)

Circumferential strain is given by

$$\frac{d r_A}{r_{o_A}} = \frac{1}{E}\left[\sigma_{h_A} - \mu \sigma_{r_A}\right]$$

Putting the value of σ_{h_A} and σ_{r_A}

$$\Rightarrow d r_A = \frac{100}{200 \times 10^3}\left[\frac{-20(100^2 + 60^2)}{100^2 - 60^2} - 0.3 \times -20\right]$$

$$\Rightarrow d r_A = -0.01825 \text{ mm.}$$

At outer cylinder :- At Inner radius of outer cylinder.

Hoop stress $\sigma_{h_B} = \frac{P(R_{O_B}^2 + R_{O_A}^2)}{R_{O_B}^2 - R_{O_A}^2}$ (tensile)

and Radial stress $\sigma_{r_B} = -P$ (compressible)

Circumferential strain is given by

$\frac{dr_B}{r_B} = \frac{1}{E}\left[\sigma_{h_B} - \mu\sigma_{r_B}\right]$ (where dr_B is radial displacement at junction)

$\Rightarrow dr_B = \frac{100}{100\times10^3}\left[\frac{20(120^2+100^2)}{120^2-100^2} - 0.32\times(-20)\right]$

$\Rightarrow dr_B = 0.11731$ mm.

Necessary difference in radius of two cylinder at junction is given by $= |dr_A| + |dr_B|$

$= 0.1355$ mm.

$\therefore$ Difference in dia $= (2\times0.1355)$ mm

Difference in dia = 0.2711 mm

Let the temperature to which it should be heated be ΔT.

Expansion of outer cylinder (Radial) $= r\alpha\Delta T$.

$\therefore$ Expansion of outer cylinder must be equal to difference in radii for slipping.

$\Rightarrow r\alpha\Delta T = \frac{0.2711}{2}$

$\Rightarrow \Delta T = \frac{0.2711}{2\times120\times11\times10^{-6}}$

calculation error

$\Delta T = 102.696°C$

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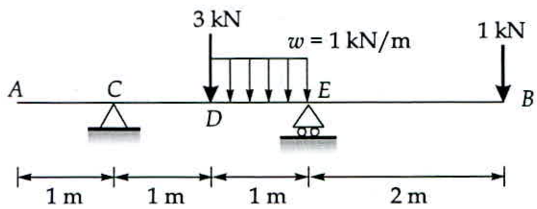
c) A beam is loaded as shown in figure. Determine the distance of point of contraflexure from point *A* and maximum moment and its location.



[20 marks]

Let the Reaction at C and E be R_C and R_E

$R_C + R_E = 5$

Taking moment at E.

$\Rightarrow R_C \times 2 + 1 \times 2 = 3 \times 1 + 1 \times 1 \times 0.5$

$\Rightarrow$ ~~$R_C = 0.758$ kN~~
~~$R_E = 3.5$ kN~~

$\Rightarrow R_C = 0.75$ kN
$R_E = 4.25$ kN

S.F calculation

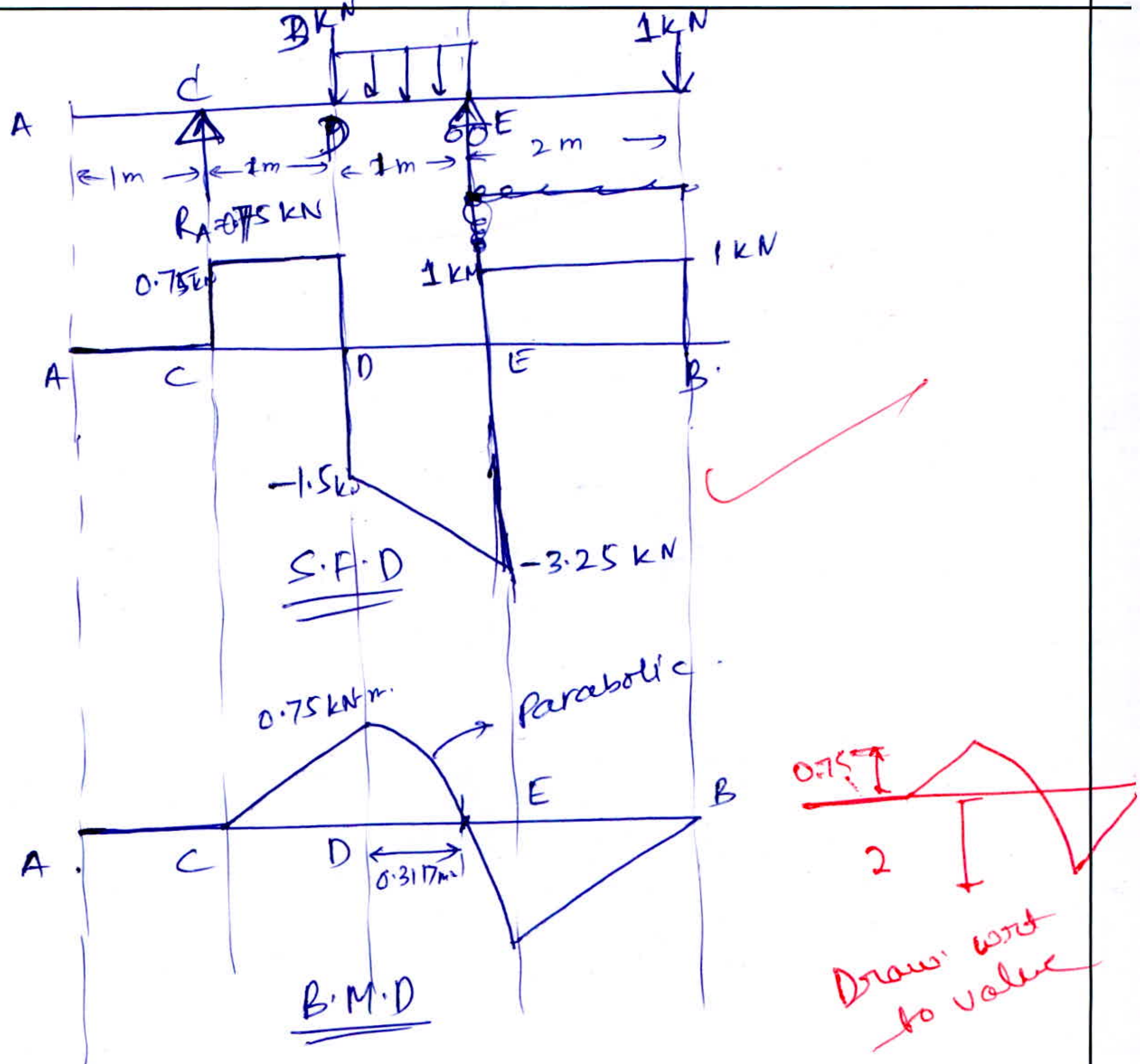
For AC $\rightarrow$ S.F = 0.

For C-D $\rightarrow$ S.F = $R_C = 0.75$ kN.

For D-E $\rightarrow$ S.F = $0.75 - 3 - wx$ [where x is from D].

$= -2.25 - x$

$\therefore$ at E $\Rightarrow x = 1$ m S.F = -3.25.



B.M.D calculation.

For CD [x from C]

$$B.M = R_C x = 0.75x$$

$$\therefore (BM)_C = 0, \quad (BM)_D = 0.75 \text{ kN-m}$$

For DE [x from D].

$$B.M = 0.75(1+x) - 3x - \frac{x^2}{2}$$

$$B.M = 0.75 - 2.25x - \frac{x^2}{2}$$

$\therefore$ Location of BM = 0.

$$0.75 - 2.25x - \frac{x^2}{2} = 0$$

$$\Rightarrow \boxed{x = 0.31173 \text{ m}}$$

Point of contraflexure from A

= 2.31173 mm

$(BM)_D = 0.75$ kN·m

$(BM)_E = -2$ kN·m.

<u>For section BE</u> (x from B)

B.M = $-1 \times x$

$\therefore (BM)_E = -2$ kN·m.

$\therefore$ Maximum B.M = -2 kN·m
Location = 3m from end A

19

■■■■

Space for Rough Work