CHAPTER 1

Introduction

§1.3 Strength and Serviceability

Photo 1.1 Wind damage

§1.5 Basic Structural Elements

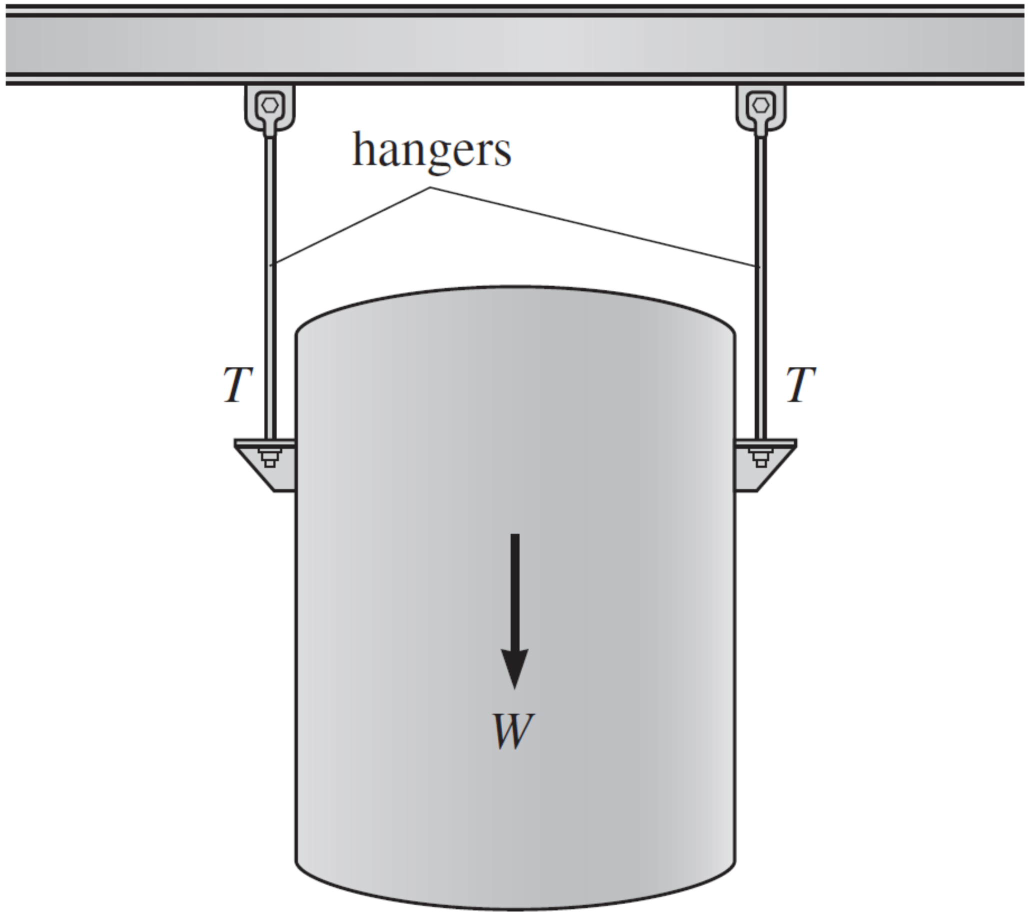
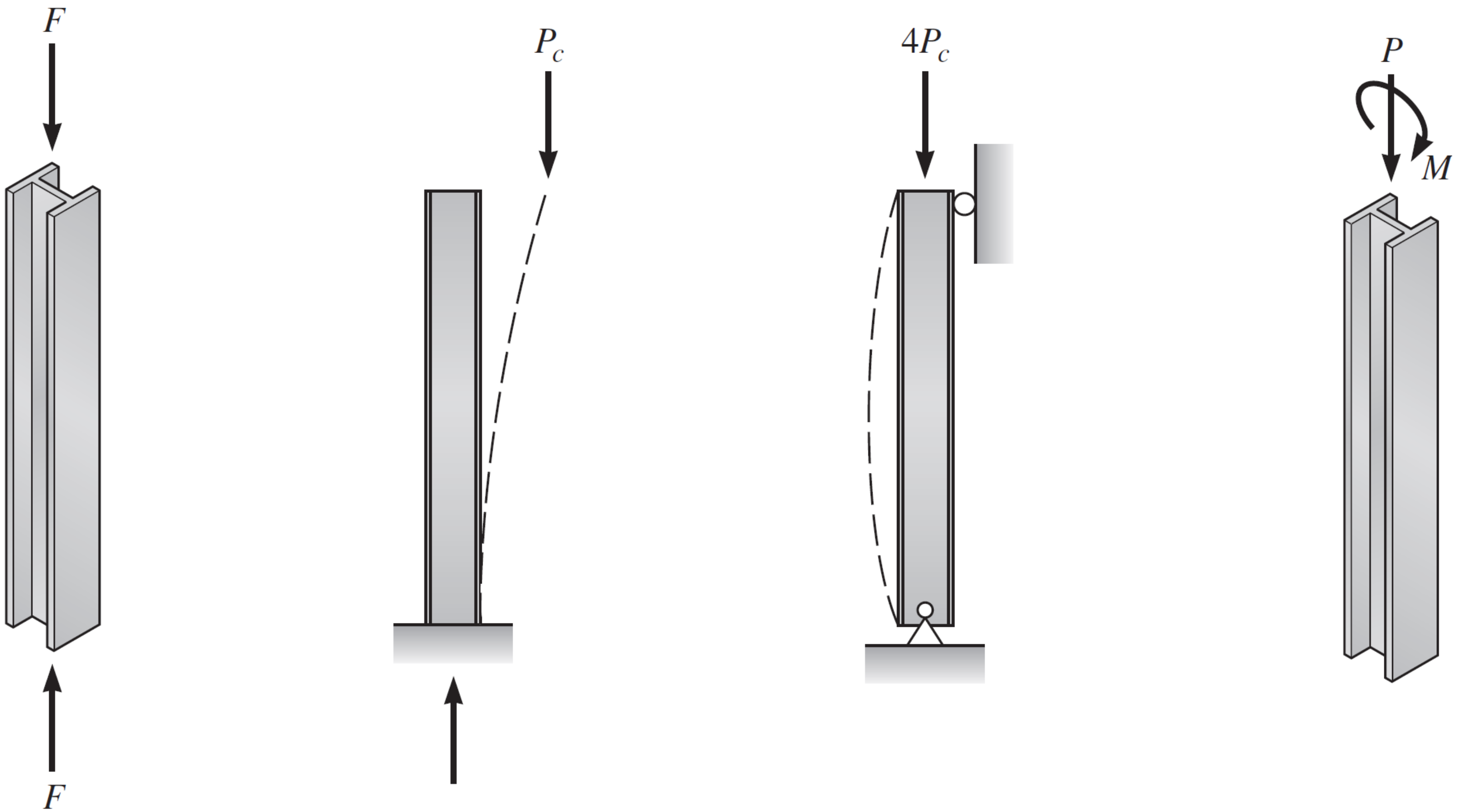


Figure 1.4 Chemical storage tank supported by tension hangers carrying force T

§1.5 Basic Structural Elements



Axially loaded column

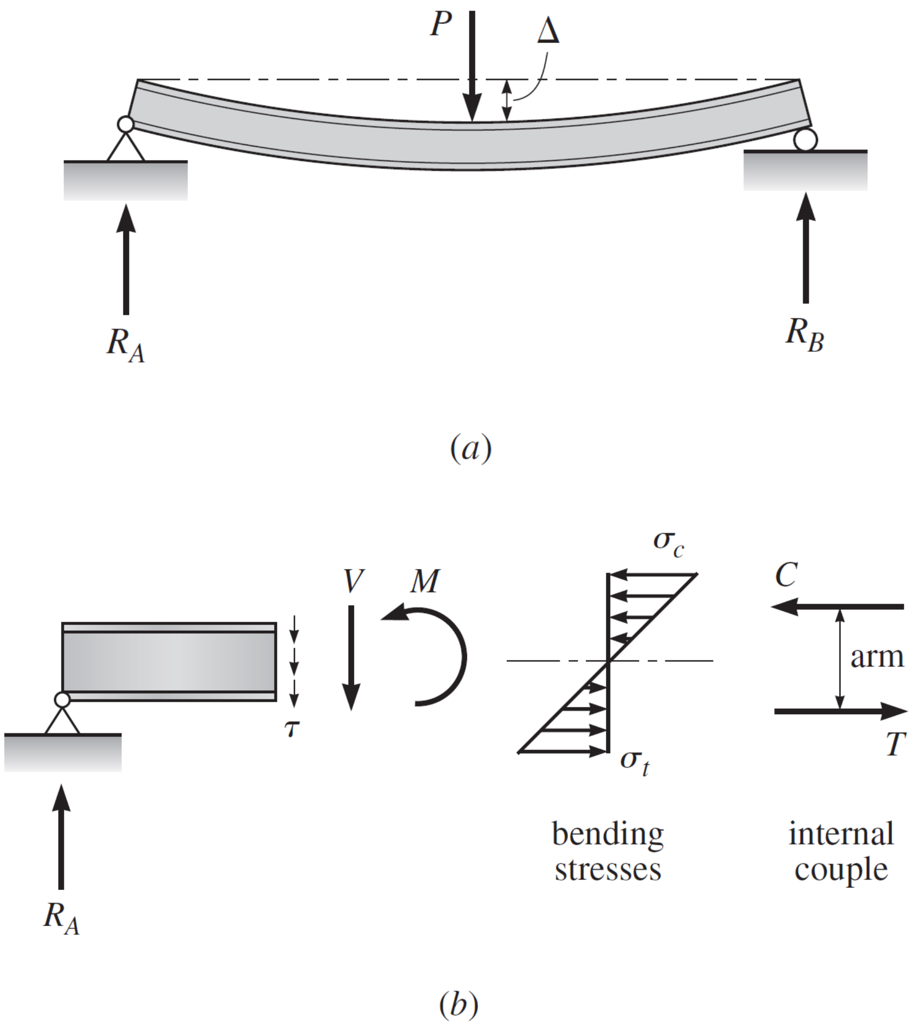
Cantilever column with buckling load P_c

Pin-supported column with buckling load $4P_c$

Beam-column

Figure 1.5

§1.5 Basic Structural Elements

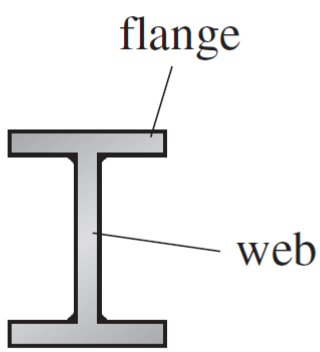


Beam deflects into a shallow curve

Internal forces (shear *V* and moment *M*)

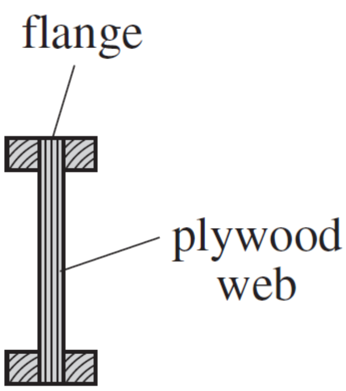
Figure 1.6

§1.5 Basic Structural Elements



(c)

I-shaped
steel section



(d)

Glue-laminated
wood I-beam

Figure 1.6 (continued)

§1.5 Basic Structural Elements

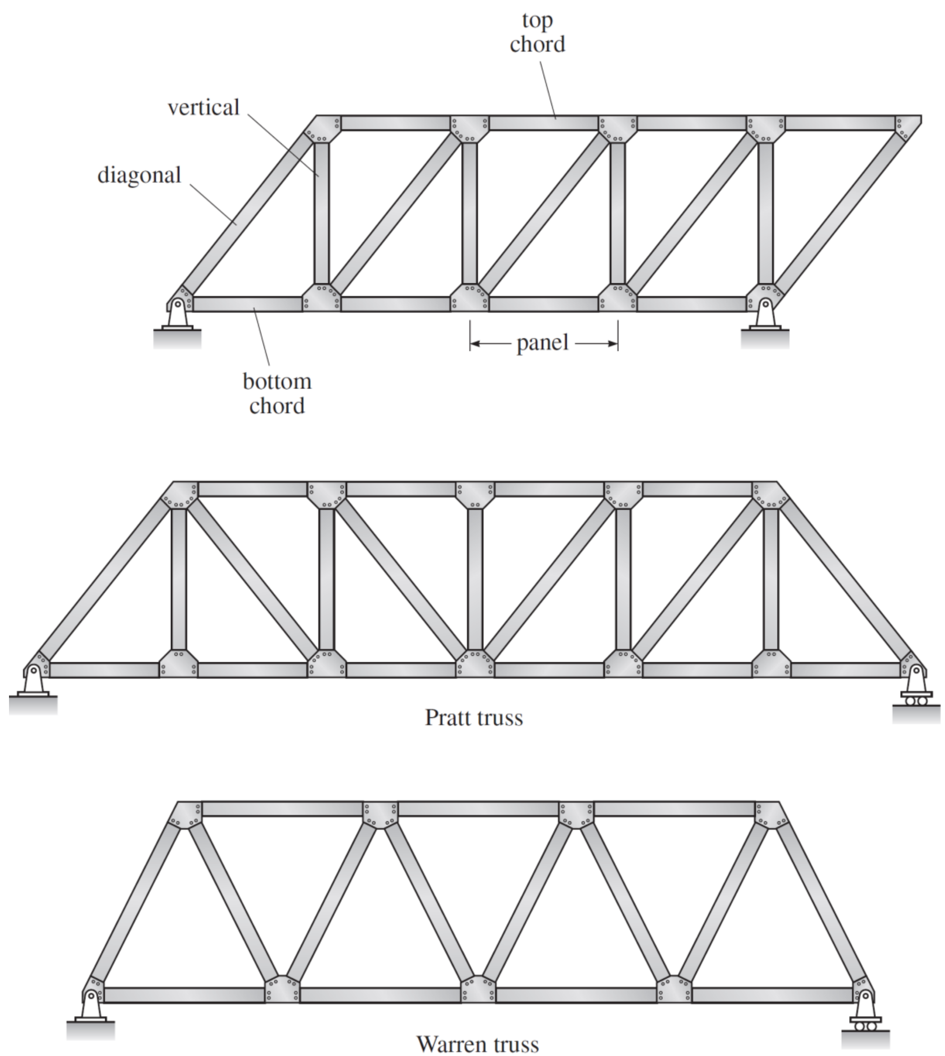
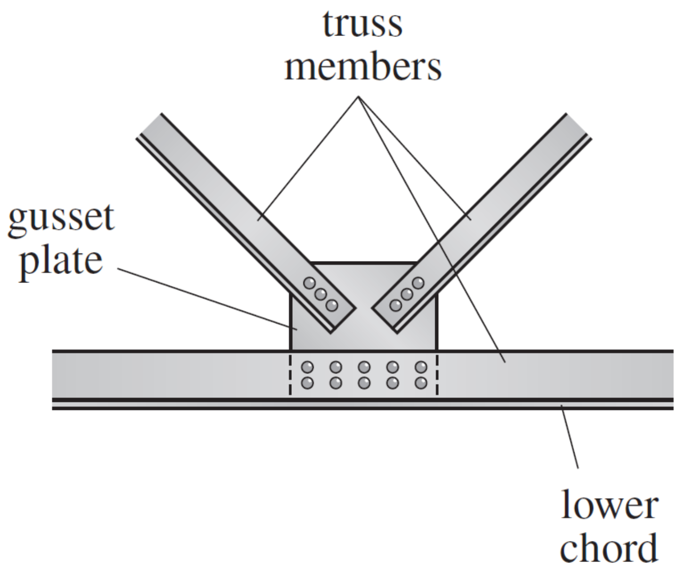
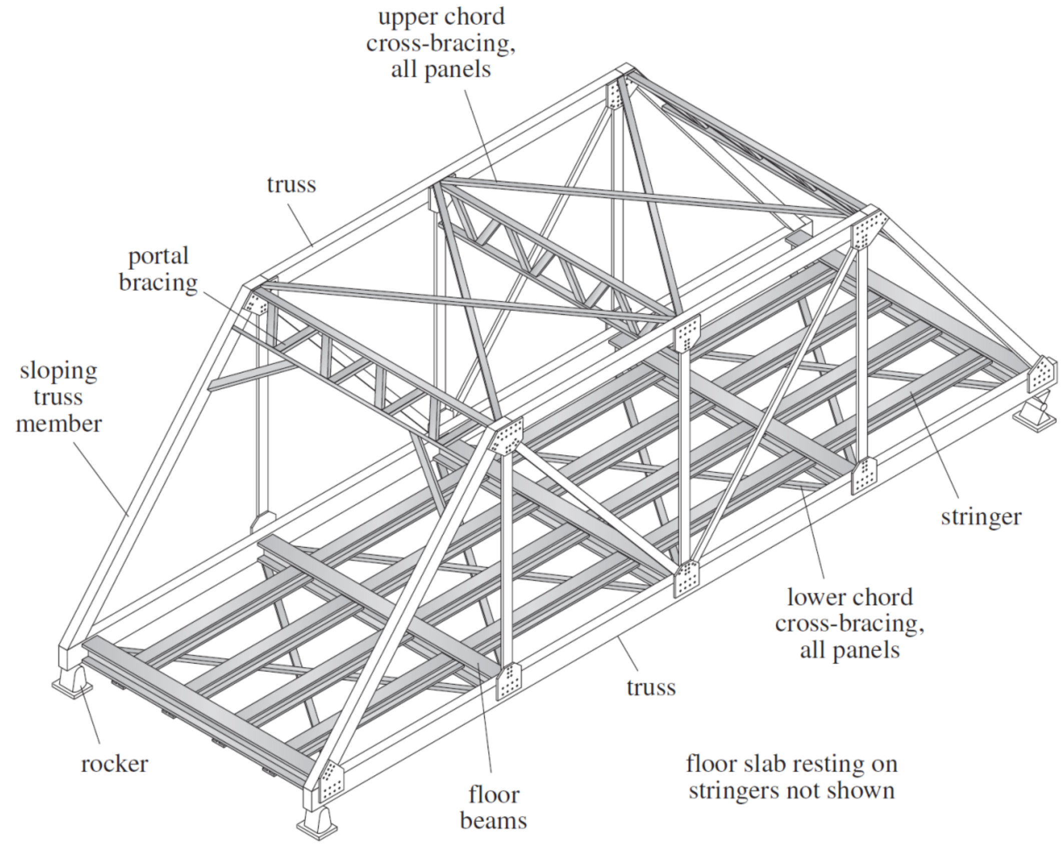


Figure 1.7 Trusses

§1.5 Basic Structural Elements



Bolted joint detail

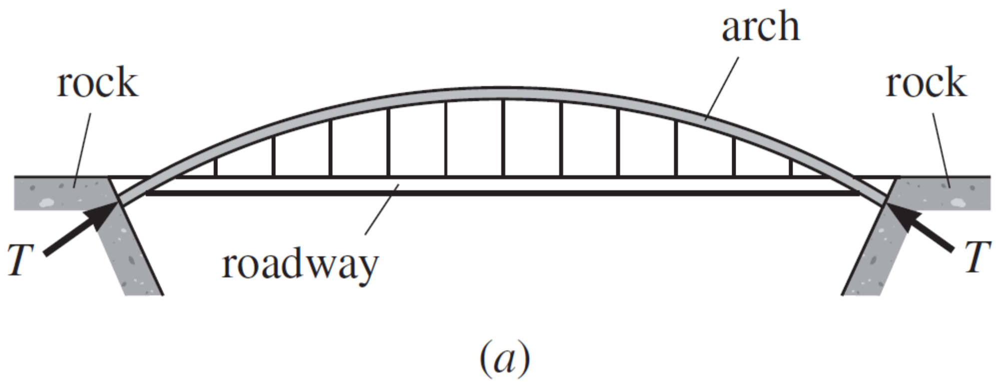


Truss bridge showing cross-bracing needed to stabilize the two main trusses

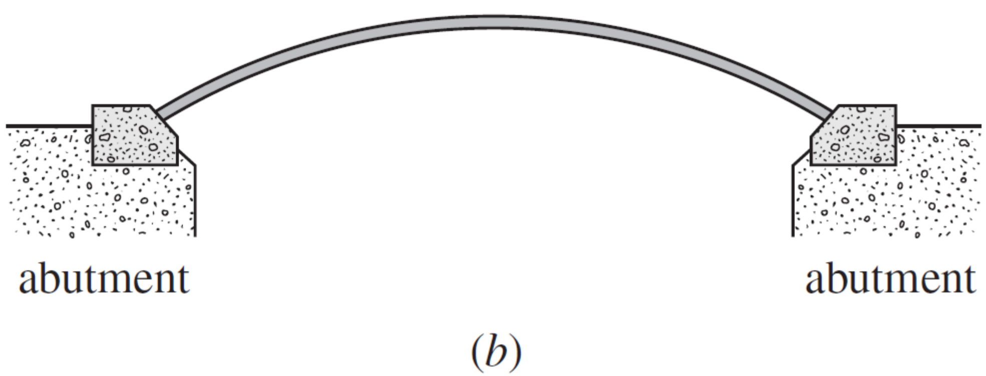
Figure 1.8

-

§1.5 Basic Structural Elements



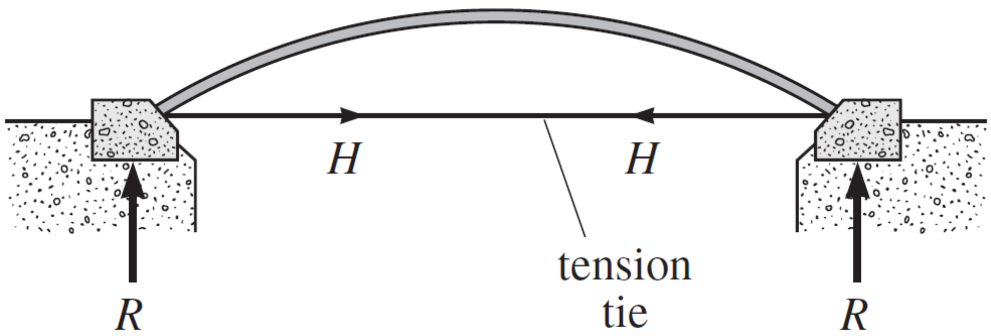
Fixed-end arch carries roadway over a canyon where rock walls provide a natural support for arch thrust *T*



Large abutments provided to carry arch thrust

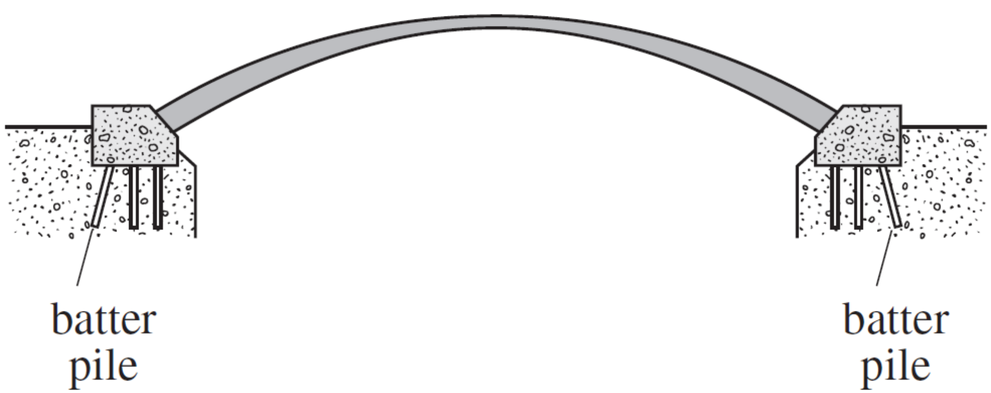
Figure 1.9 Truss bridge

§1.5 Basic Structural Elements



(c)

Tension tie added at base to carry horizontal thrust, foundations designed only for vertical reaction *R*

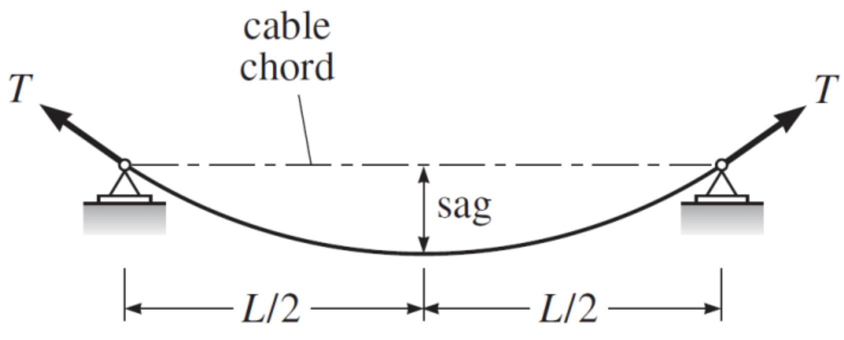


(d)

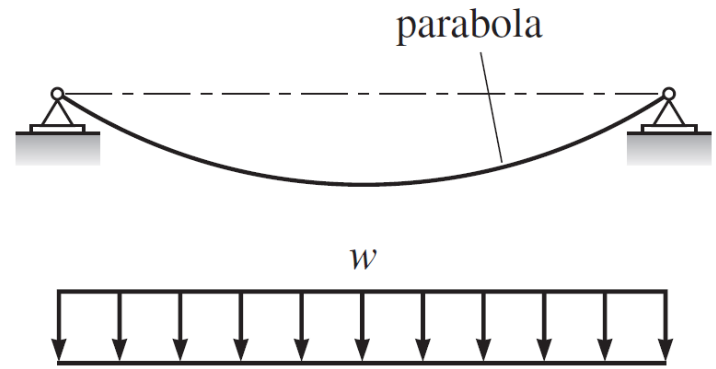
Foundation placed on piles, batter piles used to transfer horizontal component of thrust into ground

Figure 1.9 Truss bridge (continued)

§1.5 Basic Structural Elements



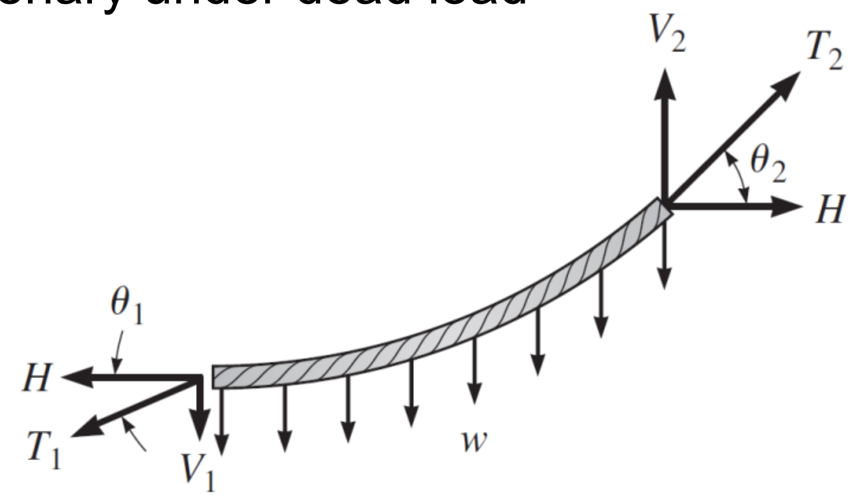
(a)



(b)

Cable in the shape of a catenary under dead load

Parabolic cable produced by a uniform load



(c)

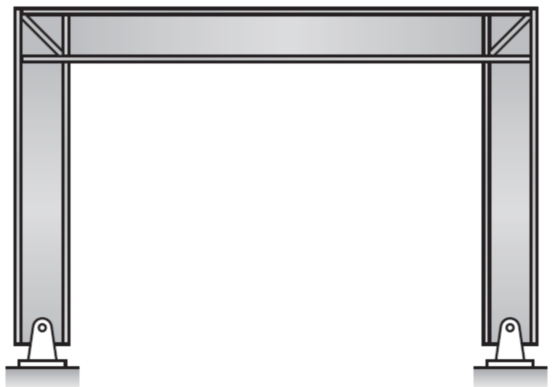
Freebody diagram of a section of cable

Figure 1.10

§1.5 Basic Structural Elements

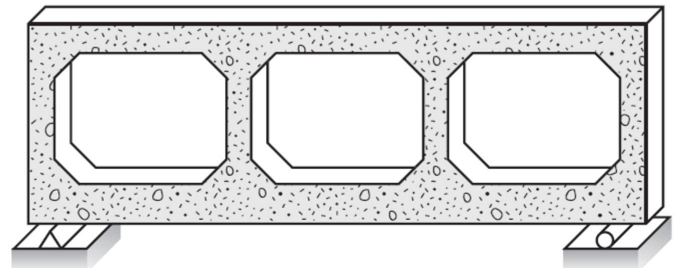
Photo 1.4 Golden Gate Bridge and Rhine River Bridge

§1.5 Basic Structural Elements



(a)

One story rigid frame

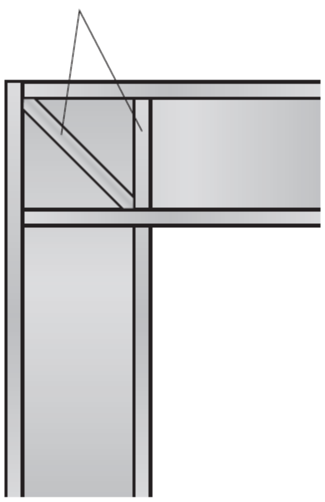


(b)

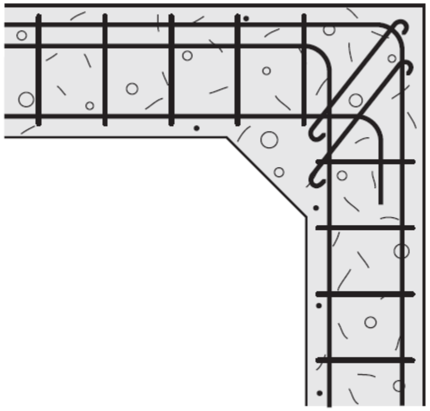
Vierendeel truss, loads transmitted both by direct stress and bending

Figure 1.13 Rigid-jointed structures

§1.5 Basic Structural Elements



(c)



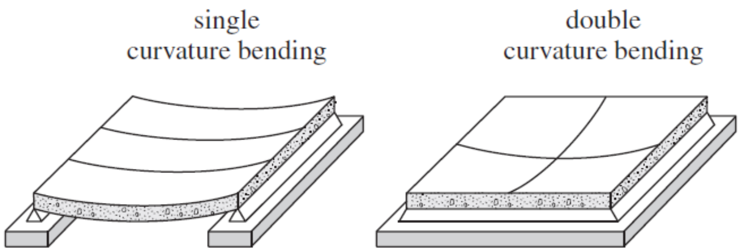
(d)

Details of a welded joint at the corner of a steel rigid frame

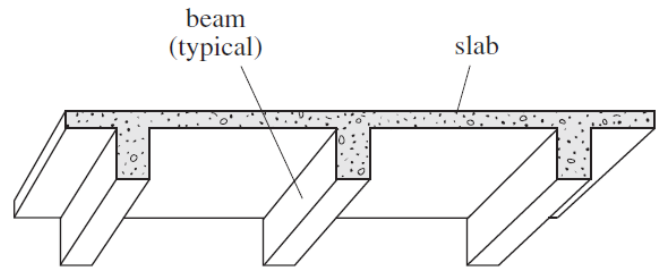
Reinforcing detail for corner of concrete frame

Figure 1.13 Rigid-jointed structures (continued)

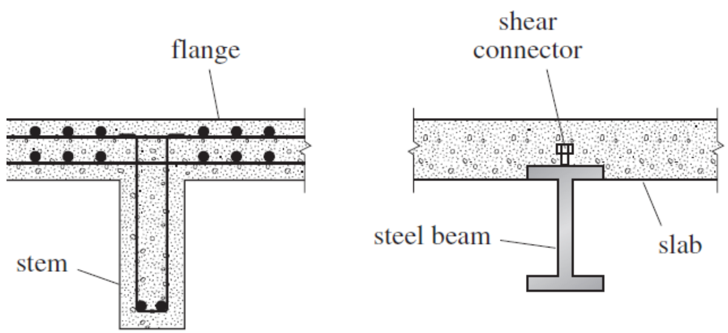
§1.5 Basic Structural Elements



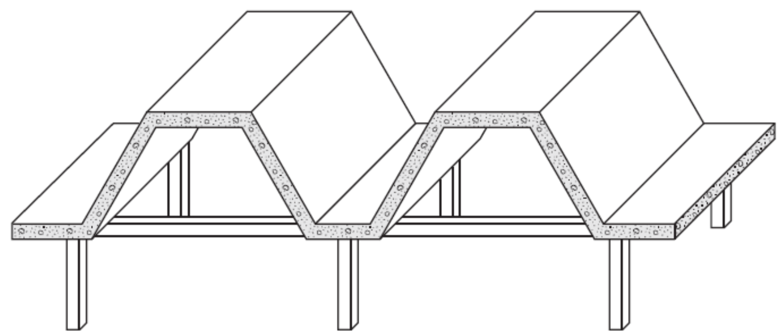
Influence of boundaries on curvature



Beam and slab system



A folded plate roof



Slab and beams act as a unit

Figure 1.14

§1.5 Basic Structural Elements

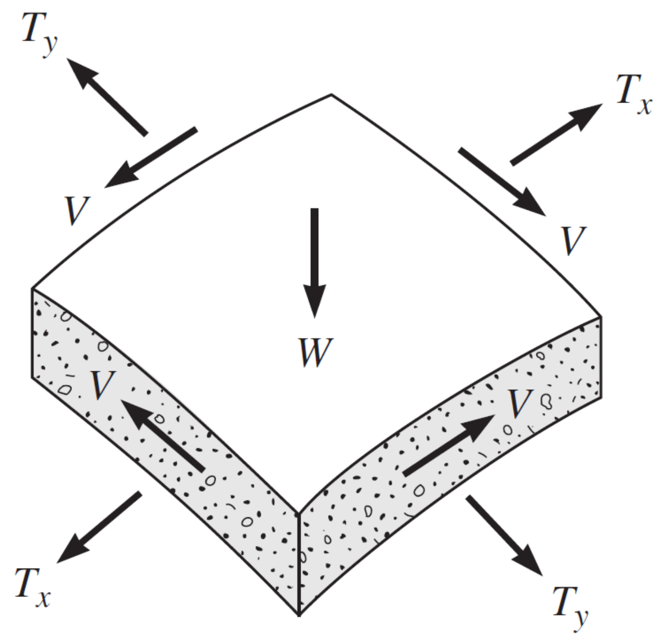
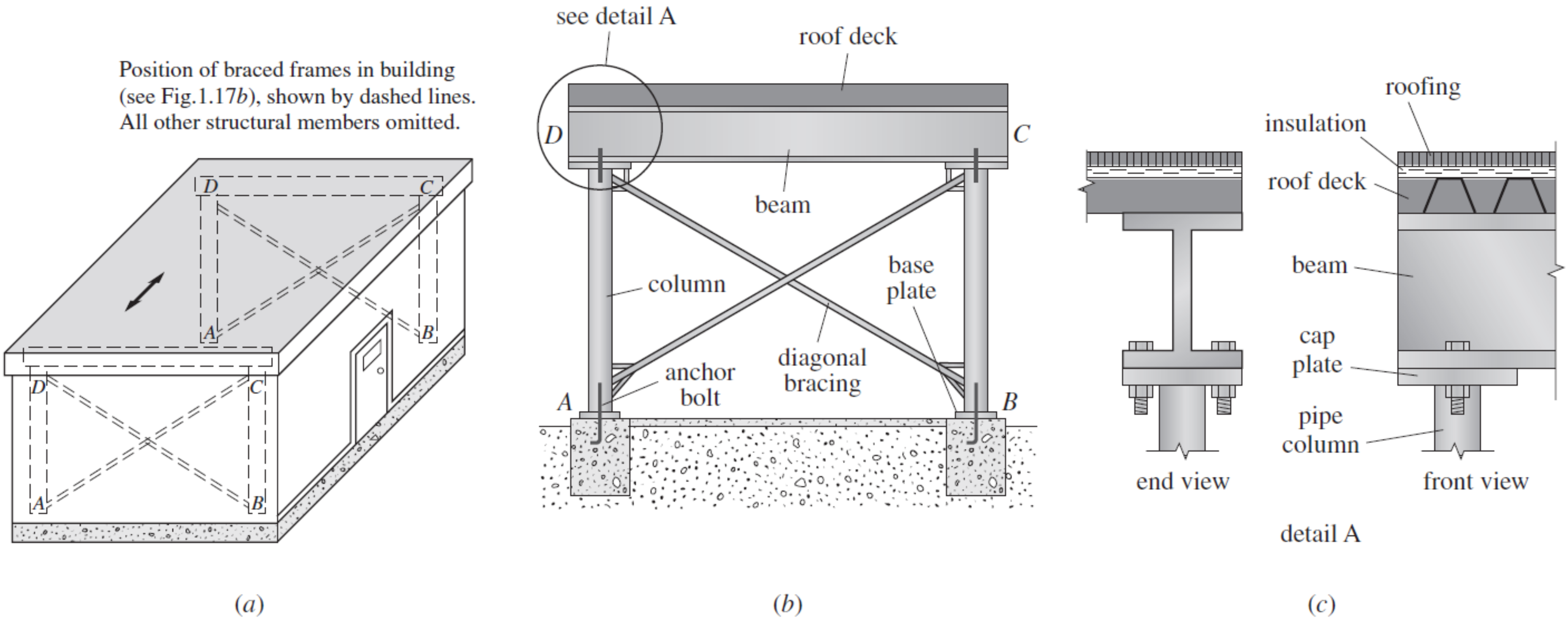


Figure 1.15 Membrane stresses acting on a small shell element

-

§1.6 Assembling Basic Elements to Form a Stable Structural System



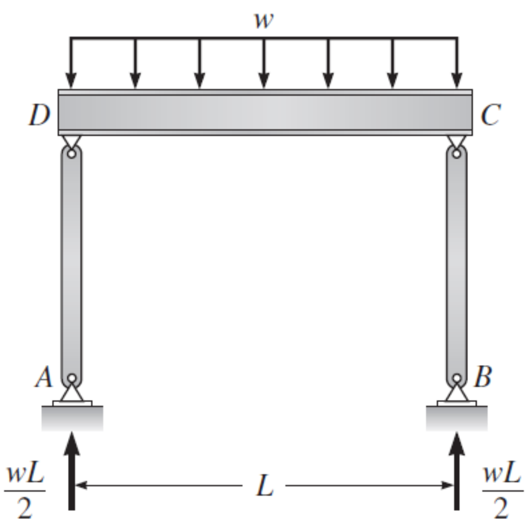
Three-dimensional view of building (arrow indicates direction in which roof deck spans

Details of cross braced frame with bolted joints

Details of beam-to-column connections

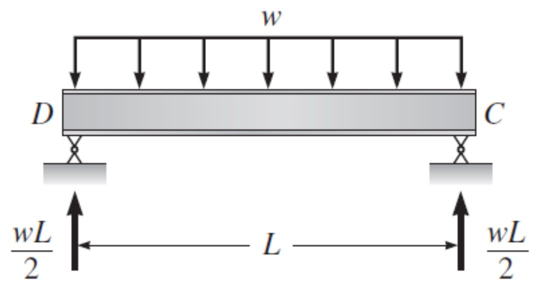
Figure 1.17

§1.6 Assembling Basic Elements to Form a Stable Structural System



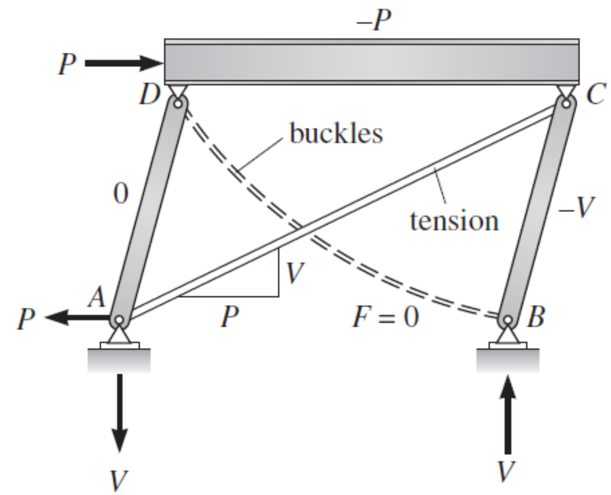
(d)

Idealized model of structural system transmitting gravity loads from roof



(e)

Model of beam *CD*



(f)

Idealized model of truss system for transmitting lateral load acting to the right. Diagonal member *DB* buckles and is ineffective.

Figure 1.17 (continued)

CHAPTER 2

Design Loads

Outline

§2.1 Building and Design Code

§2.2 Loads

§2.3 Dead Loads

§2.4 Live Loads

§2.5 Snow Loads

§2.6 Wind Loads

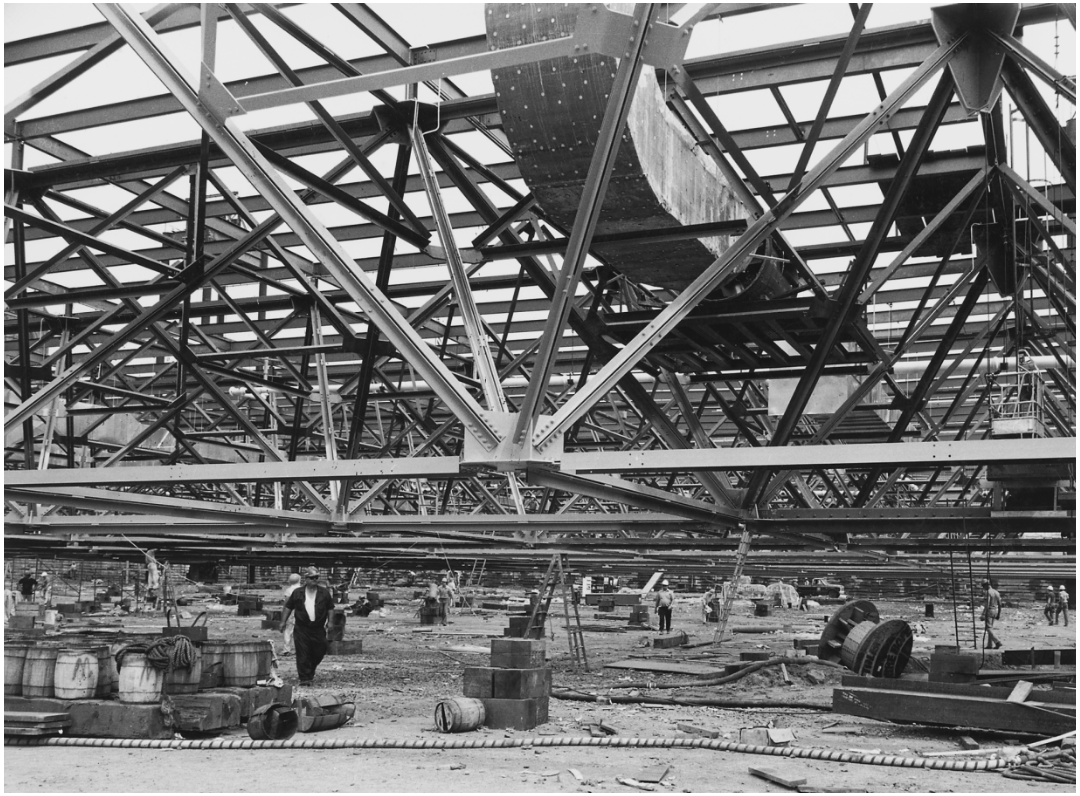
§2.7 Earthquake Loads

§2.8 Other Loads

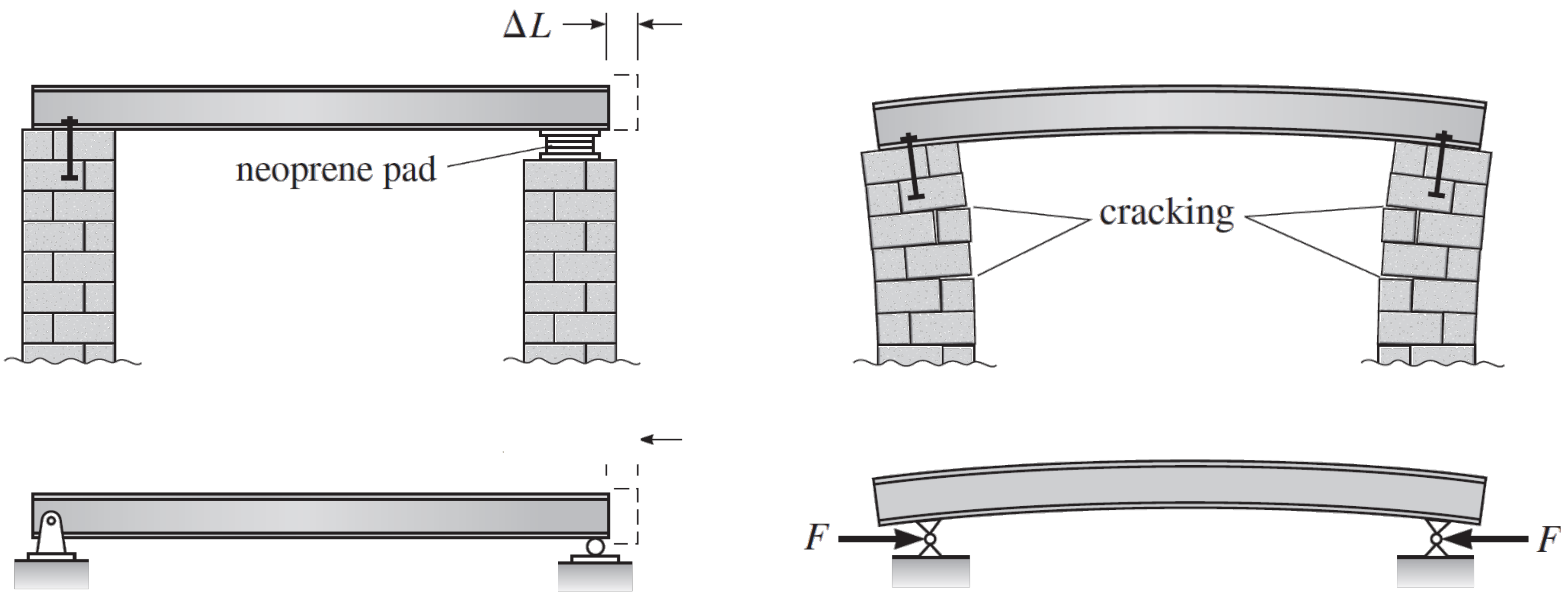
§2.9 Load Combinations

CHAPTER 3

Statics of Structures—Reactions



§3.3 Supports



Right end is free to expand laterally, no stresses created by temperature change

Both ends are restrained, compressive and bending stresses develop in beam

Figure 3.10 Influence of supports

§3.3 Supports

Photo 3.1 Pin support for 2.1-mile long steel box-girder San Diego-Coronado Bridge

§3.3 Supports

Photo 3.2 Roller support for the San Diego-Coronado Bridge

§3.3 Supports

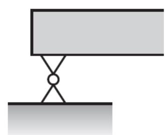
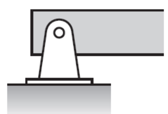
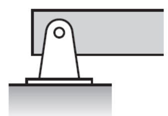
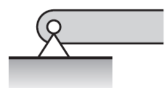
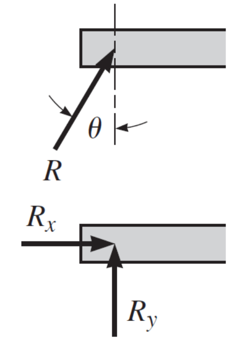
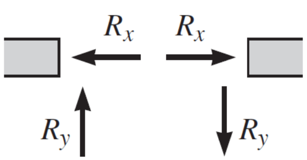
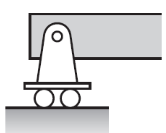
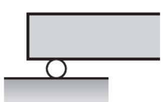
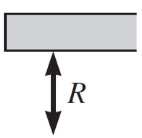
Type	Sketch	Symbol	Movements Allowed or Prevented	Reaction Forces	Unknowns Created
(*a*) Pin	 OR 	 OR 	*Prevented:* horizontal translation, vertical translation *Allowed:* rotation	A single linear force of unknown direction or equivalently A horizontal force and a vertical force which are the components of the single force of unknown direction	
(*b*) Hinge			*Prevented:* relative displacement of member ends *Allowed:* both rotation and horizontal and vertical displacement	Equal and oppositely directed horizontal and vertical forces	
(*c*) Roller			*Prevented:* vertical translation *Allowed:* horizontal translation, rotation	A single linear force (either upward or downward*)	

Table 3.1 Characteristics of Supports

§3.3 Supports

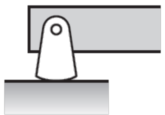
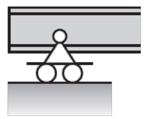
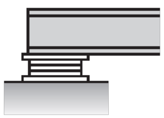
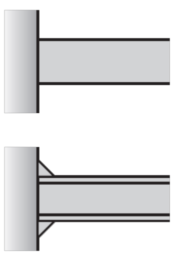
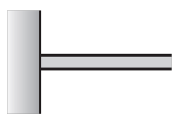
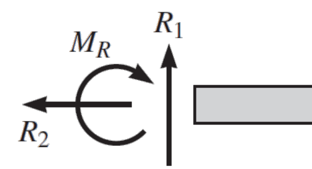
Type	Sketch	Symbol	Movements Allowed or Prevented	Reaction Forces	Unknowns Created
(*d*) Rocker		OR 			
(*e*) Elastomeric pad					
(*f*) Fixed end			*Prevented:* horizontal translation, vertical translation, rotation *Allowed:* none	Horizontal and vertical components of a linear resultant; moment	

Table 3.1 Characteristics of Supports (continued)

§3.3 Supports

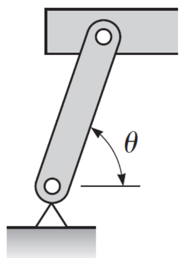
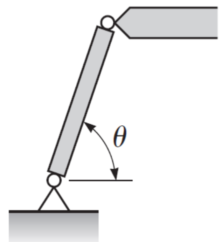
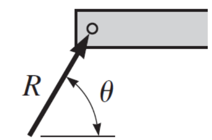
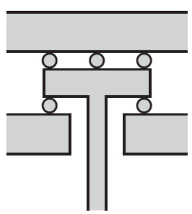
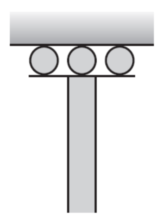
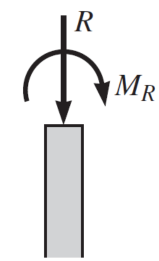
Type	Sketch	Symbol	Movements Allowed or Prevented	Reaction Forces	Unknowns Created
(g) Link			*Prevented:* translation in the direction of link *Allowed:* translation perpendicular to link, rotation	A single linear force in the direction of the link	
(h) Guide			*Prevented:* vertical translation, rotation *Allowed:* horizontal translation	A single vertical linear force; moment	

Table 3.1 Characteristics of Supports (continued)

§3.3 Supports

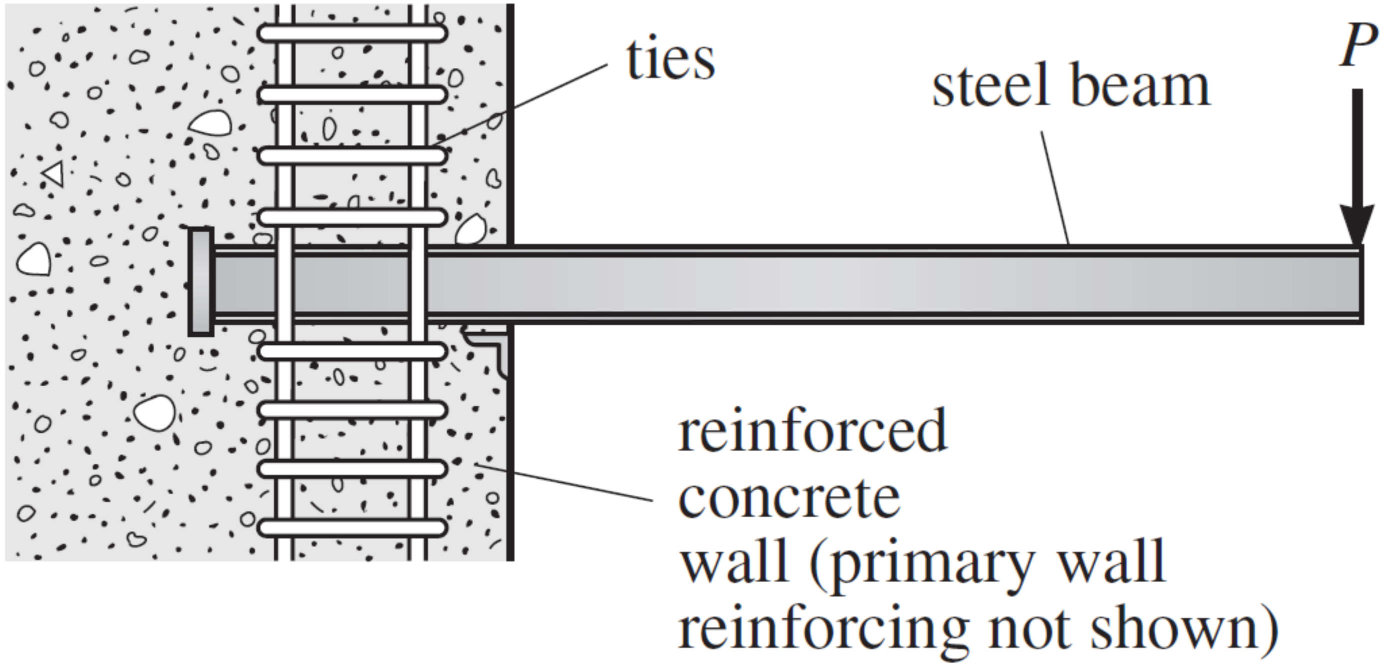


Figure 3.11 Fixed-end beam produced by embedding its left end in a reinforced concrete wall

§3.3 Supports

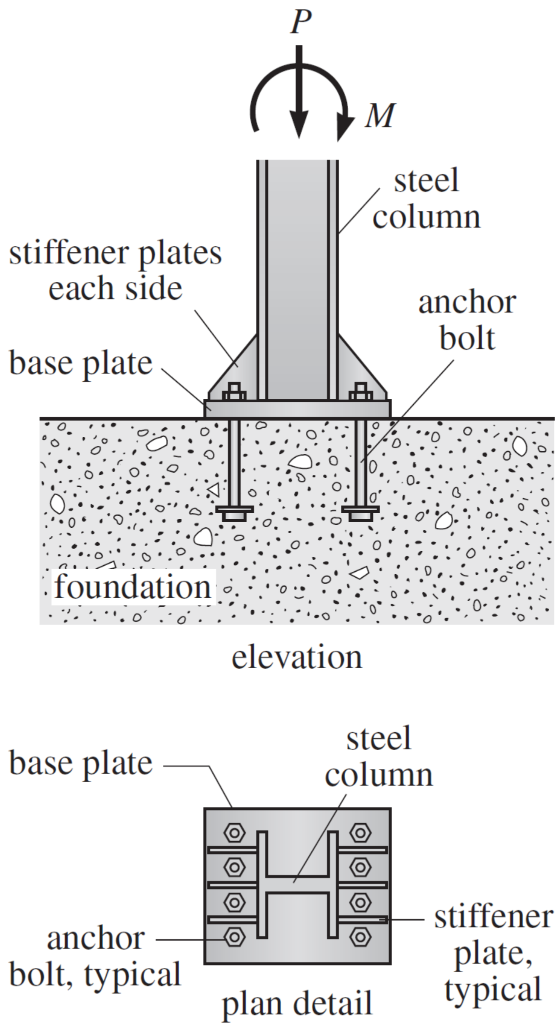


Figure 3.12 A steel column supported on a stiffened baseplate, which is bolted to a concrete foundation, producing a fixed-end condition at its base

§3.3 Supports

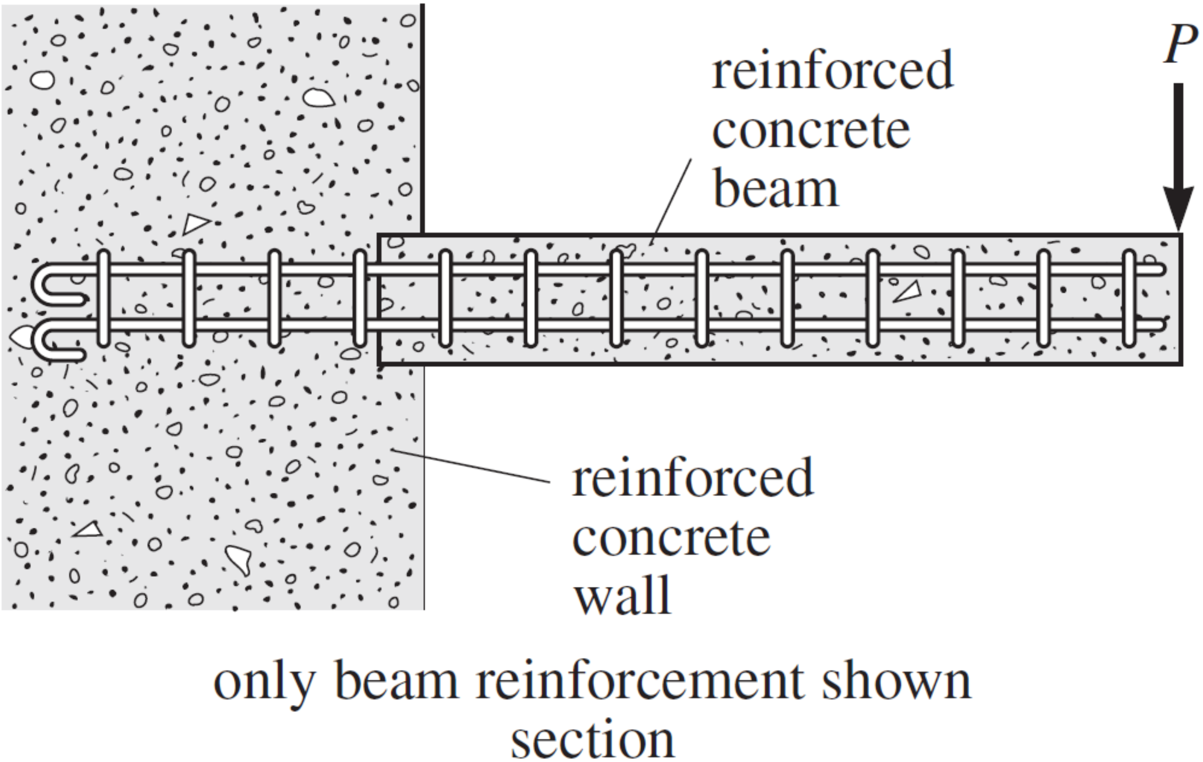


Figure 3.13 A reinforced concrete beam with a fixed end

§3.3 Supports

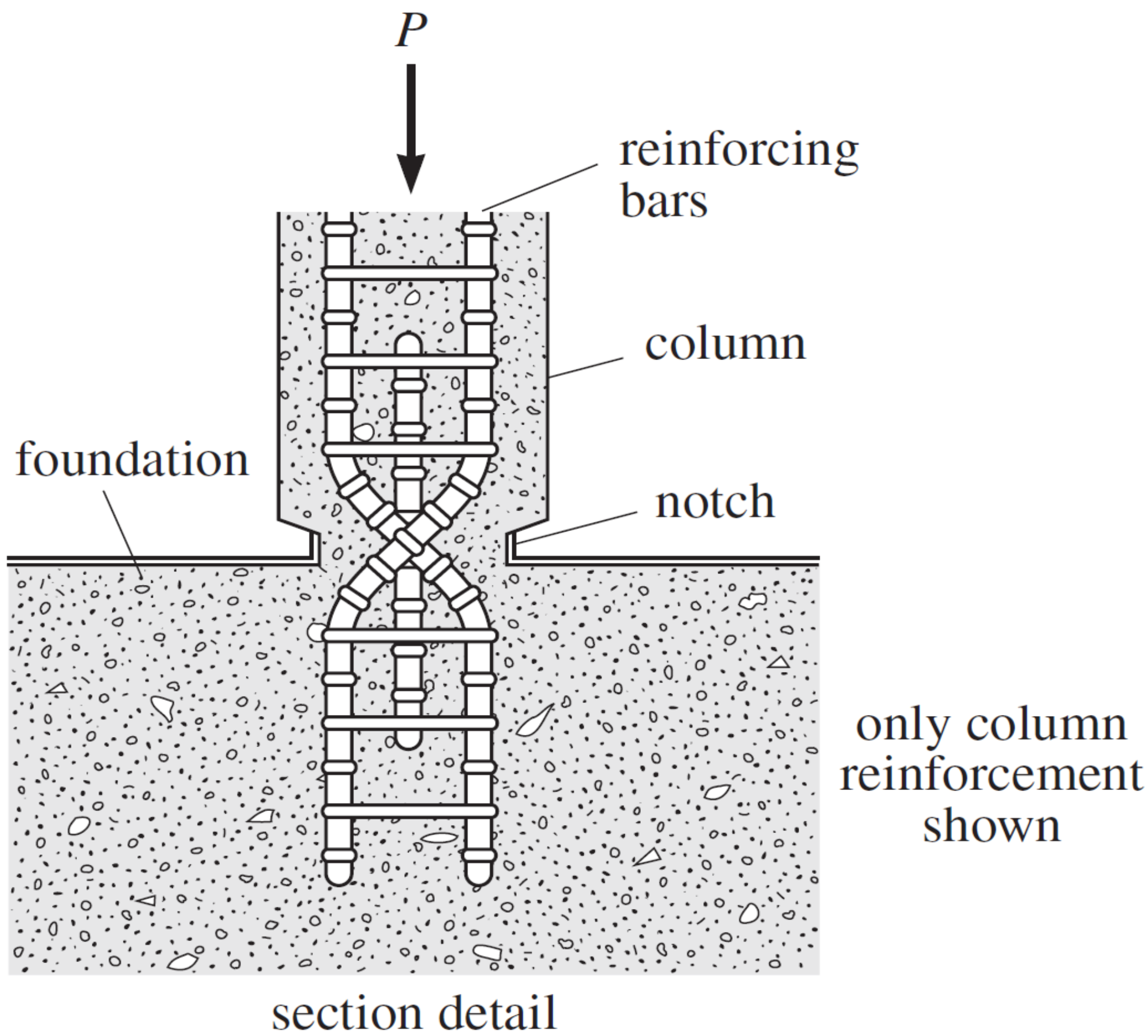
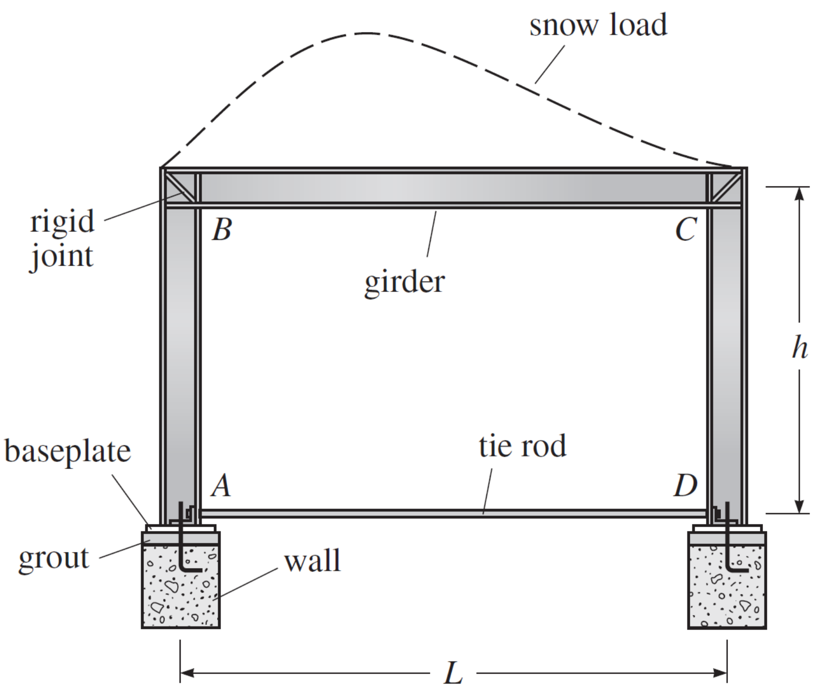
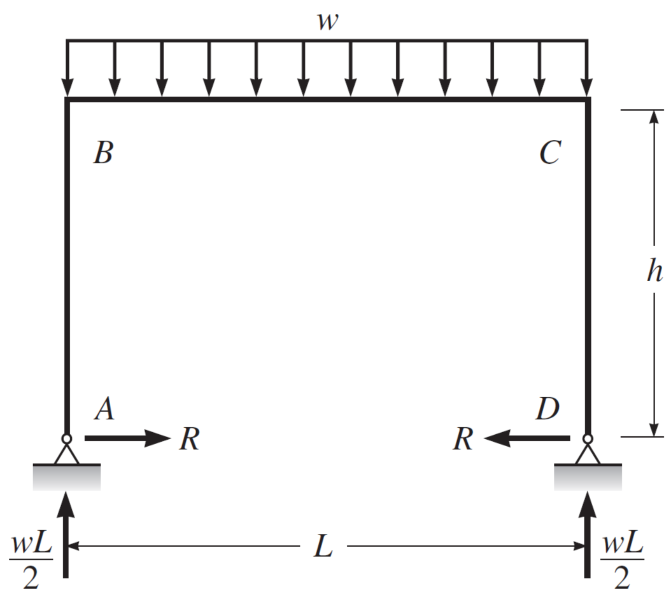


Figure 3.13 A reinforced concrete column whose lower end is detailed to act as a pin (continued)

§3.4 Idealizing Structures



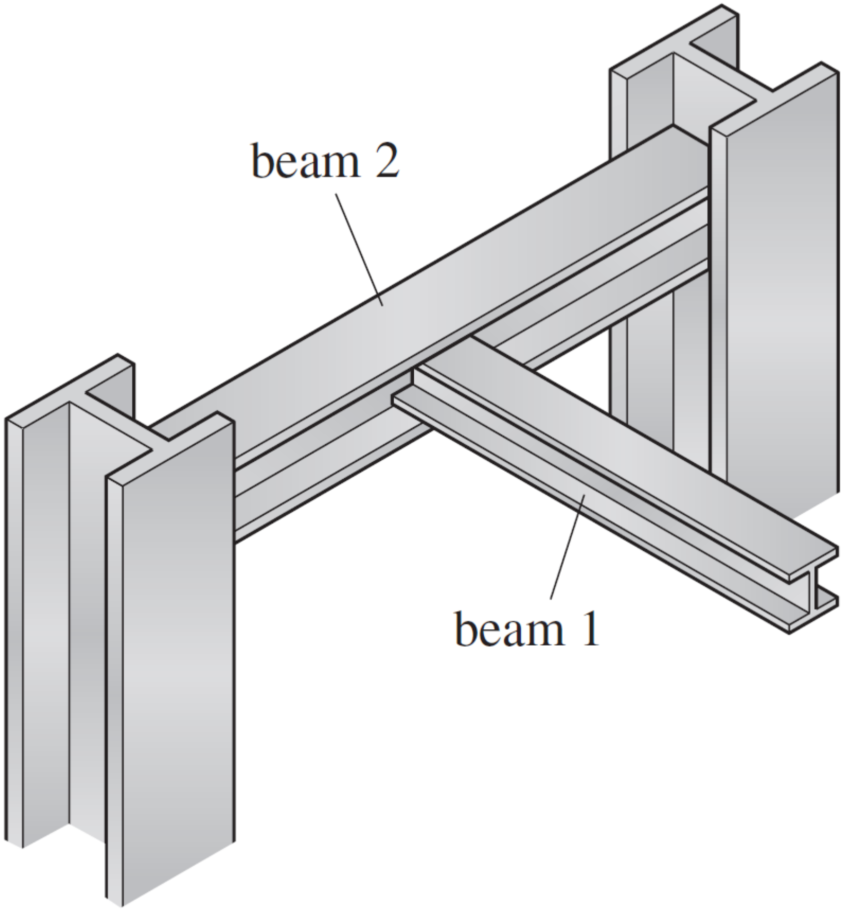


Welded rigid frame with snow load

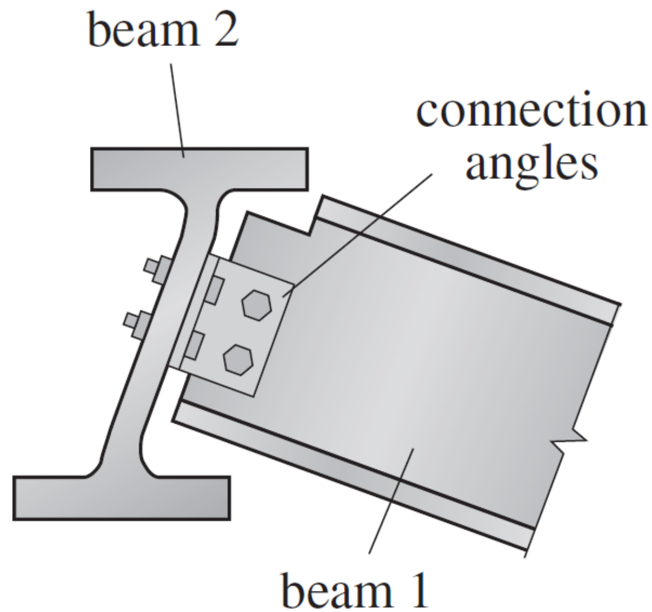
Idealized frame on which analysis is based

Figure 3.14

§3.4 Idealizing Structures



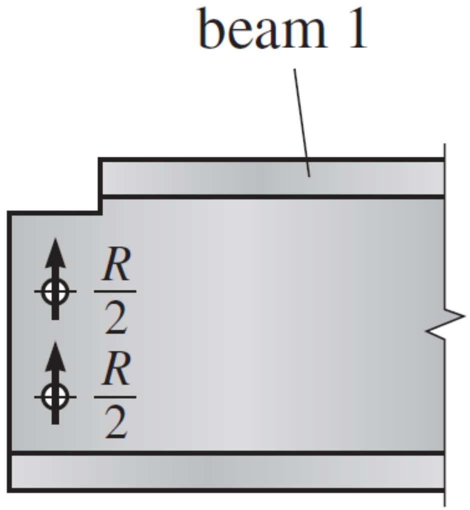
Perspective of joint



Details of connection shown to an exaggerated scale: slope of beam 1 bends the flexible web of beam 2

Figure 3.15 Bolted web connection idealized as a pin support

§3.4 Idealizing Structures



Since the connection supplies only vertical restraint (its capacity for lateral restraint is not mobilized), we are free to model the joint as a pin or roller support

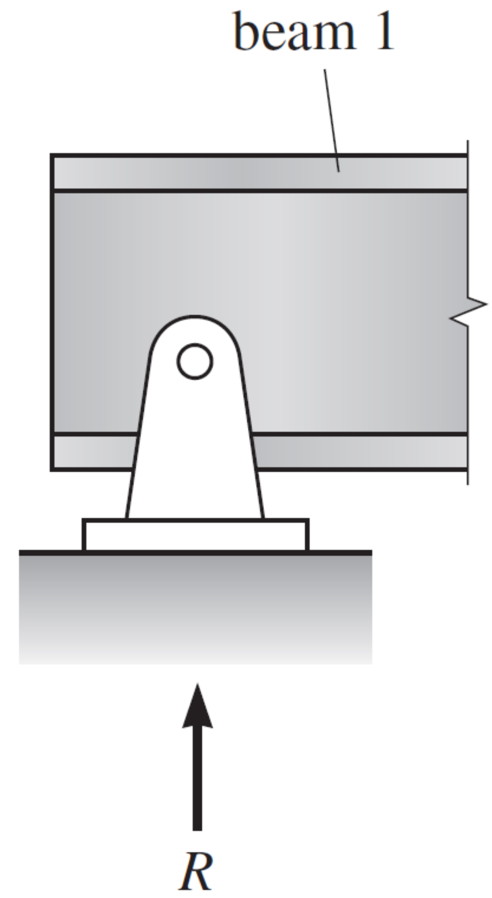
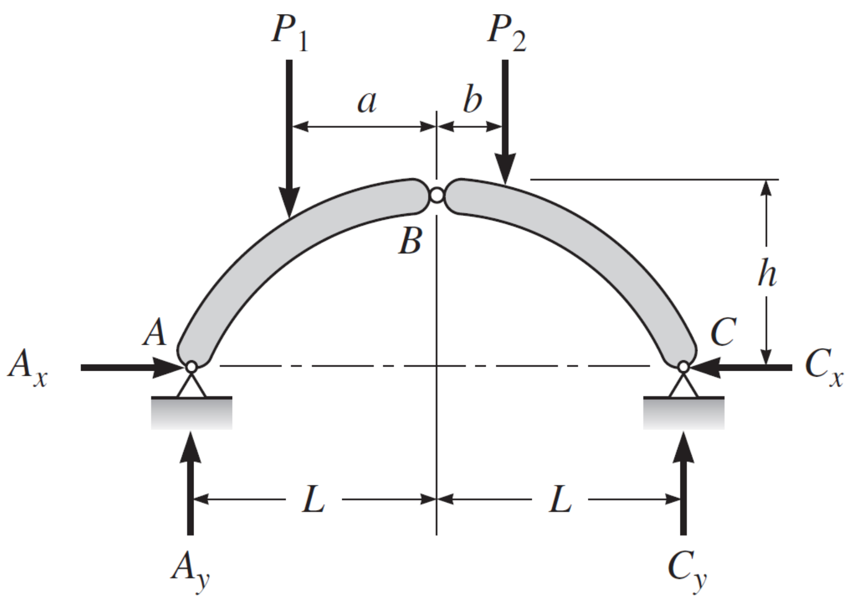
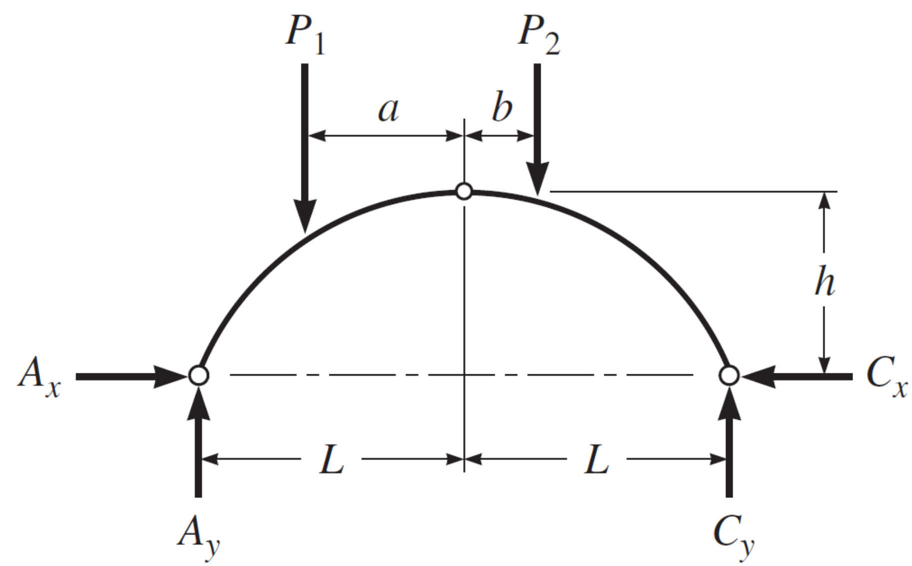


Figure 3.15 Bolted web connection idealized as a pin support (continued)

§3.5 Free Body Diagrams



Free-body diagram of three-hinged arch

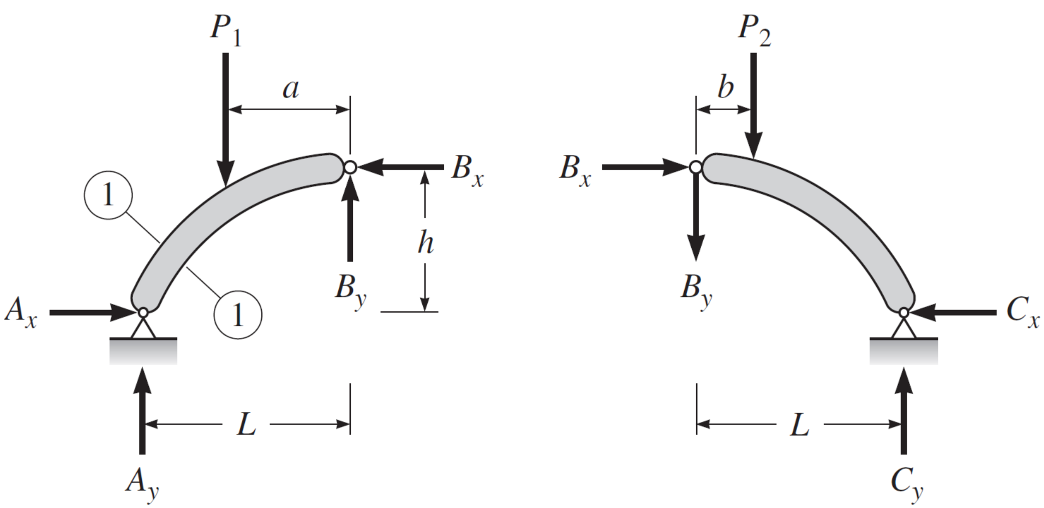


Simplified free body of arch

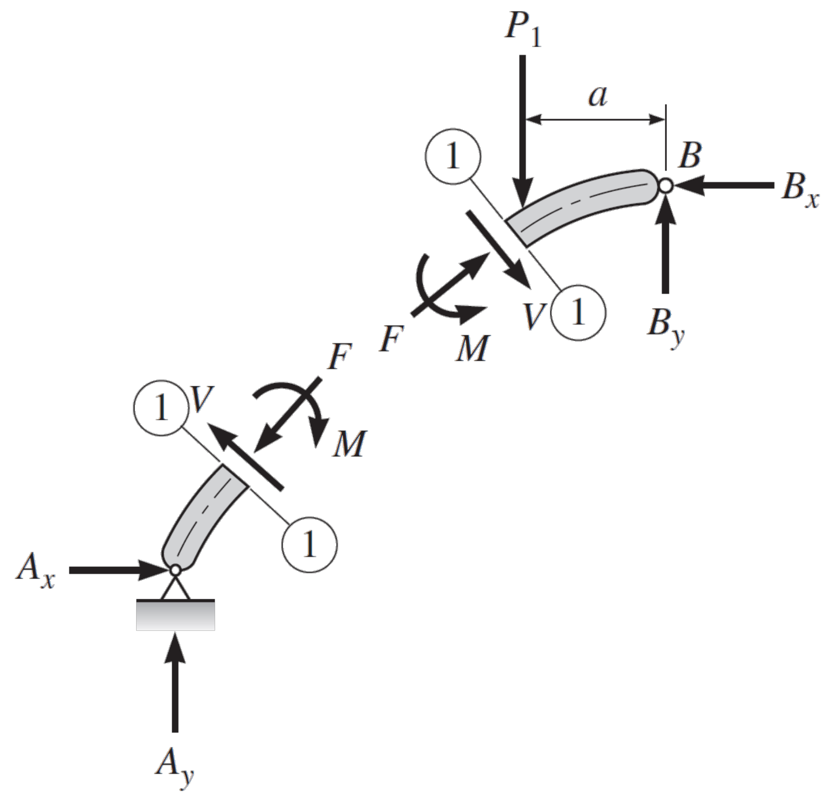
Figure 3.16 Free-body diagrams

-

§3.5 Free Body Diagrams



Free-body diagrams
of arch segments



Free-body diagrams to
analyze internal forces
at section 1-1

Figure 3.16 Free-body diagrams (continued)

§3.6 Equations of Static Equilibrium

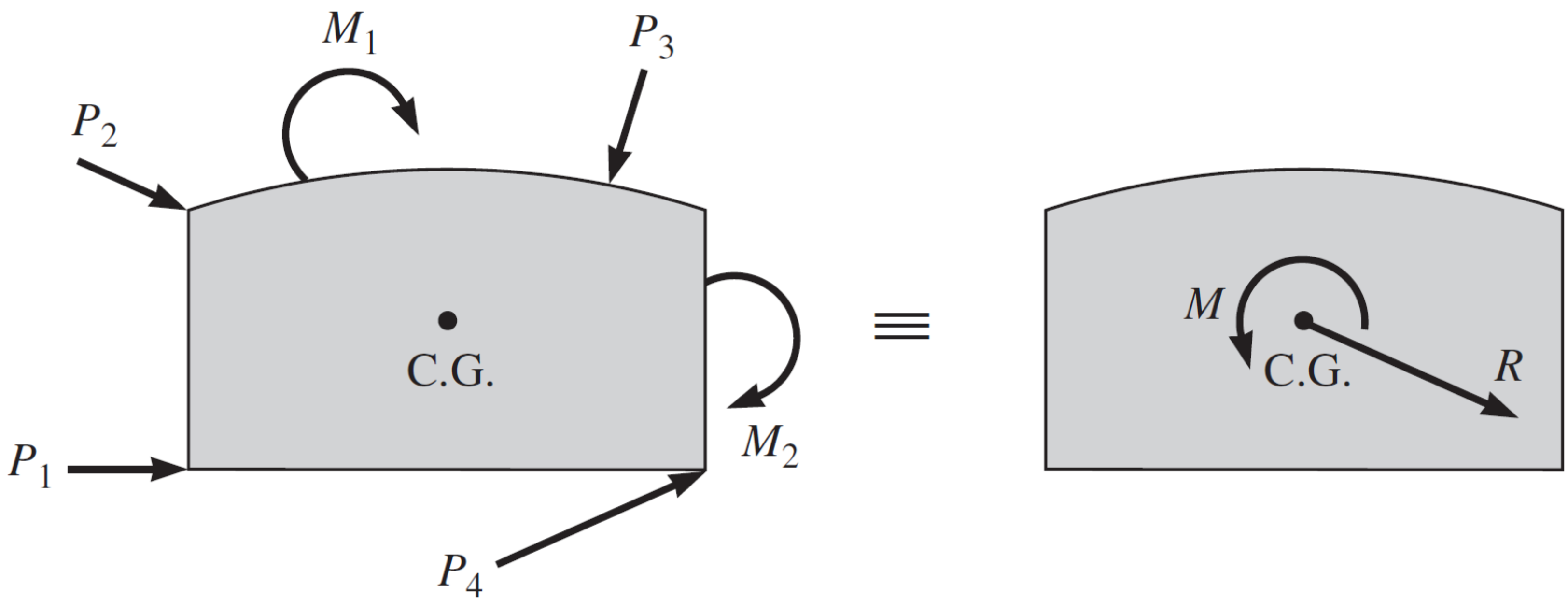
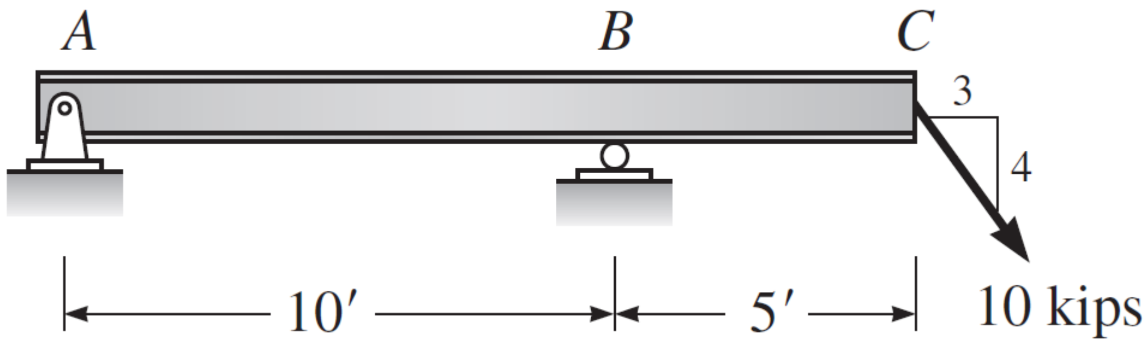


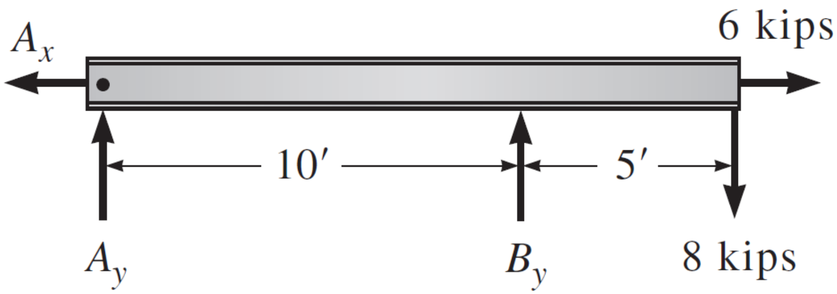
Figure 3.17 Equivalent planar force systems acting on a rigid body

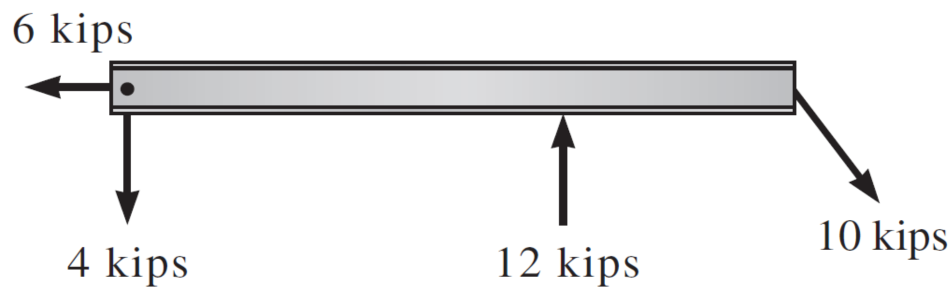
Example 3.5

Compute the reactions for the beam.



Example 3.5 Solution





- Resolve the force at *C* into components and assume directions for the reactions at *A* and *B*.

$$\rightarrow + \quad \Sigma F_x = 0 \qquad -A_x + 6 = 0$$

$$\overset{+}{\uparrow} \quad \Sigma F_y = 0 \qquad A_y + B_y - 8 = 0$$

$$\circlearrowright^{+} \quad \Sigma M_A = 0 \qquad -10B_y + 8(15) = 0$$

- Solving Equations 1, 2, and 3 gives

$$A_x = 6\text{ kips} \qquad B_y = 12\text{ kips} \qquad A_y = -4\text{ kips} \qquad \textbf{Ans.}$$

Example 3.5 Solution (continued)

- Recompute reactions, using equilibrium equations that contain only one unknown. One possibility is

$$\circlearrowright^{+} \quad \Sigma M_A = 0 \qquad -B_y(10) + 8(15) = 0$$

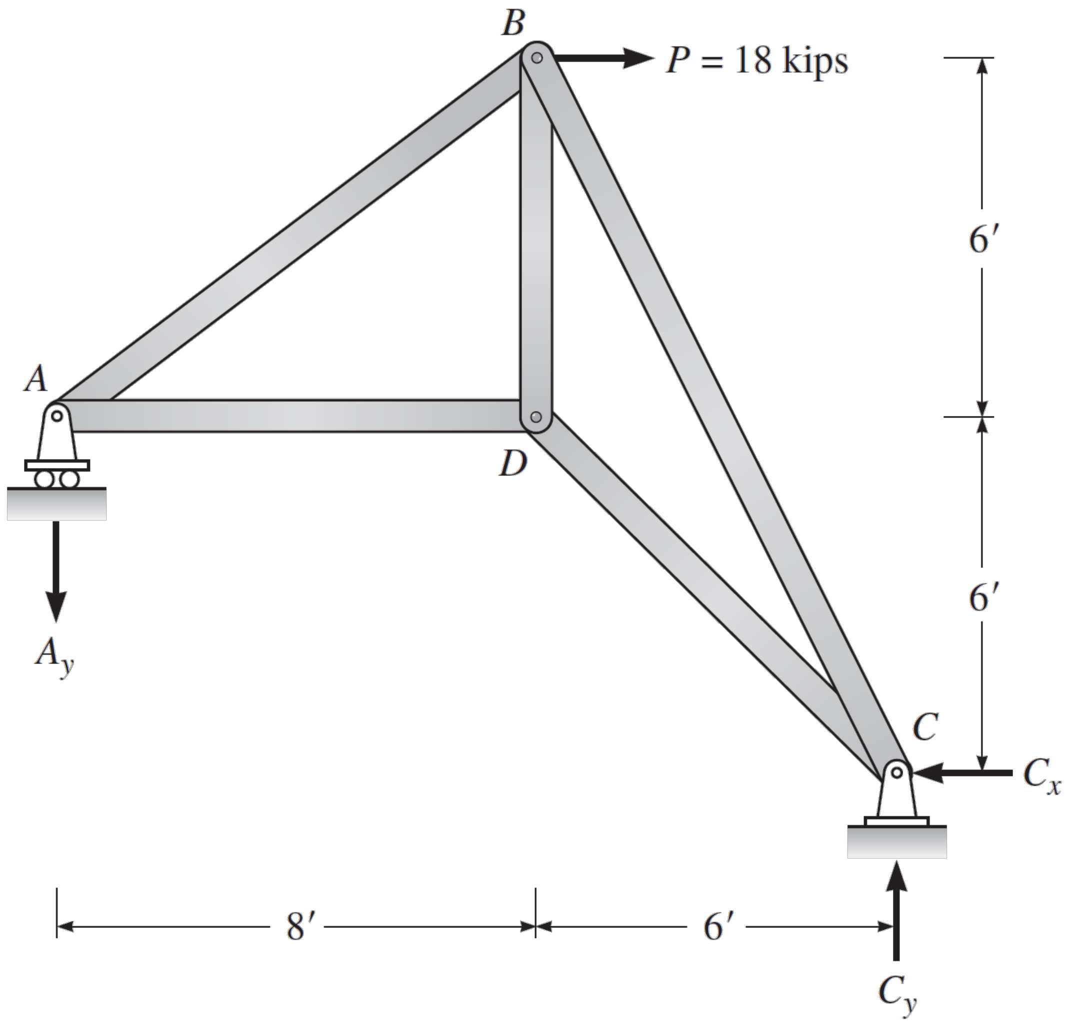
$$\circlearrowright^{+} \quad \Sigma M_B = 0 \qquad A_y(10) + 8(5) = 0$$

$$\rightarrow + \quad \Sigma F_x = 0 \qquad -A_x + 6 = 0$$

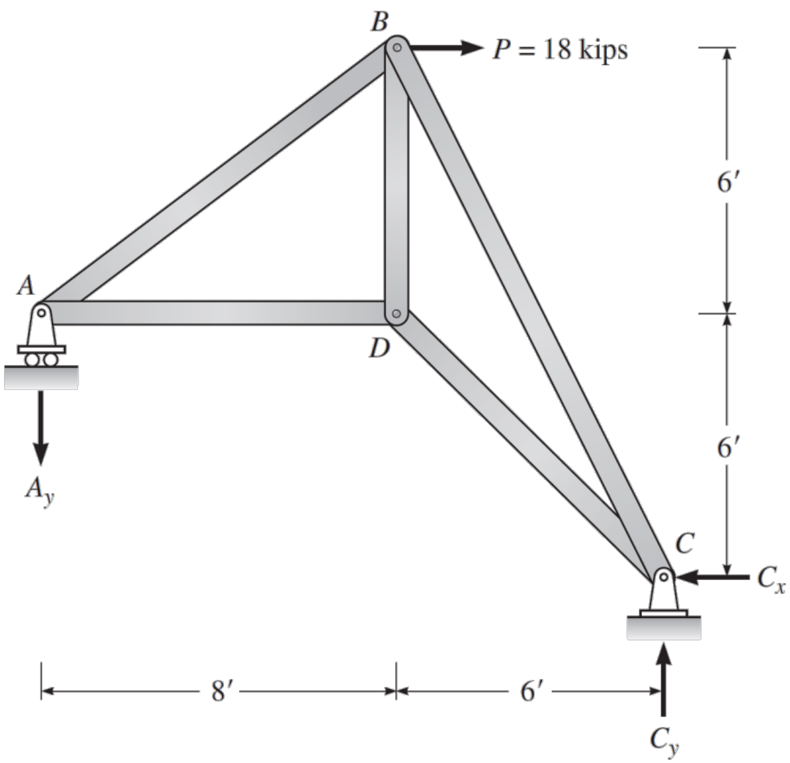
- Solving again gives $A_x = 6$ kips, $B_y = 12$ kips, $A_y = -4$ kips

Example 3.6

Compute the reactions for the truss.



Example 3.6 Solution



- Treat the truss as a rigid body. Assume directions for reactions.

$$\circlearrowright^{+} \quad \Sigma M_C = 0 \qquad 18(12) - A_y(14) = 0$$

$$\xrightarrow{+} \quad \Sigma F_x = 0 \qquad 18 - C_x = 0$$

$$+\uparrow \quad \Sigma F_y = 0 \qquad -A_y + C_y = 0$$

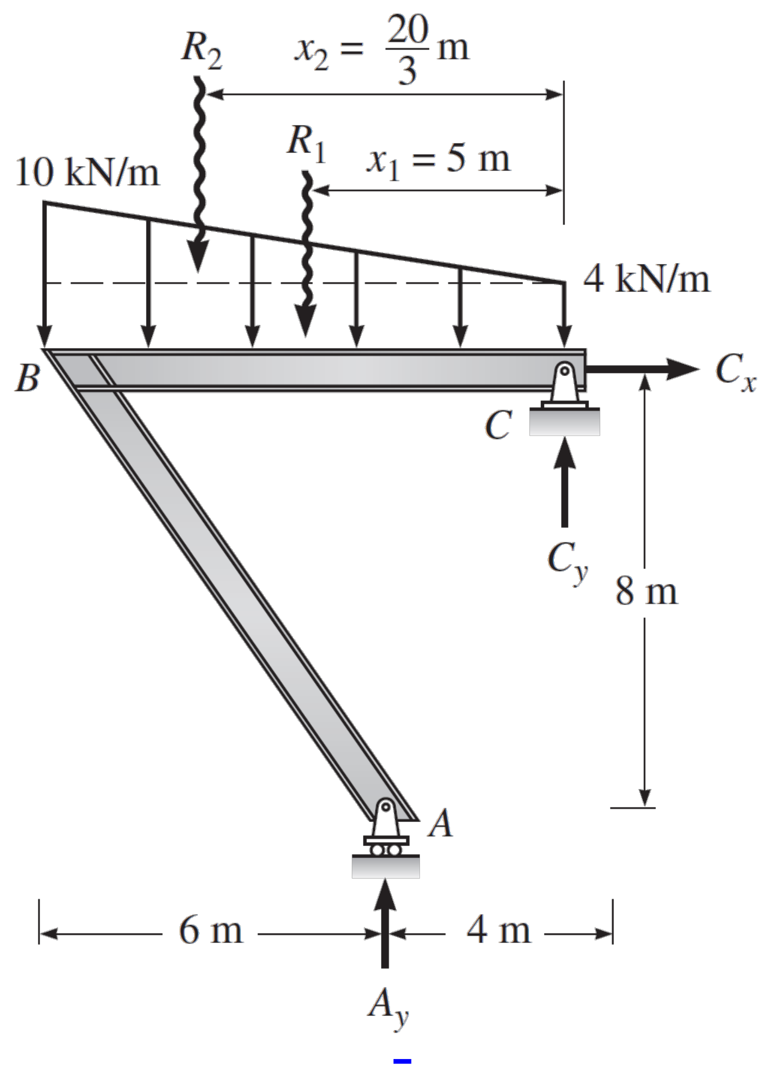
- Solving equations,

$$C_x = 18 \text{ kips} \qquad A_y = 15.43 \text{ kips}$$

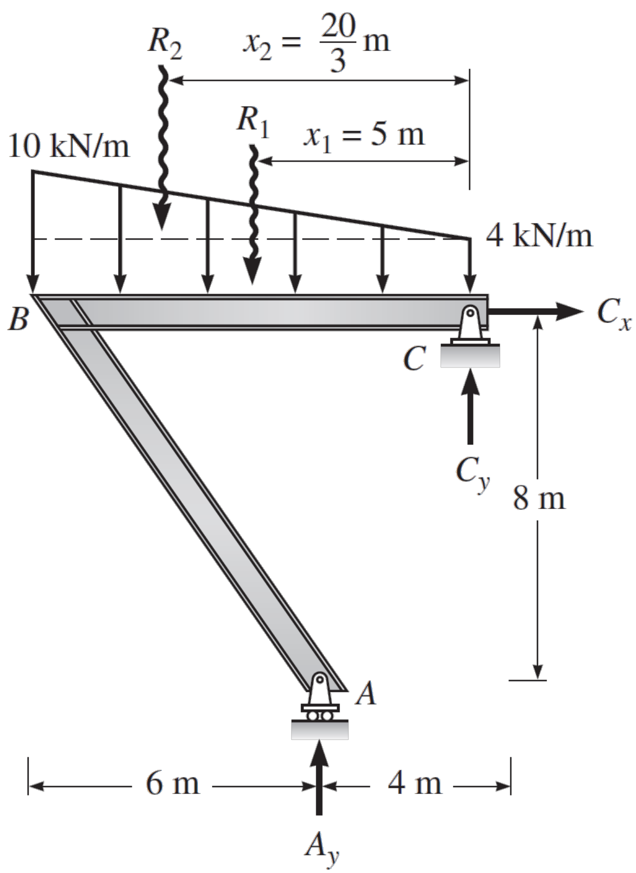
$$C_y = 15.43 \text{ kips} \qquad \textbf{Ans.}$$

Example 3.7

The frame in Figure 3.20 carries a distributed load that varies from 4 to 10 kN/m. Compute the reactions.



Example 3.7 Solution



- Divide the distributed load into a triangular and a rectangular distributed load. Replace the distributed loads by their resultant

$$R_1 = 10(4) = 40 \text{ kN}$$

$$R_2 = \frac{1}{2}(10)(6) = 30 \text{ kN}$$

- Compute A_y

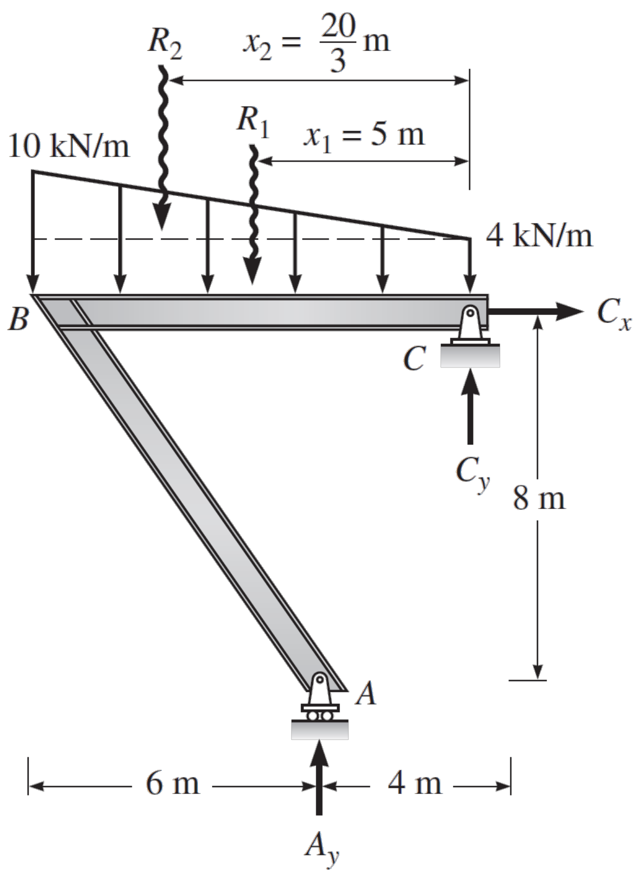
$$\circlearrowright^{+} \quad \Sigma M_C = 0$$

$$A_y(4) - R_1(5) - R_2\left(\frac{20}{3}\right) = 0$$

$$A_y = 100 \text{ kN}$$

Ans.

Example 3.7 Solution (continued)



- Compute C_y

$$+\uparrow \quad \Sigma F_y = 0$$

$$100 - R_1 - R_2 + C_y = 0$$

$$C_y = -30 \text{ kN} \downarrow$$

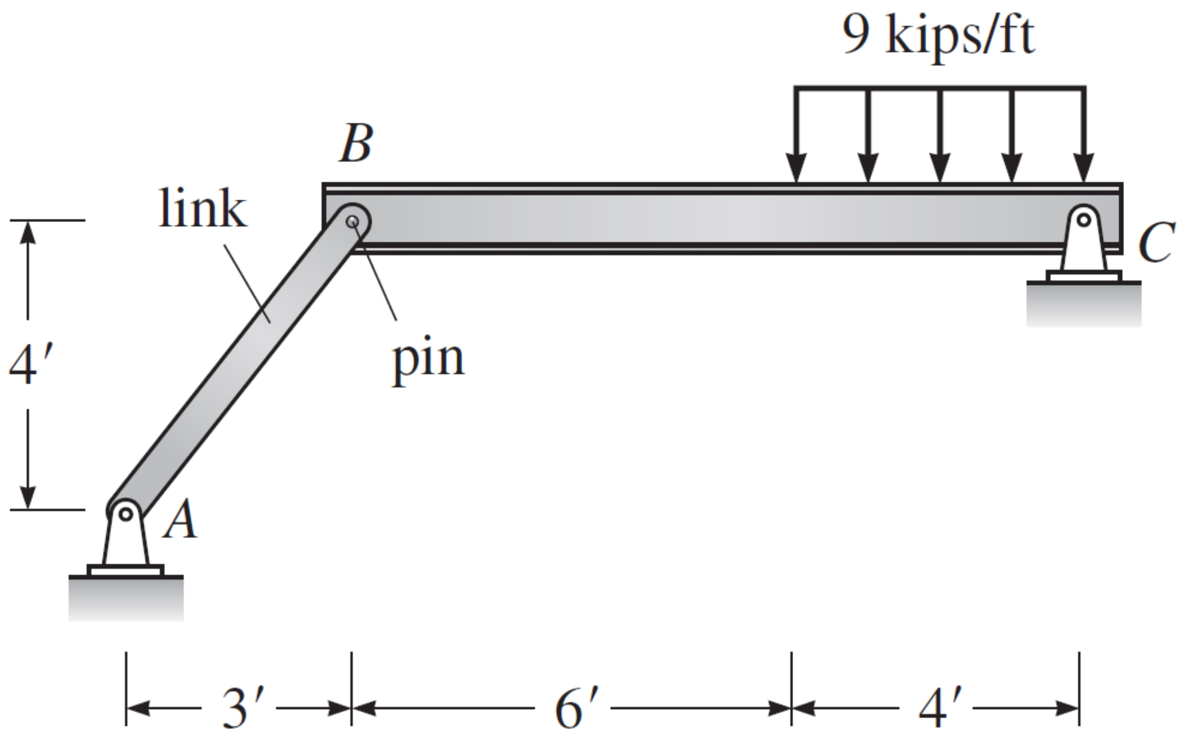
- Compute C_x

$$\xrightarrow{+} \quad \Sigma F_x = 0$$

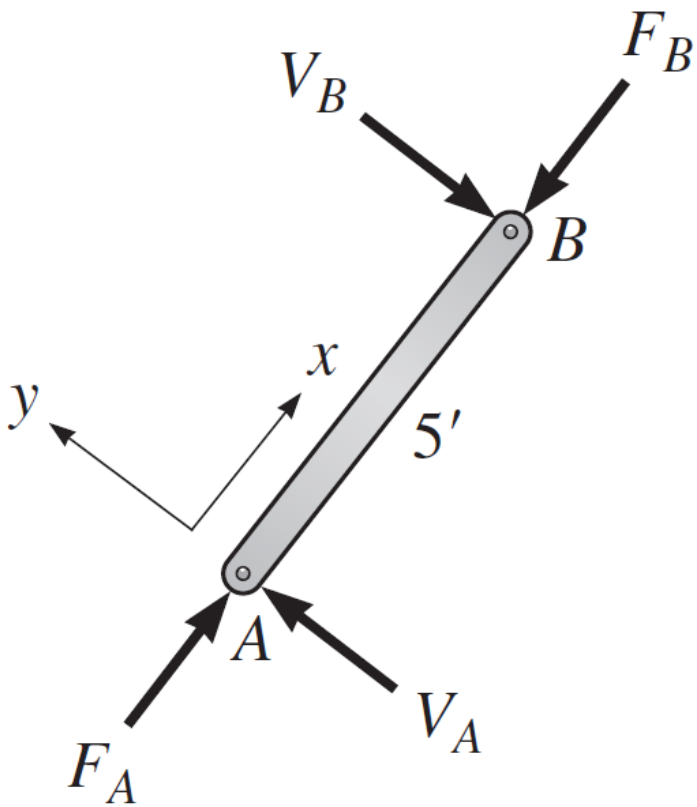
$$C_x = 0 \qquad \textbf{Ans.}$$

Example 3.8

Compute the reactions for the beam in Figure 3.21*a*, treating member *AB* as a link.



Example 3.8 Solution



Free body of link *AB*

- First compute the forces in the link.

$$\xrightarrow{+} \quad \Sigma F_x = 0 \qquad 0 = F_A - F_B$$

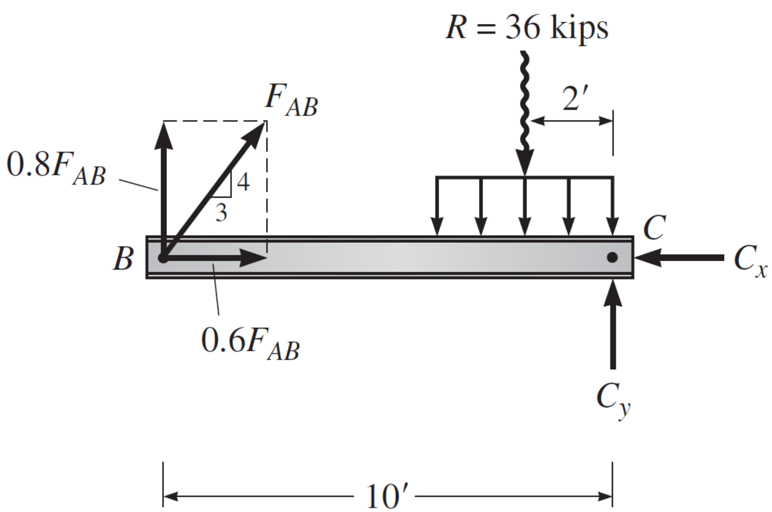
$$\overset{+}{\uparrow} \quad \Sigma F_y = 0 \qquad 0 = V_A - V_B$$

$$\circlearrowright^{+} \quad M_A = 0 \qquad 0 = V_B(5)$$

- Solving the equations above gives

$$F_A = F_B \text{ (call } F_{AB}) \quad \text{and} \quad V_A = V_B = 0$$

Example 3.8 Solution (continued)



- Resolve F_{AB} into components at B and sum moments about C

$$\circlearrowright^{+} \quad \Sigma M_c = 0 \qquad 0 = 0.8F_{AB}(10) - 36(2)$$

$$\xrightarrow{+} \quad \Sigma F_x = 0 \qquad 0 = 0.6F_{AB} - C_x$$

$$+\uparrow \quad \Sigma F_y = 0 \qquad 0 = 0.8F_{AB} - 36 + C_y$$

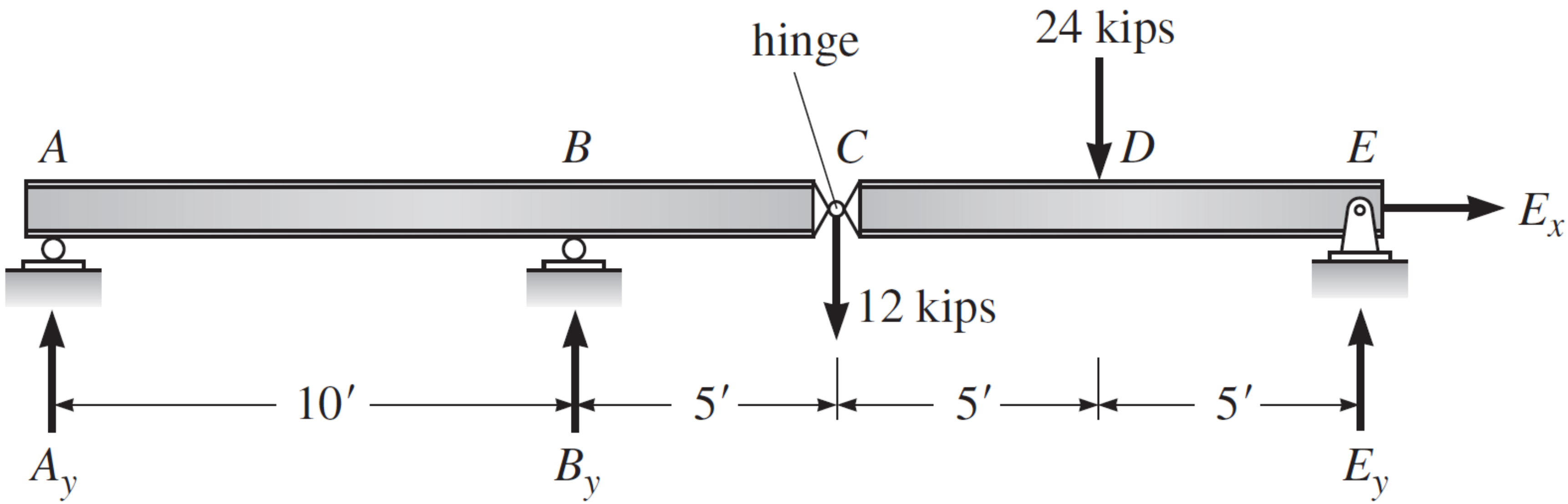
- Solving gives F_{AB}

$F_{AB} = 9$ kips, $C_x = 5.4$ kips,

and $C_y = 28.8$ kips.

Example 3.9

Compute the reactions for the beam in Figure 3.22*a*. A load of 12 kips is applied directly to the hinge at *C*.



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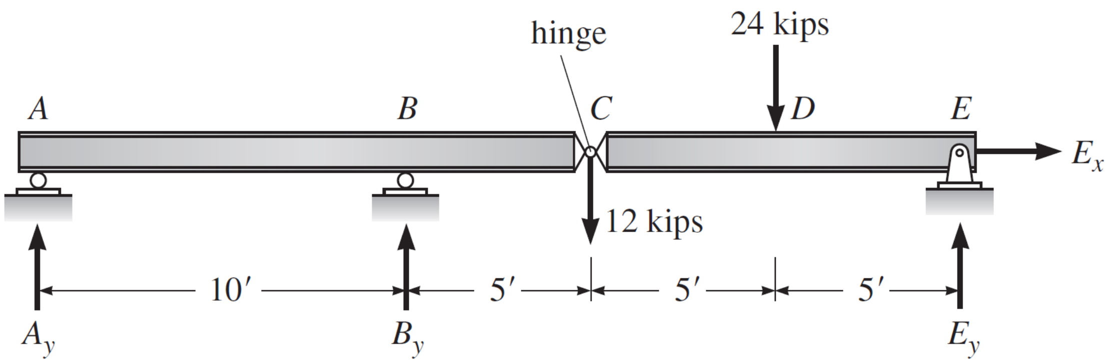
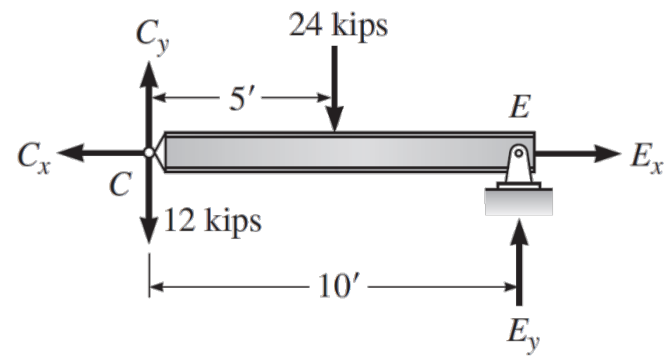
Example 3.9 Solution





- Compute E_y by summing moments about C

$$\circlearrowright^{+} \quad \Sigma M_c = 0$$

$$0 = 24(5) - E_y(10) \qquad \text{and} \qquad E_y = 12 \text{ kips} \qquad \textbf{Ans.}$$

Example 3.9 Solution (continued)

- Complete the analysis

$$\xrightarrow{+} \quad \Sigma F_x = 0 \qquad 0 + E_x = 0$$

$$E_x = 0 \qquad \textbf{Ans.}$$

$$\circlearrowright^{+} \quad \Sigma M_A = 0 \qquad 0 = -B_y(10) + 12(15) + 24(20) - 12(25)$$

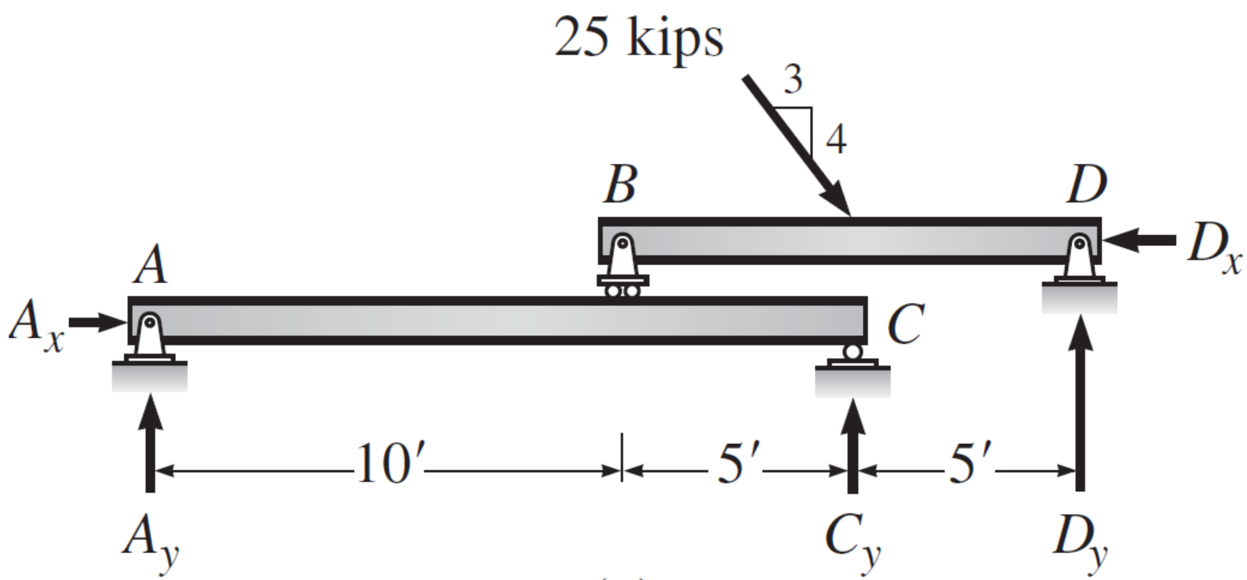
$$B_y = 36 \text{ kips} \qquad \textbf{Ans.}$$

$$\overset{+}{\uparrow} \quad \Sigma F_y = 0 \qquad 0 = A_y + B_y - 12 - 24 + E_y$$

Substituting $B_y = 36$ kips and $E_y = 12$ kips, we compute $A_y = -12$ kips (down).

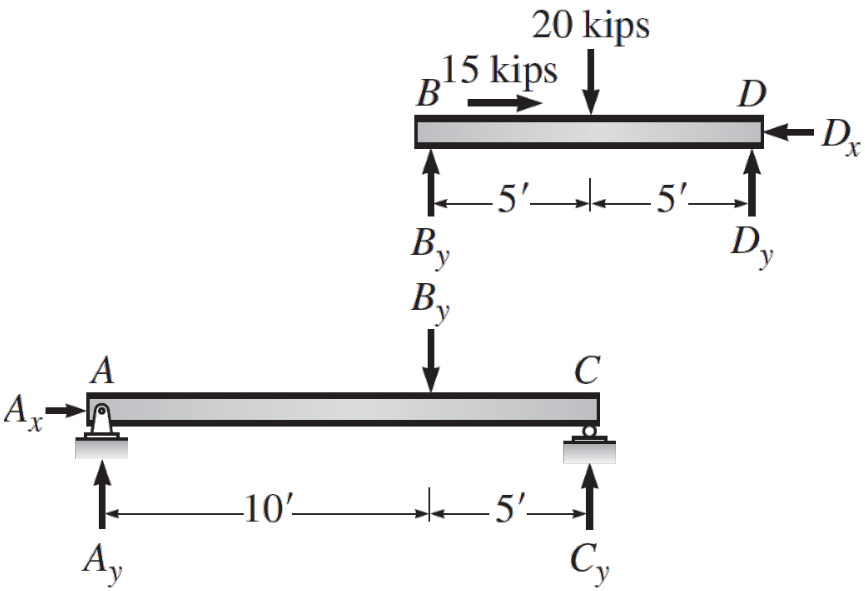
Example 3.10

Compute the reactions for the beams.



(a)

Example 3.10 Solution



(b)

- Applying the equations of equilibrium to member *BD*,

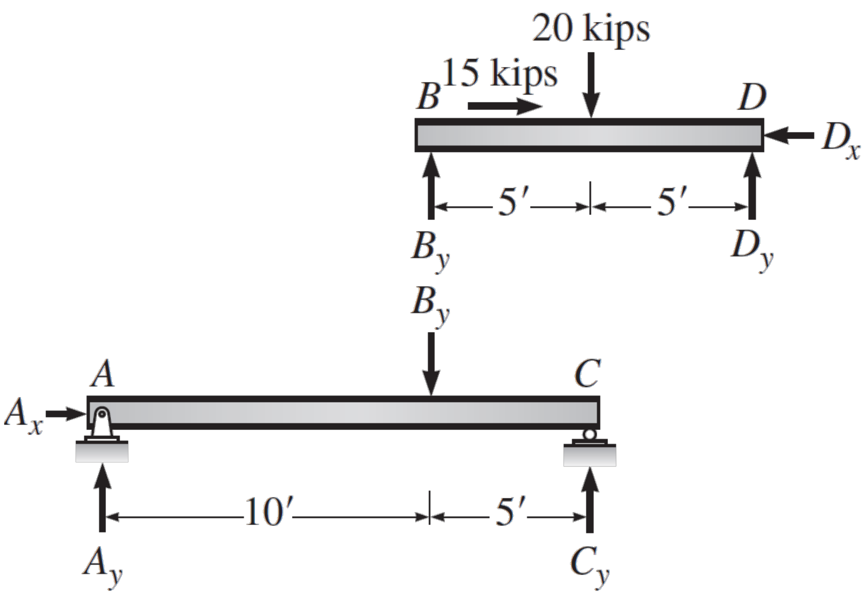
$$\xrightarrow{+} \quad \Sigma F_x = 0 \qquad 0 = 15 - D_x$$

$$\circlearrowright^{+} \quad \Sigma M_D = 0 \qquad 0 = B_y(10) - 20(5)$$

$$+\uparrow \quad \Sigma F_y = 0 \qquad 0 = B_y - 20 + D_y$$

- Solving Equations, compute D_x = 15 kips, B_y =10 kips, and D_y = 10 kips

Example 3.10 Solution (continued)



(b)

- With B_y evaluated, apply the equations of equilibrium to member *AC*

$$\xrightarrow{+} \quad \Sigma F_x = 0 \qquad 0 = A_x$$

$$\circlearrowright^{+} \quad \Sigma M_A = 0 \qquad 0 = 10(10) - 15C_y$$

$$\overset{+}{\uparrow} \quad \Sigma F_y = 0 \qquad 0 = A_y - 10 + C_y$$

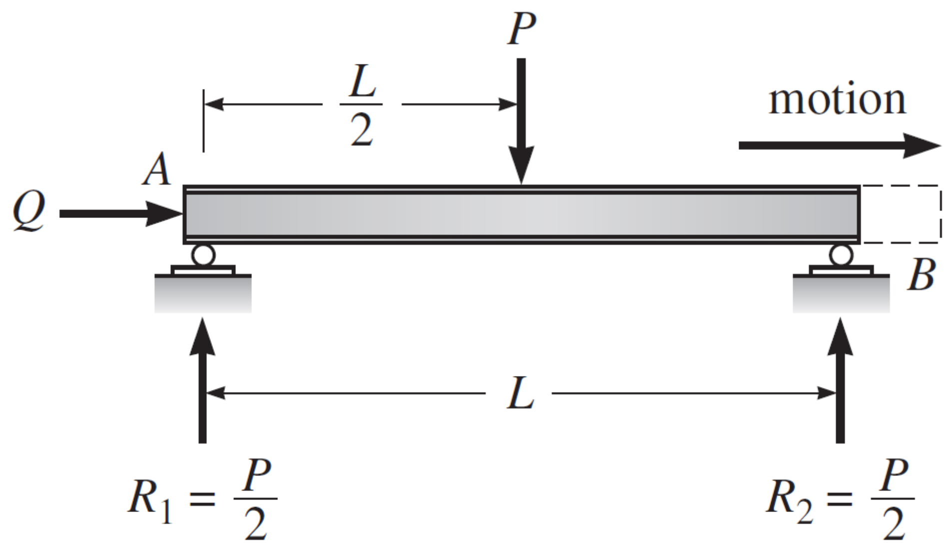
- Static check: To verify the accuracy of the computations, apply $\Sigma F_y = 0$ to the entire structure

$$A_y + C_y + D_y - 0.8(25) = 0$$

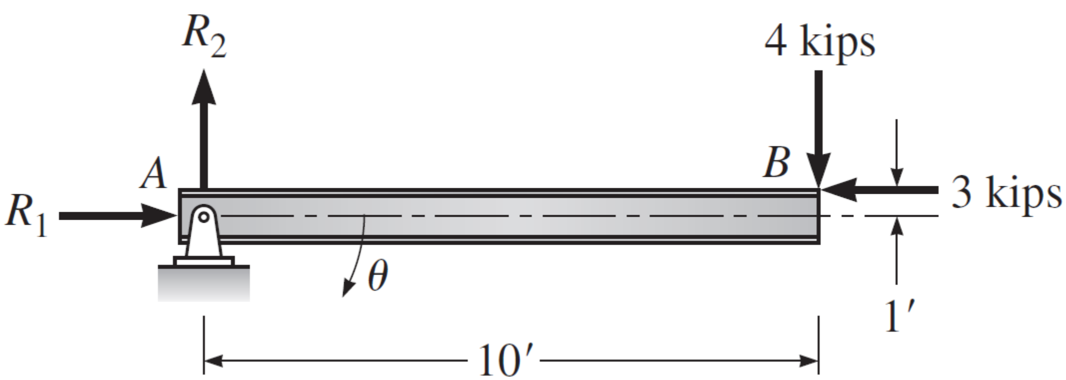
$$\frac{10}{3} + \frac{20}{3} + 10 - 20 = 0$$

$$0 = 0 \qquad \text{OK}$$

§3.8 Influence of Reaction on Stability and Determinacy of Structures



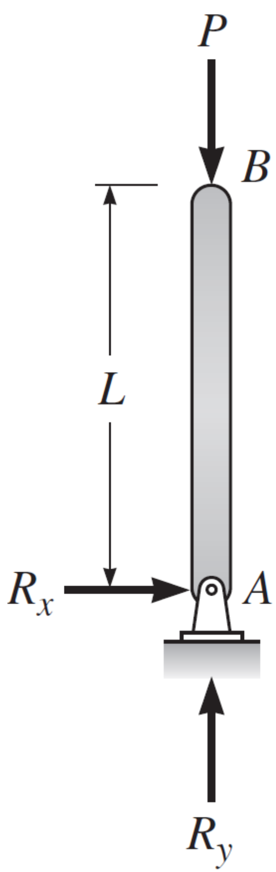
Unstable, horizontal restraint missing



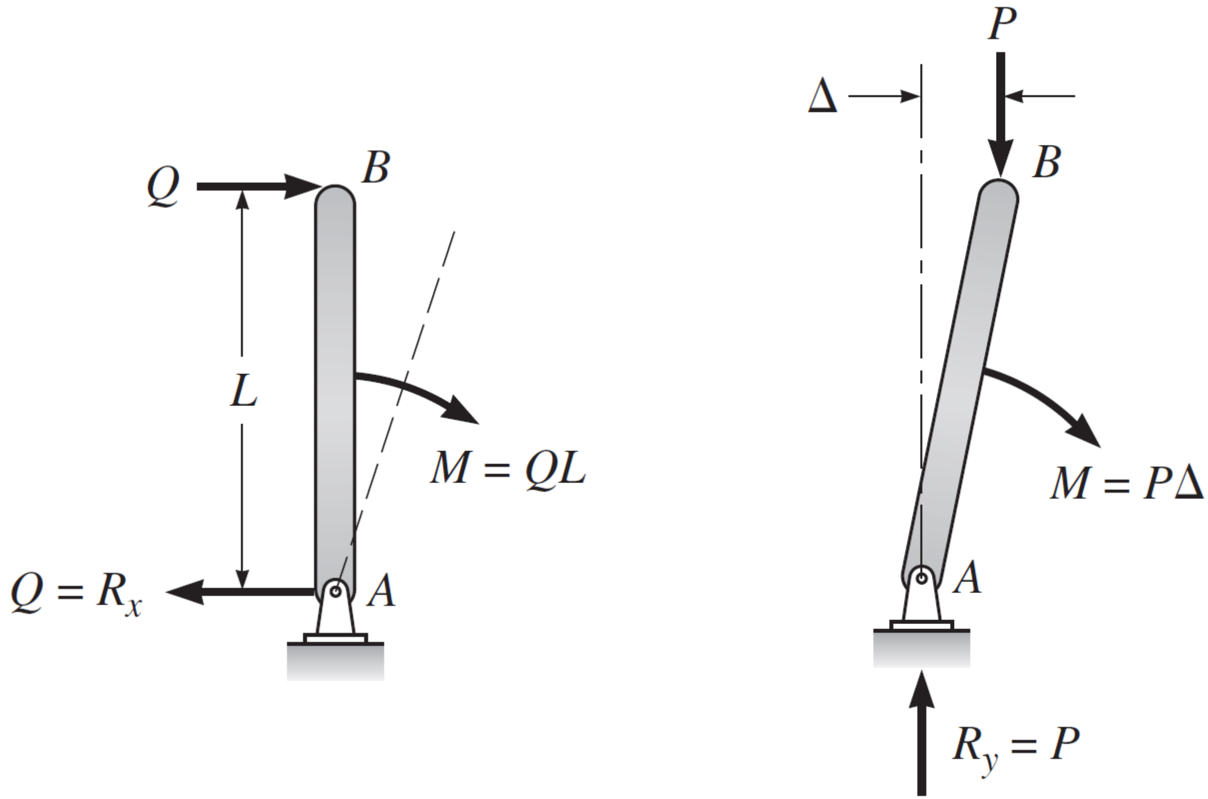
Unstable, free to rotate about *A*

Figure 3.24

§3.8 Influence of Reaction on Stability and Determinacy of Structures



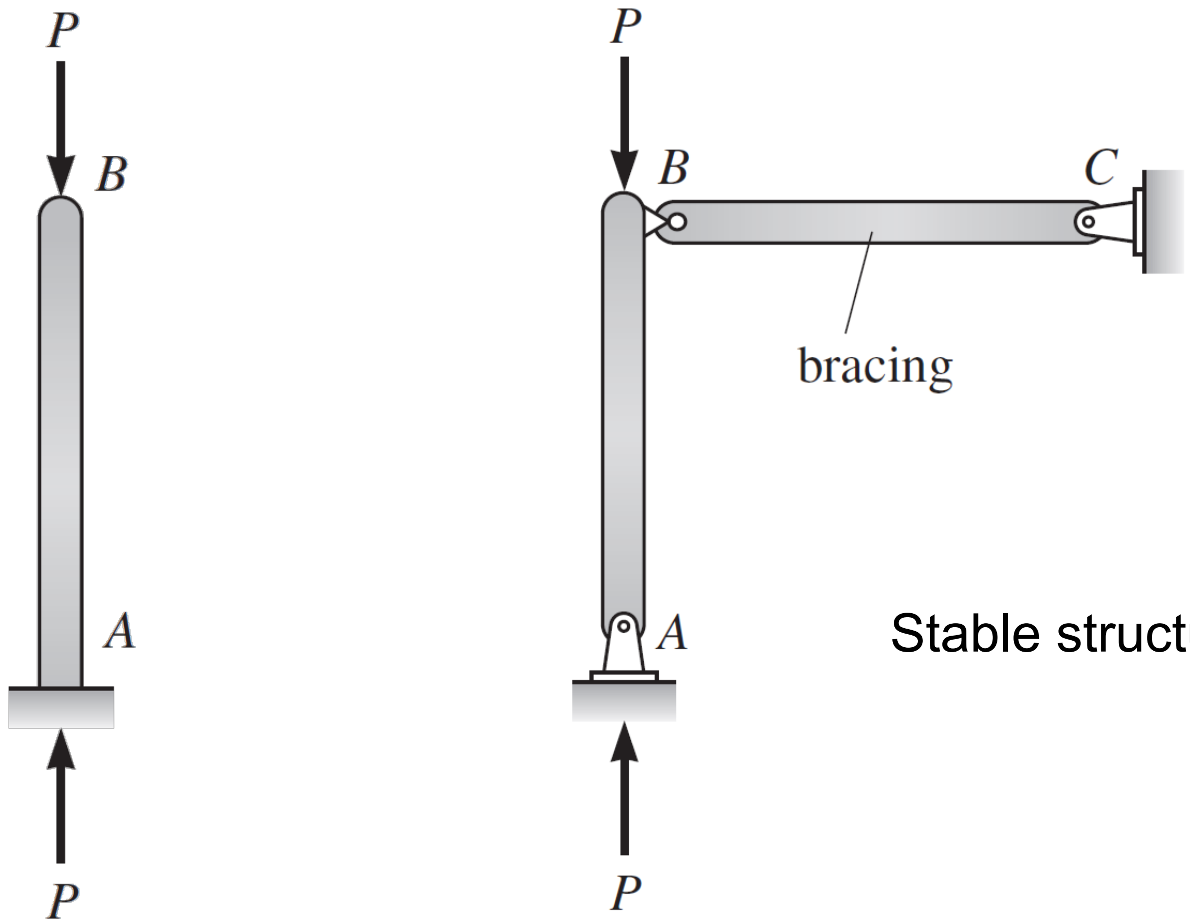
Unstable, free to rotate about *A*



Unbalanced moments produce failure

Figure 3.24 (continued)

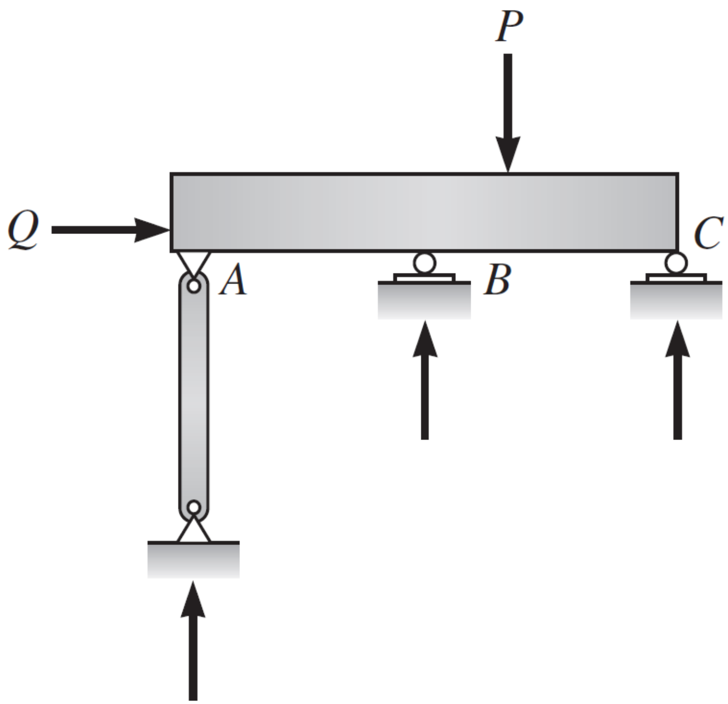
§3.8 Influence of Reaction on Stability and Determinacy of Structures



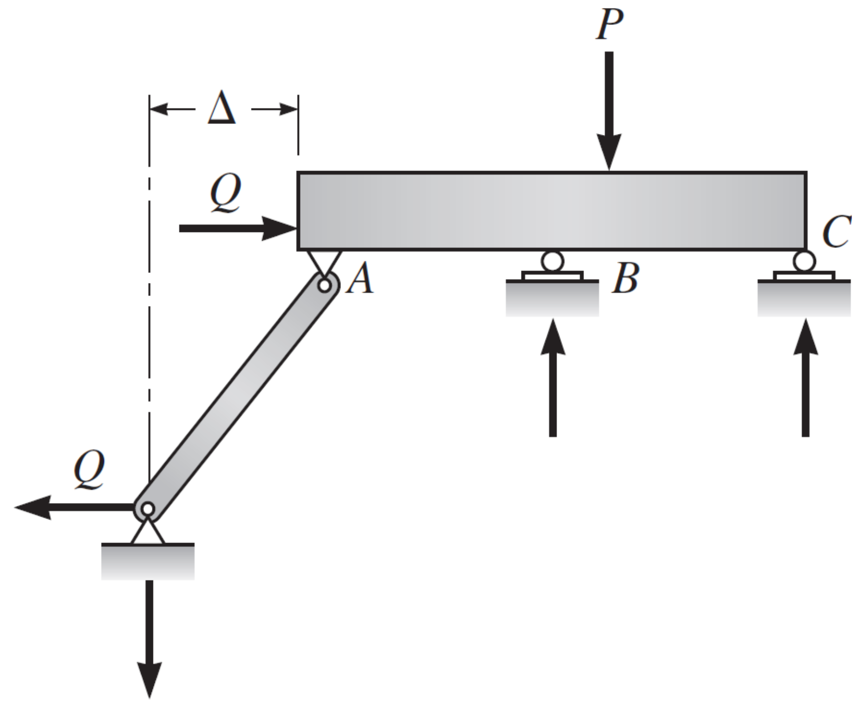
Stable structures

Figure 3.24 (continued)

§3.8 Influence of Reaction on Stability and Determinacy of Structures



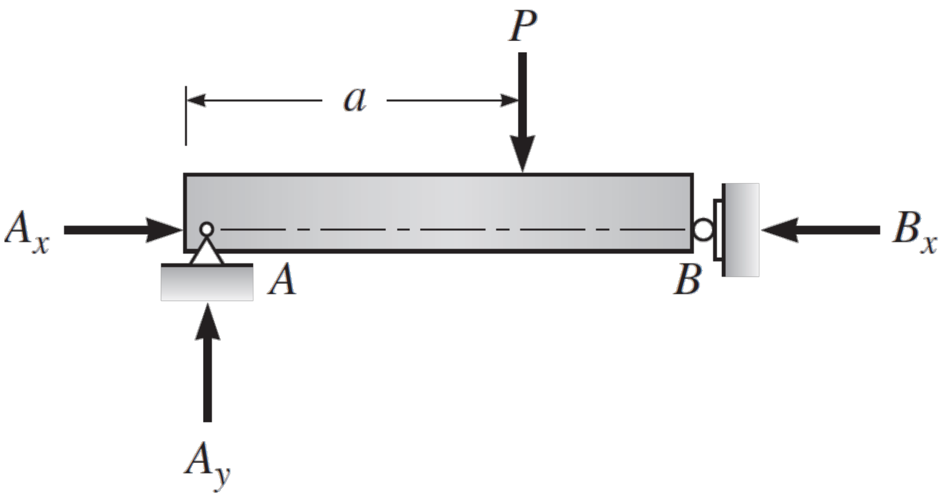
Geometrically unstable, reactions form a parallel force system



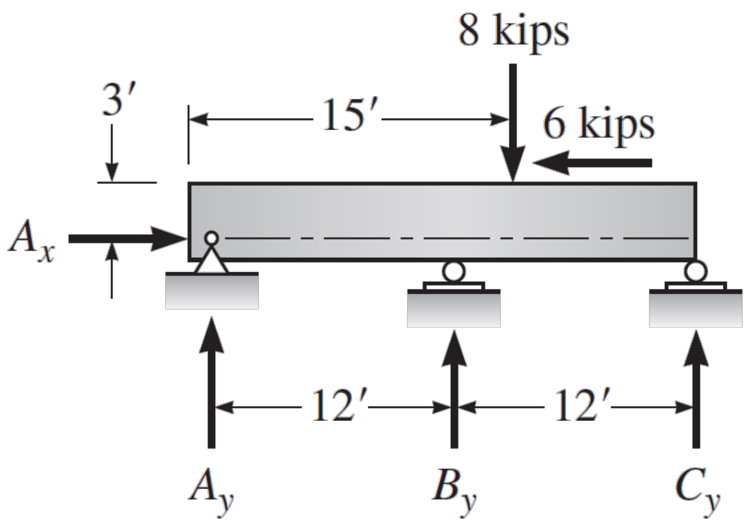
Equilibrium position, horizontal reaction develops as link elongates and changes slope

Figure 3.25

§3.8 Influence of Reaction on Stability and Determinacy of Structures



Geometrically unstable—reactions form a concurrent force system passing through the pin at *A*



Indeterminate beam

Figure 3.25 (continued)

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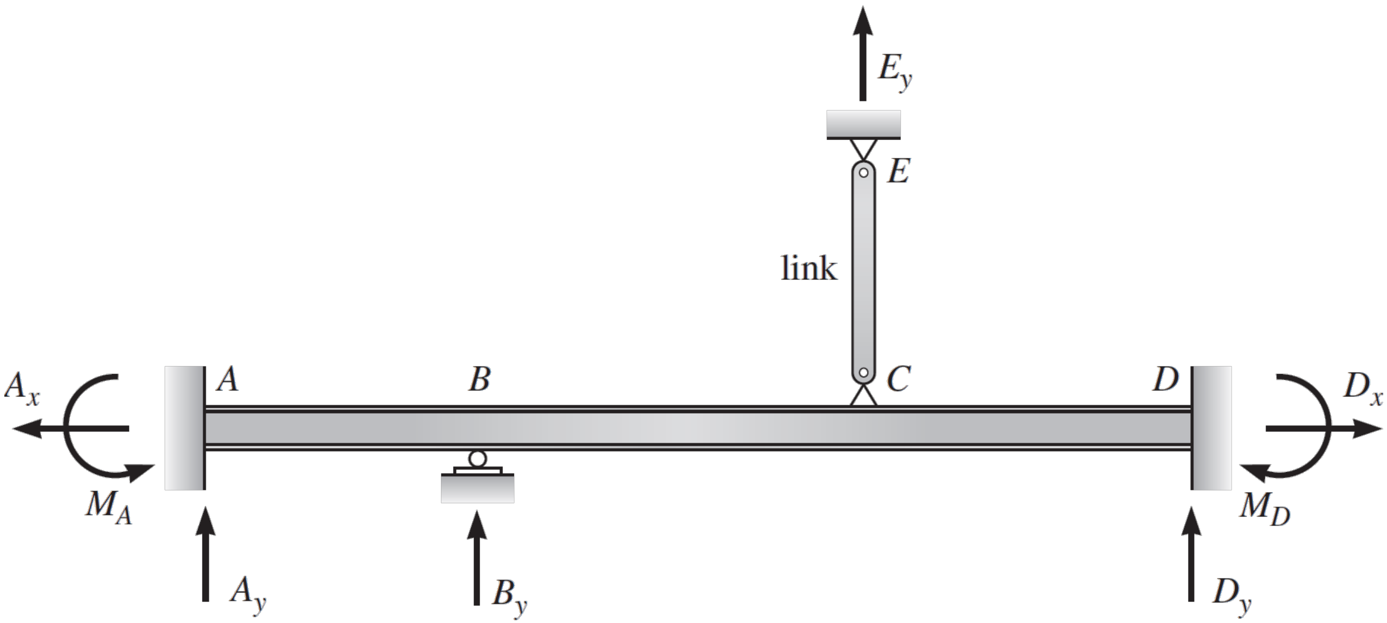
§3.8 Influence of Reaction on Stability and Determinacy of Structures



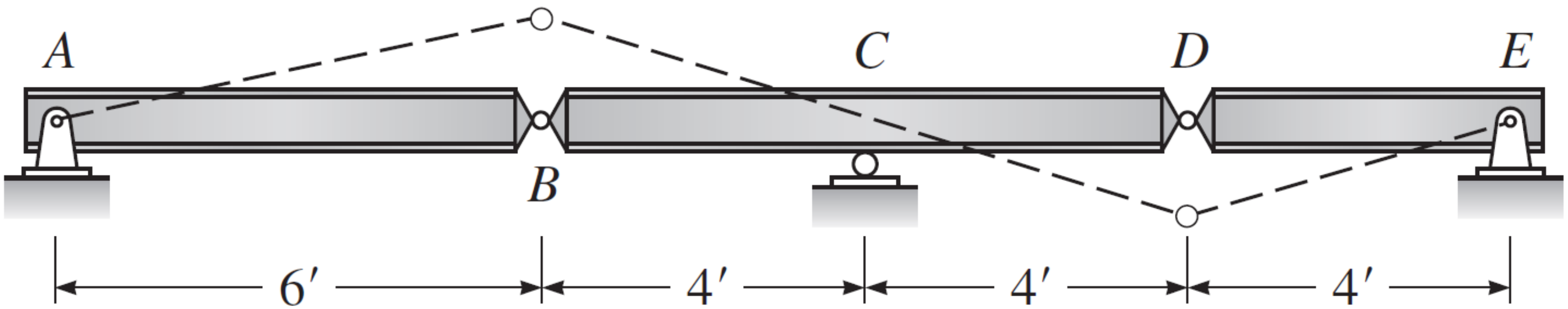
Indeterminate structure

Base (or released) structure remaining after redundant supports removed

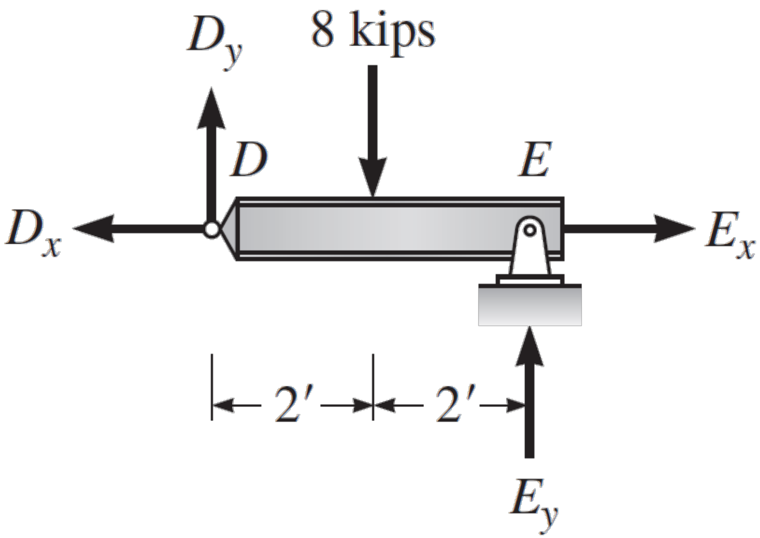
Figure 3.26

Example 3.11

Investigate the stability of the structure. Hinges at joints *B* and *D*.



Example 3.11 Solution



Free body of member *DE*

- A necessary condition for stability requires

$$R = 3 + C$$

- Check the equilibrium of *DE*

$$\xrightarrow{+} \quad \Sigma F_x = 0 \qquad E_x - D_x = 0$$

$$E_x = D_x$$

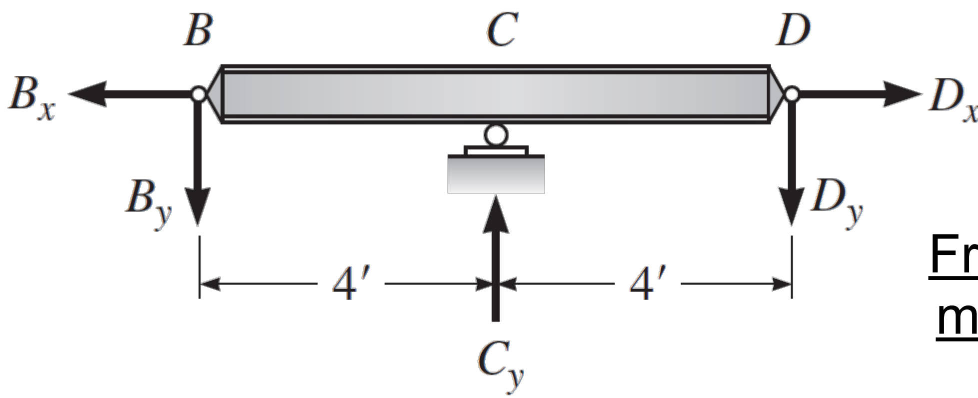
$$\circlearrowright^{+} \quad \Sigma M_D = 0 \qquad 8(2) - 4E_y = 0$$

$$E_y = 4 \text{ kips}$$

$$+\uparrow \quad \Sigma F_y = 0 \qquad D_y + E_y - 8 = 0$$

$$D_y = 4 \text{ kips}$$

Example 3.11 Solution (continued)



Free body of member *BD*

- Check the equilibrium of member *BD*

$$\circlearrowright^{+} \quad \Sigma M_c = 0 \qquad 4D_y - 4B_y = 0$$

$$B_y = D_y = 4 \text{ kips} \qquad \textbf{Ans.}$$

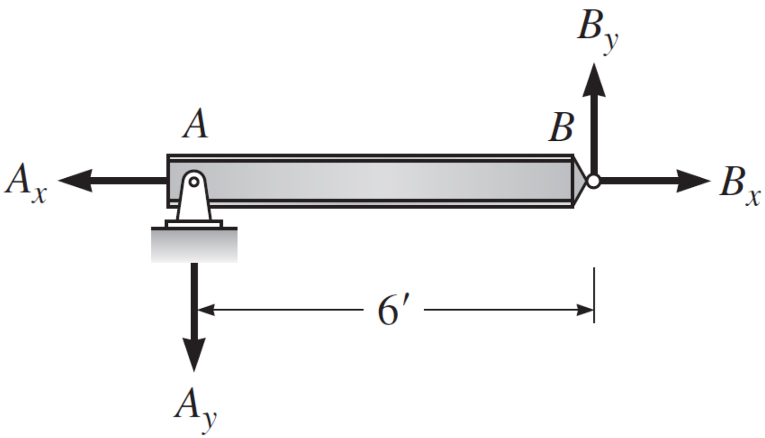
$$\rightarrow + \quad \Sigma F_x = 0 \qquad D_x - B_x = 0$$

$$D_x = B_x$$

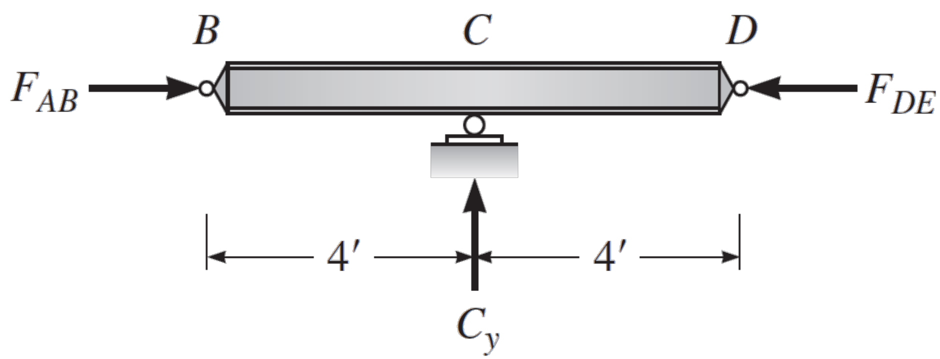
$$\overset{+}{\uparrow} \quad \Sigma F_y = 0 \qquad -B_y + C_y - D_y = 0$$

$$C_y = 8 \text{ kips} \qquad \textbf{Ans.}$$

Example 3.11 Solution (continued)



Free body of member *AB*



Unstable structure

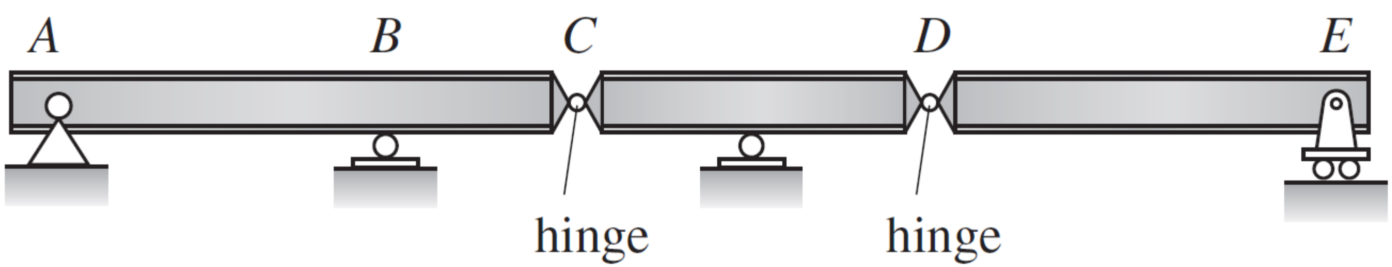
- Check the equilibrium of member *AB*

$$\circlearrowright^{+} \quad \Sigma M_A = 0 \qquad 0 = -B_y(6) \quad \text{(inconsistent equation)}$$

- Unstable structure

§3.9 Classifying Structures

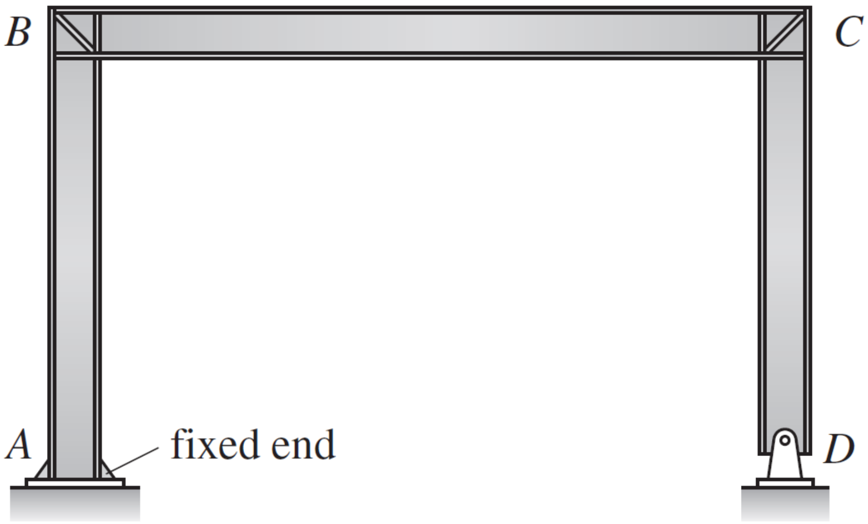
Indeterminate to first degree



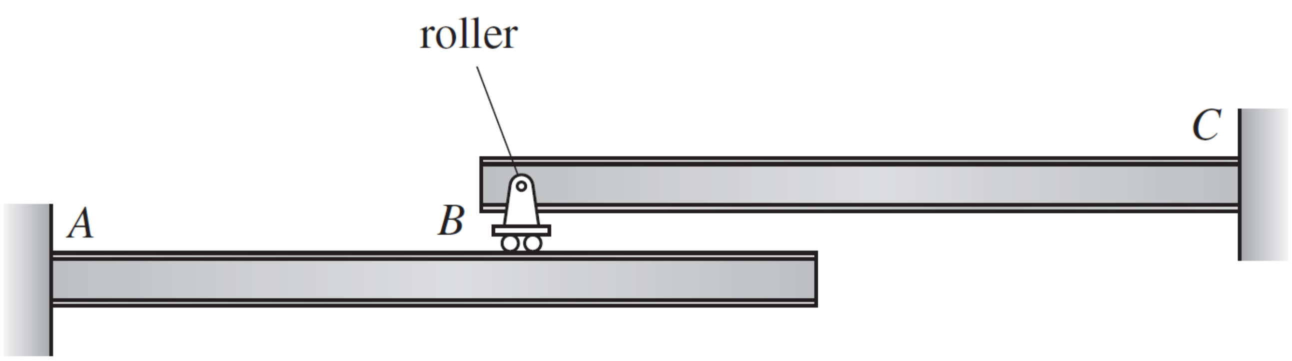
Stable and determinate

Figure 3.28 Examples of stable and unstable structures

§3.9 Classifying Structures



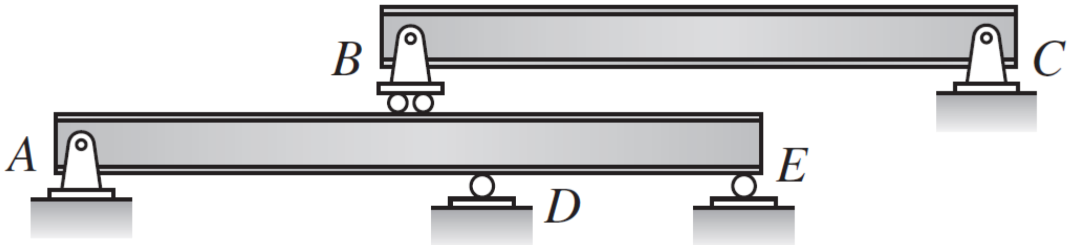
Indeterminate to second degree



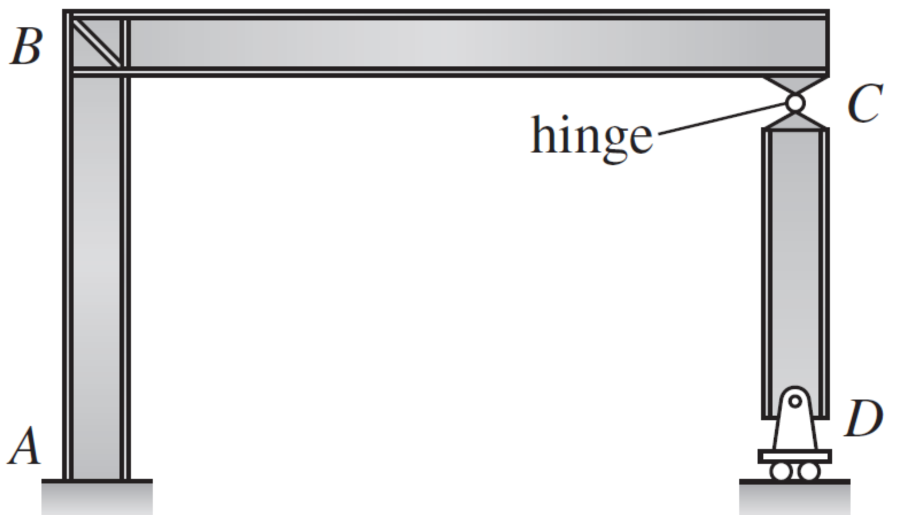
Indeterminate to first degree

Figure 3.28 Examples of stable and unstable structures (continued)

§3.9 Classifying Structures



Indeterminate first degree

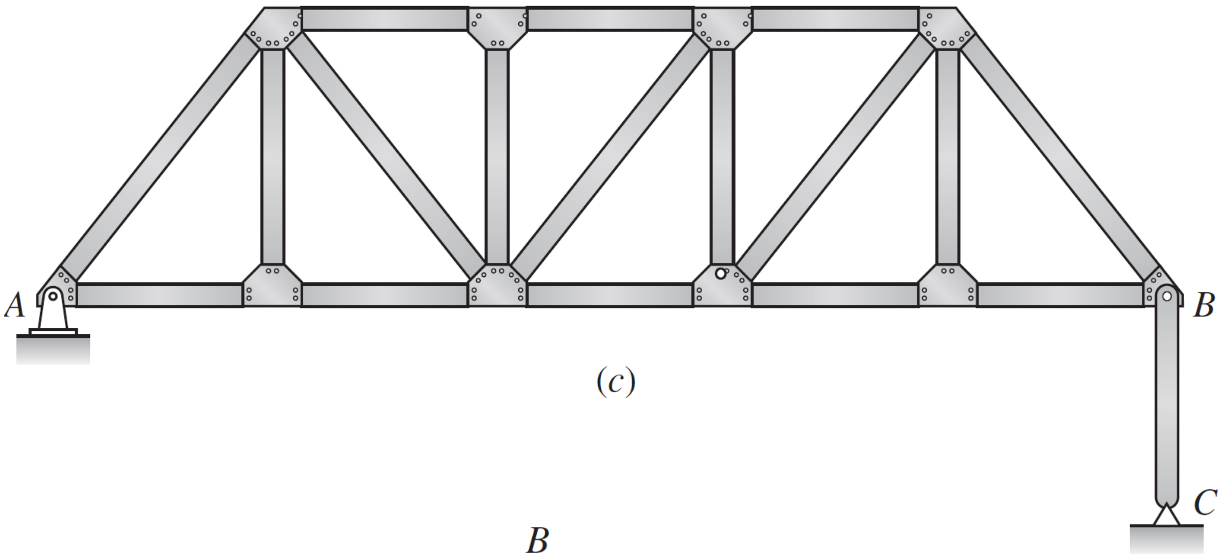


(b)

Unstable—reactions applied to *CD* form a concurrent force system

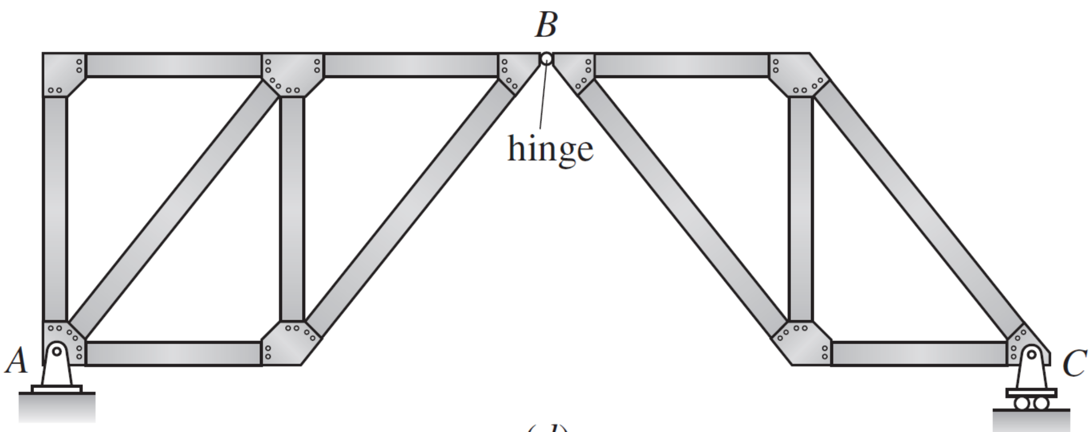
Figure 3.29

§3.9 Classifying Structures



(c)

Stable and determinate

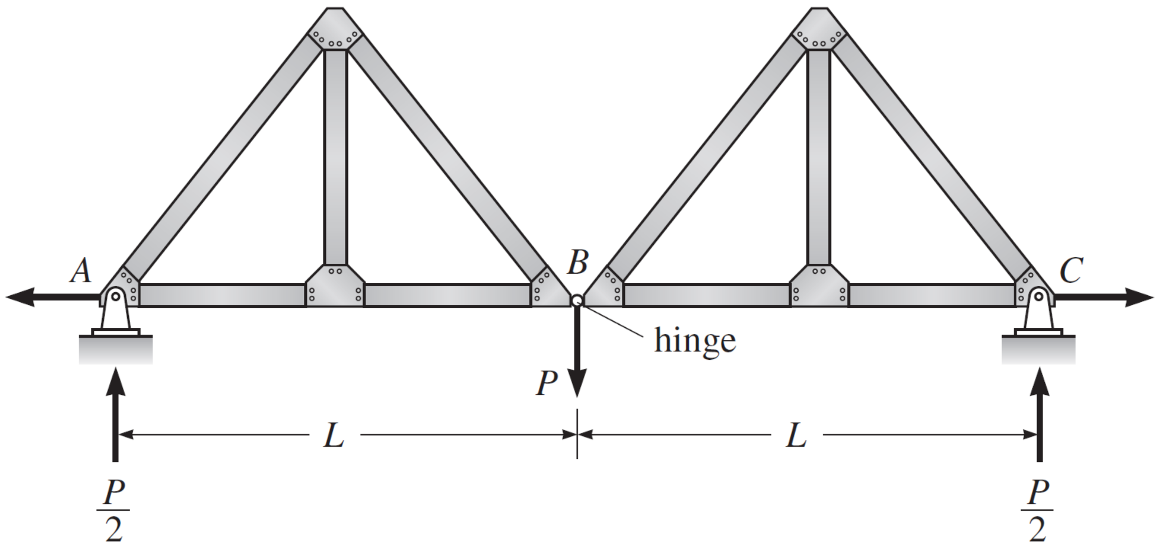


(d)

Unstable $R < 3 + C$

Figure 3.29 (continued)

§3.9 Classifying Structures



Unstable, reactions applied to each truss form a concurrent force system

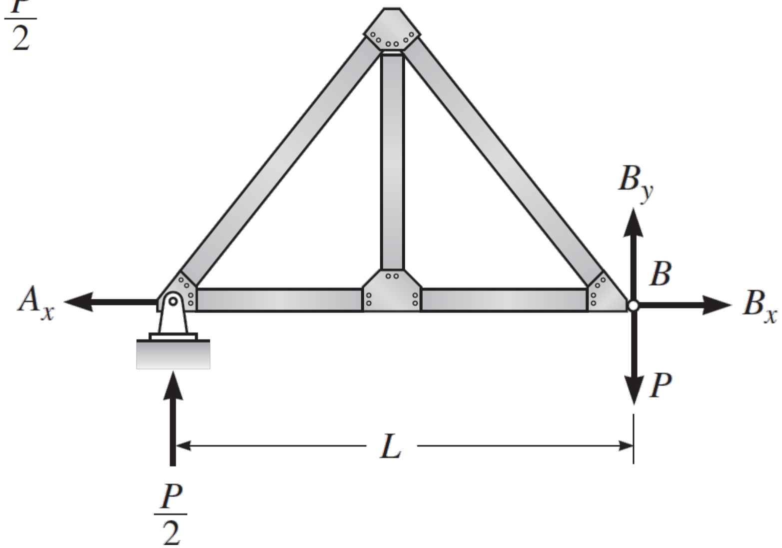


Figure 3.29 (continued)

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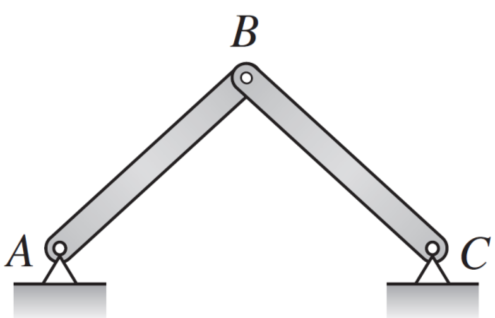
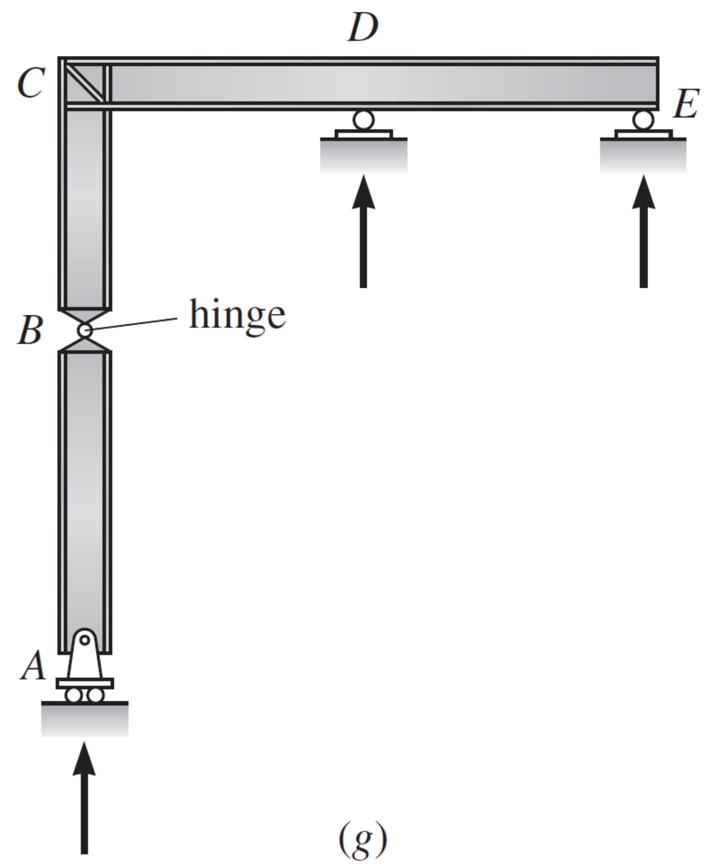
§3.9 Classifying Structures



(f)

Stable and indeterminate

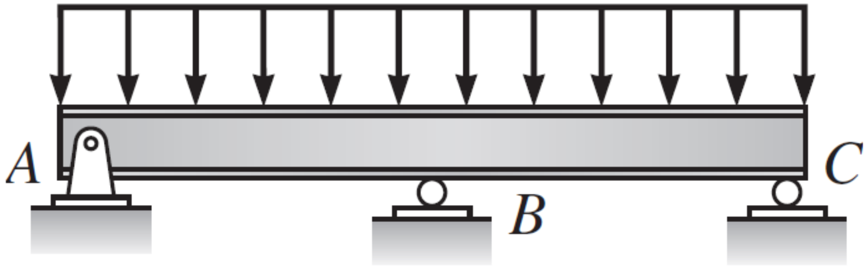


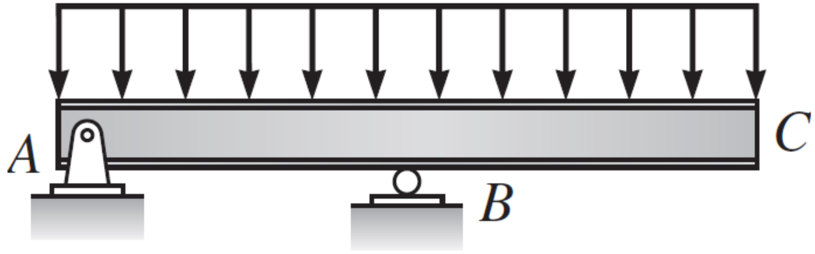
(g)

Unstable, reactions on *BCDE* equivalent to a parallel force system

Figure 3.29 (continued)

§3.10 Comparison between Determinate and Indeterminate Structures





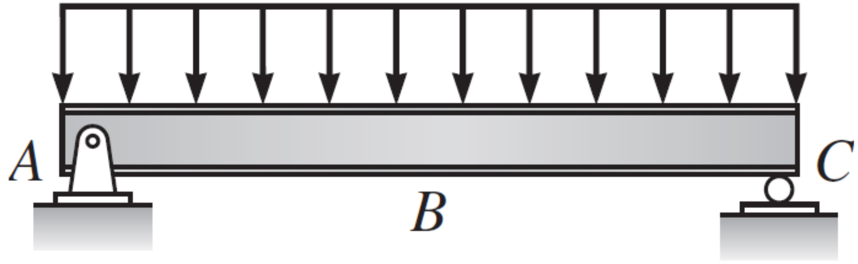


Figure 3.30 Alternative modes of transmitting load to supports

§3.10 Comparison between Determinate and Indeterminate Structures

Photo 3.3 The collapse of a bridge composed of simply supported beams during the 1964 Nigata earthquake

§3.10 Comparison between Determinate and Indeterminate Structures

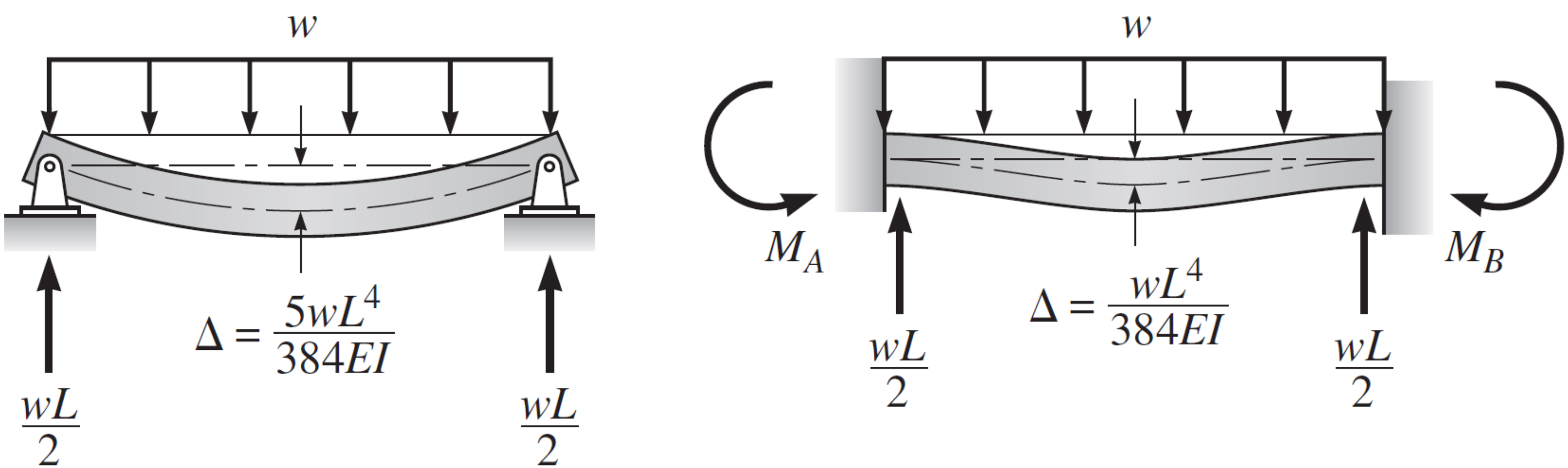
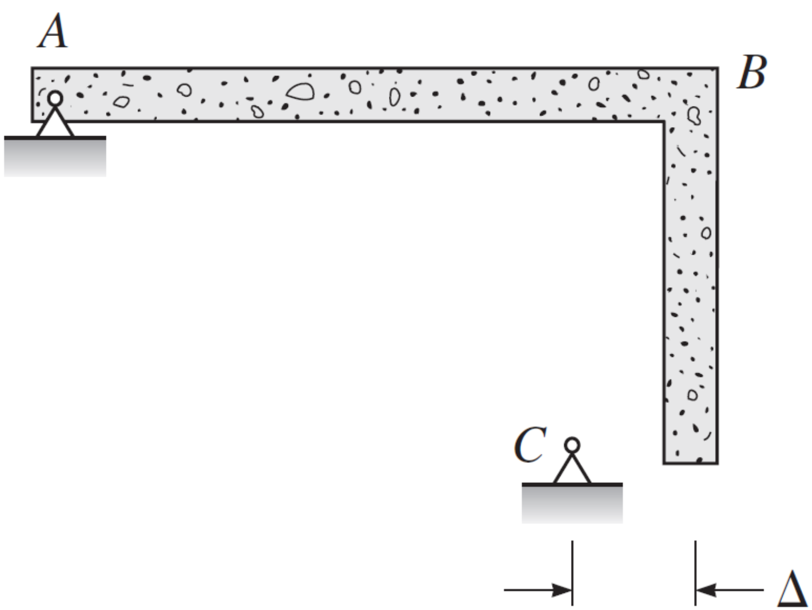
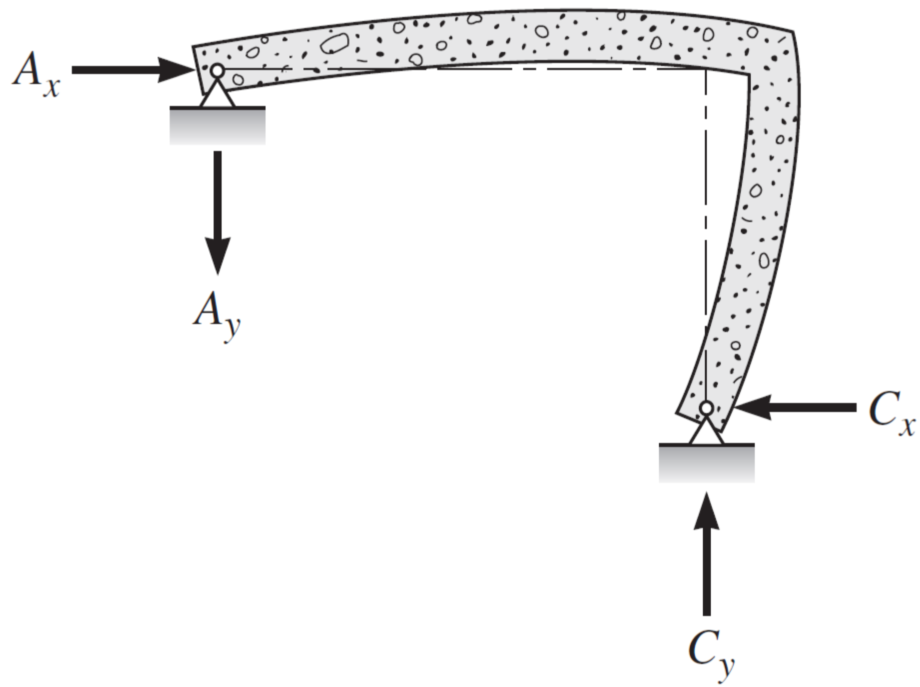


Figure 3.31 Comparison of flexibility between a determinate and indeterminate structure

§3.10 Comparison between Determinate and Indeterminate Structures



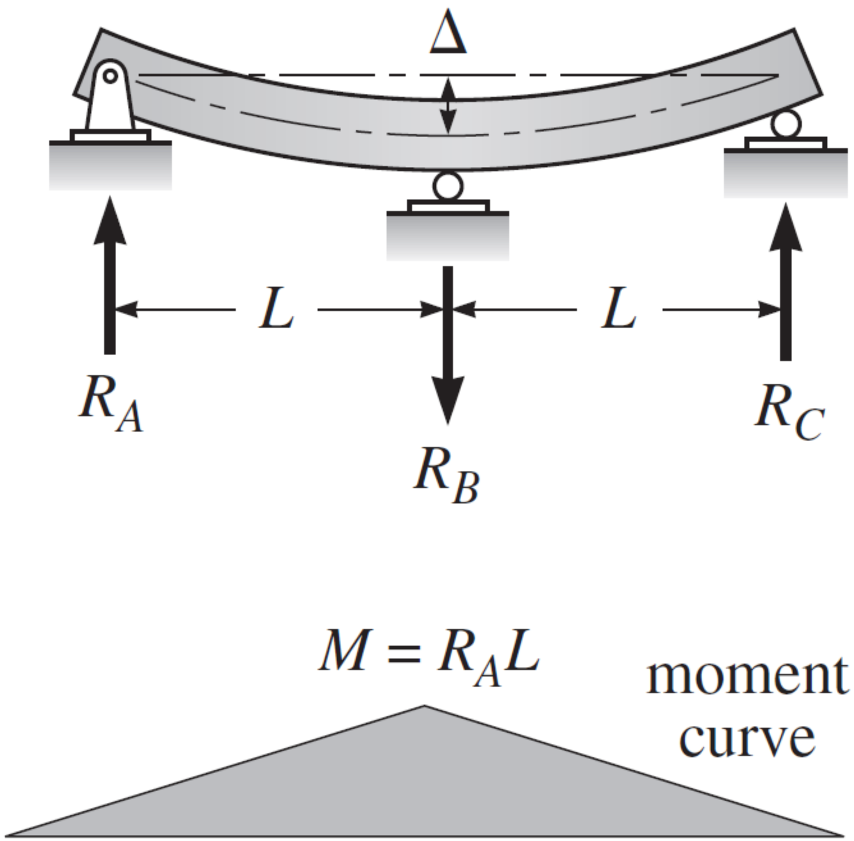
Column extends beyond support because girder is too long



Reactions produced by forcing the bottom of the column into the supports

Figure 3.32 Consequences of fabrication error

§3.10 Comparison between Determinate and Indeterminate Structures



Support *B* settles, creating reactions

Moment curve produced by support settlement

Figure 3.33