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"On my honor, as an Aggie, I have neither given nor received unauthorized aid on this exam."

________________________________________
Signature of student

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Appendix C. Properties of Rolled-Steel Shapes  
(U.S. Customary Units)

**W Shapes**  
(Wide-Flange Shapes)

<table>
<thead>
<tr>
<th>Designation</th>
<th>Area (A_{\text{in}^2})</th>
<th>Depth (d_{\text{in}})</th>
<th>Flange</th>
<th>Web</th>
<th>Axis X-X</th>
<th>Axis Y-Y</th>
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<tbody>
<tr>
<td></td>
<td>Width (b_{\text{in}})</td>
<td>Thickness (t_{\text{in}})</td>
<td>Width (b_{\text{in}})</td>
<td>Thickness (t_{\text{in}})</td>
<td>(I_{x_{\text{in}^4}})</td>
<td>(S_{x_{\text{in}^2}})</td>
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<tr>
<td>W36 × 300</td>
<td>88.3</td>
<td>36.74</td>
<td>16.655</td>
<td>1.680</td>
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</table>
Problem 1) Draw the shear and moment diagram for the beam loaded as shown. \( W = 3 \text{ k/ft}, \ L_1 = 8 \text{ ft}, \ L_2 = 10 \text{ ft}, \ L_3 = 4 \text{ ft}. \)

\[ W \]

\[ 3 \text{ k/ft} \]

\[ \text{ft} \]

\[ R_1 = 7 \text{ kips} \]

\[ \sum M_A = -42 \text{ kips} \cdot \text{ft} + R_2 \cdot 10 \text{ ft} = 0 \]

\[ R_2 = 35 \text{ kips} \]

\[ \sum M_0 = 42 \text{ kips} \cdot \text{ft} - R_1 \cdot 10 \text{ ft} = 0 \]

\[ R_1 = 7 \text{ kips} \]

\[ A_1 = 7 \text{ kips} \cdot 8 \text{ ft} = 56 \text{ kip-ft} \]

\[ A_2 = \frac{7}{5} \text{ ft} \cdot 7 \text{ kips} \cdot \frac{1}{2} = 8.17 \text{ kip-ft} \]

\[ A_3 = \frac{23}{3} \text{ ft} \cdot -23 \text{ kips} \cdot \frac{1}{2} = 88.17 \text{ kip-ft} \]

\[ A_4 = 12 \text{ kips} \cdot 4 \text{ ft} \cdot \frac{1}{2} = 24 \text{ kip-ft} \]

\[ 5W + 8.17 - 88.17 + 24 = 0 \]
Problem 2) The eight foot long W30x173 wide flange cantilever beam shown below is supported on the left end at a wall. Loads P1 = 100 kips, P2 = 1200 kips, and P3 = 12 kips are applied as shown. Determine the stress occurring at the top right corner of the beam at the wall (point a.) Omit the weight of the beam.

\[ \sigma_{ref} = \frac{MC}{I} = \frac{800 \text{kft} \times (15.22 \text{in})}{8200 \text{in}^4} = \frac{9600 \text{kft}\text{in} \times (15.22 \text{in})}{8200 \text{in}^4} = 17.82 \text{ksi} \text{ TENSION} \]

\[ \sigma_{P2} = \frac{1200 \text{k}}{A} = \frac{1200 \text{k}}{50.8 \text{in}^2} = 23.62 \text{ ksi TENSION} \]

\[ \sigma_{P3} = \frac{MC}{I} = \frac{(12 \text{k} \times 8.44) \times 7.4925 \text{in}}{598 \text{in}^4} = 14.43 \text{ ksi COMPRESSION} \]

\[ \sigma = 17.82 \text{ ksi} + 23.62 \text{ ksi} - 14.43 \text{ ksi} = 27.01 \text{ ksi} \]
Problem 3) Solve for the maximum principal normal and shear stresses for an element with $\sigma_x = 20$ MPa (tension), $\sigma_y = -30$ MPa (compression), and $\tau_{xy} = 15$ MPa (down on the left vertical face of the element.) You can use either Mohr's Circle or the equations.

\[ \sigma_{\text{avg}} = \frac{20 + (-30)}{2} = 2.5 \text{ MPa} \]

\[ R = \sqrt{15^2 + 25^2} = 29.15 \text{ MPa} \]

\[ \sigma_{\text{P}_1} = 24.15 \text{ MPa} \]

\[ \sigma_{\text{P}_2} = -34.15 \text{ MPa} \]

\[ \sigma_{\text{P}_{\text{max}}} = 34.15 \text{ MPa \, COMPRESSION} \]

\[ \tau_{\text{max}} = R = 29.15 \text{ MPa} \]
Problem 4) Design the thinnest wood beam shown to safely carry a uniform load of 2 kip/foot over the right half of the beam. You can omit the weight of the beam. The beam is 10 feet long by 12 inches tall.

Determine the minimum width of the beam required. The allowed compressive stress for the wood is 8 ksi, allowed tensile stress is 12 ksi, and allowed shear stress is 2 ksi.

\[ \sigma_c = 8 \text{ ksi} \]
\[ \sigma_t = 12 \text{ ksi} \]
\[ \gamma_a = 2 \text{ ksi} \]

\[ \sigma_{\text{max}} = 12 \text{ ksi} = \frac{MC}{I} = \frac{75 \text{ kN} \cdot \text{m} \cdot 5 \text{ ft}}{I} \]

\[ I = \frac{W \cdot 12^3}{12} = 144 \text{ in}^4 \]

\[ 12 \text{ ksi} = \frac{900 \text{ ksi} \times (6 \text{ in})}{144 \text{ in}^4} \]

\[ W = 3.125 \text{ in} \]

\[ \sigma_{\text{max}} = \frac{MC}{I} = \frac{900 \text{ ksi} \times (6 \text{ in})}{144 \text{ in}^4} = 8 \text{ ksi} \]

\[ W = \frac{4.6875 \text{ in}}{} \]

\[ \gamma_{\text{max}} = \sqrt{\frac{Q}{I}} = \frac{10 \text{ kN} \cdot (18 \text{ in}) \cdot W}{144 \text{ in}^4 \cdot W} = \frac{180W}{144W^2} = \frac{180}{144W} \]

\[ \gamma_{\text{max}} = 2 \text{ ksi} = \frac{180}{144W} \]

\[ W = 1.625 \text{ in} \]

The safest width is 4.6875 in b/c it is the min width in which the allowable comp. stress will be held. Since it is the thickest of the three constrains it is the minimum width.
\[ M = (2^{1/3})(5\text{ ft})(7.5\text{ ft}^3)(12\prime\prime) = 900 \text{ in}^3 \]

\[ I = b(12)^3 = 144b \text{ in}^4 \]

\[ \sigma = \frac{M_c}{I} = \frac{8b}{144b} = \frac{(900 \text{ in}^3)(12\prime\prime)}{144 \text{ in}^3 (8\text{ in}^3)} = \frac{4.69 \text{ in}}{\text{wider by 4\prime\prime \text{ Experimental}}} \]

\[ b = \frac{(900 \text{ in}^3)(6\prime\prime)(18\prime\prime)}{144 \text{ in}^3 (8\text{ in}^3)} = 4.69 \text{ in} \]

\[ V = (2^{1/3})(5\text{ ft}) = 10 \text{ ft} \]

\[ Q = \frac{6\prime\prime}{6\prime\prime, 12\prime\prime} = (b)(6\prime\prime)(3\prime\prime) = 18b \]

\[ T = \frac{2b}{1\text{ in}^2} = \frac{VQ}{144b^3} = \frac{(10b)(18\text{ in}^2, b)}{b(12\text{ in}^3)^3, b} \]

\[ b = \frac{(10^2)(18\text{ in}^2)}{144 \text{ in}^3 (2\text{ in})} = 0.625 \text{ in} \]

Answer = 4.69 in wider
Problem 5) The rectangular hollow steel beam shown below is 20 cm deep by 8 cm wide, outside dimensions. The walls are 1 cm thick. The maximum vertical shear on the section (from a shear and moment diagram) is 120 kN. Determine the maximum shearing stress in the beam.

\[ V_{\text{max}} = 120 \text{kN} \]

**Max Shear Occurs at Centroid of Cross Section**

\[ A = \frac{20 \text{cm}(8 \text{cm}) - 18 \text{cm}(6 \text{cm})}{2} = \frac{52 \text{cm}^2}{2} = 26 \text{cm}^2 \]

\[ J = \frac{8 \text{cm}(10 \text{cm})^3}{12} - \frac{6 \text{cm}(18 \text{cm})^3}{12} = 2417.33 \text{cm}^4 \]

\[ \tau_{\text{max}} = \frac{VQ}{IY} \quad Q = AY \]

\[ \tau_{\text{max}} = \frac{120 \text{kN} Q}{2417.33 \text{cm}^4 / (2 \text{cm})} \]

\[ Q = 10 \text{cm}(1 \text{cm}) 5 \text{cm}(2) + 6 \text{cm}(1 \text{cm}) 9.5 \text{cm} = 157 \text{cm}^3 \]

\[ \tau_{\text{max}} = \frac{1.2 \times 10^6 \text{N} \left(1.57 \times 10^{-4} \text{m}^3\right)}{2417.33 \times 10^{-6} \text{m}^4 / (1.02 \text{m})} = 3896.86 \times 10^7 \text{Pa} \]

\[ = 38.97 \text{MPa} \]
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Signature of student

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(U.S. Customary Units)

## W Shapes
(Wide-Flange Shapes)

<table>
<thead>
<tr>
<th>Designation</th>
<th>Area $A$, in$^2$</th>
<th>Depth $d$, in</th>
<th>Width $b$, in</th>
<th>Thickness $t_b$, in</th>
<th>Web Thickness $t_w$, in</th>
<th>Flange $I_x$, in$^4$</th>
<th>Section Modulus $S_x$, in$^3$</th>
<th>Flange $I_y$, in$^4$</th>
<th>Section Modulus $S_y$, in$^3$</th>
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</thead>
<tbody>
<tr>
<td>W36 × 300</td>
<td>88.3</td>
<td>36.74</td>
<td>16.655</td>
<td>1.680</td>
<td>0.945</td>
<td>20300</td>
<td>7800</td>
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<td>W36 × 250</td>
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# Appendix D. Properties of Rolled-Steel Shapes
(U.S. Customary Units)

## W Shapes
(Wide-Flange Shapes)
Problem 1) Solve for the maximum principal normal and shear stresses for an element with \( \sigma_x = -40 \text{ MPa} \) (compression), \( \sigma_y = 20 \text{ MPa} \) (tension), and \( \tau_{xy} = 8 \text{ MPa} \) (up on the left vertical face of the element.) You can use either Mohr’s Circle or the equations.

\[
R = \sqrt{8^2 + 30^2} = 31.04 \text{ ksi}
\]

So \( \sigma_1 = -10 + 31.04 \text{ ksi} = 21.04 \text{ ksi tension} \)

\( \sigma_2 = -10 - 31.04 \text{ ksi} = -41.04 \text{ ksi compressive} \)

\( \tau_\rho = 31.04 \text{ ksi} \)
Problem 2) Design the thinnest wood beam shown to safely carry a uniform load of 3 kip/foot over the right half of the beam. You can omit the weight of the beam. The beam is 8 feet long by 14 inches tall. Determine the minimum width of the beam required. The allowed compressive stress for the wood is 10 ksi, allowed tensile stress is 14 ksi, and allowed shear stress is 3 ksi.

\[ \sigma = \frac{M c}{I} = 10 \text{ kip/ft}^2 \]

\[ M = (3 \text{ kip/ft}) (4 \text{ ft}) (6 \text{ ft}) \left( \frac{12}{2} \text{ ft} \right) = 864 \text{ in.k} \]

\[ I = \frac{b h^3}{12} = \frac{b (14 \text{ in})^3}{12} = 228.76 \text{ in}^3 \]

\[ c = \frac{14 \text{ in}}{2} = 7 \text{ in} \]

\[ 10 \text{ kip/hr}^2 = 864 \text{ in.k} (7 \text{ in}) / 228.76 \text{ in}^3 \]

\[ b = \frac{864 \text{ in.k} (7 \text{ in})}{228.76 \text{ in}^3} \frac{1 \text{ in}^2}{10 \text{ kip}} = 2.645 \text{ in} \]

\[ T = \frac{Vq}{I t} = (3 \text{ kip/ft}) (4 \text{ ft}) \left[ \frac{b (7 \text{ in}) \left( \frac{7}{2} \text{ in} \right)}{228.76 \text{ in}^4 \cdot b \text{ in}} \right]^4 \]

\[ b = (3 \text{ kip/ft}) (4 \text{ ft}) (7 \text{ in}) \left( \frac{7}{2} \text{ in} \right) \frac{1 \text{ in}^2}{228.76 \text{ in}^3 \cdot 3 \text{ kip}} = 0.429 \text{ in} \]

\[ t_{\text{required}} = 2.645 \text{ in} \]
Problem 3) The ten foot long W24x104 wide flange cantilever beam shown below is supported on the left end at a wall. Loads $P_1 = 80$ kips, $P_2 = 1000$ kips, and $P_3 = 14$ kips are applied as shown. Determine the stress occurring at the bottom left corner of the beam at the wall (point c.) Omit the weight of the beam.

\[ \sigma_{axial} = \frac{P_2}{A} = \frac{1000}{30.6} \]

\[ \sigma_{Bending\ about\ x-x} = \frac{M_{xx}}{S_{xx}} = \frac{80 \text{ kips} \times 12 \text{ in/ft}}{258 \text{ in}^3} \]

\[ \gamma = \frac{M_{yy}}{S_{yy}} = \frac{14 \text{ kips} \times 12 \text{ in/ft}}{40.7 \text{ in}^3} \]

\[ \sigma_a = +\frac{P_2}{2} + \frac{M_{xx}}{S_{xx}} - \frac{M_{yy}}{S_{yy}} \]
Problem 3) The ten foot long W24x104 wide flange cantilever beam shown below is supported on the left end at a wall. Loads P1 = 80 kips, P2 = 1000 kips, and P3 = 14 kips are applied as shown. Determine the stress occurring at the bottom left corner of the beam at the wall (point c.) Omit the weight of the beam.

Area of W24x104 = 30.6 in²

\[ \sqrt{Axial} = \frac{1000 \text{kip}}{30.6 \text{in}^2} = 32.67 \text{ksi} \]

\[ M_{xx} = 80 \text{kip} \times (10 \text{ft}) \times (12 \text{ in/ft}) = 9600 \text{ kip in} \]

\[ M_{yy} = 14 \text{kip} \times (10 \text{ft}) \times (12 \text{ in/ft}) = 1680 \text{ kip in} \]

\[ J = \frac{M}{s} \]

\[ S_{xx} = 258 \text{ in}^3 \]

\[ S_{yy} = 40.7 \text{ in}^3 \]

\[ \sigma_{xy} = \frac{M_{xx}}{S_{xx}} = 37.2 \text{ ksi} \]

\[ \sigma_{yy} = \frac{M_{yy}}{S_{yy}} = 41.3 \text{ ksi} \]

\[ \sigma_{Normal \ at \ c} = M_{yy} - M_{xx} + \sqrt{Axial} \]

\[ \sigma_{Normal \ at \ c} = 36.77 \text{ ksi} \]
Problem 4) The rectangular hollow steel beam shown below is 18 cm deep by 10 cm wide, outside dimensions. The walls are 2 cm thick. The maximum vertical shear on the section (from a shear and moment diagram) is 180 kN. Determine the maximum shearing stress in the beam.

\[ I = \frac{(10\text{ cm})(18\text{ cm})^3}{12} - \frac{(6\text{ cm})(14\text{ cm})^3}{12} \]
\[ = \frac{3488\text{ cm}^4}{12} \]
\[ Q = (9\text{ cm})(10\text{ cm})(9.5\text{ cm}) - (7\text{ cm})(6\text{ cm})(7\text{ cm}) \]
\[ = 258\text{ cm}^3 \]
\[ t = 4\text{ cm} \]

\[ \tau = \frac{VQ}{I t} = \frac{(180\text{ kN})(258\text{ cm}^3)}{3488\text{ cm}^4 \cdot 4\text{ cm}} = \frac{3,329\text{ kN}}{cm^2} \]
\[ = \frac{3,329\text{ kN}}{cm^2} \cdot \frac{(100\text{ cm})^2}{(1\text{ m})^2} = \frac{33290,000\text{ N}}{m^2} \]
\[ = 33.29\text{ MPa} \]
Problem 4) The rectangular hollow steel beam shown below is 18 cm deep by 10 cm wide, outside dimensions. The walls are 2 cm thick. The maximum vertical shear on the section (from a shear and moment diagram) is 180 kN. Determine the maximum shearing stress in the beam.

$$V_{\text{max}} = 180 \text{ kN} = 180 \times 10^3 \text{ N}$$
$$= 180,000 \text{ N}$$

Design:

$$Z_{\text{max}}$$

$$I_{zz} = \frac{1}{12} BH^3 - \frac{1}{12} bh^3$$
$$= \frac{1}{12} (10 \text{ cm})(18 \text{ cm})^3 - \frac{1}{12} (6 \text{ cm})(14 \text{ cm})^3$$
$$I = 3488 \text{ cm}^4$$

$$b = 10 \text{ cm} - 2(2 \text{ cm}) = 6 \text{ cm}$$
$$h = 18 \text{ cm} - 2(2 \text{ cm}) = 14 \text{ cm}$$

Q will be max @ axis!

$$Q = A_1 \overline{y}_1 + A_2 (A_2 \overline{y}_2)$$
$$= (10 \text{ cm})(2 \text{ cm})(8 \text{ cm}) + 2 \left[ (2 \text{ cm})(7 \text{ cm})(3.5 \text{ cm}) \right]$$
$$= 258 \text{ cm}^3$$

$$t = 2 \text{ cm} + 2 \text{ cm} = 4 \text{ cm}$$

$$Z_{\text{max}} = \frac{VQ}{I_t}$$

$$= \frac{(180,000 \text{ N})(258 \text{ cm}^3)}{\left(3488 \text{ cm}^4 \right)(4 \text{ cm})}$$

$$Z_{\text{max}} = 3328.56 \text{ kN/cm}^2$$

$$= 3328.56 \text{ kN} \cdot \frac{\text{cm}^2}{1 \text{ m}} \cdot \frac{\text{cm}}{1 \text{ m}}$$

$$= 332856 \times 10^7 \text{ N/m}^2$$

$$Z_{\text{max}} = 33.3 \text{ MPa}$$
Problem 5) Draw the shear and moment diagram for the beam loaded as shown. \( L_1 = 4 \text{ ft}, L_2 = 10 \text{ ft}, L_3 = 8 \text{ ft}, W = 2 \text{ k/ft}. \)

\[
W = 2 \text{ k/ft}
\]

\[
\Sigma M_{R_1} = 0 = (2 \text{ k/ft})(14 \text{ ft})(36 \text{ ft}) - R_2(18 \text{ ft})
\]

\[
R_2 = 4.667 \text{ k}
\]

\[
\Sigma M_{R_2} = 0 = (2)(14)(15 \text{ ft}) - R_1(18 \text{ ft})
\]

\[
R_1 = 23.333 \text{ k}
\]

\[
\Sigma F_V = 0 = -2(14) + 4.667 + 23.333 = 0 \checkmark
\]

\[
A_1 = \frac{1}{2}(8 \text{ k})(4') = -16 \text{ k-ft}
\]