Problems

1.5-1  A 20-foot-long W8 × 67 is suspended from one end. If the modulus of elasticity is 29,000 ksi, determine the following.
a. What is the maximum tensile stress?
b. What is the maximum normal strain?

1.5-2  The strain in member AB was measured to be 8.9 × 10⁻⁴. If the member is an L3 × 2½ × ⅛ of A36 steel, determine the following.
a. What is the change in length in inches?
b. What is the force in the member?

1.5-3  During a tensile test of a specimen of unknown material, an increase in length of 6.792 × 10⁻³ inches within the gage length was recorded at a load of 5000 lb. The specimen diameter was 0.5 inch and the gage length was 8 inches. (The gage length is the distance between two marks placed along the length of the specimen.)
a. Based on this one data point, what is the modulus of elasticity?
b. If the maximum load reached before fracture was 14,700 lb, what is the ultimate tensile stress?

1.5-4  A tensile test was conducted on a specimen with a diameter of 0.5 inch. A strain gage was bonded to the specimen so that the strain could be obtained directly. The following data were obtained:

<table>
<thead>
<tr>
<th>Load (lb)</th>
<th>Strain (micro in./in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,000</td>
<td>47</td>
</tr>
<tr>
<td>2,500</td>
<td>220</td>
</tr>
<tr>
<td>3,000</td>
<td>500</td>
</tr>
<tr>
<td>3,500</td>
<td>950</td>
</tr>
<tr>
<td>4,000</td>
<td>1,111</td>
</tr>
<tr>
<td>4,500</td>
<td>1,200</td>
</tr>
<tr>
<td>5,000</td>
<td>1,702</td>
</tr>
</tbody>
</table>
a. Create a table of stress and strain values.
b. Plot these data points, and draw a best-fit straight line through them.
c. What is the slope of this line? What does this value represent?

1.5-5

A tension test was conducted on a specimen with a circular cross section of diameter 0.5 inch and a gage length of 8 inches. (The gage length is the distance between two marks on the specimen. The deformation is measured within this length.) The stress and strain were computed from the test data and plotted. Two plots are shown here; the first one shows the entire test range, and the second shows a portion near the proportional limit.

a. Draw best-fit lines to obtain stress–strain curves.
b. Estimate the proportional limit.
c. Use the slope of the best-fit line to estimate the modulus of elasticity.
d. Estimate the 0.2% offset yield strength.
e. Estimate the ultimate stress.
f. If a load of 10 kips is applied and then removed, estimate the permanent deformation in inches.

FIGURE P1.5-5
1.5-6  The data shown in the table were obtained from a tensile test of a metal specimen with a diameter of 0.500 inch and a gage length (the length over which the elongation is measured) of 2.00 inches. The specimen was not loaded to failure.

a. Generate a table of stress and strain values.

b. Plot these values and draw a best-fit line to obtain a stress–strain curve.

c. Use the slope of the best-fit line to estimate the modulus of elasticity.

d. Estimate the value of the proportional limit.

e. Use the 0.2% offset method to determine the yield strength.

<table>
<thead>
<tr>
<th>Load (kips)</th>
<th>Elongation (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.0010</td>
</tr>
<tr>
<td>2</td>
<td>0.0014</td>
</tr>
<tr>
<td>2.5</td>
<td>0.0020</td>
</tr>
<tr>
<td>3.5</td>
<td>0.0024</td>
</tr>
<tr>
<td>5</td>
<td>0.0036</td>
</tr>
<tr>
<td>6</td>
<td>0.0044</td>
</tr>
<tr>
<td>7</td>
<td>0.0050</td>
</tr>
<tr>
<td>8</td>
<td>0.0060</td>
</tr>
<tr>
<td>9</td>
<td>0.0070</td>
</tr>
<tr>
<td>10</td>
<td>0.0080</td>
</tr>
<tr>
<td>11.5</td>
<td>0.0120</td>
</tr>
<tr>
<td>12</td>
<td>0.0180</td>
</tr>
</tbody>
</table>

1.5-7  The data shown in the table were obtained from a tensile test of a metal specimen with a rectangular cross section of 0.2 in.² in area and a gage length (the length over which the elongation is measured) of 2.000 inches.

a. Generate a table of stress and strain values.

b. Plot these values and draw a best-fit line to obtain a stress–strain curve.

c. Determine the modulus of elasticity from the slope of the linear portion of the curve.

d. Estimate the value of the proportional limit.

e. Use the 0.2% offset method to determine the yield stress.

<table>
<thead>
<tr>
<th>Load (kips)</th>
<th>Elongation × 10³ (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>0.160</td>
</tr>
<tr>
<td>1.0</td>
<td>0.352</td>
</tr>
<tr>
<td>1.5</td>
<td>0.706</td>
</tr>
<tr>
<td>2.0</td>
<td>1.012</td>
</tr>
<tr>
<td>2.5</td>
<td>1.434</td>
</tr>
<tr>
<td>3.0</td>
<td>1.712</td>
</tr>
<tr>
<td>3.5</td>
<td>1.986</td>
</tr>
<tr>
<td>4.0</td>
<td>2.286</td>
</tr>
<tr>
<td>4.5</td>
<td>2.612</td>
</tr>
<tr>
<td>5.0</td>
<td>2.938</td>
</tr>
<tr>
<td>5.5</td>
<td>3.274</td>
</tr>
<tr>
<td>6.0</td>
<td>3.632</td>
</tr>
<tr>
<td>6.5</td>
<td>3.976</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load (kips)</th>
<th>Elongation × 10³ (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0</td>
<td>4.386</td>
</tr>
<tr>
<td>7.5</td>
<td>4.640</td>
</tr>
<tr>
<td>8.0</td>
<td>4.988</td>
</tr>
<tr>
<td>8.5</td>
<td>5.432</td>
</tr>
<tr>
<td>9.0</td>
<td>5.862</td>
</tr>
<tr>
<td>9.5</td>
<td>6.362</td>
</tr>
<tr>
<td>10.0</td>
<td>7.304</td>
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<tr>
<td>10.5</td>
<td>8.072</td>
</tr>
<tr>
<td>11.0</td>
<td>9.044</td>
</tr>
<tr>
<td>11.5</td>
<td>11.310</td>
</tr>
<tr>
<td>12.0</td>
<td>14.120</td>
</tr>
<tr>
<td>12.5</td>
<td>20.044</td>
</tr>
<tr>
<td>13</td>
<td>29.106</td>
</tr>
</tbody>
</table>
Problems

Note

All given loads are service loads.

2-1
A column in the upper story of a building is subjected to a compressive load from the following sources: dead load = 30.8 kips, occupancy live load = 1.7 kips, roof live load = 18.7 kips, and snow load = 19.7 kips.

a. If load and resistance factor design is used, determine the factored load (required strength) to be used in the design of the column. Which AISC load combination controls?

b. What is the required design strength of the column?

c. What is the required nominal strength of the column for a resistance factor $\phi$ of 0.90?

d. If allowable strength design is used, determine the required load capacity (required strength) to be used in the design of the column. Which AISC load combination controls?

e. What is the required nominal strength of the column for a safety factor $\Omega$ of 1.67?

2-2
A column is subjected to the following loads: dead load = 26 kips, occupancy live load = 15 kips, roof live load = 5 kips, snow load = 8 kips, rain load = 5 kips, and wind load = 8 kips. All loads are compression except for the wind load, which can be either tension or compression.

a. If load and resistance factor design is used, determine the factored load (required strength) to be used in the design of the column. Which AISC load combination controls?

b. What is the required design strength of the column?

c. What is the required nominal strength of the column for a resistance factor $\phi$ of 0.90?

d. If allowable strength design is used, determine the required load capacity (required strength) to be used in the design of the column. Which AISC load combination controls?

e. What is the required nominal strength of the column for a safety factor $\Omega$ of 1.67?

2-3
The loads on a roof beam consist of a dead load of 0.2 kips/ft, a roof live load of 0.13 kips/ft, and a snow load of 0.14 kips/ft.

a. If load and resistance factor design is used, determine the factored load (required strength) to be used in the design of this beam. Which AISC load combination controls?

b. If allowable strength design is used, determine the required load capacity (required strength) to be used in the design of the column. Which AISC load combination controls?
2-4 Beams will be designed for the roof and floor systems of an office building. The loads for these systems are as follows:

*Roof:* dead load = 30 psf, roof live load = 20 psf, snow load = 21 psf, and a rain load consisting of 4 inches of water.

*Floor:* dead load = 62 psf and occupancy live load = 80 psf.

a. For each of these systems, determine the required factored load capacity for LRFD. Which load combination controls?
b. For each of these systems, determine the required ASD load capacity. Which load combination controls?

2-5 Structural steel buildings frequently are designed with diagonal bracing systems to resist *lateral loads* (horizontal forces resulting from wind or earthquake loadings). A certain bracing system is subjected to the following loads: dead load = 13.3 kips, occupancy live load = 6.9 kips, roof live load = 1.3 kips, snow load = 1.3 kips, wind load = 150.6 kips, and earthquake load = 161.1 kips.

a. Determine the required factored load capacity for LRFD. Which load combination controls?
b. Determine the required ASD load capacity. Which load combination controls?
Problems

Tensile Strength

3.2-1 A PL $\frac{3}{8} \times 7$ tension member is connected with three 1-inch-diameter bolts, as shown in Figure P3.2-1. The steel is A36. Assume that $A_e = A_n$ and compute the following.

a. The design strength for LRFD.

b. The allowable strength for ASD.

FIGURE P3.2-1

3.2-2 A PL $\frac{1}{2} \times 8$ tension member is connected with six 1-inch-diameter bolts, as shown in Figure P3.2-2. The steel is ASTM A242. Assume that $A_e = A_n$ and compute the following.

a. The design strength for LRFD.

b. The allowable strength for ASD.

FIGURE P3.2-2

3.2-3 A C12 $\times$ 30 is connected with 1-in. diameter bolts in each flange, as shown in Figure P3.2-3. If $F_y = 50$ ksi, $F_u = 65$ ksi, and $A_e = 0.90A_n$, compute the following.

a. The design strength for LRFD.

b. The allowable strength for ASD.
3.2-4  A PL $\frac{3}{8} \times 6$ tension member is welded to a gusset plate as shown in Figure P3.2-4. The steel is A36. Assume that $A_e = A_g$ and compute the following.

a. The design strength for LRFD.
b. The allowable strength for ASD.

3.2-5  The tension member shown in Figure P3.2-5 is a PL $\frac{1}{2} \times 8$ of A36 steel. The member is connected to a gusset plate with-1$\frac{1}{8}$ inch-diameter bolts. It is subjected to the dead and live loads shown. Does this member have enough strength? Assume that $A_e = A_u$.

a. Use LRFD.
b. Use ASD.
3.2-6 A double-angle tension member, 2L 3 × 2 × 1/4 LLBB, of A36 steel is subjected to a dead load of 12 kips and a live load of 36 kips. It is connected to a gusset plate with 3/4-inch-diameter bolts through the long legs. Does this member have enough strength? Assume that $A_e = 0.85A_n$.

- Use LRFD.
- Use ASD.

**Figure P3.2-6**

3.2-7 A C8 × 11.5 is connected to a gusset plate with 3/8-inch-diameter bolts as shown in Figure P3.2-7. The steel is A572 Grade 50. If the member is subjected to dead load and live load only, what is the total service load capacity if the live-to-dead load ratio is 3? Assume that $A_e = 0.85A_n$.

- Use LRFD.
- Use ASD.

**Figure P3.2-7**

**Effective area**

3.3-1 Determine the effective area $A_e$ for each case shown in Figure P3.3-1.
3.3-2 For the tension member shown, compute the following.

a. The tensile design strength.
b. The allowable tensile strength.
3.3-3 Determine the nominal tensile strength based on the effective net area.

![Diagram of 2L5 x 3 x \(\frac{3}{4}\) LLBB (two angles, long legs back-to-back) A242 steel with 3" dimensions and \(\frac{3}{8}\) in.-diameter bolts.]

**FIGURE P3.3-3**

3.3-4 For the tension member shown, compute the following.

a. The tensile design strength.

b. The allowable tensile strength.

![Diagram of PL \(\frac{1}{4} \times 6\) A36 steel with 6" dimensions.]

**FIGURE P3.3-4**

3.3-5 A W16 x 45 of A992 steel is connected to a plate at each flange as shown in Figure P3.3-5. Determine the nominal strength based on the net section as follows:

a. Use Equation 3.1 for the shear lag factor, \(U\).

b. Use the alternative value of \(U\) from AISC Table D3.1.

![Diagram of W16 x 45 with 2\(\frac{1}{4}\)" dimensions and \(\frac{3}{8}\) in.-diameter bolts.]

**FIGURE P3.3-5**
3.3-6 The tension member shown in Figure P3.3-6 is a C12 × 20.7 of A572 Grade 50 steel. Will it safely support a service dead load of 60 kips and a service live load of 125 kips? Use Equation 3.1 for $U$.

a. Use LRFD.
b. Use ASD.

![Diagram of C12 × 20.7 tension member with 2″, 2 1/2″, 2 1/2″, and 2 1/2″ dimensions.]

3.3-7 A double-angle tension member, 2L4 × 3 × 1/4 LLBB, is connected with welds as shown in Figure P3.3-7. A36 steel is used.

a. Compute the available strength for LRFD.
b. Compute the available strength for ASD.

![Diagram of double-angle tension member with 8″ and 4″ dimensions.]

3.3-8 An L5 × 5 × 1/2 tension member of A242 steel is connected to a gusset plate with six 3/4-inch-diameter bolts as shown in Figure P3.3-8. If the member is subject to dead load and live load only, what is the maximum total service load that can be applied if the ratio of live load to dead load is 2.0? Use the alternative value of $U$ from AISC Table D3.1.

a. Use LRFD.
b. Use ASD.
Staggered Fasteners

3.4-1  A36 steel is used for the tension member shown in Figure P3.4-1.
a. Determine the nominal strength based on the gross area.
b. Determine the nominal strength based on the net area.

3.4-2  The tension member shown in Figure 3.4-2 is a PL \( \frac{3}{8} \times 10 \), and the steel is A36. The bolts are \( \frac{3}{8} \)-inch in diameter.
a. Determine the design strength for LRFD.
b. Determine the allowable strength for ASD.
3.4-3 An MC 9 × 23.9 is connected with 3/4-inch-diameter bolts as shown in Figure P3.4-3. A572 Grade 50 steel is used.
   a. Determine the design strength.
   b. Determine the allowable strength.

3.4-4 A992 steel is used for the tension member shown in Figure P3.4-4. The bolts are 3/4 inch in diameter. The connection is to a 3/8-in.-thick gusset plate.
   a. Determine the nominal strength based on the gross area.
   b. Determine the nominal strength based on the effective net area.
3.4-5 The tension member shown in Figure P3.4-5 is an L6 × 3 1/2 × 5/16. The bolts are 3/4 inch in diameter. If A36 steel is used, is the member adequate for a service dead load of 31 kips and a service live load of 31 kips?
   a. Use LRFD.
   b. Use ASD.

3.4-6 A double-channel shape, 2C10 × 20, of A572 Grade 50 steel is used for a built-up tension member as shown in Figure P3.4-6. The holes are for 1/2-inch-diameter bolts. Determine the total service load capacity if the live load is three times the dead load.
   a. Use LRFD.
   b. Use ASD.
Block Shear

3.5-1 The tension member is a PL $\frac{3}{8} \times 5\frac{1}{2}$ of A242 steel. It is connected to a $\frac{3}{8}$-in. thick gusset plate, also of A242 steel, with $\frac{3}{4}$-inch diameter bolts as shown in Figure P3.5-1. Determine the nominal block shear strength of the tension member.

3.5-2 A square hollow structural section (HSS) is used as a tension member and is welded to a gusset plate of A36 steel as shown in Figure P3.5-2. Compute the nominal block shear strength of the gusset plate.
3.5-3 A WT8 × 13 of A992 steel is used as a tension member. The connection is with \( \frac{7}{8} \)-in. diameter bolts as shown in Figure P3.5-3. Compute the nominal block shear strength.

3.5-4 Compute the available block shear strength of the gusset plate.
   a. Use LRFD.
   b. Use ASD.
3.5-5 A C7 × 9.8 tension member is connected to a 3/8-in.-thick gusset plate as shown in Figure P3.5-5. Both the member and the gusset plate are A36 steel.

a. Compute the available block shear strength of the tension member for both LRFD and ASD.

b. Compute the available block shear strength of the gusset plate for both LRFD and ASD.

![Figure P3.5-5]

3.5-6 A double-channel shape, 2C8 × 18.75, is used as a tension member. The channels are bolted to a 3/8-inch gusset plate with 7/8-inch diameter bolts. The tension member is A572 Grade 50 steel and the gusset plate is A36. If LRFD is used, how much factored tensile load can be applied? Consider all limit states.

![Figure P3.5-6]
Design of Tension Members

3.6-1 Select a single-angle tension member of A36 steel to resist the following service loads: dead load = 50 kips, live load = 100 kips, and wind load = 45 kips. The member will be connected through one leg with 1-inch diameter bolts in two lines. There will be four bolts in each line. The member length is 20 feet.
   a. Use LRFD.
   b. Use ASD.

FIGURE P3.6-1

3.6-2 Use A36 steel and select a double-angle tension member to resist a service dead load of 20 kips and a service live load of 60 kips. Assume that the member will be connected to a 3/8-inch-thick gusset plate with a single line of five 7/8-inch diameter bolts. The member is 15 feet long.
   a. Use LRFD.
   b. Use ASD.

FIGURE P3.6-2

3.6-3 Select an ST shape to be used as a 20-ft-long tension member to resist the following service loads: dead load = 38 kips, live load = 115 kips, and snow load = 75 kips. The connection is through the flange with three 3/4-inch diameter bolts in each line. Use A572 Grade 50 steel.
   a. Use LRFD.
   b. Use ASD.
3.6-4 Select an S shape for the tension member shown in Figure P3.6-4. The member shown will be connected between two plates with eight \( \frac{3}{8} \)-in. diameter bolts. The service dead load is 216 kips, the service live load is 25 kips, and the length is 22 ft. Use A36 steel.
   a. Use LRFD.
   b. Use ASD.

3.6-5 Choose a pipe to be used as a tension member to resist a service dead load of 10 kips and a service live load of 25 kips. The ends will be connected by welding completely around the circumference of the pipe. The length is 8 feet.
   a. Use LRFD.
   b. Use ASD.

3.6-6 Use LRFD and select an American Standard Channel shape for the following tensile loads: dead load = 54 kips, live load = 80 kips, and wind load = 75 kips. The connection will be with two 9-in.-long longitudinal welds. Use an estimated shear lag factor of \( U = 0.85 \). Once the member has been selected, compute the value of \( U \) with Equation 3.1 and revise the design if necessary. The length is 17.5 ft. Use \( F_y = 50 \) ksi and \( F_u = 65 \) ksi.

**Threaded Rods and Cables**

3.7-1 Select a threaded rod to resist a service dead load of 43 kips and a service live load of 4 kips. Use A36 steel.
   a. Use LRFD.
   b. Use ASD.
3.7-2  A W16 × 36 is supported by two tension rods AB and CD, as shown in Figure P3.7-2. The 30-kip load is a service live load. Use load and resistance factor design and select threaded rods of A36 steel for the following load cases.

a. The 30-kip load cannot move from the location shown.

b. The 30-kip load can be located anywhere between the two rods.

![Figure P3.7-2](image)

3.7-3  Same as problem 3.7-2, but use allowable stress design.

3.7-4  As shown in Figure P3.7-4, members AC and BD are used to brace the pin-connected structure against a horizontal wind load of 10 kips. Both of these members are assumed to be tension members and not resist any compression. For the load direction shown, member AC will resist the load in tension, and member BD will be unloaded. Select threaded rods of A36 steel for these members. Use load and resistance factor design.

![Figure P3.7-4](image)
3.7-5  What size A36 threaded rod is required for member AB, as shown in Figure P3.7-5? The load is a service live load. (Neglect the weight of member CB.)
   a. Use LRFD.
   b. Use ASD.

3.7-6  A pipe is supported at 12-foot intervals by a bent, threaded rod, as shown in Figure P3.7-6. If an 8-inch-diameter standard weight steel pipe full of water is used, what size A36 steel rod is required?
   a. Use LRFD.
   b. Use ASD.

Tension Members in Roof Trusses

3.8-1  Use A992 steel and select a structural tee for the top chord of the welded roof truss shown in Figure P3.8-1. All connections are made with longitudinal plus transverse welds. Assume a connection length of 12 inches. The spacing of trusses in the roof system is 15 feet. Design for the following loads.
Snow: 20 psf of horizontal projection  
Roofing: 12 psf  
MC8 x 8.5 purlins  
Truss weight: 1000 lb (estimated)

a. Use LRFD.  
b. Use ASD.

3.8-2 Use ASD and select single-angle shapes for the web tension members of the truss loaded as shown in Figure P3.8-2. The loads are service loads. All connections are with longitudinal welds. Use A36 steel and an estimated shear lag factor, \( U \), of 0.85.

3.8-3 Compute the factored joint loads for the truss of Problem 3.8-2 for the following conditions.

- Trusses spaced at 18 feet  
- Weight of roofing = 8 psf  
- Snow load = 20 psf of horizontal projection  
- W10 x 33 purlins located only at the joints  
- Total estimated truss weight = 5000 lb

3.8-4 Use LRFD and design the tension members of the roof truss shown in Figure P3.8-4. Use double-angle shapes throughout and assume 3/8-inch-thick gusset plates and welded connections. Assume a shear lag factor of \( U = 0.80 \). The trusses are spaced at 30 feet. Use A36 steel and design for the following loads.
Metal deck: 4 psf of roof surface
Built-up roof: 12 psf of roof surface
Purlins: 3 psf of roof surface (estimated)
Snow: 20 psf of horizontal projection
Truss weight: 5 psf of horizontal projection (estimated)

![Diagram of a truss structure with dimensions 8' height and 8 @ 10' = 80']

**FIGURE P3.8-4**

**3.8-5** Use A36 steel and design sag rods for the truss of Problem 3.8-4. Assume that, once attached, the metal deck will provide lateral support for the purlins; therefore, the sag rods need to be designed for the purlin weight only.

a. Use LRFD.
b. Use ASD.