Chapter 12: Civil Engineering: The Art and Engineering of Bridge Design

12-1. When estimating the live load for a new bridge design, you want that estimate to be **conservative**. In other words, you want to err on the safe side by basing the estimate on the worst possible scenario—for example, bumper-to-bumper traffic, the heaviest vehicles, the worst environmental conditions, etc. With this in mind, estimate the live load for the following proposed bridge designs:

a. A foot bridge with a 174. ft span and two separate 4.-ft wide lanes to allow for pedestrian traffic in both directions.

b. A four-lane highway with a 300. ft span.

(a)

**Need:** conservative estimate of live load for a foot bridge

**Know:** bridge is 174 ft long with two 4-ft wide lanes

**How:** As a worst case, assume:
- 1 person weighs 250 lb
- In each lane, 2 persons (walking arm-in-arm) for every 2 ft of span

**Solve:** Live Load = \( \text{span} \times \text{no. of people per ft of span} \times \text{weight of one person} \times \text{no. of lanes} \)

\[
= (174) (1) (250) (2) \left[\text{ft/lane}\right]\left[\text{persons/ft}\right]\left[\text{lb/person}\right]\left[\text{lanes}\right]
= 87000 \text{ lb}
\]

(b)

**Need:** conservative estimate of live load for a highway bridge

**Know:** bridge is 300 ft long with 4 lanes

**How:** As a worst case, assume:
- 4 passengers each weighing 250 lb
- Empty car weighs 3300 lb
- Length of each car is 14.2 ft
- Traffic is bumper-to-bumper

**Solve:** Live Load = \((\text{span} / \text{car length}) \times \text{weight of one car} \times \text{no. of lanes}\)

\[
= (300/14.2) (4300) (4) \left[\text{ft/lane}\right]\left[\text{lb/car}\right]\left[\text{lanes}\right]
\]

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\[ = 360,000 \text{ lb} \]

For each of the rope bridges defined in exercises 2 through 4, determine the forces acting on the ends of the rope by (1) drawing the free-body diagram, (2) counting unknowns and equations to check determinacy, (3) writing the equilibrium equations, and (4) solving the equations.
Need: Forces acting on the ends of the rope

Know: Geometry of the rope; applied force of 1.50 kN; forces at ends align with the rope.

How: Draw the FBD; count unknowns and equations; write the equilibrium equations; solve the equations.

Solve:
First draw the FBD:

\[
\begin{align*}
1.50 \text{ kN} \\
\end{align*}
\]

where \( \theta = \tan^{-1} \frac{8}{15} = 28.1^\circ \)

Counts unknowns and equations:
2 unknowns (A,B) and 2 equations; therefore statically determinate

Write the equilibrium equations:
\[
\begin{align*}
\sum F_x &= 0 \quad \Rightarrow -A \cos(28.1^\circ) + B \cos(28.1^\circ) = 0 \\
\sum F_y &= 0 \quad \Rightarrow A \sin(28.1^\circ) + B \sin(28.2^\circ) - 1.50 = 0
\end{align*}
\]

Solve the equations by substitution to obtain:
\[
A = 1.59 \text{ kN} \quad \text{and} \quad B = 1.59 \text{ kN}
\]
Need:  Forces acting on the ends of the rope

Know:  Geometry of the rope; applied force of 1.20 kN; forces at ends align with the rope.

How:  Draw the FBD; count unknowns and equations; write the equilibrium equations; solve the equations.

Solve:
First draw the FBD:

\[
\text{where } \theta_1 = \tan^{-1} \frac{4}{20} = 11.3^\circ; \quad \theta_2 = \tan^{-1} \frac{1}{8} = 7.13^\circ
\]

Counts unknowns and equations:
2 unknowns (A,B) and 2 equations; therefore statically determinate

Write the equilibrium equations:
\[
\sum F_x = 0 \quad -A \cos(11.3^\circ) + B \cos(7.13^\circ) = 0
\]
\[ \sum F_y = 0 \quad A \sin(11.3^\circ) + B \sin(7.13^\circ) - 1.20 = 0 \]

Solve the equations by substitution to obtain:
\[ A = 3.77 \text{ kN} \quad ; \quad B = 3.72 \text{ kN} \]
Need: Forces acting on the ends of the rope

Know: Geometry of the rope; applied force of 1.20 kN; forces at ends align with the rope.

How: Draw the FBD; count unknowns and equations; write the equilibrium equations; solve the equations.

Solve:
First draw the FBD:

\[ \begin{align*}
\theta_1 &= \tan^{-1} \frac{2}{10} = 11.3^\circ; \\
\theta_2 &= \tan^{-1} \frac{7}{14} = 26.6^\circ
\end{align*} \]

Counts unknowns and equations:
2 unknowns (A, B) and 2 equations; therefore statically determinate

Write the equilibrium equations:
\[ \begin{align*}
\sum F_x &= 0 \\
\sum F_y &= 0
\end{align*} \]

\[ \begin{align*}
-A\cos(11.3^\circ) + B\cos(26.6^\circ) &= 0 \\
A\sin(11.3^\circ) + B\sin(26.6^\circ) - 500 &= 0
\end{align*} \]

Solve the equations by substitution to obtain:
\[ \begin{align*}
A &= 726. \text{ lb} \\
B &= 799. \text{ lb}
\end{align*} \]
12-5. For the given structure, do your best to identify all of its members as beams, compression members, or tension members.

Need: Identify member types

Know: Topology of the structure; the locations of the forces; cables are present

How: Cables are tension members; triangles are composed of tension and compression members; other polygonal shapes are composed of beams; if loaded at mid-span by a transverse load, it’s a beam.

Solve: Beams: JH (because it will bend under the transverse force at mid-span and CD, DE (because they are not triangulated)

Tension members: AJ and GH (because they are cables)

Tension or compression members: AB, BC, BJ, CJ, EF, FG, FH, EH (because they are sides of triangles)
Photos of four existing bridges are shown. For each bridge, write a paragraph that describes in specific terms the strategies used by the designer to make it an efficient structure. General strategies to draw from include: efficient beam cross-sections, trusses, arches, use of tension members (or cable) to avoid problems with buckling.

a. Akashi Kaikyo Bridge, Japan

b. Bridge of the Americas, Panama
c. Forth Bridge, United Kingdom

e. Whipple Bridge, USA

**Need:** Determine what makes these bridges efficient structures
Know: Some basic strategies for making a structure efficient including: beams, trusses, arches

How: Examine the structural topology of these bridges.

Solve:
Students should pose their responses in paragraph form to exercise their writing skills. Here we will just list some of the main features that make these bridges efficient structures

(a) Akaski Kaikyo Bridge
- Truss beam supports the highway
- Pier/tower is triangulated.
- Catenary cable supports highway from above. Extensive use of cables in suspension bridges avoids problems with buckling

(b) Bridge of the Americas
- Employs an arch.
- Arch is in the form of a truss
- Cables suspended from the arch support the highway from above, thus avoiding some buckling issues.
- Efficient cross-sections are used, i.e. cross-section of the arch gets larger where bending is greatest (at the ends of the arch where the piers are located)

(c) Forth Bridge
- This is essentially a truss beam of variable cross-section (cross-section gets larger towards the piers where bending moment is greatest)

(d) Whipple Bridge
- This is a truss.
- Members running along the top form an arch

For each of the trusses shown in exercises 7 through 12, determine the forces on all members by the method of joints. Use a spreadsheet to solve the equations.
12-7.

Need: Forces on all members of the truss

Know: Geometry of the truss and the forces acting on it

How: By the method of joints

Solve:
First draw the FBDs:

where \( \theta = \tan^{-1} \frac{5}{7} = 35.5^\circ \)

Counts unknowns and equations:
6 unknowns and 6 equations (2 per FBD); therefore statically determinate

Write the equilibrium equations:
Pin A:
\[
\sum F_x = 0 \quad F_{AB} \cos(35.5^\circ) + F_{AC} + A_x = 0
\]
\[
\sum F_y = 0 \quad F_{AB} \sin(35.5^\circ) + A_y = 0
\]

Pin B:
\[
\sum F_x = 0 \quad -F_{AB} \cos(35.5^\circ) + F_{BC} \cos(35.5^\circ) = 0
\]
\[
\sum F_y = 0 \quad -F_{AB} \sin(35.5^\circ) - F_{BC} \sin(35.5^\circ) - 1000 = 0
\]

Pin C:
\[
\sum F_x = 0 \quad -F_{AC} - F_{BC} \cos(35.5^\circ) = 0
\]
\[
\sum F_y = 0 \quad F_{BC} \sin(35.5^\circ) + C_y = 0
\]

Tabulate coefficients and right-hand side constants:

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<thead>
<tr>
<th>EQ</th>
<th>$F_{AB}$</th>
<th>$F_{AC}$</th>
<th>$F_{BC}$</th>
<th>$A_x$</th>
<th>$A_y$</th>
<th>$C_y$</th>
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</table>

Solve the equations using a spreadsheet:

Solution of the Equations for Exercise 7

\[
[A] = \begin{bmatrix}
0.814 & 1 & 0 & 1 & 0 & 0 & 0 \\
0.581 & 0 & 0 & 0 & 1 & 0 & 0 \\
-0.814 & 0 & 0.814 & 0 & 0 & 0 & 0 \\
-0.581 & 0 & -0.581 & 0 & 0 & 0 & 1000 \\
0 & -1 & -0.814 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.581 & 0 & 0 & 1 & 0
\end{bmatrix} \quad \{b\} = \begin{bmatrix}
0 \\
0 \\
0 \\
0 \\
0 \\
0
\end{bmatrix}
\]

\[
[A^{-1}] = \begin{bmatrix}
0.614 & -0.614 & -0.861 & 0 & 0 & -861 & = F_{AB} \\
0 & 0.5 & 0.701 & -1 & 0 & 700.5 & = F_{AC} \\
0 & 0 & 0.614 & -0.861 & 0 & 0 & -861 & = F_{BC} \\
1 & 0 & 1 & 0 & 0 & 0 & = A_x \\
0 & 1 & 0.357 & 0.5 & 0 & 500 & = A_y \\
0 & 0 & -0.357 & 0.5 & 0 & 1 & 500 & = C_y
\end{bmatrix}
\]
Need: Forces on all members of the truss

Know: Geometry of the truss and the forces acting on it

How: By the method of joints

Solve:
First draw the FBDs:

\[
\begin{align*}
\text{A} & \quad F_{AB} \quad 18.4^\circ \\
\text{B} & \quad F_{AB} \quad F_{BD} \\
\text{C} & \quad F_{BC} \quad F_{CD} \quad 18.4^\circ \\
\text{D} & \quad F_{AD} \quad F_{BD} \quad F_{CD} \quad 18.4^\circ
\end{align*}
\]

where \( \theta = \tan^{-1} \frac{5}{15} = 18.4^\circ \)

Counts unknowns and equations:

8 unknowns and 8 equations (2 per FBD); therefore statically determinate

Write the equilibrium equations:

\[
\sum F_x = 0 \quad F_{AB} + F_{AD} \cos(18.4^\circ) + A_x = 0
\]
\[
\sum F_y = 0 \quad -F_{AD} \sin(18.4^\circ) + A_y = 0
\]

**Pin B:**
\[
\sum F_x = 0 \quad F_{BC} - F_{AB} = 0
\]
\[
\sum F_y = 0 \quad -F_{BD} - 900 = 0
\]

**Pin C:**
\[
\sum F_x = 0 \quad -F_{BC} - F_{CD} \cos(18.4^\circ) = 0
\]
\[
\sum F_y = 0 \quad -F_{CD} \sin(18.4^\circ) + C_y = 0
\]

**Pin D:**
\[
\sum F_x = 0 \quad F_{CD} \cos(18.4^\circ) - F_{AD} \cos(18.4^\circ) = 0
\]
\[
\sum F_y = 0 \quad F_{CD} \sin(18.4^\circ) + F_{AD} \sin(18.4^\circ) + F_{BD} = 0
\]

Tabulate coefficients and right-hand side constants:

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<tr>
<th>EQ</th>
<th>( F_{AB} )</th>
<th>( F_{BC} )</th>
<th>( F_{CD} )</th>
<th>( F_{BD} )</th>
<th>( F_{AD} )</th>
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Solve the equations using a spreadsheet:
Solution of the Equations for Exercise 8

\[
\begin{bmatrix}
1 & 0 & 0 & 0 & 0.949 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -0.316 & 0 & 1 & 0 & 0 \\
-1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{bmatrix}
\]

\[
(b) = 900
\]

\[
[A] =
\begin{bmatrix}
0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & -1 & -0.949 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -0.316 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0.949 & 0 & -0.949 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.316 & 1 & 0.316 & 0 & 0 & 0 & 0 \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
0 & 0 & -1 & -1.5 & -1 & 0 & -0.5 & -1.502 \\
0 & 0 & 0 & -1.5 & -1 & 0 & -0.5 & -1.502 \\
0 & 0 & 0 & 1.582 & 0 & 0 & 0.5269 & 1.582 \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1.582 & 0 & 0 & 0.527 & 1.582 \\
1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0.5 & 0 & 0 & 0.1666 & 0.5 \\
0 & 0 & 0 & 0.5 & 0 & 1 & 0.1665 & 0.5 \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
0 & 1351 & = F_{AB} \\
0 & 1351 & = F_{BC} \\
0 & 1424 & = F_{CD} \\
0 & -900 & = F_{BD} \\
0 & 1424 & = F_{AD} \\
0 & 450 & = A_x \\
0 & 450 & = A_y \\
0 & 450 & = C_y \\
\end{bmatrix}
\]
Need: Forces on all members of the truss

Know: Geometry of the truss and the forces acting on it

How: By the method of joints

Solve:
First draw the FBDs:

\[
\begin{align*}
\text{B} & : F_{BC}, F_{BE} \\
\text{C} & : F_{BC}, F_{CE}, F_{CD} \\
\text{A} & : F_{AE}, F_{AB} \\
\text{D} & : F_{CD}, F_{DE} \\
\text{E} & : F_{AE}, F_{DE}
\end{align*}
\]

where \( \theta = \tan^{-1} \frac{3}{1.5} = 63.4^\circ \)

Counts unknowns and equations:
10 unknowns and 10 equations (2 per FBD); therefore statically determinate

Write the equilibrium equations:

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Pin A:
\[ \sum F_x = 0 \quad F_{AB} \cos(63.4^\circ) + F_{AE} + A_x = 0 \]
\[ \sum F_y = 0 \quad F_{AB} \sin(63.4^\circ) + A_y = 0 \]

Pin B:
\[ \sum F_x = 0 \quad -F_{AB} \cos(63.4^\circ) + F_{BE} \cos(63.4^\circ) + F_{BC} = 0 \]
\[ \sum F_y = 0 \quad -F_{AB} \sin(63.4^\circ) - F_{BE} \sin(63.4^\circ) = 0 \]

Pin C:
\[ \sum F_x = 0 \quad -F_{BC} - F_{CE} \cos(63.4^\circ) + F_{CD} \cos(63.4^\circ) = 0 \]
\[ \sum F_y = 0 \quad -F_{CE} \sin(63.4^\circ) - F_{CD} \sin(63.4^\circ) = 0 \]

Pin D:
\[ \sum F_x = 0 \quad -F_{CD} \cos(63.4^\circ) - F_{DE} = 0 \]
\[ \sum F_y = 0 \quad F_{CD} \sin(63.4^\circ) + D_y = 0 \]

Pin E:
\[ \sum F_x = 0 \quad F_{DE} + F_{CE} \cos(63.4^\circ) - F_{BE} \cos(63.4^\circ) - F_{AE} = 0 \]
\[ \sum F_y = 0 \quad F_{BE} \sin(63.4^\circ) + F_{CE} \sin(63.4^\circ) - 5.00 = 0 \]

Tabulate coefficients and right-hand side constants:

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<th>F_{AB}</th>
<th>F_{BC}</th>
<th>F_{CD}</th>
<th>F_{DE}</th>
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Solve the equations using a spreadsheet:
Solution of the Equations for Exercise 9

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0 & -1 & 0.448 & 0 & 0 & -0.448 & 0 & 0 & 0 & 0 \\
0 & 0 & -0.894 & 0 & 0 & -0.894 & 0 & 0 & 0 & 0 \\
0 & 0 & -0.448 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.894 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & -1 & 0.448 & -0.448 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.894 & 0.894 & 0 & 0 & 0 \\
\end{bmatrix} \quad \{b\} = \begin{bmatrix}
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
\end{bmatrix}
\]

\[
\{x\} = \begin{bmatrix}
1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\
0 & 1 & 0.4989 & 0.75 & 0.4989 & 0.25 & 0 & 0 & 0 & 0.5 \\
0 & 0 & -0.4989 & 0.25 & -0.4999 & 0.75 & 0 & 1 & 0 & 0.5 \\
\end{bmatrix}
\]

\[
\text{inv}[A] = \begin{bmatrix}
0 & 0 & -0.558 & -0.8389 & -0.558 & -0.28 & 0 & 0 & 0 & -0.559 \\
0 & 0 & 0.5 & -0.2506 & -0.5 & -0.251 & 0 & 0 & 0 & -0.501 \\
0 & 0 & 0.558 & -0.2796 & 0.558 & -0.839 & 0 & 0 & 0 & -0.559 \\
0 & 0 & -0.25 & 0.1253 & -0.25 & 0.3758 & -1 & 0 & 0 & 0.2506 \\
0 & 0 & 0.1253 & 0.3758 & 0.1253 & -0.25 & 0.2506 & 0 & -1 & 0.2506 \\
0 & 0 & -0.575 & 0.3758 & -0.75 & 0.1253 & -1 & 0 & -1 & 0.2506 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5593 \\
1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\
0 & 1 & 0.4989 & 0.75 & 0.4989 & 0.25 & 0 & 0 & 0 & 0.5 \\
0 & 0 & -0.4989 & 0.25 & -0.4999 & 0.75 & 0 & 1 & 0 & 0.5 \\
\end{bmatrix}
\]

\[
\begin{align*}
F_{AB} &= -2.8 \\
F_{BC} &= -2.51 \\
F_{CD} &= -2.8 \\
F_{DE} &= 1.253 \\
F_{AE} &= 1.253 \\
F_{CE} &= 2.796 \\
F_{BE} &= 2.796 \\
A_x &= 0 \\
A_y &= 2.5 \\
D_y &= 2.5
\end{align*}
\]
Need: Forces on all members of the truss

Know: Geometry of the truss and the forces acting on it

How: By the method of joints

Solve: First draw the FBDs:

Counts unknowns and equations:

12 unknowns and 12 equations (2 per FBD); therefore statically determinate

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Write the equilibrium equations:

**Pin A:**
\[ \sum F_x = 0 \quad F_{AF} + A_x = 0 \]
\[ \sum F_y = 0 \quad F_{AB} + A_y = 0 \]

**Pin B:**
\[ \sum F_x = 0 \quad F_{BC} + F_{BF} \cos(45^\circ) = 0 \]
\[ \sum F_y = 0 \quad -F_{AB} - F_{BF} \sin(45^\circ) = 0 \]

**Pin C:**
\[ \sum F_x = 0 \quad F_{CD} - F_{BC} = 0 \]
\[ \sum F_y = 0 \quad -F_{CF} = 0 \]

**Pin D:**
\[ \sum F_x = 0 \quad -F_{CD} - F_{DF} \cos(45^\circ) = 0 \]
\[ \sum F_y = 0 \quad -F_{DE} - F_{DF} \sin(45^\circ) = 0 \]

**Pin E:**
\[ \sum F_x = 0 \quad -F_{EF} = 0 \]
\[ \sum F_y = 0 \quad F_{DE} + E_y = 0 \]

**Pin F:**
\[ \sum F_x = 0 \quad F_{EF} + F_{DF} \cos(45^\circ) - F_{BF} \cos(45^\circ) - F_{AF} = 0 \]
\[ \sum F_y = 0 \quad F_{DF} \sin(45^\circ) + F_{CF} + F_{BF} \sin(45^\circ) - 8.00 = 0 \]

Tabulate coefficients and right-hand side constants:

<table>
<thead>
<tr>
<th>EQ</th>
<th>$F_{AB}$</th>
<th>$F_{BC}$</th>
<th>$F_{CD}$</th>
<th>$F_{DF}$</th>
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Solve the equations using a spreadsheet:

**Solution of the Equations for Exercise 10**

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0.707 & 0 & 0 & 0 & 0 & 0 \\
-1 & 0 & 0 & 0 & 0 & 0 & -0.707 & 0 & 0 & 0 & 0 & 0 \\
0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

\[\{b\} = 0\]

\[\begin{bmatrix}
0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & -0.707 & 0 & 0 & 0 \\
0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & -0.707 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 1 & -1 & -0.707 & 0 & 0.707 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0.707 & 1 & 0.707 & 0 & 0 & 0
\end{bmatrix}
\]

\[\{x\} = 0\]

\[\begin{bmatrix}
0 & 0 & -0.5 & -1 & -0.5 & 0.5 & -0.5 & 0 & 0 & 0 & 0 & -0.5 \\
0 & 0 & 0.5 & 0 & -0.5 & 0.5 & -0.5 & 0 & 0 & 0 & 0 & -0.5 \\
0 & 0 & 0.5 & 0 & 0.5 & 0.5 & -0.5 & 0 & 0 & 0 & 0 & -0.5 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 & -1 & 0 & -1 & 0 & -1 & 0 & -1 & 0
\end{bmatrix}
\]

\[\text{inv}[A] = \]

\[\begin{bmatrix}
0 & 0 & 0.7072 & 0 & 0.7072 & -0.707 & 0.7072 & 0 & 0 & 0 & 0 & 0.7072 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -0.707 & 0 & -0.707 & -0.707 & -0.707 & 0 & 0 & 0 & 0 & 0.7072 \\
1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\
0 & 1 & 0.5 & 1 & 0.5 & -0.5 & 0.5 & 0 & 0 & 0 & 0 & 0.5 \\
0 & 0 & -0.5 & 0 & -0.5 & -0.5 & 1 & 0 & 1 & 0 & 0 & 0.5
\end{bmatrix}
\]

\[\text{ax} = \]

\[\text{ay} = \]

\[\text{ez} = \]

\[\text{ef} = \]

\[\text{eb} = \]

\[\text{ec} = \]

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\[\text{ex} = \]

\[\text{ef} = \]

\[\text{ed} = \]

\[\text{ex} = \]
Need:  Forces on all members of the truss

Know:  Geometry of the truss and the forces acting on it

How:  By the method of joints

Solve:  

\[
\begin{align*}
\theta &= \tan^{-1} \frac{10}{7} = 55.0^\circ \\
\text{Counts unknowns and equations:} 
\end{align*}
\]
12 unknowns and 12 equations (2 per FBD); therefore statically
determinate

Write the equilibrium equations:

**Pin A:**
\[ \sum F_x = 0 \quad F_{AB} \cos(55.0^\circ) + F_{AF} + A_x = 0 \]
\[ \sum F_y = 0 \quad F_{AB} \sin(55.0^\circ) + A_y = 0 \]

**Pin B:**
\[ \sum F_x = 0 \quad - F_{AB} \cos(55.0^\circ) + F_{BC} = 0 \]
\[ \sum F_y = 0 \quad - F_{AB} \sin(55.0^\circ) - F_{BF} = 0 \]

**Pin C:**
\[ \sum F_x = 0 \quad - F_{BC} - F_{CF} \cos(55.0^\circ) + F_{CD} \cos(55.0^\circ) = 0 \]
\[ \sum F_y = 0 \quad - F_{CF} \sin(55.0^\circ) - F_{CE} - F_{CD} \sin(55.0^\circ) = 0 \]

**Pin D:**
\[ \sum F_x = 0 \quad - F_{DE} - F_{CD} \cos(55.0^\circ) = 0 \]
\[ \sum F_y = 0 \quad F_{CD} \sin(55.0^\circ) + D_y = 0 \]

**Pin E:**
\[ \sum F_x = 0 \quad F_{DE} - F_{EF} = 0 \]
\[ \sum F_y = 0 \quad F_{CE} - 1000 = 0 \]

**Pin F:**
\[ \sum F_x = 0 \quad - F_{AF} + F_{CF} \cos(55.0^\circ) + F_{EF} = 0 \]
\[ \sum F_y = 0 \quad F_{BF} + F_{CF} \sin(55.0^\circ) - 1000 = 0 \]

Tabulate coefficients and right-hand side constants:

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<th>EQ</th>
<th>( F_{AB} )</th>
<th>( F_{BC} )</th>
<th>( F_{CD} )</th>
<th>( F_{DE} )</th>
<th>( F_{EF} )</th>
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Solve the equations using a spreadsheet:

Solution of the Equations for Exercise 11

\[
[A] = \begin{bmatrix}
0.574 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0.819 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
-0.574 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.819 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\
0 & -1 & 0.574 & 0 & 0 & 0 & 0 & -0.574 & 0 & 0 \\
0 & 0 & -0.819 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\
0 & 0 & 0.819 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & -1 & 0 & 0.574 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0.819 & 0 & 0 & 0 \\
\end{bmatrix}
\]

\{b\} = 0

\[\text{inv}[A] = \begin{bmatrix}
0 & 0 & -0.581 & -0.814 & -0.581 & -0.407 & 0 & 0 & 0 & -0.407 & 0 & -0.814 \\
0 & 0 & 0.6667 & -0.467 & -0.333 & -0.2336 & 0 & 0 & 0 & -0.234 & 0 & -0.4672 \\
0 & 0 & 0.5807 & -0.407 & 0.581 & -0.814 & 0 & 0 & 0 & -0.814 & 0 & -0.407 \\
0 & 0 & -0.333 & 0.2336 & -0.333 & 0.4672 & -1 & 0 & 0 & 0.467 & 0 & 0.2336 \\
0 & 0 & -0.333 & 0.2336 & -0.333 & 0.4672 & -1 & 0 & -1 & 0.467 & 0 & 0.2336 \\
0 & 0 & 0.6667 & -0.467 & -0.667 & 0.2336 & -1 & 0 & -1 & 0.234 & -1 & 0.4672 \\
0 & 0 & 0.4756 & -0.333 & 0.476 & 0.3333 & 0 & 0 & 0 & 0.333 & 0 & 0.6667 \\
0 & 0 & -0.581 & 0.407 & -0.581 & -0.407 & 0 & 0 & 0 & -0.407 & 0 & 0.407 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\
0 & 1 & 0.4756 & 0.6667 & 0.476 & 0.3333 & 0 & 0 & 0 & 0.333 & 0 & 0.6667 \\
0 & 6E-17 & -0.476 & 0.3333 & -0.476 & 0.6667 & 0 & 1 & 0 & 0.667 & 0 & 0.3333 \\
\end{bmatrix}
\]

\{x\} = \begin{bmatrix}
-1221 \\
700.9 \\
-1221 \\
700.9 \\
700.9 \\
700.9 \\
1000 \\
-6E-14 \\
1000 \\
1000 \\
1000 \\
1000 \\
\end{bmatrix}

\(F_{AB} = 700.9\)

\(F_{BC} = 1221\)

\(F_{CD} = 700.9\)

\(F_{DE} = 700.9\)

\(F_{FA} = 1000\)

\(F_{FB} = 1221\)

\(F_{FC} = 1000\)

\(F_{FD} = 1000\)

\(F_{FE} = 1000\)

\(F_{FF} = 1000\)

\(F_{AA} = 1000\)

\(F_{BF} = 1000\)

\(F_{CF} = 1000\)

\(F_{DF} = 1000\)

\(F_{EF} = 1000\)

\(F_{FA} = 1000\)

\(F_{FB} = 1000\)

\(F_{FC} = 1000\)

\(F_{FD} = 1000\)

\(F_{FE} = 1000\)

\(F_{FF} = 1000\)
Need: Forces on all members of the truss

Know: Geometry of the truss and the forces acting on it

How: By the method of joints

Solve: First draw the FBDs:

Counts unknowns and equations:

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16 unknowns and 16 equations (2 per FBD); therefore statically determinate

Write the equilibrium equations:

**Pin A:**
\[ \sum F_x = 0 \]
\[ F_{AB} \cos(45.0^\circ) + F_{AH} + A_x = 0 \]
\[ \sum F_y = 0 \]
\[ F_{AB} \sin(45.0^\circ) + A_y = 0 \]

**Pin B:**
\[ \sum F_x = 0 \]
\[ -F_{AB} \cos(45.0^\circ) + F_{BC} \cos(45.0^\circ) + F_{BG} \cos(45.0^\circ) = 0 \]
\[ \sum F_y = 0 \]
\[ -F_{AB} \sin(45.0^\circ) - F_{BH} - F_{BG} \sin(45.0^\circ) + F_{BC} \sin(45.0^\circ) = 0 \]

**Pin C:**
\[ \sum F_x = 0 \]
\[ -F_{BC} \cos(45.0^\circ) + F_{CD} \cos(45.0^\circ) = 0 \]
\[ \sum F_y = 0 \]
\[ -F_{BC} \sin(45.0^\circ) - F_{CD} \sin(45.0^\circ) - F_{CG} = 0 \]

**Pin D:**
\[ \sum F_x = 0 \]
\[ -F_{CD} \cos(45.0^\circ) - F_{DG} \cos(45.0^\circ) + F_{DE} \cos(45.0^\circ) = 0 \]
\[ \sum F_y = 0 \]
\[ F_{CD} \sin(45.0^\circ) - F_{DG} \sin(45.0^\circ) - F_{DE} \sin(45.0^\circ) - F_{DF} = 0 \]

**Pin E:**
\[ \sum F_x = 0 \]
\[ -F_{DE} \cos(45.0^\circ) - F_{EF} = 0 \]
\[ \sum F_y = 0 \]
\[ F_{DE} \sin(45.0^\circ) + E_y = 0 \]

**Pin F:**
\[ \sum F_x = 0 \]
\[ -F_{GF} + F_{EF} = 0 \]
\[ \sum F_y = 0 \]
\[ F_{DF} - 800 = 0 \]

**Pin G:**
\[ \sum F_x = 0 \]
\[ -F_{GH} - F_{BG} \cos(45.0^\circ) + F_{DG} \cos(45.0^\circ) + F_{GF} = 0 \]
\[ \sum F_y = 0 \]
\[ F_{BG} \sin(45.0^\circ) + F_{DG} \sin(45.0^\circ) + F_{CG} - 1600 = 0 \]

**Pin H:**
\[ \sum F_x = 0 \]
\[ -F_{AH} + F_{GH} = 0 \]
\[ \sum F_y = 0 \]
\[ F_{BH} - 800 = 0 \]

Tabulate coefficients and right-hand side constants:
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<th>$F_{CD}$</th>
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<th>$F_{BH}$</th>
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Solve the equations using a spreadsheet:
### Solution of the Equations for Exercise 12

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\[
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\]
12-13. A truss that is pinned at one end and on rollers at the other will be statically
determinate if it satisfies the following equation:

\[ 0 = 2j - m - 3 \]

where \( j \) is the number of joints and \( m \) is the number of members. This is a quick way to
check for static determinacy without drawing the FBDs. Apply this equation to:

a. Verify that the trusses in exercises 7 through 12 are statically determinate.
b. Sketch three statically determinate truss bridges with the following numbers of
members: (1) 11 members, (2) 15 members, and (3) 19 members.

(a)  
**Need:** Verify that the trusses in Exercises 7-12 are statically determinate.

**Know:** Geometry of the trusses

**How:** Count joints and members, then substitute into \( 0 = 2j - m + 3 \) to verify that
this relationship is satisfied.

**Solve:**

<table>
<thead>
<tr>
<th>Exer.</th>
<th>( j )</th>
<th>( m )</th>
<th>( 2j - m + 3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3</td>
<td>3</td>
<td>( 2(3) - 3 - 3 = 0 )</td>
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<tr>
<td>8</td>
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<td>5</td>
<td>( 2(4) - 5 - 3 = 0 )</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>7</td>
<td>( 2(5) - 7 - 3 = 0 )</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>9</td>
<td>( 2(6) - 9 - 3 = 0 )</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>9</td>
<td>( 2(6) - 9 - 3 = 0 )</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>13</td>
<td>( 2(8) - 13 - 3 = 0 )</td>
</tr>
</tbody>
</table>

Therefore all 6 trusses in Exercises 7-12 are statically determinate.

(b)  
**Need:** Generate statically determinate truss topologies with the requisite number
of members.

**Know:** A truss that is pinned at one end and on rollers at the other and that
satisfies
\( 0 = 2j - m - 3 \) will be a statically determinate truss.

**How:** Sketch fully triangulated structures with the required number of members,
then check for determinacy using \( 0 = 2j - m - 3 \)

**Solve:** There are many possibilities. The following are representative solutions:

11 members:
where \( j = 7, \ m = 11, \) and \( 2j - m - 3 = 0 \)

15 members:

where \( j = 9, \ m = 15, \) and \( 2j - m - 3 = 0 \)

19 members:

where \( j = 11, \ m = 19, \) and \( 2j - m - 3 = 0 \)
12-14. Calculate the overall factor of safety of a truss that has the member forces, lengths, and cross-sectional areas given in the table. Assume steel members ($S_Y = 36000 \text{ lbf/in}^2$, $E = 29. \times 10^6 \text{ lbf/in}^2$) with square cross-sections, and consider buckling.

<table>
<thead>
<tr>
<th>Member</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force (lbf)</td>
<td>-9060</td>
<td>-9060</td>
<td>12300</td>
<td>12300</td>
<td>5410</td>
</tr>
<tr>
<td>Area (in$^2$)</td>
<td>0.400</td>
<td>0.400</td>
<td>0.500</td>
<td>0.500</td>
<td>0.250</td>
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<tr>
<td>Length (ft)</td>
<td>3.60</td>
<td>3.60</td>
<td>4.20</td>
<td>4.20</td>
<td>3.00</td>
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</tbody>
</table>

**Need:** The overall factor of safety ($N$) of the truss.

**Know:** The yield strength ($S_Y$), the elastic modulus ($E$), the forces on the members ($F$), the cross-sectional areas of the members ($A$), and the lengths ($L$) of the members.

**How:** Calculate the stress in each member using $\sigma = \frac{F}{A}$. Then calculate the factors of safety of the individual members using equation (12.6) with tension members and equation (12.9) with compression members. Finally, take the smallest of these factors of safety to be the overall factor of safety.

**Solve:** Begin by calculating the stress in each member:

- **Member 1:** $\sigma_1 = \frac{F_1}{A_1} = \frac{-9060}{0.400} = -22600 \text{ lb/in}^2$ (compression)
- **Member 2:** $\sigma_2 = \frac{F_2}{A_2} = \frac{-9060}{0.400} = -22600 \text{ lb/in}^2$ (compression)
- **Member 3:** $\sigma_3 = \frac{F_3}{A_3} = \frac{12300}{0.500} = 24600 \text{ lb/in}^2$ (tension)
- **Member 4:** $\sigma_4 = \frac{F_4}{A_4} = \frac{12300}{0.500} = 24600 \text{ lb/in}^2$ (tension)
- **Member 5:** $\sigma_5 = \frac{F_5}{A_5} = \frac{5410}{0.250} = 21600 \text{ lb/in}^2$ (tension)

Calculate the factors of safety of the tension members:

- **Member 3:** $N_3 = \frac{S_Y}{|\sigma_3|} = \frac{36000}{24600} = 1.46$
- **Member 4:** $N_4 = \frac{S_Y}{|\sigma_4|} = \frac{36000}{24600} = 1.46$

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Member 5: \[ n_5 = \frac{S_y}{|\sigma_5|} = \frac{36000}{21600} = 1.67 \]

Calculate the buckling strength and the factor of safety of each compression member:

Member 1:
\[
S_{b1} = \frac{\pi^2 E A_1}{12L_1^2} = \frac{\pi^2 (29. \times 10^6)(0.400)}{12 (3.60)^2(12)^2} = 5110. \text{ lb/in}^2
\]
\[ N_1 = \frac{\min(S_y, S_{b1})}{|\sigma_1|} = \frac{5110}{22600} = 0.226 \]

Member 2:
\[
S_{b2} = \frac{\pi^2 E A_2}{12L_2^2} = \frac{\pi^2 (29. \times 10^6)(0.400)}{12 (3.60)^2(12)^2} = 5110. \text{ lb/in}^2
\]
\[ N_2 = \frac{\min(S_y, S_{b2})}{|\sigma_2|} = \frac{5110}{22600} = 0.226 \]

Determine the overall factor of safety:
\[ N = \min(N_1, N_2, N_3, N_4, N_5) = \min(0.226, 0.226, 1.46, 1.46, 1.67) = 0.226 \]

Therefore you can expect this truss to fail.
12-15. Calculate the required cross-sectional areas of the members comprising the truss bridge of Figure 12.14. Refer to Figure 12.17 for the forces and design for a factor of safety of $N = 5.0$. Assume steel members ($S_Y = 36000$ lbf/in$^2$, $E = 29. \times 10^6$ lbf/in$^2$) with square cross-sections, and consider buckling.

**Need:** The required cross-sectional areas of the members comprising the truss bridge.

**Know:** The yield strength ($S_Y$), the elastic modulus ($E$), the forces on the members ($F$), the required factor of safety ($N$). The lengths ($L$) of the members can be determined from the geometry of the truss-bridge.

**How:** First calculate the lengths of the members by reference to Figure 12.14. Then calculate the required cross-sectional area of each member using equation (12.7) with tension members and equation (12.10) with compression members.

**Solve:** First calculate the lengths of the members. The resulting lengths and corresponding forces are given in the following table:

<table>
<thead>
<tr>
<th>Member</th>
<th>Length (ft)</th>
<th>Force (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>87.2</td>
<td>-3.36×10$^5$</td>
</tr>
<tr>
<td>BC</td>
<td>87.2</td>
<td>-3.36×10$^5$</td>
</tr>
<tr>
<td>CD</td>
<td>87.2</td>
<td>3.36×10$^5$</td>
</tr>
<tr>
<td>AD</td>
<td>87.2</td>
<td>3.36×10$^5$</td>
</tr>
<tr>
<td>BD</td>
<td>13.0</td>
<td>-5.00×10$^4$</td>
</tr>
</tbody>
</table>

Calculate the cross-sectional areas of the tension members:

Member CD: \[ A = \frac{N|F|}{S_Y} = \frac{(5.0)(3.36\times10^5)}{36000} = 46.7 \text{ in}^2 \]

Member AD: same as CD

Calculate the cross-sectional areas of the compression members:

Member AB: \[ A = \max \left( \frac{N|F|}{S_Y}, \left( \frac{12N|F|L^2}{\pi^2E} \right)^{0.5} \right) \]

\[ A = \max \left( \frac{5.0 \times 3.36 \times 10^5}{36000}, \left( \frac{12 \times 5.0 \times 3.36 \times 10^5 \times (87.2)^2 \times 12^2}{\pi^2 (29.0 \times 10^6)} \right)^{0.5} \right) \]

\[ A = \max(46.7, 278.) \]

\[ A = 278. \text{ in}^2 \]
Member BC: same as AB

Member BD: 

\[ A = \max \left( \frac{N|F|}{S_f}, \left( \frac{12N|F|L^2}{\pi^2 E} \right)^{0.5} \right) \]

\[
A = \max \left( \frac{(5.0) - 5.00 \times 10^4}{36000}, \frac{(12)(5.0) - 5.00 \times 10^4(13.0)^2(12)^2}{\pi^2 (29.0 \times 10^6)} \right)^{0.5}
\]

\[ A = \max(6.94, 16.0) \]

\[ A = 16.0 \text{ in}^2 \]
12-16. Depending on which of exercises 7 through 12 you have completed, determine the overall factor of safety of one or more of the following structures. Assume steel members with a yield strength of \(S_Y = 36000 \text{ lbf/in}^2\) (or 250 MPa) and an elastic modulus of \(E = 29. \times 10^6 \text{ lbf/in}^2\) (or 200 GPa). Also assume square cross-sections, and consider buckling.

a. The truss in exercise 7. Assume \(A = 0.50 \text{ in}^2\) for all members.
b. The truss in exercise 8. Assume \(A = 1.00 \text{ in}^2\) for all members.
c. The truss in exercise 9. Assume \(A = 4.00 \text{ cm}^2\) for all members
d. The truss in exercise 10. Assume \(A = 2.25 \text{ cm}^2\) for all members.
e. The truss in exercise 11. Assume \(A = 1.50 \text{ in}^2\) for all members.
f. The truss in exercise 12. Assume \(A = 2.00 \text{ in}^2\) for all members.

**Need:** The overall factor of safety \((N)\) of the truss.

**Know:** The yield strength \((S_Y)\), the elastic modulus \((E)\), the forces on the members \((F)\), and the cross-sectional areas of the members \((A)\). The lengths \((L)\) of the members can be determined from the geometry of the truss.

**How:** Calculate the stress in each member using \(\sigma = F/A\). Then calculate the factors of safety of the individual members using equation (12.6) with tension members and equation (12.9) with compression members. Finally, take the smallest of these factors of safety to be the overall factor of safety.

**Solve:** See the solution to Prob. 14 for details on how to perform these calculations. Here the results for each truss are presented in the form of an Excel spreadsheet. The overall factor of safety appears in the lower right-hand corner of each table.

### a. exercise 7

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12-17. Depending on which of exercises 7 through 12 you have completed, determine the required cross-sectional areas of the members comprising one or more of the following structures. Assume steel members with a factor of safety of $N = 3.0$, a yield strength of $S_Y = 36000 \text{ lbf/in}^2$ (or 250 MPa), and an elastic modulus of $E = 29. \times 10^6 \text{ lbf/in}^2$ (or 200 GPa). Also assume square cross-sections, and consider buckling.

a. The truss in exercise 7.
b. The truss in exercise 8.
c. The truss in exercise 9.
d. The truss in exercise 10.
e. The truss in exercise 11.
f. The truss in exercise 12.

**Need:** The required cross-sectional areas of the members comprising each truss.

**Know:** The yield strength ($S_Y$), the elastic modulus ($E$), the forces on the members ($F$), the required factor of safety ($N$). The lengths ($L$) of the members can be determined from the geometry of the truss.

**How:** First calculate the lengths of the members. Then calculate the required cross-sectional area of each member using equation (12.7) with tension members and equation (12.10) with compression members.

**Solve:** See the solution to Prob. 15 for details on how to perform these calculations. Here the results for each truss are presented in the form of an Excel spreadsheet. The required cross-sectional areas are given in the right-most column of each table.

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12-18. Download the West Point Bridge Designer software from http://bridgecontest.usma.edu and use it to design a truss.

No solution offered here. Please go to the web site for extensive documentation on how to run this software.
In 1985 a judge found the structural engineers for the Hyatt Regency Hotel guilty of gross negligence in the July 17, 1981 collapse of two suspended walkways in the hotel lobby that killed 114 and injured 200 people. Many of those killed were dancing on the 32-ton walkways when an arrangement of rods and box beams suspending them from the ceiling failed.

The judge found the project manager guilty of "a conscious indifference to his professional duties as the Hyatt project engineer who was primarily responsible for the preparation of design drawings and review of shop drawings for that project." He also concluded that the chief engineer’s failure to closely monitor the project manager’s work betrayed "a conscious indifference to his professional duties as an engineer of record." Responsibility for the collapse, it was decided, lay in the engineering design for the suspended walkways. Expert testimony claimed that even the original beam design fell short of minimum safety standards. Substantially less safe, however, was the design that actually was used.

Use the Engineering Ethics Matrix to analyze the ethical issues that occurred in this case.

In this case, the engineers involved had two options:

a) Approve the design
b) Reject the design

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<th>b. Reject</th>
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<td>No</td>
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</tr>
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<td>Perform services only in the area of your competence</td>
<td>Yes</td>
<td>Yes</td>
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<td>Issue public statements only in an objective and truthful manner</td>
<td>Maybe- not clear if public statements were made</td>
<td>Maybe not clear if public statements were made</td>
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<td>Act for each employer or client as faithful agents or trustees</td>
<td>No- as an agent, you are expected to alert management to potential problems</td>
<td>No- as an agent, you are expected to alert management to potential problems</td>
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<td>Avoid deceptive acts</td>
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<td>Maybe-not clear if deception was involved</td>
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<tr>
<td>Conduct themselves honorably …</td>
<td>No-showed “conscious indifference”</td>
<td>No-showed “conscious indifference”</td>
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Hold *paramount* the safety, health and welfare of the public. This is the controlling phrase. So b) reject the design is the only ethical conclusion.
12-20. Sara, a recent graduate, accepts a position at a small engineering design firm. Her new colleagues form a tightly knit, congenial group, and she often joins them for get-togethers after work.

Several months after she joins the firm, the firm’s president advises her that his wife has objected to her presence on the staff, feeling that it is inappropriate for a young, single female to work and socialize with a group of male engineers, many of whom are married. The president’s wife encouraged him to terminate Sara’s employment, and although the president himself has no issues with Sara or her work, he suggests to her that she should look for another employer.

Everyone in the firm become aware of the wife’s objections, and Sara begins to notice a difference in her work environment. Although her colleagues are openly supportive of her, she nevertheless feels that the wife’s comments have altered their perception of her. She stops receiving invitations to her company’s parties and is excluded from after-hours gatherings. Even worse, although previously she had found her work both interesting and challenging, she no longer receives assignments from the firm’s president and she begins to sense that her colleagues are treating her as someone who will not be a long-term member of the staff. Believing that she is no longer taken seriously as an engineer and that she will have little opportunity to advance within the firm, she begins searching for a new position. However, before she can do so her supervisor announces a downsizing of the firm, and she is the first engineer to be laid off.

Use the Engineering Ethics Matrix to examine potential ethics violations for an engineering employer to exclude and ultimately discharge an employee on the basis of sex, age, or marital status.

**Apply the Fundamental Canons and the Engineering Ethics Matrix:** In this exercise, we will use the Engineering Ethics Matrix to evaluate the ethical conduct of the engineering employer.

In this case, the firm’s president had two options:

a) Use his wife’s comments to influence his management decisions
b) Not permit his wife’s comments to influence his management decisions

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<td>Yes- does not put public at risk</td>
<td>Yes- does not put public at risk</td>
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<table>
<thead>
<tr>
<th>Perform services only in the area of your competence</th>
<th>No- no evidence that president or wife is an expert in workplace environment</th>
<th>Yes</th>
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<td>Yes-no public statement involved</td>
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<tr>
<td>Avoid deceptive acts</td>
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<td>Yes – is not deceptive</td>
</tr>
<tr>
<td>Conduct themselves honorably …</td>
<td>No- it is dishonorable to mix the personal and the professional</td>
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</table>

The president of the company should not let his wife’s views influence his business decisions. Do b).