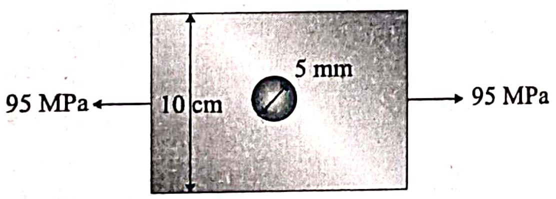
Chapter 1 Static Loading

One Mark Questions

01. In the design of shafts made of ductile materials subjected to twisting moment and bending moment, the recommended theory of failure is **(GATE-ME-88)**
    (a) maximum principal stress theory
    (b) maximum principal strain theory
    (c) maximum shear stress theory
    (d) maximum strain – energy theory

02. Strength to weight ratio for a circular shaft transmitting power is directly proportional to the
    (a) square root of the diameter **(GATE-ME-91)**
    (b) diameter
    (c) square of the diameter
    (d) cube of the diameter

03. A large uniform plate containing a rivet hole is subjected to uniform uniaxial tension of 95 MPa. The maximum stress in the plate is **(GATE-ME-92)**



    (a) 100 MPa (b) 285 MPa
    (c) 190 MPa (d) indeterminate

04. The outside diameter of a hollow shaft is twice its inside diameter. The ratio of its torque carrying capacity to that of a solid shaft of the same material and the same out side diameter is **(GATE-ME-93)**
    (a) 15/16 (b) 3/4 (c) 1/2 (d) 1/16

05. Two shafts A and B are made of the same material. The diameter of shaft B is twice that of shaft A. The ratio of power which can be transmitted by shaft A to that of shaft B is **(GATE-ME-94)**
    (a) 1/2 (b) 1/4 (c) 1/8 (d) 1/16

06. A solid shaft can resist a bending moment of 3.0 kNm and a twisting moment of 4.0 kNm together, then the maximum torque that can be applied is **(GATE-ME-96)**
    (a) 7.0 kNm (b) 3.5 kNm
    (c) 4.5 kNm (d) 5.0 kNm

07. Which theory of failure will you use for aluminium components under steady loading
    (a) principal stress theory **(GATE-ME-98)**
    (b) principal strain theory
    (c) strain energy theory
    (d) maximum shear stress theory

08. Match the following criteria of material failure, under biaxial stresses σ_1 and σ_2 and yield stress σ_y, with their corresponding graphic representations: **(GATE-ME-11)**

    P. Maximum normal stress criterion
    Q. Maximum distortion energy criterion
    R. Maximum shear stress criterion

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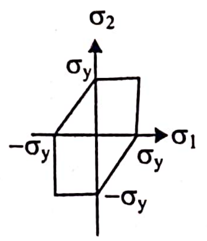

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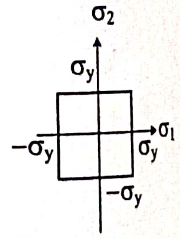

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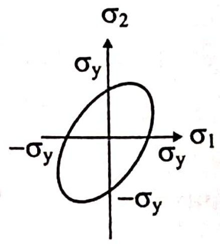


    (a) P-M, Q-L, R-N
    (b) P-N, Q-M, R-L
    (c) P-M, Q-N, R-L
    (d) P-N, Q-L, R-M

09. Which one of following is NOT correct?

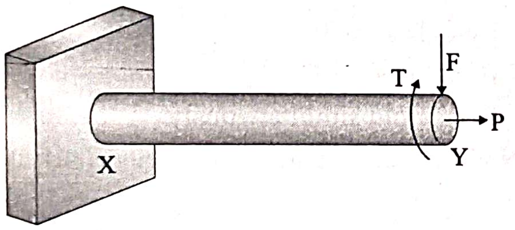
(GATE-ME- 2014-SET-3)

(a) Intermediate principal stress is ignored when applying the maximum principal stress theory
(b) The maximum shear stress theory gives the most accurate results amongst all the failure theories
(c) As per the maximum strain energy theory, failure occurs when the strain energy per unit volume exceeds a critical value
(d) As per the maximum distortion energy theory, failure occurs when the distortion energy per unit volume exceeds a critical value

10. The uniaxial yield stress of a material is 300 MPa. According to von-Mises criterion, the shear yield stress (in MPa) of the material is ______

(GATE –15 –Set 2)

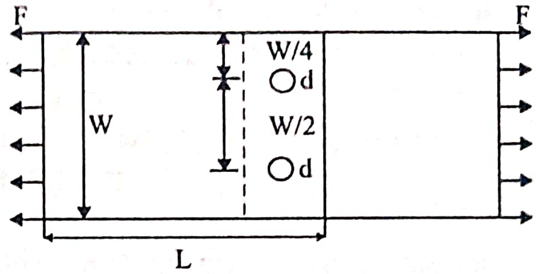
11. A machine element XY, fixed at end X, is subjected to an axial load P, transverse load F, and a twisting moment T at its free end Y. The most critical point from the strength point of view is



(GATE – 16 – SET – 2)

(a) a point on the circumference at location Y
(b) a point at the center at location Y
(c) a point on the circumference at location X
(d) a point at the center at location X

12. Consider the schematic of a riveted lap joint subjected to tensile load F, as shown below. Let *d* be the diameter of the rivets, and S_f be the maximum permissible tensile stress in the plates. What should be the minimum value for the thickness of the plates to guard against tensile failure of the plates? Assume the plates to be identical.



(GATE – 17 – SET – 1)

(a) $\dfrac{F}{S_f(W-2d)}$ (b) $\dfrac{F}{S_f W}$
(c) $\dfrac{F}{S_f(W-d)}$ (d) $\dfrac{2F}{S_f W}$

13. The von Mises stress at a point in a body subjected to forces is proportional to the square root of the

(GATE–21_SET–2)

(a) dilatational strain energy per unit volume
(b) total strain energy per unit volume
(c) distortional strain energy per unit volume
(d) plastic strain energy per unit volume

14. A given steel has identical yield strength of 700 MPa in uni-axial tension and uni-axial compression. If the steel is subjected to pure shear stress such that the three principal stresses are $\sigma_1 = \sigma$, $\sigma_2 = 0$, $\sigma_3 = -\sigma$ with $\sigma_1 \geq \sigma_2 \geq \sigma_3$, then the stress σ in MPa for the initiation of plastic yielding in the steel as per von Mises yield criterion is_______ [*round off to 2 decimal places*] **(GATE_PI–21)**

15. A structural member under loading has a uniform state of plane stress which in usual notations is given by $\sigma_x = 3P$, $\sigma_y = -2P$ and $\tau_{xy} = \sqrt{2}P$, where $P > 0$. The yield strength of the material is 350 MPa. If the member is designed using the maximum distortion energy theory, then the value of P at which yielding starts (according to the maximum distortion energy theory) is **(GATE-22_SET-2)**

(a) 70 MPa (b) 90 MPa
(c) 120 MPa (d) 75 MPa

16. Yielding starts in a material when the principal stresses are 100 MPa, 100 MPa and 200 MPa. As per the von Mises criterion, yield stress (in MPa) of the material is__________. [round off to nearest integer] **(GATE_PI-22)**

17. The principal stresses at a point P in a solid are 70 MPa,−70 MPa and 0. The yield stress of the material is 100 MPa. Which prediction(s) about material failure at P is/are CORRECT? **(GATE_ME-23)**
(b) Maximum normal stress theory predicts that the material fails
(b) Maximum shear stress theory predicts that the material fails
(c) Maximum normal stress theory predicts that the material does not fail
(d) Maximum shear stress theory predicts that the material does not fail

Two Marks Questions

01. A small element at the critical section of a component in bi – axial state of stress with the two principal stresses being 360 MPa and 140 MPa. The maximum working stress according to distortion energy theory is **(GATE-ME-97)**
(a) 220 MPa (b) 110 MPa
(c) 314 MPa (d) 330 MPa

02. The homogeneous state of stress for a metal part undergoing plastic deformation is

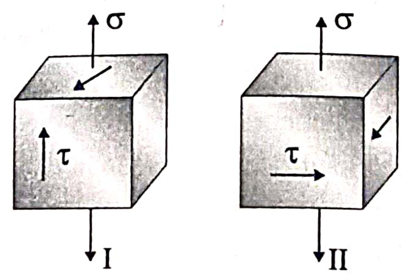
$$T = \begin{pmatrix} 10 & 5 & 0 \\ 5 & 20 & 0 \\ 0 & 0 & -10 \end{pmatrix}$$

Where the stress component values are in MPa. Using von Mises yield criterion, the value of estimated shear yield stress, in MPa is **(GATE-ME-12)**
(a) 9.50 (b) 16.07 (c) 28.52 (d) 49.41

03. A solid circular shaft needs to be designed to transmit a torque of 50 N.m. If the allowable shear stress of the material is 140 MPa, assuming a factor of safety of 2, the minimum allowable design diameter in mm is **(GATE-ME-12)**
(a) 8 (b) 16 (c) 24 (d) 32

04. The state of stress at a point is given by $\sigma_x = -6$ MPa, $\sigma_y = 4$ MPa, and $\tau_{xy} = -8$ MPa. The maximum tensile stress (in MPa) at the point is ______ **(GATE-ME-14-SET-1)**

05. Consider the two states of stress as shown in configurations I and II in the figure below. From the standpoint of distortion energy (von-Mises) criterion, which one of the following statements is true ? **(GATE-ME-14-SET-2)**



(a) I yields after II
(b) II yields after I
(c) Both yield simultaneously
(d) Nothing can be said about their relative yielding

06. A shaft is subjected to pure torsional moment. The maximum shear stress developed in the shaft is 100 MPa. The yield and ultimate strengths of the shaft material in tension are 300 MPa and 450 MPa, respectively. The factor of safety using maximum distortion energy (von-Mises) theory is ______ **(GATE-ME-14-SET-4)**

07. A machine element is subjected to the following bi-axial state of stress: $\sigma_x = 80$ MPa; $\sigma_y = 20$ MPa; $\tau_{xy} = 40$ MPa. If the shear strength of the material is 100 MPa, the factor of safety as per Tresca's maximum shear stress theory is **(GATE –15 –Set 1)**
(a) 1.0 (b) 2.0 (c) 2.5 (d) 3.3

08. The principal stresses at a point inside a solid object are $\sigma_1 = 100$ MPa, $\sigma_2 = 100$ MPa and $\sigma_3 = 0$ MPa. The yield strength of the material is 200 MPa. The factor of safety calculated using Tresca (maximum shear stress) theory is n_T and the factor of safety calculated using von-Mises (maximum distortional energy) theory is n_v.
Which one of the following relations is TRUE?
(GATE – 16 – SET – 1)

(a) $n_T = \left(\frac{\sqrt{3}}{2}\right)n_v$ (b) $n_T = (\sqrt{3})n_v$

(c) $n_T = n_v$ (d) $n_v = (\sqrt{3})n_T$

09. The principal stresses at a point in a critical section of a machine component are $\sigma_1 = 60$ MPa, $\sigma_2 = 5$ MPa and $\sigma_3 = -40$ MPa. For the material of the component, the tensile yield strength is $\sigma_y = 200$ MPa. According to the maximum shear stress theory, the factor of safety is **(GATE–17–SET–2)**

(a) 1.67 (b) 2.00

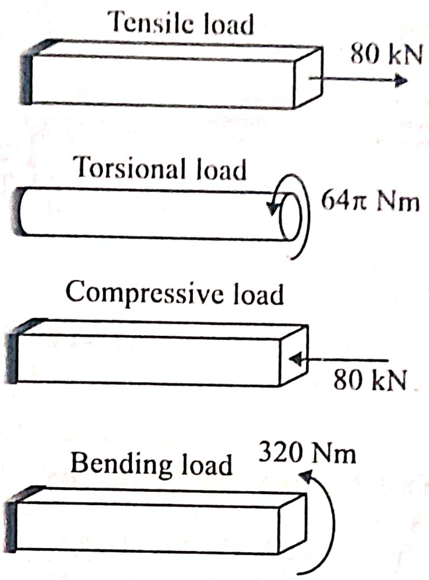
(c) 3.60 (d) 4.00

10. A solid circular shaft is subjected to a bending moment M and torque T simultaneously. Neglecting the effects of stress concentration, the equivalent bending moment is expressed as **(GATE–PI–17)**

(a) $\frac{1}{2}(M+\sqrt{M^2+T^2})$ (b) $\left(\frac{M}{2}+\sqrt{M^2+T^2}\right)$

(c) $\frac{1}{2}(M+\sqrt{M^2+4T^2})$ (d) $\left(\frac{M}{2}+\sqrt{M^2+4T^2}\right)$

11. Bars of square and circular cross-section with 0.5 m length are made of a material with shear strength of 20 MPa. The square bar cross-section dimension is 4 cm × 4 cm and the cylindrical bar cross-section diameter is 4 cm. The specimens are loaded as shown in the figure. **(GATE–20–SET–1)**



Which specimen(s) will fail due to the applied load as per maximum shear stress theory ?

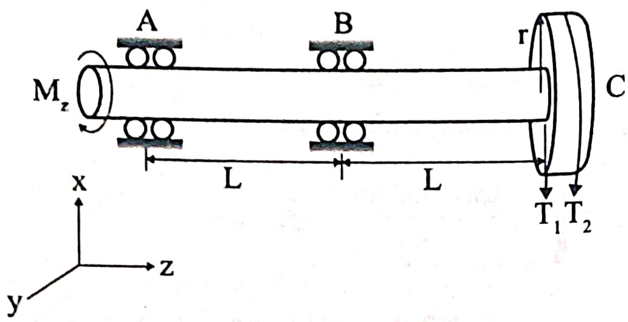
(a) Bending load specimen

(b) None of the specimens

(c) Tensile and compressive load specimens

(d) Torsional load specimen

12. A shaft AC rotating at a constant speed carries a thin pulley of radius r = 0.4 m at the end C which drives a belt. A motor is coupled at the end A of the shaft such that it applies a torque M_z about the shaft axis without causing any bending moment. The shaft is mounted on narrow frictionless bearings at A and B where AB = BC = L = 0.5 m. The taut and slack side tensions of the belt are $T_1 = 300$ N and $T_2 = 100$ N, respectively. The allowable shear stress for the shaft material is 80 MPa. The self-weights of the pulley and the shaft are negligible. Use the value of π available in the on-screen virtual calculator. Neglecting shock and fatigue loading and assuming maximum shear stress theory, the minimum required shaft diameter is _______ mm (round off to 2 decimal places).



(GATE-22_SET-2)

KEY & Detailed Solutions

ONE MARK QUESTIONS

01. (c)	02. (b)	03. (a)	04. (a)	05. (c)
06. (d)	07. (d)	08. (c)	09. (b)	10. 173.1
11. (c)	12. (a)	13. (c)	14. 404.15	
15. (a)	16. 100	17. (b,c)		

TWO MARKS QUESTIONS

01. (c)	02. (b)	03. (b)	04. 8.434 MPa	
05. (c)	06. 1.7 to 1.8		07. (b)	08. (c)
09. (b)	10. (a)	11. (c)	12. 23.94	

One Mark Solutions

01. Ans: (c)

Sol: For ductile materials maximum shear stress and distortion energy theories can be used.
Principal stress theory is suitable for brittle materials only.

02. Ans: (b)

Sol: $$\frac{T}{W}=\frac{\frac{\pi}{16}\tau d^3}{\rho\times\frac{\pi}{4}d^2\times\ell\times g}\propto\frac{d^3}{d^2}\propto d$$

03. Ans: (a)

Sol: $$\sigma_{max}=\frac{\text{Load}}{A_{min}}=\frac{95\times100\times t}{(100-5)\times t}=100\text{ MPa}$$

04. Ans: (a)

Sol: $$\frac{T_H}{T_S}=\frac{\frac{\pi}{16}\tau D^3(1-k^4)}{\frac{\pi}{16}\tau D^3}=1-k^4=1-\left(\frac{1}{2}\right)^4=\frac{15}{16}$$

05. Ans: (c)

Sol: $$P=\frac{2\pi NT}{60}\Rightarrow P\propto T$$

$$\frac{T_A}{T_B}=\frac{\frac{\pi}{16}\tau D_A^3}{\frac{\pi}{16}\tau(2D_A)^3}=\frac{1}{8}$$

06. Ans: (d)

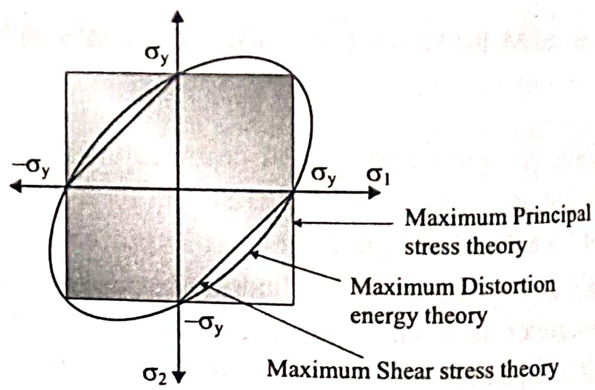
Sol: $$T_e=\sqrt{M^2+T^2}=\sqrt{3^2+4^2}=5$$

07. Ans: (d)

Sol: For ductile materials like aluminium maximum shear stress and distortion energy theories can be used.

08. Ans: (c)

Sol: If all the theories of failure are plotted together, they will seem like



09. Ans: (b)

Sol: Distortion energy theory gives more accurate value.

10. Ans: 173.1 **(Range 171 to 175)**

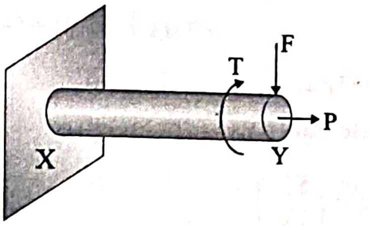
Sol: According von-Mises theory of failure

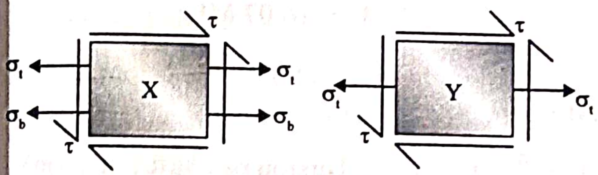
$S_{sy} = 0.577 S_{yt}$

$\tau = 0.577 \times 300 = 173.1$ MPa

11. Ans: (c)

Sol:





Element Y($\sigma_b = 0$)

At centre $\sigma_b = 0$ and torsional shear stress is zero.

12. Ans: (a)

Sol: s_f = permissible tensile stress in plates

d = diameter of rivet

F = tensile load

t = ?

For tearing failure of plates,

$$F = (W - 2d)t \times \frac{S_{yt}}{FS} = (W - 2d) \times t \times S_f$$

$$\therefore t = \frac{F}{(W - 2d) \times s_f}$$

13. Ans: (c)

Sol: The distortion energy per unit volume is,

$$U_d = \frac{(1+\mu)}{6 \times E}\{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2\}$$

and, von-mises stress is,

$$\sigma_{vm} = \sqrt{\frac{1}{2}\{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2\}}$$

$$U_d = \frac{(1+\mu)}{3 \times E} \times \sigma_{vm}^2$$

$$U_d \propto (\sigma_{vm})^2$$

14. Ans: (404.15)

Sol: Given data

(i) $\sigma_1 = \sigma$; $\sigma_2 = 0$ and $\sigma_3 = -\sigma$

$s_{yt} = 700$ MPa

(ii) Von-mises stress,

$$\sigma_{vm} = \left[\frac{1}{2} \times \{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2\}\right]^{\frac{1}{2}}$$

$$\therefore \sigma_{vm} = \left[\frac{1}{2} \times \{(\sigma - 0)^2 + (\sigma - (-\sigma))^2 + (0 - (-\sigma)^2)\}\right]^{\frac{1}{2}}$$

$$\therefore \sigma_{vm} = \sqrt{3} \times \sigma$$

(iii) As per von-mises criterion for yielding,

$\sigma_{vm} \geq s_{yt}$

$\therefore \sigma_{vm} = s_{yt}$

$\therefore \sqrt{3} \times \sigma = 700$

$\therefore \sigma = 404.145$ MPa

15. Ans: (a)

Sol: Given, $\sigma_x = 3P$, $\sigma_y = -2P$

and $\tau_{xy} = \sqrt{2}P$

According to maximum distortion energy theory,

$$\sqrt{\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2} = \frac{S_{yt}}{FOS}$$

$$P\sqrt{3^2 - 3(-2) + (-2)^2 + 3(\sqrt{2})^2} = \frac{350}{1}$$

$P \times 5 = 350$

$\Rightarrow P = 70$ MPa

16. Ans: 100

Sol: Given data:

$\sigma_1 = 100$ MPa, $\sigma_2 = 100$ MPa, $\sigma_3 = 200$ MPa

According to maximum distortion energy theory,

$$\sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - (\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)} = S_{yt}$$

$$\sqrt{100^2 + 100^2 + 200^2 - \begin{pmatrix}100 \times 100 + 100 \times 200 \\ +200 \times 100\end{pmatrix}} = S_{yt}$$

$S_{yt} = 100$ MPa

17. Ans: (b, c)

Sol: Given that:

$\sigma_1 = 70$ MPa, $\sigma_2 = -70$ MPa, $\sigma_3 = 0$

$S_{yt} = 100$ MPa

According to Normal stress theory,

for Safety, $\sigma_{max} \le S_{yt}$

$\therefore \quad 70 \le 100$ MPa

Therefore, normal stress theory predicts safety.

According to maximum shear stress theory,

for Safety, $\sigma_{max} - \sigma_{min} \le S_{yt}$

$\therefore \quad 70 - (-70) \le 100$

Therefore, maximum shear stress theory predicts failure.

Two Marks Solutions

01. Ans: (c)

Sol: According to Distortion Energy Theory

$$S_{yt} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2}$$

$$\therefore S_{yt} = \sqrt{360^2 + 140^2 - (360 \times 140)}$$

$$\Rightarrow S_{yt} = 314.32 \text{ MPa}$$

02. Ans: (b)

Sol: Given, $\sigma_x = 10$ MPa, $\sigma_y = 20$ MPa, $\tau_{xy} = 5$ MPa and $\sigma_z = -10$ MPa

Maximum Principal Stress, (σ_1)

$$\sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$= \frac{10+20}{2} + \sqrt{\left(\frac{10-20}{2}\right)^2 + 5^2}$$

$$= 15 + 5\sqrt{2} = 22.07 \text{ MPa},$$

Similarly, Minimum principal stress, (σ_2)

$$\sigma_2 = \frac{\sigma_x + \sigma_y}{2} - \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\sigma_2 = 15 - 5\sqrt{2} = 7.93 \text{ MPa}$$

According to von-Mises yield criterion, permissible value of tensile yield strength,

$$\frac{S_{yt}}{FS} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - (\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)}$$

$$= \sqrt{\begin{aligned}&22.07^2 + 7.93^2 + (-10)^2 - (22.07 \times 7.93) \\ &+ (7.93 \times -10) + (-10 \times 22.07)\end{aligned}}$$

$$= 27.838 \text{ MPa}$$

$\therefore$ Estimate value of shear stress,

$$\frac{S_{sy}}{FS} = 0.577\left(\frac{S_{yt}}{FS}\right)$$

$$= 0.577 \times 27.838 = 16.07 \text{ MPa}$$

03. Ans: (b)

Sol: $T = \frac{\pi}{16}\tau d^3$ (Torsion of Shaft Equation)

$$T = \frac{\pi}{16}\left(\frac{S_{sy}}{FS}\right)d^3$$

(T is in N-mm, d in mm and τ in N/mm²)

$$50 \times 10^3 = \frac{\pi}{16} \times \frac{140}{2} \times d^3$$

$$\Rightarrow \quad d = 16 \text{ mm}$$

04. Ans: 8.434 MPa.

Sol: $\sigma_x = -6$ MPa, $\sigma_y = 4$ MPa, $\tau_{xy} = -8$ MPa.

$$\sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\sigma_1 = \frac{-6+4}{2} + \sqrt{\left(\frac{-6-4}{2}\right)^2 + 8^2} = 8.434 \text{ MPa}$$

05. Ans: (c)

Sol:
$$\frac{S_{yt}}{FS} = \sqrt{\begin{aligned}&\frac{1}{2}\left[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2\right] \\ &+ 3\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right)\end{aligned}}$$

Given,

For first stress element,

$\sigma_x = 0$, $\sigma_y = \sigma$, $\sigma_z = 0$

$\tau_{xy} = 0$, $\tau_{yz} = \tau$, $\tau_{xz} = 0$

So, $\frac{S_{yt}}{FS} = \sqrt{\sigma^2 + 3\tau^2}$

For second stress element

$\sigma_x = 0, \quad \sigma_y = \sigma, \quad \sigma_z = 0$

$\tau_{xy} = 0, \quad \tau_{yz} = 0, \quad \tau_{xz} = \tau$

So, $\frac{S_{yt}}{FS} = \sqrt{\sigma^2 + 3\tau^2}$

As $\frac{S_{yt}}{FS}$ is same for both yield simultaneously.

06. Ans : 1.7 to 1.8

Sol: For pure shear condition

$\sigma_1 = \tau, \quad \sigma_2 = -\tau$

Maximum Distortion energy theory

$$\sqrt{\sigma_1^2 + \sigma_2^2 - (\sigma_1 \times \sigma_2)} = \frac{S_{yt}}{F.S}$$

$$\sqrt{\tau^2 + (-\tau)^2 - (\tau \times -\tau)} = \frac{S_{yt}}{F.S}$$

$$\sqrt{3} \times \tau = \frac{S_{yt}}{F.S} \Rightarrow F.S = \frac{300}{\sqrt{3} \times 100} = 1.732$$

07. Ans: (b)

Sol: $\sigma_x = 80$ MPa, $\sigma_y = 20$ MPa,

$\tau_{xy} = 40$ MPa, $S_{sy} = 100$ MPa

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

$$= \sqrt{\left(\frac{80 - 20}{2}\right)^2 + 40^2} = 50 \text{ MPa}$$

According to maximum shear stress theory,

$$\tau_{max} = \frac{S_{sy}}{F.S} \Rightarrow 50 = \frac{100}{F.S}$$

F.S. = 2

08. Ans: (c)

Sol: According to maximum shear stress theory

$$Z_{max} = \frac{S_{yt}}{2n_T} \Rightarrow n_T = \frac{200}{100} = 2$$

According to Distortion Energy Theory:

$$\sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2} = \frac{S_{yt}}{n_v}$$

But $\sigma_1 = \sigma_2$, let it is σ_1

$$\sqrt{\sigma_1^2 + \sigma_1^2 - \sigma_1^2} = \frac{S_{yt}}{n_v}$$

$$\Rightarrow n_v = \frac{S_{yt}}{\sigma_1} = \frac{200}{100} = 2$$

$\therefore n_T = n_V$

09. Ans: (b)

Sol: $\sigma_1 = 60$ MPa, $\sigma_2 = 5$ MPa,

$\sigma_3 = -40$ MPa, $s_{yt} = 200$ MPa

According to MSST,

$$\tau_{max} = \frac{S_{yt}}{2 \times FS}$$

$$\frac{\sigma_1 - \sigma_3}{2} = \frac{S_{yt}}{2 \times FS}$$

$$\sigma_1 - \sigma_3 = \frac{S_{yt}}{FS}$$

$$60 - (-40) = \frac{200}{FS}$$

$$100 = \frac{200}{FS} \Rightarrow FS = 2$$

10. Ans: (a)

Sol: Bending stress $(\sigma) = \frac{32M}{\pi d^3}$

Torsional Shear Stress$(\tau) = \frac{16T}{\pi d^3}$

Maximum normal stress (Principal stress),

$$(\sigma_b)_{max} = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2}$$

$$\therefore \frac{32M_{eq}}{\pi d^3} = \frac{32M}{2\pi d^3} + \left[\sqrt{\left(\frac{32M}{2\pi d^3}\right)^2 + \left(\frac{16T}{\pi d^3}\right)^2}\right]$$

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

11. Ans: (c)

Sol: According to maximum shear stress theory,

maximum normal stress $\sigma_{max} = \frac{\sigma_{yt}}{fos} = \frac{2.\tau_{yt}}{fos}$

maximum shear stress $\tau_{max} = \frac{\tau_{yt}}{fos} = \frac{\sigma_{yt}}{2 \times fos}$

Tensile Load $\sigma_{max} = \frac{80 \times 10^3}{40 \times 40} = \frac{2 \times 20}{fos}$,

FOS = 0.8

The component under tensile loading fails after reaching a load of (0.8 × 80 kN) = 64 kN

Compressive load:

Assuming same properties in tension and compression.

$$\sigma_{max} = \frac{2 \times \tau_{yt}}{fos}$$

$$\frac{80 \times 10^3}{40 \times 40} = \frac{40}{fos}$$

$\Rightarrow$ FOS = 0.8

Under compressive loading, the component fails after the load reaches 64 kN.

Torsional load :

$$\tau_{max} = \frac{16.T}{\pi d^3} = \frac{\tau_{yt}}{fos}$$

$$\frac{16 \times 64\pi \times 10^3}{\pi \times 40^3} = \frac{20}{fos}$$

$\Rightarrow$ FOS $= \frac{5}{4}$

The component under torsional load fails after the load reaches $\frac{5}{4} \times 64\pi = 80\pi$

Bending Load:

$$\sigma_{max} = \frac{6M}{b\,d^3} = \frac{\sigma_{yt}}{fos}$$

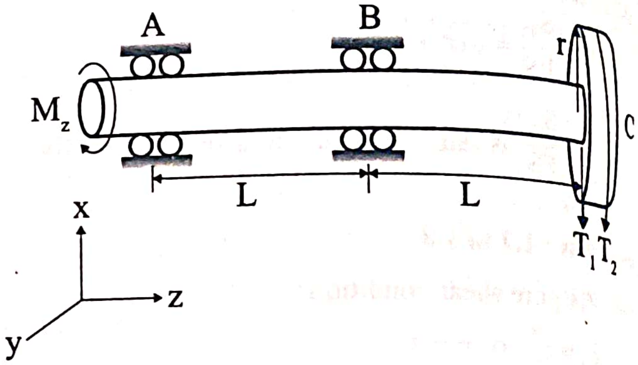
$$\frac{6 \times 320 \times 10^3}{40^3} = \frac{40}{fos}$$

$\Rightarrow$ FOS = 1.33

The component under bending load fails after the load reaches (1.33 × 320) = 426.66 N.m

12. Ans: 23.94

Sol:



$$M_{max} = 400 \times L = 400 \times 0.5 \times 10^3$$
$$= 200 \times 10^3 \text{ N.mm}$$

$$T_{max} = M_z$$
$$= (T_1 - T_2) \times r$$
$$= 200 \times 0.4 \times 10^3$$

$T_{max} = 80 \times 10^3$ N.mm

Here section - B is critical due to loading,

Critical particle :

According to maximum shear stress theory,

$$\frac{16}{\pi d^3}\sqrt{M_{max}^2 + T_{max}^2} = \frac{S_{ys}}{FOS}$$

$$\frac{16 \times 10^3}{\pi d^3}\sqrt{200^2 + 80^2} = \frac{80}{1}$$

$\Rightarrow$ d = 23.94 mm