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Director's Message



B. Singh (Ex. IES)

Engineering is one of the most chosen graduating field. Taking engineering is usually a matter of interest but this eventually develops into “purpose of being an engineer” when you choose engineering services as a career option.

Train goes in tunnel we don't panic but sit still and trust the engineer, even we don't doubt on signalling system, we don't think twice crossing over a bridge reducing our travel time; every engineer has a purpose in his department which when coupled with his unique talent provides service to mankind.

I believe *“the educator must realize in the potential power of his pupil and he must employ all his art, in seeking to bring his pupil to experience this power”*. To support dreams of every engineer and to make efficient use of capabilities of aspirant, MADE EASY team has put sincere efforts in compiling all the previous years' ESE-Pre questions with accurate and detailed explanation. The objective of this book is to facilitate every aspirant in ESE preparation and so, questions are segregated chapterwise and topicwise to enable the student to do topicwise preparation and strengthen the concept as and when they are read.

I would like to acknowledge efforts of entire MADE EASY team who worked hard to solve previous years' papers with accuracy and I hope this book will stand up to the expectations of aspirants and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

B. Singh (Ex. IES)
CMD, MADE EASY Group

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UNIT

I

Strength of Materials and Engineering Mechanics

Syllabus

Analysis of System of Forces, Friction, Centroid and Centre of Gravity, Dynamics; Stresses and Strains-Compound Stresses and Strains, Bending Moment and Shear Force Diagrams, Theory of Bending Stresses-Slope and deflection-Torsion, Thin and thick Cylinders, Spheres.

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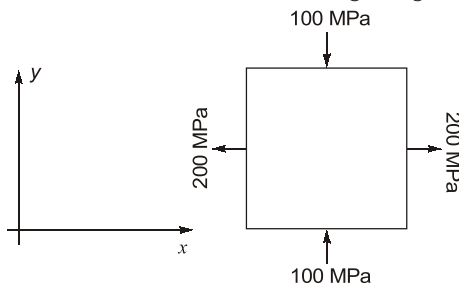
3

Principal Stresses and Strains and Mohr's Circle

- 3.1 A circular shaft subjected to twisting moment results in maximum shear stress of 60 MPa. Then the maximum compressive stress in the material is
 (a) 30 MPa (b) 60 MPa
 (c) 90 MPa (d) 120 MPa

[ESE : 2003]

- 3.2 Consider a two dimensional state of stress given for an element as shown in the diagram given below:



What are the coordinates of the centre of Mohr's circle?

- (a) (0, 0) (b) (100, 200)
 (c) (200, 100) (d) (50, 0)

[ESE : 2004]

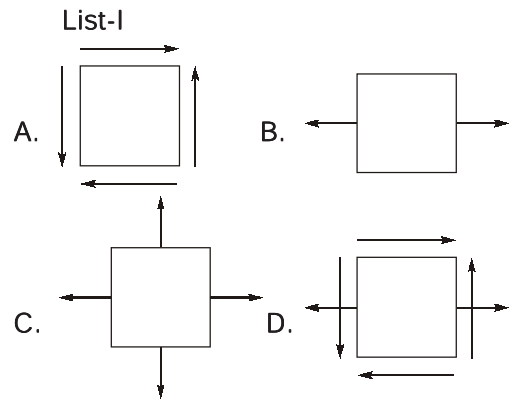
- 3.3 At a point in two-dimensional stress system $\sigma_x = 100 \text{ N/mm}^2$, $\sigma_y = \tau_{xy} = 40 \text{ N/mm}^2$. What is the radius of the Mohr circle for stress drawn with a scale of $1 \text{ cm} = 10 \text{ N/mm}^2$.
 (a) 3 cm (b) 4 cm
 (c) 5 cm (d) 6 cm

[ESE : 2005]

- 3.4 Normal stresses of equal magnitude σ , but of opposite signs, act at a point of a strained material in perpendicular direction. What is the magnitude of the stress on a plane inclined at 45° to the applied stresses?
 (a) 2σ (b) $\sigma/2$
 (c) $\sigma/4$ (d) Zero

[ESE : 2005]

- 3.5 Match List-I (State of stress) with List-II (Kind of loading) and select the correct answer using the codes given below the lists:



List-II

1. Combined bending and torsion of circular shaft
2. Torsion of circular shaft
3. Thin cylinder subjected to internal pressure
4. Tie bar subjected to tensile force

Codes:

	A	B	C	D
(a)	2	1	3	4
(b)	3	4	2	1
(c)	2	4	3	1
(d)	3	1	2	4

[ESE : 2006]

- 3.6 A body is subjected to a pure tensile stress of 100 units. What is the maximum shear produced in the body at some oblique plane due to the above?

- (a) 100 units (b) 75 units
 (c) 50 units (d) 0 units

[ESE : 2006]

- 3.7 In a strained material, normal stresses on two mutually perpendicular planes are σ_x and σ_y (both alike) accompanied by a shear stress τ_{xy} . One of the principal stresses will be zero, only if

- (a) $\tau_{xy} = \frac{\sigma_x \times \sigma_y}{2}$ (b) $\tau_{xy} = \sigma_x \times \sigma_y$
 (c) $\tau_{xy} = \sqrt{\sigma_x \times \sigma_y}$ (d) $\tau_{xy} = \sqrt{\sigma_x^2 + \sigma_y^2}$

[ESE : 2006]

3.8 In a Mohr's circle, the radius of the circle is taken as

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

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

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

(d) $\sqrt{(\sigma_x - \sigma_y)^2 - (\tau_{xy})^2}$

where, σ_x and σ_y are normal stresses along x and y directions respectively, and τ_{xy} is the shear stress

[ESE : 2006]

3.9 Principal strains at a point are $+100 \times 10^{-6}$ and -200×10^{-6} . What is the maximum shear strain at the point?

- (a) 300×10^{-6} (b) 200×10^{-6}
(c) 150×10^{-6} (d) 100×10^{-6}

[ESE : 2006]

3.10 In a strained material one of the principal stresses is twice the other. The maximum shear stress in the same case is $\tau_{\max}$. Then, what is the value of the maximum principal stress?

- (a) $\tau_{\max}$ (b) $2\tau_{\max}$
(c) $4\tau_{\max}$ (d) $8\tau_{\max}$

[ESE : 2007]

3.11 For a general two dimensional stress system, what are the coordinates of the centre of Mohr's circle?

- (a) $\frac{\sigma_x - \sigma_y}{2}, 0$ (b) $0, \frac{\sigma_x + \sigma_y}{2}$
(c) $\frac{\sigma_x + \sigma_y}{2}, 0$ (d) $0, \frac{\sigma_x - \sigma_y}{2}$

[ESE : 2007]

3.12 Maximum shear stress in a Mohr's Circle

- (a) is equal to radius of Mohr's circle
(b) is greater than radius of Mohr's circle
(c) is less than radius of Mohr's circle
(d) could be any the above

[ESE : 2008]

3.13 The principal stresses at a point in two-dimensional stress system are σ_1 and σ_2 and corresponding principal strains are ϵ_1 and ϵ_2 . If E and μ denote Young's modulus and Poisson's ratio, respectively, then which one of the following is correct?

(a) $\sigma = E \epsilon_1$

(b) $\sigma = \frac{E}{1 - \mu^2} [\epsilon_1 + \mu \epsilon_2]$

(c) $\sigma = \frac{E}{1 - \mu^2} [\epsilon_1 - \mu \epsilon_2]$

(d) $\sigma = E (\epsilon_1 - \mu \epsilon_2)$

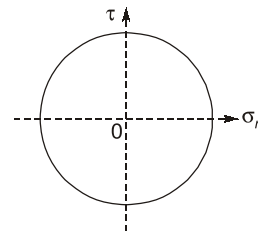
[ESE : 2008]

3.14 A point in a two dimensional state of strain is subjected to pure shearing strain of magnitude γ_{xy} radians. Which one of the following is the maximum principal strain?

(a) γ_{xy} (b) $\frac{\gamma_{xy}}{\sqrt{2}}$

(c) $\frac{\gamma_{xy}}{2}$ (d) $2\gamma_{xy}$ [ESE : 2008]

3.15 Consider the Mohr's circle shown below:



What is the state of stress represented by this circle?

- (a) $\sigma_x = \sigma_y \neq 0, \tau_{xy} = 0$ (b) $\sigma_x = \sigma_y = 0, \tau_{xy} \neq 0$
(c) $\sigma_x = 0, \sigma_y = \tau_{xy} \neq 0$ (d) $\sigma_x \neq 0, \sigma_y = \tau_{xy} = 0$

[ESE : 2008]

3.16 Assertion (A): Mohr's construction is possible for stresses, strains and area moment of inertia.

Reason (R) : Mohr's circle represents the transformation of second-order tensor.

- (a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2009]

3.17 Consider the following statements :

- Two-dimensional stresses applied to a thin plate in its own plane represent the plane stress condition.
- Under plane stress condition, the strain in the direction perpendicular to the plane is zero.
- Normal and shear stresses may occur simultaneously on a plane.

Which of these statements is/are correct?

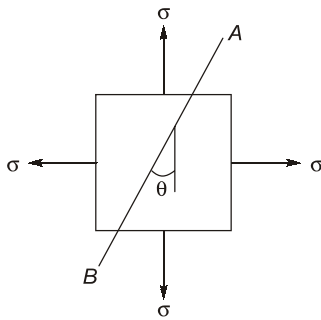
- (a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 1 and 3 [ESE : 2009]

3.18 The principal strains at a point in a body, under biaxial state of stress, are 1000×10^{-6} and -600×10^{-6} . What is the maximum shear strain at that point?

- (a) 200×10^{-6} (b) 800×10^{-6}
(c) 1000×10^{-6} (d) 1600×10^{-6}

[ESE : 2009]

3.19



A point in two-dimensional stress state, is subjected to biaxial stress as shown in the above figure. The shear stress acting on the plane AB is

- (a) Zero (b) σ
(c) $\sigma \cos^2 \theta$ (d) $\sigma \sin \theta \cdot \cos \theta$

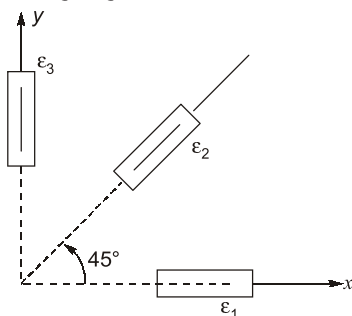
[ESE : 2010]

3.20 If the principal stresses and maximum shearing stresses are of equal numerical value at a point in a stressed body, the state of stress can be termed as

- (a) Isotropic (b) Uni-axial
(c) Pure shear
(d) Generalized plane state of stress

[ESE : 2010]

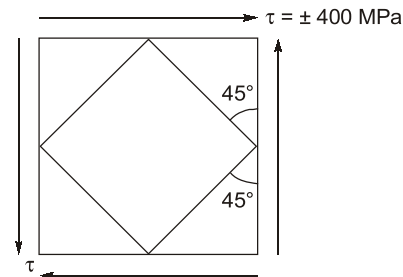
3.21 A rectangular strain rosette, shown in figure, give following readings in a strain measurement task $\epsilon_1 = 1000 \times 10^{-6}$, $\epsilon_2 = 800 \times 10^{-6}$ and $\epsilon_3 = 600 \times 10^{-6}$. The direction of the major principal strain with respect to gauge 1 is



- (a) 0° (b) 15°
(c) 30° (d) 45°

[ESE : 2011]

3.22 What are the normal and shear stresses on the 45° planes shown?



- (a) $\sigma_1 = -\sigma_2 = 400 \text{ MPa}$ and $\tau = 0$
(b) $\sigma_1 = \sigma_2 = 400 \text{ MPa}$ and $\tau = 0$
(c) $\sigma_1 = \sigma_2 = -400 \text{ MPa}$ and $\tau = 0$
(d) $\sigma_1 = \sigma_2 = \tau = \pm 200 \text{ MPa}$

[ESE : 2011]

3.23 A piece of material is subjected to two perpendicular tensile stresses of 70 MPa and 10 MPa. The magnitude of the resultant stress on a plane in which the maximum shear stress occurs is

- (a) 70 MPa (b) 60 MPa
(c) 50 MPa (d) 10 MPa

[ESE : 2012]

3.24 Statement (I): Mohr's circle of stress can be related to Mohr's circle of strain by some constant of proportionality.

Statement (II): The relationship is a function of yield strength of the material.

- (a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2012]

3.25 The state of plane stress at a point in a loaded member is given by :

$$\sigma_x = +800 \text{ MPa}, \quad \sigma_y = +200 \text{ MPa}$$

$$\tau_{xy} = \pm 400 \text{ MPa}$$

The maximum principal stress and maximum shear stress are given by :

- (a) $\sigma_{\max} = 800 \text{ MPa}$ and $\tau_{\max} = 400 \text{ MPa}$
(b) $\sigma_{\max} = 800 \text{ MPa}$ and $\tau_{\max} = 500 \text{ MPa}$

- (c) $\sigma_{\max} = 1000 \text{ MPa}$ and $\tau_{\max} = 500 \text{ MPa}$
 (d) $\sigma_{\max} = 1000 \text{ MPa}$ and $\tau_{\max} = 400 \text{ MPa}$

[ESE : 2013]

3.26 Mohr's circle construction is valid for both stress, as well as the area moment of inertia because :

- (a) Both are tensors of first order
 (b) Both are tensors of second order
 (c) Both are axial vectors
 (d) Both occur under plane stress condition

[ESE : 2013]

3.27 Two principal tensile stresses of magnitude 40 MPa and 20 MPa are acting at a point across two perpendicular planes. An oblique plane makes an angle of 30° with the major principle plane. The normal stress on the oblique plane is

- (a) 8.66 MPa (b) 17.3 MPa
 (c) 35.0 MPa (d) 60.0 MPa

[ESE : 2014]

3.28 The state of stress at a point under plane stress condition is

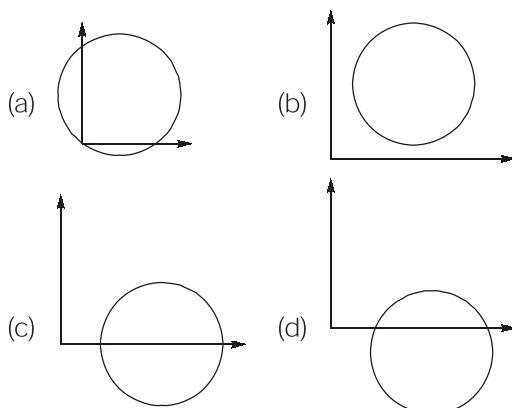
$$\sigma_{xx} = 60 \text{ MPa}, \sigma_{yy} = 120 \text{ MPa} \text{ and } \tau_{xy} = 40 \text{ MPa}$$

The radius of Mohr's circle representing the given state of stress in MPa is

- (a) 40 (b) 50
 (c) 60 (d) 120

[ESE : 2014]

3.29 Which of the following figures may represent Mohr's circle?



[ESE : 2014]

3.30 If Mohr's circle is drawn for the shear stress developed because of torque applied over a shaft, then the maximum shear developed will be equal to

- (a) diameter of the Mohr's circle
 (b) radius of the Mohr's circle

- (c) half of the radius of the Mohr's circle
 (d) 1.414 times radius of the Mohr's circle

[ESE : 2014]

3.31 A system under biaxial loading induces principal stresses of 100 N/mm^2 tensile and 50 N/mm^2 compressive at a point. The normal stress at that point on the maximum shear stress plane is

- (a) 75 N/mm^2 tensile
 (b) 50 N/mm^2 compressive
 (c) 100 N/mm^2 tensile
 (d) 25 N/mm^2 tensile

[ESE : 2015]

3.32 In a biaxial state of stress, normal stresses are $\sigma_x = 900 \text{ N/mm}^2$, $\sigma_y = 100 \text{ N/mm}^2$ and shear stress $\tau = 300 \text{ N/mm}^2$. The maximum principal stress is

- (a) 800 N/mm^2 (b) 900 N/mm^2
 (c) 1000 N/mm^2 (d) 1200 N/mm^2

[ESE : 2015]

3.33 The state of stress at a point in a body is given by $\sigma_x = 100 \text{ MPa}$ and $\sigma_y = 200 \text{ MPa}$. One of the principal stresses $\sigma_1 = 250 \text{ MPa}$. The magnitudes of the other principal stress and the shearing stress τ_{xy} are respectively

- (a) $50\sqrt{3} \text{ MPa}$ and 50 MPa
 (b) 100 MPa and $50\sqrt{3} \text{ MPa}$
 (c) 50 MPa and $50\sqrt{3} \text{ MPa}$
 (d) $50\sqrt{3} \text{ MPa}$ and 100 MPa

[ESE : 2015]

3.34 The magnitudes of principal stresses at a point are 250 MPa tensile and 150 MPa compressive. The magnitudes of the shearing stress on a plane on which the normal stress is 200 MPa tensile and the normal stress on a plane at right angle to this plane are

- (a) $50\sqrt{7} \text{ MPa}$ and 100 MPa (tensile)
 (b) 100 MPa and 100 MPa (compressive)
 (c) $50\sqrt{7} \text{ MPa}$ and 100 MPa (compressive)
 (d) 100 MPa and $50\sqrt{7} \text{ MPa}$ (tensile)

[ESE : 2015]

3.35 The state of stress at a point is given by $\sigma_x = 100 \text{ MPa}$ and $\sigma_y = -50 \text{ MPa}$ and $\tau_{xy} = 100 \text{ MPa}$. The centre of Mohr's circle and its radius will be

- (a) ($\sigma_x = 75$ MPa, $\tau_{xy} = 0$) and 75 MPa
 (b) ($\sigma_x = 25$ MPa, $\tau_{xy} = 0$) and 125 MPa
 (c) ($\sigma_x = 25$ MPa, $\tau_{xy} = 0$) and 150 MPa
 (d) ($\sigma_x = 75$ MPa, $\tau_{xy} = 0$) and 125 MPa

[ESE : 2015]

3.36 Consider the following statements related to Mohr's circle for stresses in case of plane stress:

1. The construction is for variations of stress in a body.
2. The radius of the circle represents the magnitude of the maximum shearing stress.
3. The diameter represents the difference between the two principal stresses.

Which of the above statements are correct?

- (a) 1, 2 and 3 (b) 2 and 3 only
 (c) 1 and 3 only (d) 1 and 2 only

[ESE : 2015]

3.37 At a point in a body, $\epsilon_1 = 0.0004$ and $\epsilon_2 = -0.00012$. If $E = 2 \times 10^5$ MPa and $\mu = 0.3$, the smallest normal stress and the largest shearing stress are

- (a) 40 MPa and 40 MPa
 (b) 0 MPa and 40 MPa
 (c) 80 MPa and 0 MPa
 (d) 0 MPa and 80 MPa

[ESE : 2015]

3.38 Two strain gauges fixed along the principal directions on a plane surface of a steel member recorded strain values of 0.0013 tensile and 0.0013 compressive respectively.

Given that the value of $E = 2 \times 10^5$ MPa and $\mu = 0.3$, the largest normal and shearing stress at this point are

- (a) 200 MPa and 200 MPa
 (b) 400 MPa and 200 MPa
 (c) 260 MPa and 260 MPa
 (d) 260 MPa and 520 MPa

[ESE : 2015]

3.39 The state of stress at a point when completely specified enables one to determine the

1. maximum shearing stress at the point
2. stress components on any arbitrary plane containing that point

Which of the above is/are correct?

- (a) 1 only (b) 2 only
 (c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2016]

3.40 A body is subjected to a direct tensile stress of 300 MPa in one plane accompanied by a simple shear stress of 200 MPa. The maximum normal stress on the plane will be

- (a) 100 MPa (b) 200 MPa
 (c) 300 MPa (d) 400 MPa

[ESE : 2016]

3.41 A metal piece under the state of stress of three principal stresses 30, 10 and 5 kg/mm² is undergoing plastic deformation. The principal strain rates will be in the proportions of

- (a) 15, -5 and -10 (b) -15, 5 and -10
 (c) 15, 5 and 10 (d) -15, -5 and 10

[ESE : 2016]

3.42 A state of plane stress consists of a uniaxial tensile stress of magnitude 8 kPa, exerted on vertical surfaces and of unknown shearing stresses. If the largest stress is 10 kPa, then the magnitude of the unknown shear stress will be

- (a) 6.47 kPa (b) 5.47 kPa
 (c) 4.47 kPa (d) 3.47 kPa

[ESE : 2018]

3.43 The principal stresses at a point in an elastic material are 60 N/mm² tensile, 20 N/mm² tensile and 50 N/mm² compressive. What is the volumetric strain by considering Young's Modulus as 100×10^3 N/mm² and $\mu = 0.3$?

- (a) 1.20×10^{-4} (b) 1.06×10^{-5}
 (c) 1.30×10^{-3} (d) 1.12×10^{-2}

[ESE : 2021]

3.44 The stresses on two perpendicular planes through a point in a body are 160 MPa and 100 MPa, both compressive, along with a shear stress of 80 MPa. What is the normal stress on a plane inclined at 30° to the plane of 160 MPa stress?

- (a) -42.4 MPa (b) -75.7 MPa
 (c) -59.1 MPa (d) -86.3 MPa

[ESE : 2021]

3.45 When a body is acted upon by pure shear stresses on two perpendicular planes, the planes inclined at 45° are subjected to

- (a) a tensile stress of magnitude equal to that of the shear stress
 (b) a compressive stress of magnitude equal to that of the shear stress

- (c) a torsional stress of magnitude equal to that of the shear stress
 (d) a bending stress of magnitude equal to that of the shear stress

[ESE : 2024]

3.46 A piece of material is subjected to same two perpendicular tensile stresses of 100 MPa each. What is the direct stress?

- (a) 90 MPa (b) 100 MPa
 (c) 96 MPa (d) 86 MPa

[ESE : 2024]

3.47 When a body is acted upon by pure shear stresses on two perpendicular planes, the planes inclined at 135° are subjected to

- (a) a tensile stress of same magnitude with no shear stress on these planes.
 (b) a compressive stress of same magnitude with no shear stress on these planes.
 (c) a torsional stress of same magnitude with no shear stress on these planes.
 (d) a bending stress of same magnitude with no shear stress on these planes.

[ESE : 2024]

3.48 Consider the following statements regarding general conventions in stress analysis :

1. Tensile stress is positive and compressive stress is negative.
2. A pair of shear stresses on parallel planes forming a clockwise couple is positive and a pair with a counterclockwise couple is negative.
3. Clockwise angle is taken as negative and counterclockwise couple is positive.

Which of the above statements are correct?

- (a) 1 and 2 only (b) 1 and 3 only
 (c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2024]

3.49 The planes on which the shear stress is zero are known as

- (a) normal planes (b) tangential planes
 (c) orthogonal planes (d) principal planes

[ESE : 2025]

3.50 What is the expression for normal stress when two perpendicular stresses are acting accompanied with a state of simple shear?

(a) $p_1 \cos^2 \theta + p_2 \sin^2 \theta + q \sin 2\theta$

(b) $\left\{ \frac{(p_1 + p_2)}{2} \right\} \sin 2\theta + q \cos \theta$

(c) $p_1 \sin^2 \theta + p_2 \cos^2 \theta + q \sin 2\theta$

(d) $\left\{ \frac{(p_1 + p_2)}{2} \right\} \cos 2\theta + q \sin 2\theta$

where symbols have their usual meanings.

[ESE : 2025]



Answers Principal Stresses and Strains and Mohr's Circle

- 3.1 (b) 3.2 (d) 3.3 (c) 3.4 (d) 3.5 (c) 3.6 (c) 3.7 (c) 3.8 (b) 3.9 (a)
 3.10 (c) 3.11 (c) 3.12 (a) 3.13 (b) 3.14 (c) 3.15 (b) 3.16 (a) 3.17 (d) 3.18 (d)
 3.19 (a) 3.20 (c) 3.21 (a) 3.22 (a) 3.23 (c) 3.24 (c) 3.25 (c) 3.26 (b) 3.27 (c)
 3.28 (b) 3.29 (c) 3.30 (b) 3.31 (d) 3.32 (c) 3.33 (c) 3.34 (c) 3.35 (b) 3.36 (b)
 3.37 (b) 3.38 (a) 3.39 (c) 3.40 (d) 3.41 (a) 3.42 (c) 3.43 (a) 3.44 (b) 3.45 (a, b)
 3.46 (b) 3.47 (a, b) 3.48 (d) 3.49 (d) 3.50 (a)

Explanations Principal Stresses and Strains and Mohr's Circle**3.1 (b)**

Mohr circle for pure shear in which σ_1 and σ_2 are equal to radius (60 MPa)

3.2 (d)

$$\begin{aligned}\text{Centre (a, 0)} &= \left(\frac{\sigma_x + \sigma_y}{2}, 0 \right) \\ &= \left(\frac{200 - 100}{2}, 0 \right) = (50, 0)\end{aligned}$$

3.3 (c)

Radius of mohr's circle

$$\begin{aligned}&= \sqrt{\left(\frac{100 - 40}{2} \right)^2 + (40)^2} = 50 \text{ N/mm}^2 \\ &= 5 \text{ cm} \quad (\because 1 \text{ cm} = 10 \text{ N/mm}^2)\end{aligned}$$

3.4 (d)

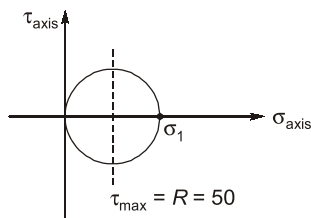
$$\sigma_\theta = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} \cos 2\theta + \tau_{xy} \sin 2\theta.$$

Here, $\sigma_x = \sigma$, $\sigma_y = -\sigma$, $\tau_{xy} = 0$ and $\theta = 45^\circ$

$$\therefore \sigma_\theta = 0$$

3.6 (c)

$$\tau_{\max} = \frac{\sigma}{2} = \frac{100}{2} = 50 \text{ units.}$$

**3.7 (c)**

If one of the principal stress = 0

$$\Rightarrow \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2} \right)^2 + \tau_{xy}^2} = 0$$

$$\therefore \tau_{xy} = \sqrt{\sigma_x \sigma_y}$$

3.8 (b)

In Mohr circle, radius of circle

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

3.9 (a)

Maximum shear strain

$$\Rightarrow \frac{\gamma_{\max}}{2} = \frac{\epsilon_1 - \epsilon_2}{2}$$

$$\Rightarrow \frac{\gamma_{\max}}{2} = \frac{100 \times 10^{-6} + 200 \times 10^{-6}}{2}$$

$$\Rightarrow \frac{\gamma_{\max}}{2} = 150 \times 10^{-6}$$

$$\therefore \gamma_{\max} = 300 \times 10^{-6}$$

3.10 (c)

Given $\sigma_1 = 2\sigma_2$

We know that

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{\sigma_1 - \frac{\sigma_1}{2}}{2}$$

$$\therefore \sigma_1 = 4 \tau_{\max}$$

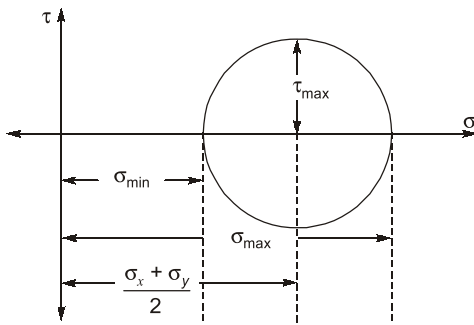
3.11 (c)

The general equation of Mohr's circle

$$\left(\sigma_0 - \frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau_0^2 = \left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2$$

$$\text{Centre} \equiv \left(\frac{\sigma_x + \sigma_y}{2}, 0\right)$$

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

3.12 (a)**3.13 (b)**

$$\epsilon_1 = \frac{\sigma_1}{E} - \mu \frac{\sigma_2}{E}$$

$$E\epsilon_1 = \sigma_1 - \mu\sigma_2 \quad \dots(i)$$

$$E\epsilon_2 = \sigma_2 - \mu\sigma_1 \quad \dots(ii)$$

From equations (i) and (ii),

$$E\epsilon_1 = \sigma_1 - \mu[E\epsilon_2 + \mu\sigma_1]$$

$$E\epsilon_1 = \sigma_1 - \mu E\epsilon_2 - \mu^2\sigma_1$$

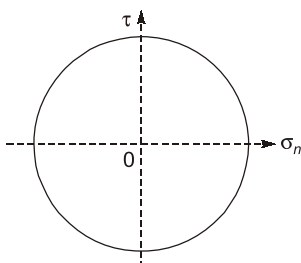
$$E(\epsilon_1 + \mu\epsilon_2) = \sigma_1(1 - \mu^2)$$

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

3.14 (c)

Pure shearing strain of magnitude $= \gamma_{xy}$ radians.

$\therefore$ Maximum principal strain $= \gamma_{xy}/2$

3.15 (b)

The state of stress represented by $\sigma_x = \sigma_y = 0, \tau_{xy} \neq 0$

3.16 (a)

1. Mohr's construction is possible for stress strains and area moment of inertia. Since Mohr's Circle represents the trans-formation of second-order tensor.

3.17 (d)

1. Two-dimensional stresses applied to a thin plate in its own plane represent the plane stress condition.
2. Under plane stress condition, the strain in the direction perpendicular to the plane is not zero.
3. Normal and shear stresses may occur simultaneously on a plane.

$$\epsilon_x = \frac{\sigma}{E}, \quad \epsilon_y = -\frac{\mu\sigma}{E}, \quad \epsilon_z = -\frac{\mu\sigma}{E}$$

3.18 (d)

$$\begin{aligned} \frac{\epsilon_x - \epsilon_y}{2} &= \frac{\gamma_{xy}}{2} \\ \Rightarrow \gamma_{xy} &= \epsilon_x - \epsilon_y \\ &= 1000 \times 10^{-6} - (-600 \times 10^{-6}) \\ &= 1600 \times 10^{-6} \end{aligned}$$

3.19 (a)

$$\tau = -\left(\frac{\sigma_x - \sigma_y}{2}\right) \sin 2\theta$$

Here, $\sigma_x = \sigma_y = \sigma$

$$\tau = -\left(\frac{\sigma - \sigma}{2}\right) \sin 2\theta = 0$$

3.20 (c)

For pure shear

$$\sigma_1 = \tau_{xy}, \quad \sigma_2 = -\tau_{xy}$$

Hence, $\sigma_1 = -\sigma_2$

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{\sigma_1 + \sigma_1}{2} = \sigma_1$$

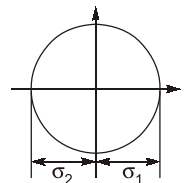
3.22 (a)

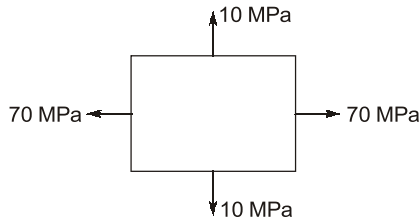
It is cause of pure shear stress.

$$\sigma_1 = +400 \text{ MPa}$$

$$\sigma_2 = -400 \text{ MPa}$$

$$\tau = 0$$



3.23 (c)

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

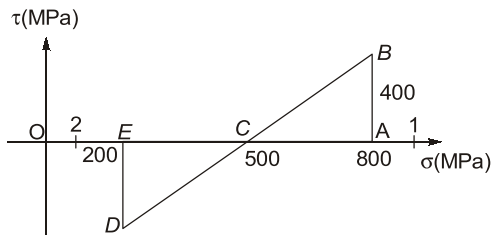
$$= 40 \pm [30]$$

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = 30 \text{ MPa}$$

Also, maximum shear stress occurs at $\theta = 45^\circ$

$$\sigma_x = \frac{\sigma_y + \sigma_x}{2} + \frac{\sigma_y - \sigma_x}{2} \cos 2\theta = 40 \text{ MPa}$$

$$\text{Resultant stress} = \sqrt{\sigma_n^2 + \tau^2} = 50 \text{ MPa}$$

3.25 (c)

BC(radius of Mohr's circle)

$$= \sqrt{400^2 + 300^2} = 500$$

$$\therefore \sigma_1 = OE + EC + BC$$

$$= 200 + 300 + 500 = 1000 \text{ MPa}$$

$$\tau_{\max} = BC = 500 \text{ MPa}$$

3.26 (b)

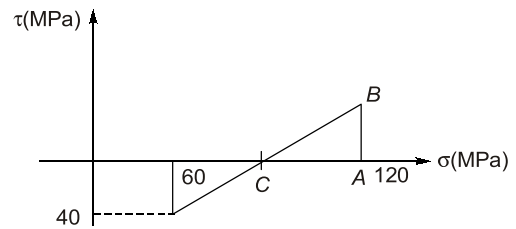
Stress at a point and area moment of inertia are 2nd order tensor which can be represented by 3×3 matrix.

3.27 (c)

$$\sigma_n = \left(\frac{\sigma_x + \sigma_y}{2}\right) + \left(\frac{\sigma_x - \sigma_y}{2}\right) \cos 2\theta$$

$$\sigma_n = \left(\frac{40 + 20}{2}\right) + \left(\frac{40 - 20}{2}\right) \cos 60^\circ$$

$$\sigma_n = 30 + 10 \times \frac{1}{2} = 35 \text{ MPa}$$

3.28 (b)

Radius of Mohr's circle = CB

$$CB = \sqrt{CA^2 + AB^2}$$

$$AB = 40$$

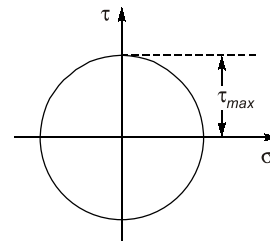
$$CA = \frac{120 - 60}{2} = 30$$

$$\therefore CB = \sqrt{30^2 + 40^2} = 50 \text{ MPa}$$

Alternate:

$$R = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} = \sqrt{\left(\frac{60 - 120}{2}\right)^2 + 40^2}$$

$$= 50 \text{ MPa}$$

3.30 (b)**3.31 (d)**

$$\sigma_1 = 100 \text{ N/mm}^2; \quad \sigma_2 = -50 \text{ N/mm}^2$$

Maximum shear stress will be corresponding to the centre of Mohr circle.

$$\text{Centre of Mohr Circle} \left[\frac{\sigma_1 + \sigma_2}{2}, 0 \right] \text{ i.e. } [25, 0]$$

So normal stress at maximum shear stress point is 25 N/mm^2 tensile.

3.32 (c)

$$\sigma_x = 900 \text{ MPa}; \quad \sigma_y = 100 \text{ MPa}$$

$$\text{and} \quad \tau_{xy} = 300 \text{ MPa}$$

$$\sigma_1 = \frac{1}{2} \left[(\sigma_x + \sigma_y) + \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2} \right]$$

$$= \frac{1}{2} [1000 + \sqrt{800^2 + 4 \times 300^2}]$$

$$\sigma_1 = \frac{1000 + 1000}{2}$$

$$= 1000 \text{ MPa} = 1000 \text{ N/mm}^2$$

3.33 (c)

$$\sigma_x = 100 \text{ MPa}; \quad \sigma_y = 200 \text{ MPa}$$

$$\sigma_1 = 250 \text{ MPa}$$

We know that

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

$$\sigma_2 = 300 - 250 = 50 \text{ MPa}$$

$$\text{and } \sigma_1 = \frac{1}{2}[(\sigma_x + \sigma_y) + \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}]$$

$$250 = \frac{1}{2}[300 + \sqrt{(-100)^2 + 4\tau_{xy}^2}]$$

$$500 = 300 + \sqrt{100^2 + 4\tau_{xy}^2}$$

$$200^2 = 100^2 + 4\tau_{xy}^2$$

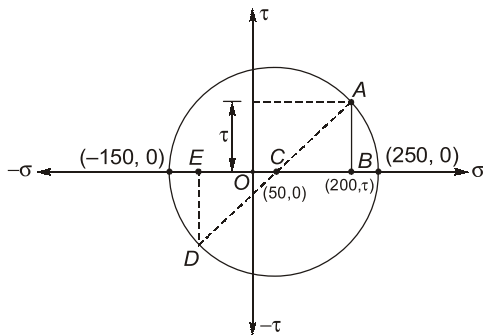
$$40000 - 10000 = 4\tau_{xy}^2$$

$$\sqrt{\frac{30000}{4}} = \tau_{xy}$$

$$\text{or } \tau_{xy} = 50\sqrt{3}$$

3.34 (c)

$$\sigma_1 = 250 \text{ MPa}; \quad \sigma_2 = -150 \text{ MPa}$$



In $\triangle ABC$

AC = radius of Mohr circle

$$= \frac{\sigma_1 - \sigma_2}{2} = \frac{400}{2} = 200$$

$$BC = 150$$

$$AB = \tau = \sqrt{200^2 - 150^2} = 50\sqrt{7} \text{ MPa}$$

$\Rightarrow CD$ plane is right angle to plane AC
(in mohr circle angle between two planes is represented by double of its actual value)

$\Rightarrow$ from $\triangle ACB$ and $\triangle ECD$

$$CB = CE = CO + OE$$

$$150 = 50 + OE$$

$$OE = 100 \text{ MPa (compressive)}$$

3.35 (b)

$$\sigma_x = 100 \text{ MPa}; \quad \sigma_y = -50 \text{ MPa}; \quad \tau_{xy} = 100 \text{ MPa}$$

$$\text{Centre of Mohr circle } \left[\frac{\sigma_x + \sigma_y}{2}, 0 \right] = [25, 0]$$

$$\text{Radius} = \frac{\sigma_1 - \sigma_2}{2}$$

$$\sigma_{1,2} = \frac{1}{2}[(\sigma_x + \sigma_y) \pm \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}]$$

$$= \frac{1}{2}[50 \pm \sqrt{150^2 + 4 \times 100^2}]$$

$$= \frac{1}{2}[50 \pm 250]$$

$$\sigma_1 = 150 \text{ MPa}; \quad \sigma_2 = -100$$

$$\text{Radius of Mohr circle} = \frac{250}{2} = 125 \text{ MPa}$$

3.36 (b)

Plane stress condition is 2-dimensional whereas body considers 3-dimensions.

$\Rightarrow$ Mohr circle's construction is for variations of stress in a plane.

3.37 (b)

$$\epsilon_1 = 0.0004; \quad \epsilon_2 = -0.00012; \quad \mu = 0.3$$

$$E = 2 \times 10^5 \text{ MPa}$$

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

$$\sigma_1 = \frac{2 \times 10^5}{1-0.09}[0.0004 + 0.3 \times (-0.00012)]$$

$$\sigma_1 = 80 \text{ MPa}$$

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

$$= \frac{2 \times 10^5}{1-0.09}(-0.00012 + 0.3 \times 0.0004)$$

$$\sigma_2 = 0$$

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{80 - 0}{2} = 40 \text{ MPa}$$

3.38 (a)

$$\epsilon_1 = 0.0013; \quad \epsilon_2 = -0.0013$$

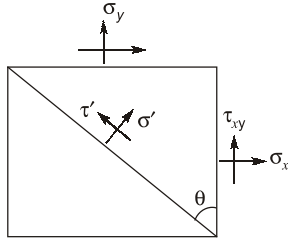
$$E = 2 \times 10^5; \quad \mu = 0.3$$

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

$$= \frac{2 \times 10^5}{1-0.09}[0.0013 - 0.3 \times 0.0013]$$

$$\sigma_1 = 200 \text{ MPa}; \sigma_2 = -200 \text{ MPa}$$

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = 200 \text{ MPa}$$

3.39 (c)

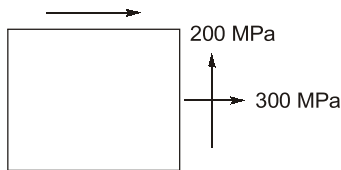
Maximum shear stress,

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

Normal stress on oblique plane

$$\sigma' = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} \cos 2\theta + \tau_{xy} \sin 2\theta$$

$$\tau' = \left(\frac{\sigma_x - \sigma_y}{2}\right) \sin 2\theta + \tau_{xy} \cos 2\theta$$

3.40 (d)

Maximum normal stress,

$$\begin{aligned} \sigma_1 &= \frac{300}{2} + \sqrt{\left(\frac{300}{2}\right)^2 + 200^2} \\ &= 150 + \sqrt{150^2 + 200^2} = 400 \text{ MPa} \end{aligned}$$

3.41 (a)

For plastic deformation,

$$\mu = 0.5$$

Principal strain,

$$\begin{aligned} \epsilon_1 &= \frac{\sigma_1}{E} - \frac{\mu \sigma_2}{E} - \frac{\mu \sigma_3}{E} \\ &= \frac{30 - (0.5 \times 10) - (0.5 \times 5)}{E} = \frac{22.5}{E} \end{aligned}$$

$$\begin{aligned} \epsilon_1 &= \frac{\sigma_2}{E} - \frac{\mu \sigma_1}{E} - \frac{\mu \sigma_3}{E} \\ &= \frac{10 - (0.5 \times 30) - (0.5 \times 5)}{E} \end{aligned}$$

$$\epsilon_2 = \frac{-7.5}{E}$$

and

$$\begin{aligned} \epsilon_3 &= \frac{\sigma_3}{E} - \frac{\mu \sigma_1}{E} - \frac{\mu \sigma_2}{E} \\ &= \frac{5 - (0.5 \times 30) - (0.5 \times 10)}{E} \\ &= \frac{-15}{E} \end{aligned}$$

$$\begin{aligned} \therefore \epsilon_1 : \epsilon_2 : \epsilon_3 &= 22.5 : -7.5 : -15 \\ &= 15 : -5 : -10 \end{aligned}$$

3.42 (c)

$$\sigma_1 = 10 \text{ kPa}$$

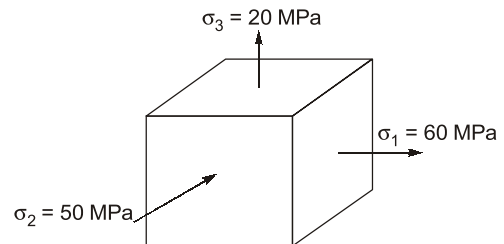
$$\sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau^2}$$

$$10 = \frac{8}{2} + \sqrt{\left(\frac{8}{2}\right)^2 + \tau^2}$$

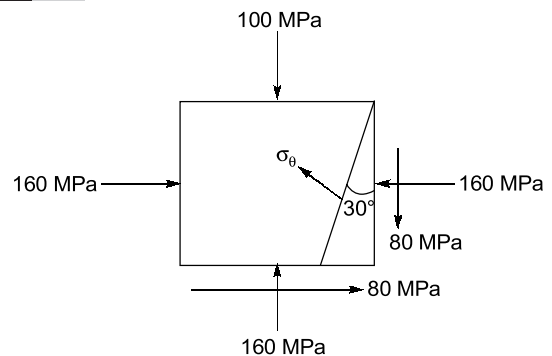
$$6 = \sqrt{4^2 + \tau^2}$$

$$36 = 16 + \tau^2 \Rightarrow \tau^2 = 20$$

$$\tau = 4.47 \text{ kPa}$$

3.43 (a)

$$\begin{aligned} \epsilon_v &= \left(\frac{1-2\mu}{E}\right)(\sigma_1 + \sigma_2 + \sigma_3) \\ &= \left(\frac{1-2 \times 0.3}{100 \times 10^3}\right)(60 - 50 + 20) \\ \epsilon_v &= 1.2 \times 10^{-4} \end{aligned}$$

3.44 (b)

$$\sigma_x = -160 \text{ MPa}$$

$$\sigma_y = -100 \text{ MPa}$$

$$\tau_{xy} = 80 \text{ MPa}$$

$$\theta = 30^\circ$$

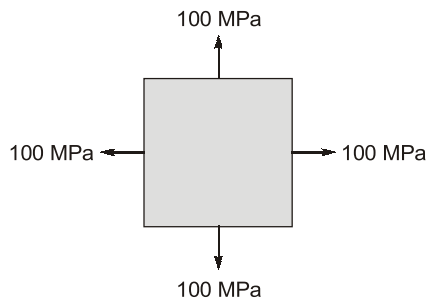
$$\begin{aligned}\sigma_\theta &= \frac{1}{2}(\sigma_x + \sigma_y) + \frac{1}{2}(\sigma_x - \sigma_y)\cos 2\theta + \tau \sin 2\theta \\ &= \frac{1}{2}(-160 - 100) + \frac{1}{2}(-160 + 100)\cos 60^\circ + 80 \sin 60^\circ \\ &= -130 + \frac{1}{2} \times -60 \times \frac{1}{2} + 80 \times \frac{\sqrt{3}}{2} \\ &= -145 + 40 \times 1.732 \\ &= -145 + 69.28 = -75.2 \text{ MPa}\end{aligned}$$

3.45 (a, b)

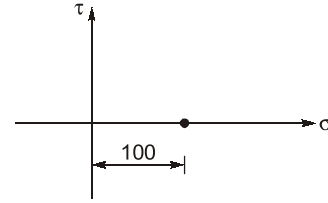
Here, it is not mentioned that the plane is inclined by 45° in clockwise or anticlockwise manner. Also, the sense of applied shear stresses is not mentioned. Hence, the stress on given plane can be both tensile or compressive.

3.46 (b)

In element is shown below



The corresponding Mohr circle will be a point as shown below:



Hence, direct stress on every plane will be 100 MPa.

3.47 (a, b)

Here, it is not mentioned that the plane is inclined by 135° in clockwise or anticlockwise manner. Also, the sense of applied shear stresses is not mentioned. Hence, the stress on given plane can be both tensile or compressive.

3.49 (d)

The planes on which the shear stress is zero are known as principal planes.

3.50 (a)

Given : $\sigma_x = p_1$, $\sigma_y = p_2$, $\tau_{xy} = q$

As we know,

$$\sigma_n = \frac{1}{2}(\sigma_x + \sigma_y) + \frac{1}{2}(\sigma_x - \sigma_y)\cos 2\theta + \tau_{xy} \sin 2\theta$$

On simplifying,

$$\sigma_n = \sigma_x \cos^2 \theta + \sigma_y \sin^2 \theta + \tau_{xy} \sin 2\theta$$

On putting, $\sigma_x = p_1$, $\sigma_y = p_2$, $\tau_{xy} = q$

$$\text{We get, } \sigma_n = p_1 \cos^2 \theta + p_2 \sin^2 \theta + q \sin 2\theta$$

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