1. Determine the internal axial forces in segments (1), (2) and (3).

(a) $N_1 = \underline{\phantom{000}0} \text{kN}$

(b) $N_2 = \underline{\phantom{000}0} \text{kN}$

(c) $N_3 = \underline{\phantom{000}0} \text{kN}$

2. Rigid bar ABC supports a weight of $W = 50 \text{kN}$. Bar $ABC$ is pinned at $A$ and supported at $B$ by rod (1). What is the axial force in rod (1)?

$N_1 = \underline{\phantom{000}0} \text{kN}$

3. Determine the axial force in bar $AB$.

$N_{AB} = \underline{\phantom{000}0} \text{kN}$
4. A torque of \( T = 32 \text{ kN-m} \) is transmitted between two flanged shafts by means of six bolts. Determine the shear force in each bolt.

\[ V_{\text{bolt}} = \underline{\:\:\:\:\:\:\:\:\:\:\:} \text{kN} \]

5. For the pin connection shown, determine the normal stress acting on the gross area, the normal stress acting on the net area, the shear stress in the pin, and the bearing stress in the steel plate at the pin.

(a) \( \sigma_{\text{gross}} = \underline{\:\:\:\:\:\:\:\:\:\:\:} \text{MPa} \)

(b) \( \sigma_{\text{net}} = \underline{\:\:\:\:\:\:\:\:\:\:\:} \text{MPa} \)

(c) \( \tau_{\text{pin}} = \underline{\:\:\:\:\:\:\:\:\:\:\:} \text{MPa} \)

(d) \( \sigma_{b} = \underline{\:\:\:\:\:\:\:\:\:\:\:} \text{MPa} \)
6. A metal rod having two different diameters is loaded by an axial force $P$. Segments (1) and (2) are circular in cross section with diameters of 40 mm and 25 mm, respectively. If the normal stress in (1) is 65 MPa, what is the normal stress in segment (2)?

$\sigma_2 = \underline{\text{MPa}}$

7. The five-bolt connection must support an applied load of $P = 600$ kN. If the diameter of each bolt is 35 mm, determine the average shear stress in each bolt.

$\tau = \underline{\text{MPa}}$

8. The three-bolt connection must support an applied load of $P = 600$ kN. If the average shear stress in each bolt must be limited to 210 MPa, determine the minimum bolt diameter that may be used in the connection.

$d = \underline{\text{mm}}$
9. The steel pipe column has an outside diameter of 8 in. and wall thickness of 0.5 in. The timber beam is 11 in. wide, and the upper plate has the same width. The load imposed on the column by the timber beam is 80 kips. Determine the length $L$ of the rectangular upper bearing plate if the average bearing stress between the steel plate and the wood beam is not to exceed 500 psi.

$L = \phantom{0} \text{in.}$

10. Rigid bar $ABCD$ is supported by two vertical bars. There is no strain in the vertical bars before load $P$ is applied. After load $P$ is applied, the axial strain in bar (2) is $700 \, \mu\text{m/m}$. Determine the axial strain in bar (1).

$\varepsilon_1 = \phantom{0} \mu\text{m/m}$

11. A thin rectangular plate is uniformly deformed as shown. Determine the shear strain $\gamma_{xy}$ at $P$.

$\gamma_{xy} = \phantom{0} \mu\varepsilon$
12. Two gage marks are placed exactly 80 mm apart on a 18-mm-diameter solid metal rod. When an axial tension force of 90 kN is applied to the rod, the distance between the gage marks in precisely measured as 80.1800 mm. Determine the modulus of elasticity of the metal.

\[ E = \text{___________ GPa} \]

13. A 1.0-in. thick rectangular alloy bar is subjected to a tensile load \( P \) by pins at \( A \) and \( B \). The width of the bar is \( w = 4.0 \) in. Strain gages bonded to the specimen measure the following strains in the longitudinal (\( x \)) and transverse (\( y \)) directions: \( \varepsilon_x = 2100 \ u\varepsilon \) and \( \varepsilon_y = -650 \ u\varepsilon \). Determine Poisson’s ratio for this specimen.

\[ \nu = \text{___________} \]

14. A tension-test specimen with a diameter of 0.500 in. and an 8.0-in gage length was tested to fracture. Two graphs of the collected data are given on the next page. Determine the following.

(a) the modulus of elasticity = \text{___________ Msi} \\
(b) the proportional limit = \text{___________ ksi} \\
(c) the ultimate strength = \text{___________ ksi} \\
(d) the yield strength (0.20% offset) = \text{___________ ksi}
This graph is zoomed to show initial data.

This graph shows all of the collected data.
TRIGONOMETRY

\[ \sin \theta = \frac{\text{opp}}{\text{hyp}} \]
\[ \cos \theta = \frac{\text{adj}}{\text{hyp}} \]
\[ \tan \theta = \frac{\text{opp}}{\text{adj}} \]

STATICS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Equation</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x, y, z )</td>
<td>centroid position</td>
<td>( \bar{y} = \frac{\Sigma y_i A_i}{\Sigma A_i} )</td>
<td>in, m</td>
</tr>
<tr>
<td>( I )</td>
<td>moment of inertia</td>
<td>( I = \Sigma (l_i + d_i^2 A_i) )</td>
<td>in(^4). m(^4)</td>
</tr>
<tr>
<td>( J )</td>
<td>polar moment of inertia</td>
<td>( J_{\text{solid circular shaft}} = \pi d^4/32 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( J_{\text{hollow circular shaft}} = \pi (d_o^4 - d_i^4)/32 )</td>
<td></td>
</tr>
<tr>
<td>( N )</td>
<td>normal force</td>
<td>( V = \int -w(x) , dx )</td>
<td>lb, N</td>
</tr>
<tr>
<td>( V )</td>
<td>shear force</td>
<td>( M = \int V(x) , dx )</td>
<td>in-lb, Nm</td>
</tr>
<tr>
<td>( M )</td>
<td>bending moment</td>
<td>( \Sigma F = 0 ) [\Sigma M_{(\text{any point})} = 0 ]</td>
<td>lb, N</td>
</tr>
</tbody>
</table>

SECOND MOMENTS OF PLANE AREAS

<table>
<thead>
<tr>
<th>Area</th>
<th>Equation</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular Area</td>
<td>( A = bh ) ( I_x = \frac{bh^3}{12} ) ( I_y = \frac{b^3 h}{3} ) ( I_{xy} = 0 )</td>
<td>in(^4). m(^4)</td>
</tr>
<tr>
<td>Triangular Area</td>
<td>( A = \frac{1}{2}bh ) ( I_x = \frac{bh^3}{36} ) ( I_y = \frac{b^3 h}{12} ) ( I_{xy} = \frac{b^3 h}{24} )</td>
<td>in(^4). m(^4)</td>
</tr>
<tr>
<td>Circular Area</td>
<td>( A = \pi R^2 ) ( I_x = \frac{\pi R^4}{4} ) ( I_y = \frac{\pi R^4}{4} ) ( I_{xy} = 0 )</td>
<td>in(^4). m(^4)</td>
</tr>
<tr>
<td>Semicircular Area</td>
<td>( A = \frac{1}{2} \pi R^2 ) ( I_x = \frac{\pi R^4}{8} ) ( I_y = \frac{\pi R^4}{8} ) ( I_{xy} = 0 ) ( I_{xy} = R^4/8 )</td>
<td>in(^4). m(^4)</td>
</tr>
<tr>
<td>Quarter-Circular Area</td>
<td>( A = \frac{1}{4} \pi R^2 ) ( I_x = \frac{\pi R^4}{16} ) ( I_y = \frac{\pi R^4}{16} ) ( I_{xy} = R^4/16 )</td>
<td>in(^4). m(^4)</td>
</tr>
</tbody>
</table>

MECHANICS OF MATERIALS

<table>
<thead>
<tr>
<th>Topic</th>
<th>Symbol</th>
<th>Meaning</th>
<th>Equation</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial</td>
<td>( \sigma ), ( \sigma )</td>
<td>normal stress</td>
<td>( \sigma_{\text{axial}} = N/A )</td>
<td>psi, Pa</td>
</tr>
<tr>
<td></td>
<td>( \sigma )</td>
<td></td>
<td>( \tau_{\text{cutting}} = V/A )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \sigma )</td>
<td></td>
<td>( \sigma_{\text{bearing}} = F_b/A_b )</td>
<td></td>
</tr>
<tr>
<td>Epsilon</td>
<td>( \epsilon ), ( \epsilon )</td>
<td>normal strain</td>
<td>( \epsilon_{\text{axial}} = \frac{\Delta L}{L_0} = \frac{\delta L_0}{L_0} )</td>
<td>in/in, m/m</td>
</tr>
<tr>
<td>Shear</td>
<td>( \gamma ), ( \gamma )</td>
<td>shear strain</td>
<td>( \gamma = \text{change in angle, } \gamma = c\theta )</td>
<td>rad</td>
</tr>
<tr>
<td>Young's modulus</td>
<td>( E )</td>
<td></td>
<td>( \sigma = E \epsilon ) \text{ (one-dimensional only)}</td>
<td>psi, Pa</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>( G )</td>
<td></td>
<td>( G = \frac{\tau}{\gamma} = \frac{E}{2(1+\nu)} )</td>
<td>psi, Pa</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>( \nu ), ( \nu )</td>
<td></td>
<td>( \nu = -\epsilon^1/\epsilon^2 )</td>
<td></td>
</tr>
<tr>
<td>Deformation, elongation, deflection</td>
<td>( \delta ), ( \delta )</td>
<td></td>
<td>( \delta = NL/EA + \alpha \Delta T L_0 )</td>
<td>in, m</td>
</tr>
<tr>
<td>Coefficient of thermal expansion (CTE)</td>
<td>( \alpha ), ( \alpha )</td>
<td></td>
<td></td>
<td>in/inF, m/mC</td>
</tr>
<tr>
<td>Factor of safety</td>
<td>F.S.</td>
<td></td>
<td>( \text{F.S.} = \text{actual strength} / \text{design strength} )</td>
<td></td>
</tr>
<tr>
<td>Topic</td>
<td>Symbol</td>
<td>Meaning</td>
<td>Equation</td>
<td>Units</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
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<td>-------</td>
</tr>
<tr>
<td>torsion</td>
<td>τ, tau</td>
<td>shear stress</td>
<td>( \tau_{\text{torsion}} = \frac{T_c}{J} )</td>
<td>psi, Pa</td>
</tr>
<tr>
<td></td>
<td>( \phi, \phi )</td>
<td>angle of twist</td>
<td>( \phi = \frac{T}{LJ} )</td>
<td>rad, degrees</td>
</tr>
<tr>
<td></td>
<td>( \theta, \theta )</td>
<td>angle of twist per unit length, rate of twist</td>
<td>( \theta = \frac{\phi}{L} )</td>
<td>rad/in, rad/m</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>power</td>
<td>( P = \tau \omega )</td>
<td>watts = Nm/s hp=6600 in-lb/s</td>
</tr>
<tr>
<td></td>
<td>( \omega, \omega )</td>
<td>angular speed, speed of rotation</td>
<td>( \omega = 2\pi f )</td>
<td>Hz = rev/s</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>stress concentration factor</td>
<td>( \tau_{\text{max}} = KT_c/J )</td>
<td>psi, Pa</td>
</tr>
<tr>
<td>flexure</td>
<td>( \sigma, \sigma )</td>
<td>normal stress</td>
<td>( \sigma_{\text{beam}} = -\frac{M_y}{I} )</td>
<td>psi, Pa</td>
</tr>
<tr>
<td></td>
<td>( \sigma, \sigma )</td>
<td>composite beams, ( n = \frac{E_B}{E_A} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \tau, \tau )</td>
<td>shear stress</td>
<td>( \tau_{\text{beam}} = \frac{VQ}{I_B} ) where ( Q = \Sigma (y_{\text{bar}} A_i) )</td>
<td>psi, Pa</td>
</tr>
<tr>
<td></td>
<td>q</td>
<td>shear flow</td>
<td>( q = \frac{V_{\text{beam}} Q}{l} = nV_{\text{fastener}}/s )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>v or y</td>
<td>beam deflection</td>
<td>( v = \int \int M(x) , dx^2 / EI )</td>
<td>in, m</td>
</tr>
</tbody>
</table>

### Stress Transformation

#### Planar Rotations

\[
\sigma_u = \frac{(\sigma_x + \sigma_y)}{2} + \frac{(\sigma_x - \sigma_y)}{2} \cos(2\theta) + \tau_{xy} \sin(2\theta)
\]

\[
\sigma_v = \frac{(\sigma_x + \sigma_y)}{2} - \frac{(\sigma_x - \sigma_y)}{2} \cos(2\theta) - \tau_{xy} \sin(2\theta)
\]

\[
\tau_{uv} = -\frac{(\sigma_x - \sigma_y)}{2} \sin(2\theta) + \tau_{xy} \cos(2\theta)
\]

#### Principals and Max In-Plane Shear

\[
\tan(2\theta_p) = \frac{\gamma_{xy}}{\sigma_x - \sigma_y}
\]

\[
\theta_s = \theta_p \pm 45^\circ
\]

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

\[
\tau_{\text{max}} = \sqrt{\left(\frac{(\sigma_x - \sigma_y)}{2}\right)^2 + \tau_{xy}^2} = \frac{(\sigma_1 - \sigma_2)}{2}
\]

\[
\sigma_{\text{avg}} = \frac{(\sigma_x + \sigma_y)}{2}
\]

### Strain Transformation

#### Planar Rotations

\[
\varepsilon_u = \frac{(\varepsilon_x + \varepsilon_y)}{2} + \frac{(\varepsilon_x - \varepsilon_y)}{2} \cos(2\theta) + \gamma_{xy} \sin(2\theta)
\]

\[
\varepsilon_v = \frac{(\varepsilon_x + \varepsilon_y)}{2} - \frac{(\varepsilon_x - \varepsilon_y)}{2} \cos(2\theta) - \gamma_{xy} \sin(2\theta)
\]

\[
\gamma_{uv} = -\frac{(\varepsilon_x - \varepsilon_y)}{2} \sin(2\theta) + \gamma_{xy} \cos(2\theta)
\]

\[
\varepsilon_z = -\nu (\varepsilon_x + \varepsilon_y) / (1 - \nu)
\]

\[
\varepsilon_{\text{avg}} = \frac{(\varepsilon_x + \varepsilon_y)}{2}
\]

#### 2D Stress to Strain

\[
\varepsilon_x = \frac{(\sigma_x - \nu \sigma_y)}{E}
\]

\[
\varepsilon_y = \frac{(\sigma_y - \nu \sigma_x)}{E}
\]

\[
\varepsilon_z = -\nu (\varepsilon_x + \varepsilon_y) / (1 - \nu)
\]

\[
\gamma_{xy} = \frac{\tau_{xy} G}{E} = 2(1 + \nu) \tau_{xy} / E
\]

### Hooke’s Law

1D Strain to Stress

\[
\sigma = E \varepsilon
\]

2D Strain to Stress

\[
\sigma_x = \frac{E (\varepsilon_x + \nu \varepsilon_y)}{(1 - \nu^2)}
\]

\[
\sigma_y = \frac{E (\varepsilon_y + \nu \varepsilon_x)}{(1 - \nu^2)}
\]

\[
\tau_{xy} = \frac{G \gamma_{xy}}{2(1 + \nu)}
\]

### Pressure

\[
\sigma_{\text{spherical}} = \frac{pr}{2t}
\]

\[
\sigma_{\text{cylindrical, hoop}} = \frac{pr}{t}
\]

\[
\sigma_{\text{cylindrical, axial}} = \frac{pr}{2t}
\]

### Failure Theories

Maximum Principal Stress Theory

\[
\sigma_{1,2} < \sigma_{\text{yp}}
\]

Maximum Shear Stress Theory

\[
\tau_{\text{max}} < 0.5 \sigma_{\text{yp}}
\]

### Units

- **psi**: pounds per square inch
- **Pa**: pascal