SCHEME OF EVALUATION

(Scoring Indicators)

Revision: 2015 Course Title: Applied Mechanics and Strength of materials				Course code: 4021
Qn No.	**Scoring indicator**	**Split up score**	**Sub Total**	**Total**
	PART-A			
I 1)	Hooks law states that, when a material is loaded within its elastic limits, the stress is directly proportional to the strain produced by the stress. Mathematically, Stress α Strain. $\sigma \ \alpha \ \varepsilon$ $\frac{Stress}{Strain} = \frac{\sigma}{\varepsilon}$ = E, A constant of proportionality known as modulus of elasticity or Young's modulus.	2	2	
2)	It is the ratio of the limiting friction to the normal reaction, between two bodies and is generally denoted by μ, such that $\mu = \tan\phi = \frac{F}{R}$ $F = \mu R$ Where μ= Coefficient of friction ϕ= Angle of friction F= Maximum frictional force. R= Normal reaction between the two bodies.	2	2	
3)	Polar moment of inertia of a plane area is defined as the moment of inertia of the area about an axis perpendicular to the plane of the figure and passing through the centre of gravity of the area. It is denoted by the symbol J.	2	2	10
4)	(see table below)	(1x2)	2	

Question 4):

SL No.	CLOSELY COILED HELICAL SPRING	OPEN COILED HELICAL SPRING
1)	The spring wires are coiled very closely, each turn is nearly at right angles to the axis of helix.	The wires are coiled such that there is a gap between the two consecutive turns.
2)	Helix angle is less than 100	Helix angle is large(›100)

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<tr><th>Sl. No</th><th>Long Column</th><th>Short column</th></tr>
<tr><td>1.</td><td>Slenderness ratio is more than 120, for long columns.</td><td>Slenderness ratio is less than 32, for short columns.</td></tr>
<tr><td>2.</td><td>In long columns, failure is only due to buckling.</td><td>In short columns, failure is due to direct crushing only; bending or buckling stress plays much less important role.</td></tr>
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</td><td>(1 x 2)</td><td>2</td><td></td></tr>
<tr><td>II

1.

2.</td><td>
<u>PART-B</u>

<u>Modulus of elasticity or Young's Modulus.</u>
The ratio of tensile or compressive stress to the corresponding strain, within the elastic limit is called modulus of elasticity or Young's Modulus. The metals with high modulus of elasticity possess high stiffness i.e., minimum deflection under load. It is denoted by E.
Modulus of elasticity, $E = \frac{\sigma}{\varepsilon}$

<u>Bulk Modulus.</u>
If an elastic body is acted upon by three mutually perpendicular direct stresses of equal magnitude, then the ratio of this direct stress to the resulting volumetric strain within the elastic limit in the body is called the Bulk modulus of that body. It is denoted by K.
Bulk Modulus , $K = \frac{direct\ stress}{volumetric\ strain}$
<u>Modulus of rigidity.</u>
It is the ratio of shear stress to shear strain within the elastic limit and is denoted by G or N (or sometimes C).It is also called shear modulus.
Modulus of rigidity, $G = \frac{Shear\ Stress}{Shear\ Strain}$

$G = \tau/\phi$

Given section is symmetrical about horizontal axis but not about vertical axis. Given section can be divided in to 3 areas, viz, a_1(Semi circle), a_2 (rectangle), a_3 (triangle).
</td><td>2 x 3</td><td>6</td><td></td></tr>
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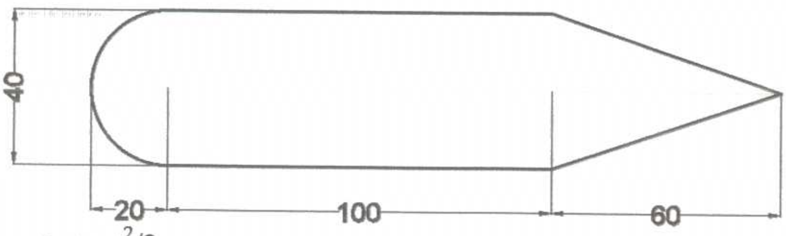


a_1 = лr^2/2
=(л x 20^2)/2 =628.3 mm^2 ; x_1 =20- (4r/3л)
=20- (4 x20/3л)
= 11.5 mm.

a_2=100 x 40= 4000 mm^2 ; x_2= 20 + 50 =70 mm.

a_3 = $\frac{1}{2}$ x40 x60 =1200mm^2 ; x_3=20+100+$\frac{60}{3}$ =140 mm

6 6

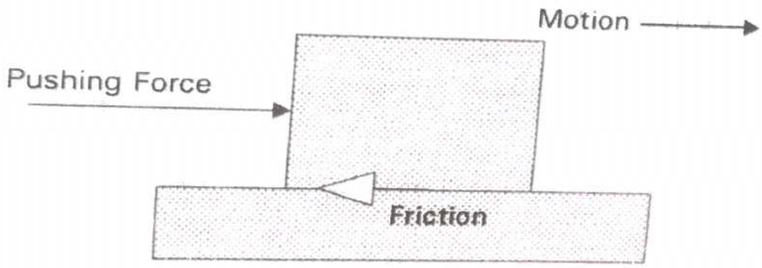
$\Sigma a_i = a_1+a_2+a_3$ = 5828 mm^2.

Moments of areas: a_1x_1 =628.3 x 11.5 = 7225 mm^3.
a_2x_2=4000 x 70 =280,000 mm^3.
a_3x_3=1200 x140 =1,68,000 mm^3.
Σa_ix_i =4,55,225 mm^3.

Position of centroid is given by $\bar{x} = \frac{\Sigma aixi}{\Sigma ai} = \frac{455225}{5828}$

=78 mm from yy vertical axis.

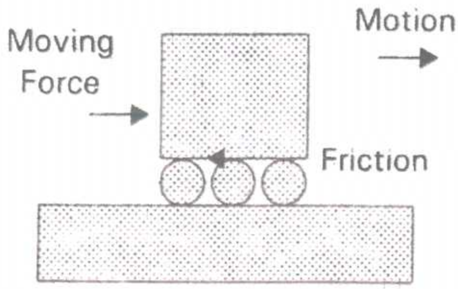
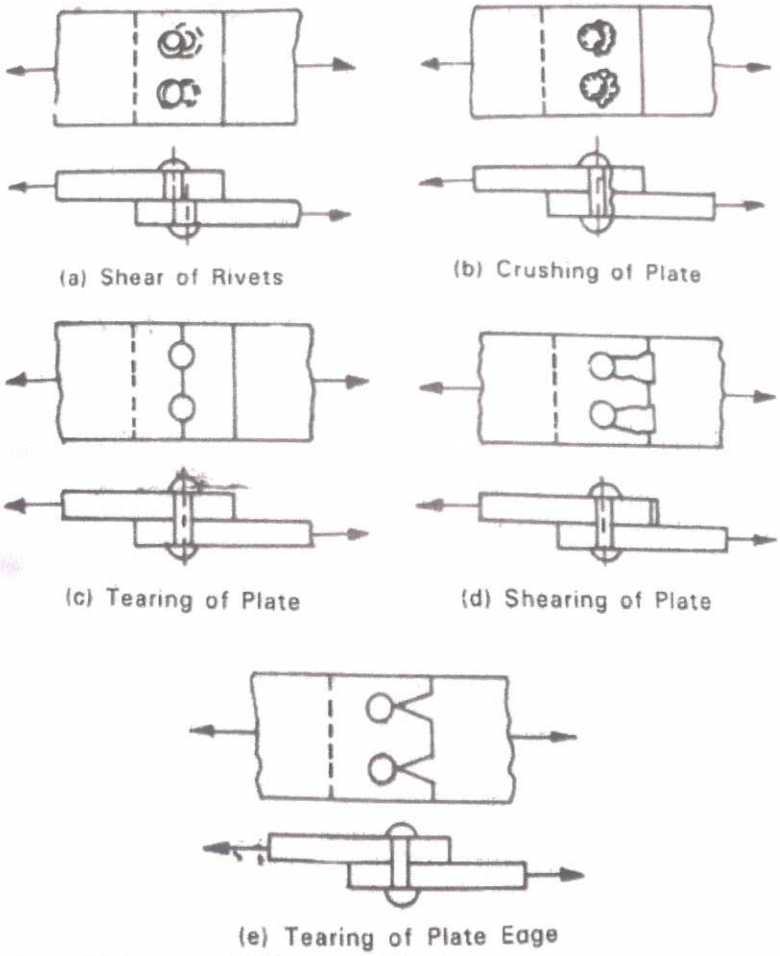
3. Sliding Friction:

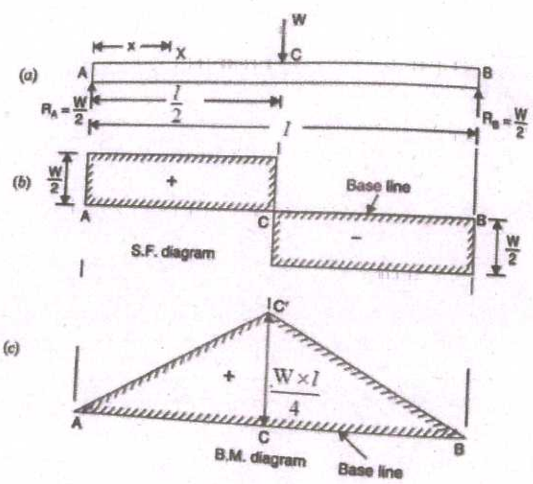


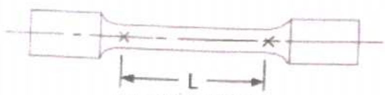
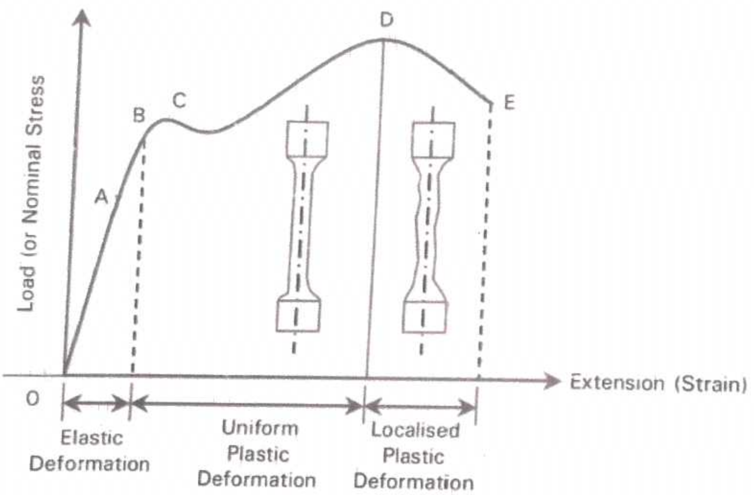
When two bodies are in contact, and one body moves on the surface of the other body by sliding on it, the force of dynamic friction that exists in between the two bodies is called sliding friction. For example, the friction existing in between the surface of a glass block and the surface of a table top when the glass block is pushed forwards. It is also known as Kinetic friction.

Rolling Friction:

When two bodies are in contact and one body rolls over the other, the force of dynamic friction that exists in between the

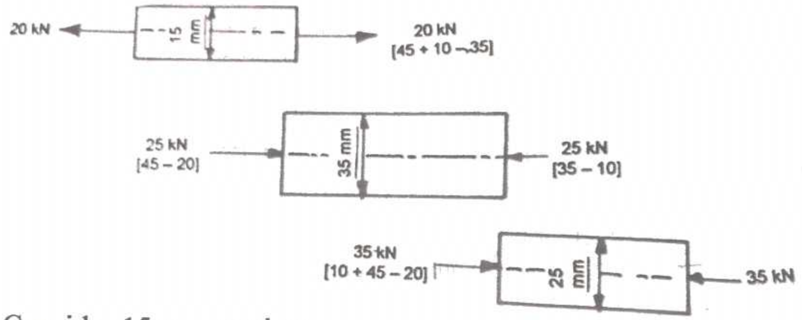
	two bodies is called rolling friction. **Rolling Friction**  Example, the friction between wheels of a vehicle and the surface of a road. Pivot Friction: It is the friction, experienced by a body, due to the motion of rotation as in case of footstep bearings.	2 x 3	6	
4.	 (a) Shear of Rivets (b) Crushing of Plate (c) Tearing of Plate (d) Shearing of Plate (e) Tearing of Plate Edge A riveted joint may fail in any of the following ways:	1.5 x 4	6	30

	(a) <u>Shearing of the rivet:</u> The rivet body is under direct shear, and if sufficient diameter is not provided, the joint will fail by the shearing of the rivet. If the rivet is sheared off at one section, then it is said to be in single shear and if it is sheared off at two sections, it is said to be in double shear. (b)<u>Crushing(or bearing) of rivet or plate:</u> The crushing or bearing is the action of a compressive force that is not uniform over the area. If the stress induced due to such forces is greater than the limiting value, crushing or bearing of the plate or rivet may takes place. (c) <u>Tearing(tensile failure) of the plates:</u> The presence of the holes for rivets decrease the strength of plates. If the resisting area of the plate is not sufficient, then the plate will be teared off at minimum cross-section i.e., section across the holes. (d)<u>Tearing of the plate between rivet hole and the edge:</u> This failure is due to insufficient distance between edge of the plate and rivet hole.			
5.	Given, d= 50 mm N= 120 RPM τ =60 N/mm^2. T= $\frac{\pi}{16}$ .d^3.τ = [π(50)^3 x60]/16 Nmm = 1471.87 Nm Power, P= $\frac{2\pi NT}{60}$ =[2πx120x1471.87]/60 = 18486.75 W= 18.486 kW	6	6	
6.		(2 x 3)	6	

7.	Assumptions made in the Eulers column theory. The following assumptions are made in the Euler's column theory: 1) The column is initially perfectly straight and the load is applied axially. 2) The cross-section of the column is uniform throughout it's length. 3) The column material is perfectly elastic, homogeneous and isotropic and obeys Hooks law. 4) The length of the column is very large as compared to its lateral dimensions. 5) The direct stress is very small as compared to the bending stress. 6) The column will fail by buckling alone. 7) The self-weight of column is negligible.	1x 6	6
III (a)	PART-C  (a) Tensile Test Specimen  (b) Stress-Strain Diagram Where A= Proportional limit. B = Elastic limit. C =Yield point. D= Ultimate strength. E = Rupture/Breaking point. The proportional limit is the maximum stress at which stress is directly proportional to the strain.	(Fig 4M + marking points 1M)	5

Elastic limit is the maximum stress at which the material regains its deformation on removing the load.
Yield point is the minimum stress at which the specimen is deformed without a noticeable increase in load i.e., strain is increased without noticeable increase in stress.
The tensile strength or ultimate tensile strength is the maximum stress that a material can withstand, without fracture, under tensile load.
Beyond the point D, deformation is concentrated at one part of the cross-section. A localised reduction of the cross-sectional area appears on the specimen, the load drops and at a certain moment, failure occurs.

b)



(Free body diagram 5M +5M Ans.) — 10

Consider 15 mm section:

Diameter, $D_1 = 15$ mm.

Area, $A_1 = \frac{\pi.(15).(15)}{4} = 176.7\ mm^2$

Stress induced $= \frac{load}{area} = (20 \times 10^3)/176.7$

$= 113.18\ N/mm^2$ (tensile)

Consider 35mm section:

Diameter, $D_2 = 35$ mm

Area, $A_2 = \frac{\pi.(35).(35)}{4} = 962.11\ mm^2$

Stress induced $= \frac{load}{area} = (25 \times 10^3)/962.11$

$= 25.98\ N/mm^2$ (compressive)

Consider 25 mm section:

Diameter, $D_3 = 25$ mm

Area, $A_3 = \frac{\pi.(25).(25)}{4} = 490.87\ mm^2$

Stress induced $= \frac{load}{area} = (35 \times 10^3)/490.87$

$= 71.3\ N/mm^2$ (compressive).

IV (a)

Weight supported, W =300 kN.
Area of cross-section of steel, $A_s = 500\ mm^2$
Area of cross-section of copper, $A_c = 2 \times 500 = 1000 mm^2$
Initial stresses in each pillar $= \frac{300 \times 1000}{3 \times 500}$

$= 200\ N/mm^2$

Let σ_s and σ_c be the stresses induced in steel and copper bars respectively. Using the relations,

	$\frac{\sigma_S}{E_S}+\frac{\sigma_C}{E_C} = t(\alpha_C-\alpha_S)$ Where t=115-15 =100^{0}C. $\frac{\sigma_s}{2\times10^5}+\frac{\sigma_c}{0.8\times10^5} = 100\ (18.5-12)\times10^{-6}$ $\frac{\sigma_s}{2}+\frac{\sigma_c}{0.8} = 65$ .... (i) Also $\sigma_s A_s = \sigma_c A_c$ $\sigma_s = \sigma_c \frac{1000}{500}$; $\sigma_s = 2\sigma_c$ .... (ii) From equations (i) and (ii) $\sigma_c = 28.89$ N/mm^2 (compressive) and $\sigma_s = 57.78$ N/mm^2 (tensile) Final stress in copper = 200 + 28.89 = **228.89 N/mm^2 (comp.) Ans.** Final stress in steel = 200 − 57.78 = **142.22 N/mm^2 (comp.) Ans.**	10	10	
(b)	Thermal stresses are the stress induced in a body due to the change in temperature. Thermal stresses are set up in a body, when the temperature of the body is raised or lowered and the body is not allowed to expand or contract freely. But if the body is allowed to expand or contract freely, no stresses will be set up in the body. If the ends of the body are fixed to rigid supports, so that it's expansion is prevented, then compressive stress and strains will be set up in the rod. These stresses and strains are known as temperature stresses and strain. Temperature strain, $\varepsilon = \alpha t$ Temperature stress, $\sigma = \alpha t E$ Where α= Coefficient of linear expansion in mm/^{0}C or mm/K. t = rise in temperature in ^{0}C or ^{0}K. E= Young's modulus in N/mm^2.	(Definition 3M +eqn. 2M)	5	60
V (a)	The maximum inclination of the plane at which a body can remain in equilibrium over the plane entirely by the assistance of friction is called the angle of repose. Figure below shows a block of weight W resting on a rough inclined plane inclined at θ with the horizontal. Let R be the normal reaction and F be the friction.			

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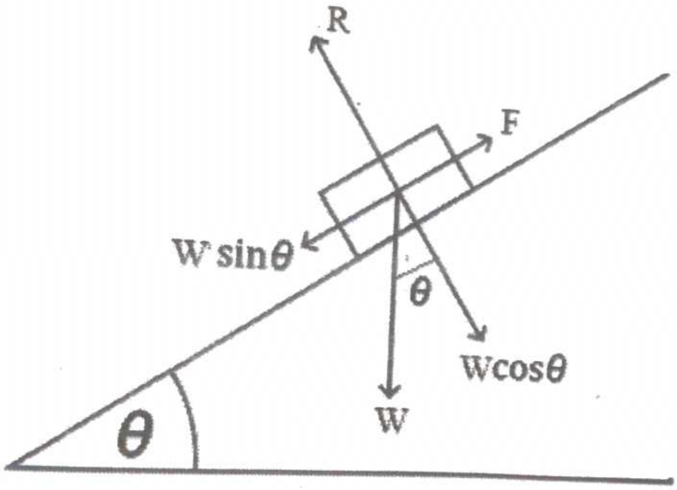
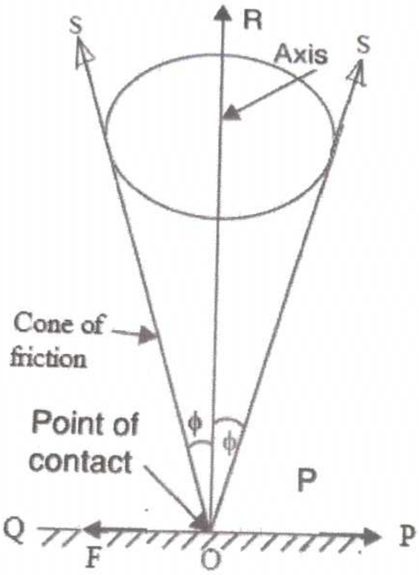


Resolving the forces along the plane,
WSin θ =F ....(i)
Resolving the forces along the normal,
WCosθ =R ....(ii)
From equations (i) and (ii) we get,
$\frac{Wsin\theta}{Wcos\theta} = \frac{F}{R}$

Tanθ =$\frac{F}{R}$
Angle of plane= Angle of friction.
But we know that the tangent of the angle of friction is also equal to $\frac{F}{R}$.
<u>Cone of Friction</u>



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<td>(2.5 x 2)</td>
<td>5</td>
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Where O= Point of contact between two bodies.

R= Normal reaction and also axis of the cone of friction.

ϕ =Angle of friction.

The combination of resultant S of frictional force F and normal reaction R obtained by applying forces in opposite directions successively form a right circular cone of angle 2ϕ, known as the cone of friction.

When a body tends to slide along a surface in the direction OP as shown in figure above. Frictional force F comes into play and it acts in the opposite direction, that is along OQ. Now the resultant of S of R and F makes an angle ϕ with its normal reaction. If the body is on the point of sliding in any other direction, the line of action of S will again makes an angle ϕ with the normal reaction.

Hence ,when the limiting friction is exerted, the line of action of the total reaction always lies in the surface of an inverted right circular cone of semi-vertical angle ϕ .This imaginary cone is called cone of friction.

Given

(b) Weight of the body, W =50 N

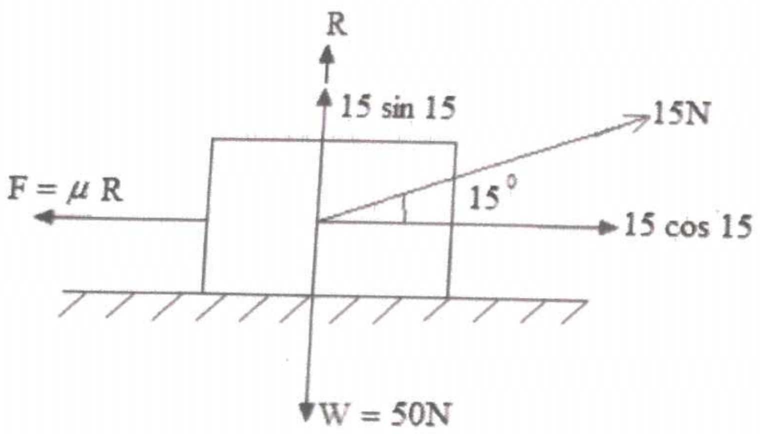
Force applied P =15 N

Angle made by force P, with horizontal =15^0

Let the coefficient of friction = μ

Normal reaction =R

When a force equal to 15N is applied to the body at an angle 15^0 to the horizontal, the body is on the point of motion in the forward direction. Hence the force of friction equal to μR will be acting in the backward direction. The body is in equilibrium under the action of forces shown in figure below. 10 10



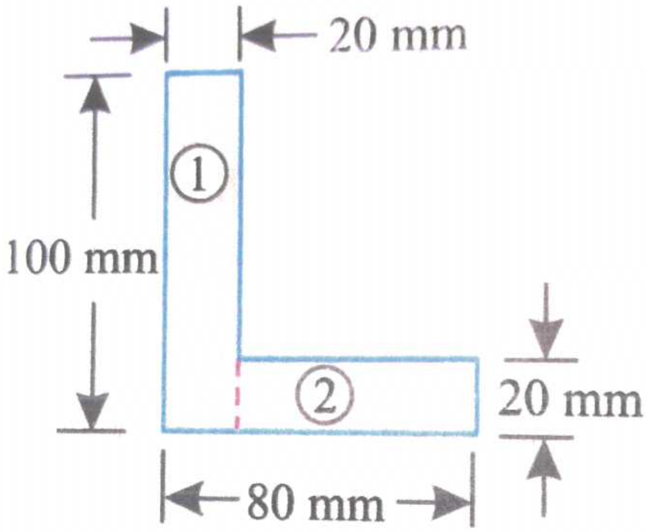
Resolving the forces along the plane, $\mu R = 15 \text{ Cos } 15^0$.....(i)
Resolving the forces normal to the plane,

$$R + 15\text{Sin } 15^0 = 50$$
$$R = 50 - 15\text{Sin}15^0 = 50 - 15 \times 0.2588$$
$$= 46.12 \text{ N}$$

Substituting the value of R in equation(i), we get

$$\mu \times 46.12 = 15\text{Cos}15^0$$
$$\mu = \frac{15Cos15}{46.12} = \frac{15 \times 0.9659}{46.12} = 0.314$$

VI (a)



Split up the section into two rectangles (1) and (2)
Moment of inertia about centroidal X-X axis
Let bottom face of the angle section be the axis of reference. — 10 — 10

Rectangle(1)

$a_1 = 100 \times 20 = 2000 mm^2$

$y_1 = \frac{100}{2} = 50$ mm

Rectangle (2)

$a_2 = (80-20) \times 20 = 1200 \text{ mm}^2$

$y_2 = \frac{20}{2} = 10$ mm.

$$\bar{y} = \frac{a_1y_1 + a_2y_2}{a_1 + a_2} = \frac{(2000\times50)+(1200\times10)}{(2000+1200)} = 35 \text{ mm}$$

Moment of inertia of rectangle(1) about an axis through it's centre of gravity and parallel to X-X axis.

$$I_{G1} = \frac{20 \times 100^3}{12} = 1.667 \times 10^6 \text{ mm}^4.$$

Distance of centre of gravity of rectangle(1) from X-X axis

$h_1 = 50 - 35 = 15$ mm.

Moment of inertia of rectangle(1) about X-X axis,

$$= I_{G1} + a_1h_1^2 = (1.667 \times 10^6) + [2000\times(15)^2] = 2.117 \times 10^6 \text{ mm}^4.$$

Similarly, moment of inertia of rectangle (2) about an axis through its centre of gravity and parallel to XX-axis.

$I_{G2}=\frac{60\times20^3}{12}=0.04\ x10^6\ mm^4$

Distance of centre of gravity of rectangle(2) from X-X axis

$h_2=35-10=25$ mm.

Moment of inertia of rectangle (2) about X-X axis,

$=I_{G2}+a_2h_2^2=(0.04\ x10^{6)}+[1200x\ (25)^2]=0.79\ x10^6mm^4$

Moment of inertia of the whole section about **X-X axis**

$=\mathbf{I_{xx}}=(2.117\ x10^6)+(0.79\ x10^6)=\mathbf{2.907\ x10^6mm^4}$

Moment of inertia about centroidal Y-Y axis

Let left face of the angle section be axis of reference.

Rectangle(1)

$a_1=2000\ mm^2$

$x_1=\frac{20}{2}=10$ mm

Rectangle(2)

$a_2=1200\ mm^2$

$x_2=20+\frac{60}{2}=50$ mm.

$\bar{x}=\frac{a_1x_1+a_2x_2}{a_1+a_2}=\frac{(2000\times10+1200\times50)}{(2000+1200)}=25$ mm.

$I_{G1}=\frac{100\times200^3}{12}=0.067\ x\ 10^6\ mm^4$.

Distance of centre of gravity of rectangle(1) from Y-Y axis,

$h_1=25-10=15$mm.

Moment of inertia of rectangle(1) about Y-Y axis

$=I_{G1}+a_1h_1^2=(0.067\ x10^6)+[2000\ x(15)^2]=0.517\ x10^6\ mm^4$.

Moment of inertia of rectangle(2) about an axis through it's centre of gravity and parallel to Y-Y axis,

$I_{G2}=\frac{20\times60^3}{12}=0.36\ x10^6\ mm^4$.

Distance of centre of gravity of rectangle (2) from Y-Y axis,

$h_2=50-25=25$ mm.

Moment of inertia of rectangle(2) about Y-Y axis,

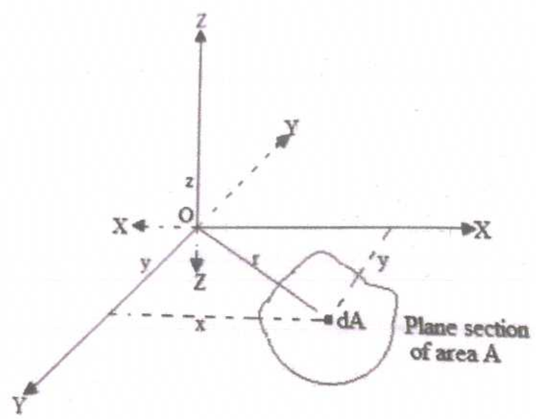
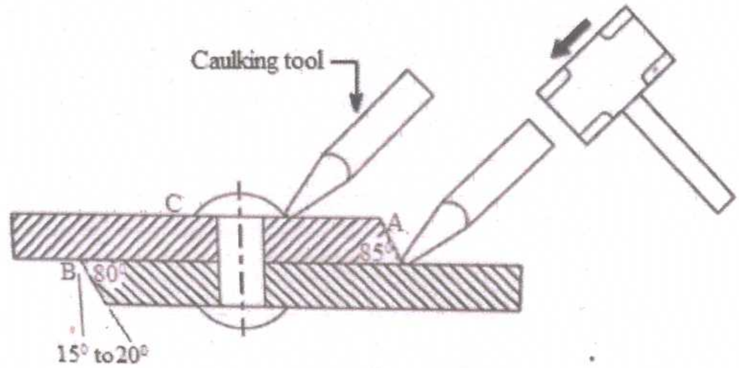
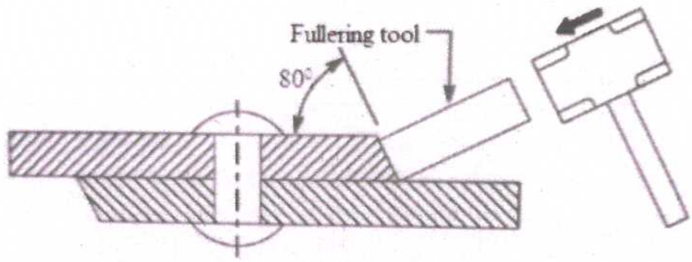
$=I_{G2}+a_2h_2^2=0.36\ x10^6+[(1200\ x(25)^2]=1.11\ x\ 10^6\ mm^4$

Moment of inertia of the whole section about **Y-Y axis,**

$\mathbf{I_{yy}}=(0.517\ x10^6)+(1.11x\ 10^6)=\mathbf{1.627\ x10^6\ mm^4}$

(b) Theorem of perpendicular axis states that if I_{xx} and I_{yy} be the moment of inertia of a plane section about two mutually perpendicular axis XX and YY in the plane of the section, then the moment of inertia of the section I_{zz} about the axis ZZ perpendicular to the plane and passing through the intersection of XX and YY axis is given by

$I_{zz}=I_{xx}+I_{yy}$.

	 	5	5	
VII (a)	Caulking and fullering.  Fig : Caulking Operation.  Fig: Fullering operation. To make the joints leak proof or fluid tight in pressure vessels like steam boilers, air receivers, tanks etc a process known as caulking is employed. In this process, a narrow tool called caulking tool, about 5mm thick and 38 mm breadth is used. The edge of the tool is ground to an angle of 80^0. The tool is moved after each blow along the edge of the plate, which is planed to bend of 75^0 to 80^0 to facilitate the forcing down of edge. It is seen that the tool burrs down the plate at A in forming a metal to metal joint. In actual practice, both the edges at A and B are	(2.5x2)	5	

	caulked. The head of the rivets as shown at C are also turned down with a caulking tool to make the joint steam tight. A great care is taken to prevent injury to the plate below the tool. A more satisfactory way of making the joints is known as fullering .In this case, a fullering tool of greater thickness is used. To facilitate the caulking and fullering operation the edges of the plate are usually machined to an angle of about 80^0 before joining them together. As a result of these operations the angle is increased to about 85^0.			
(b)	Given Thickness of the boiler shell, t = 10 mm Tensile stress, $\sigma = 105\ N/mm^2$ Efficiency of the joint, $\eta_l = 0.70$ $\eta_h = 0.30$ Diameter of the shell, $d = 1.3\ m = 1.3 \times 10^3 mm$ Internal pressure, $p = \frac{2 t \eta_l \sigma_h}{d} = \frac{2 \times 10 \times 0.70 \times 105}{1300}$ $= 1.13\ N/mm^2$. $P = \frac{4 t \eta_h \sigma_l}{d} = \frac{4 \times 10 \times 0.30 \times 105}{1300}$ $= 0.969\ N/mm^2$ (To satisfy both conditions i.e., to keep σ_h and σ_l within the limiting value, the pressure should not exceed $0.969\ N/mm^2$ i.e., smaller of the two values) Permissible intensity of Internal pressure, p =0.969 MPa.	10	10	
VIII (a)	<u>Advantages of welded joints over riveted joints.</u> 1) Quicker than riveting because it does not require drilling or punching of holes. 2) More strong and efficient than riveting. 3) Lighter in weight. 4) Welded structure has a better finish and appearance. 5) Maintenance and painting cost of welded structure is less. 6) The tension members in welded joints are not weakened as in riveted joints.	1 x 5	5	
(b)	Given , Double riveted double cover butt joint n=2 Thickness of the plate t= 20 mm. Diameter of rivet, d =25 mm. Pitch of rivet, p =100 mm.	10	10	

	Shearing stress of rivet material, σ_s=80 MPa = 80 N/mm^2 Bearing stress of rivet material ,σ_b =160 MPa =160 N/mm^2 Tensile stress of rivet material, σ_t =100 MPa =100 N/mm^2 Shearing strength $P_s = 2\text{x}\frac{\pi}{4}\times d^2 \times \sigma_s \times n = 2\text{x}\frac{\pi}{4}\text{x}25^2\text{x}80\text{x}2$ =157079.63 N Bearing strength, $P_b = \sigma_b tdn$ = 160 x20x25x2 = 160000 N Tearing strength, $P_t = \sigma_t(p-d)t$=100x(100-25)x20 =150000 N Strength of riveted joint(Pull per pitch length of the joint) =Least of P_s, P_b, P_t = 150000 N Strength of solid plate $P = \sigma_t pt$=100x100x20 =200000N Efficiency, $\eta = \frac{Least\ of P_s,P_b,P_t}{\sigma_t pt} = \frac{150000}{200000}$ =0.75= 75%			
IX (a)	<u>Types of springs</u> Various types of springs can be designed for their purpose and place; but depending upon the type of resilience, springs may be broadly divided into two categories: (a)Bending springs (b) Torsion springs <u>(a) Bending springs</u> The type of springs which are subjected to bending only and the resilience occurs due to this are called bending springs. Examples are Laminated springs, Leaf springs etc. <u>(b)Torsion springs</u> The types of springs which are subjected to a torsion or twisting only and the resilience occurs due to this are called torsion springs. Examples are Helical springs. <u>Helical springs</u> This type of springs is made by a wire coiled into a helix. It is a torsion spring. There are two types of helical springs: (i)Close-coiled helical springs. (ii) Open-coiled helical springs. <u>Close-coiled helical springs</u> In this type of spring, the wire is turned so closely that each turn is nearly right angle to the axis of the spring and the pitch distance between two consecutive turn is small. The bending stress is negligible as compared to the torsional stress. <u>Open-coiled helical springs</u> In this type of spring, the wire is coiled in such a way, that there is a large gap between two consecutive turns compared to Close-coiled helical springs. The pitch distance between two consecutive turn is large compared to the Close-coiled helical	(Types 3 +Definition 2)	5	

consecutive turn is large compared to the Close-coiled helical springs. As a result of this the spring can take compressive load also.

Spring index: It is defined as the ratio of mean coil diameter to wire diameter.

Stiffness or Spring constant: It is defined as the load per unit axial deflection or changes in load per unit deflection and is generally given in kN/m.

(b) Given, — (Slope 5M + Deflection 5M) — 10

Length of the beam, l =3m= $3\text{x}10^3$mm

Point load W=10 kN =10 x 10^3 N

Moment of inertia I =12 x 10^6 mm^4

E = 200 GPa =2 x 10^5 MPa =2 x10^5 N/mm^2

Slope, $\theta = \frac{Wl^2}{16EI} = \frac{10\text{x}10^3 \times (3\times10^3)^2}{16\times2\times10^5\times12\times10^6}$ =0.0023 rad

Deflection, $y = \frac{WL^3}{48EI} = \frac{10\times10^3\times(3\times10^3)^3}{48\times2\times10^5\times12\times10^6}$ =2.343 mm

X(a) Effective length(or equivalent length) of a column. — 2.5 x 2 — 5

The effective length of a given column with given end conditions is the length of an equivalent column of the same material and cross-section with hinged ends and having the value of the crippling load equal to that of the given column. Effective length is also called equivalent length.

Relation between equivalent length and actual length.

S.No.	End conditions of column	Crippling load in terms of Actual length	Crippling load in terms of Effective length	Relation between effective length and actual length
1.	Both ends hinged	$\frac{\pi^2 EI}{l^2}$	$\frac{\pi^2 EI}{L^2}$	$L = l$
2.	One end is fixed and other is free	$\frac{\pi^2 EI}{4l^2}$	$\frac{\pi^2 EI}{L^2}$	$L = 2l$
3.	Both ends fixed	$\frac{4\pi^2 EI}{l^2}$	$\frac{\pi^2 EI}{L^2}$	$L = \frac{l}{2}$
4.	One end fixed and other is hinged	$\frac{2\pi^2 EI}{l^2}$	$\frac{\pi^2 EI}{L^2}$	$L = \frac{l}{\sqrt{2}}$

(b) Given ,

External diameter, D =50 mm.

Internal diameter, d = 40 mm.

Area $A = \frac{\pi(50^2-40^2)}{4}$ =225 π mm^2

Moment of inertia $I = \frac{\pi(50^4-40^4)}{64}$ =57656π mm^2 — 10 — 10

	Least radius of gyration k = $\sqrt{\frac{I}{A}} = \sqrt{\frac{57656\pi}{225\pi}}$ =16 mm length of the column l= 3 m =3 x10^3 mm As both ends are fixed Effective length L= $\frac{l}{2} = \frac{3\times10^3}{2}$ =1.5 x 10^3 mm. Crushing stress, σ_c= 550 N/mm^2 Rankines constant =$\frac{1}{1600}$ Crippling load ,P= $\frac{\sigma_c A}{1+\alpha(\frac{L}{k})^2} = \frac{550\times225\pi}{1+\frac{1}{1600}(\frac{1.5\times10^3}{16})^2} = 59874N$			