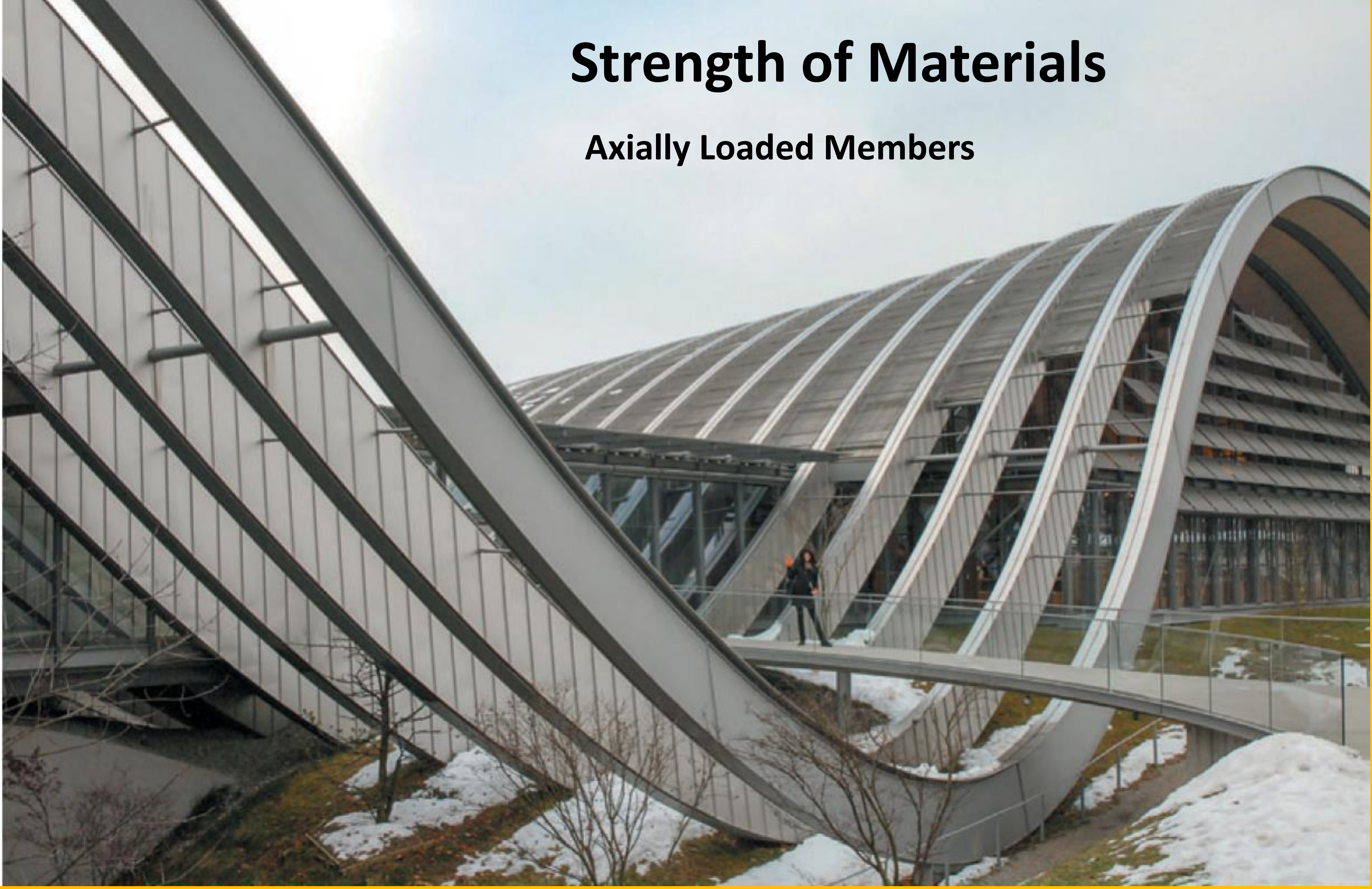
Strength of Materials

Axially Loaded Members



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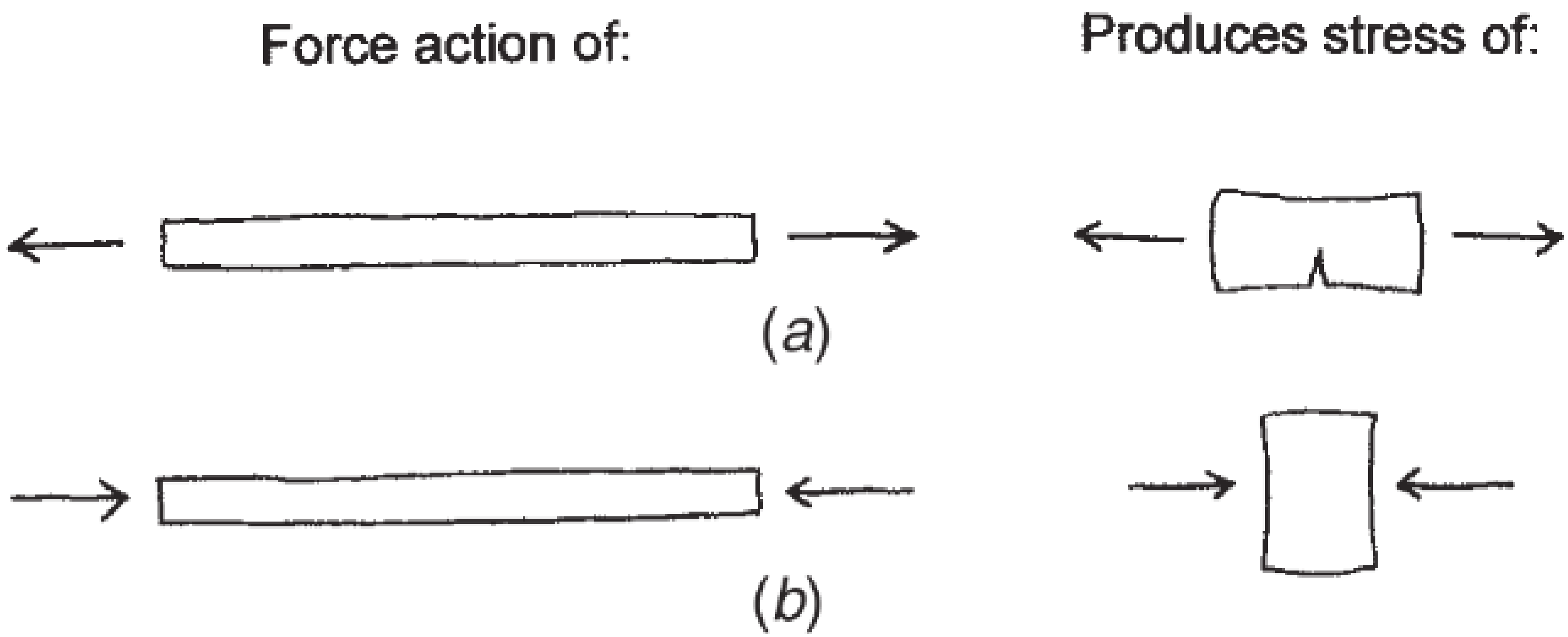


Figure 1.25 (*a*) Effects of tension. (*b*) Effects of compression.

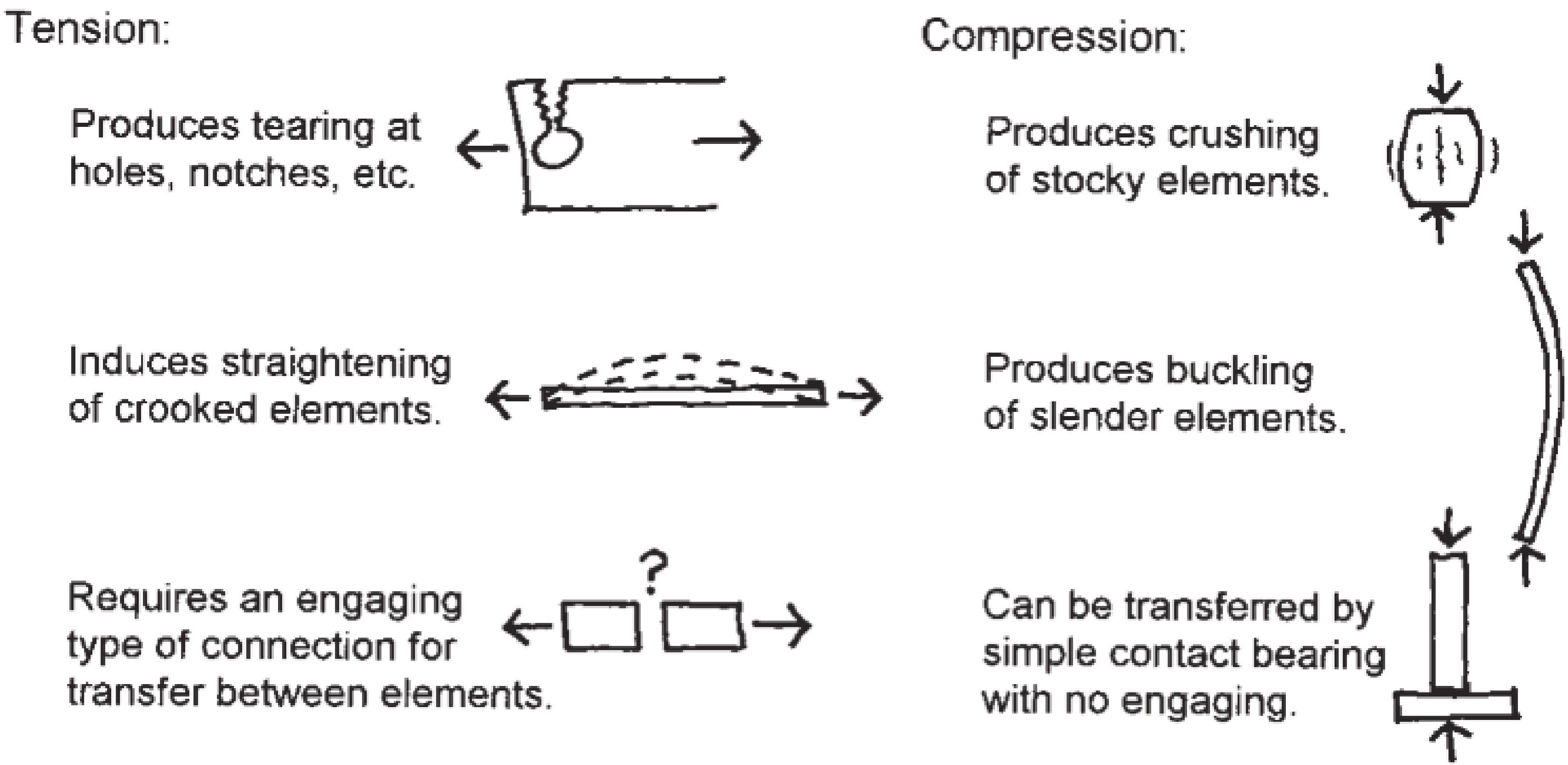
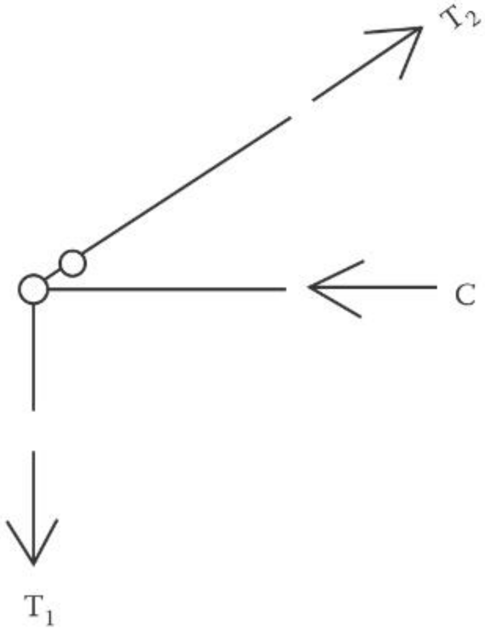


Figure 1.26 Considerations of tension and compression actions.

APPLICATION: CONCURRENT FORCES, HONG KONG AND SHANGHAI BANK (SEE PHOTOGRAPHS OVER PAGE)

There are many examples of concurrent forces in the primary structural frame of the Hong Kong and Shanghai Bank building in Hong Kong. One of the simpler ones is at the remote end of the 'outrigger trusses' that reach out beyond the main masts. The downward force from the vertical edge tension hanger is resisted by tension in the inclined hanger plus compression in the horizontal strut. Two pins were used to simplify the fabrication and construction of this remote joint. The pins are spherical in nature, to release any bending and twisting effects that might be induced by frame movements perpendicular to the plane of the outrigger truss.

Project: Hong Kong and Shanghai Bank, Hong Kong; Architect: Foster and Partners; Structural Engineer: Arup; Photos: Ian Lambot; Diagram: Arup


T2
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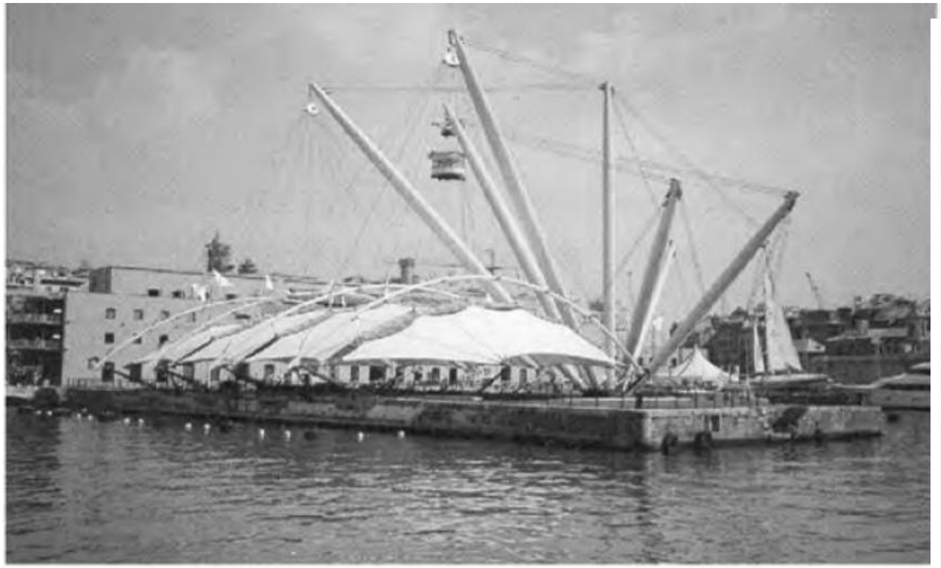
APPLICATION: TIES AND STRUTS, IL GRANDE BIGO

(SEE PHOTOGRAPHS OVER PAGE)

Built by the City of Genoa to celebrate the voyage of Christopher Columbus, 'Il Grande Bigo' (the big ship-crane) has two tall compression booms providing cable support to the tubular arches carrying the fabric roof, and another boom for suspending the cable-car elevator. All booms are of tubular steel, with the cigar-shape achieved by a series of rolled conic sections with gradually increasing taper, butt-welded together. This shape maximises cross-section width (diameter) at boom mid-length, where the buckling tendency is greatest, and so minimises the boom's slenderness ratio. This in turn maximises its compression load capacity, for a given tonnage of steel plate.

Project: Il Grande Bigo, Genoa, Italy; Architect: Renzo Piano Building Workshop, Genoa; Structural Engineer: Arup/Sidercad SA; Photos: Arup (Alistair Lenczner)



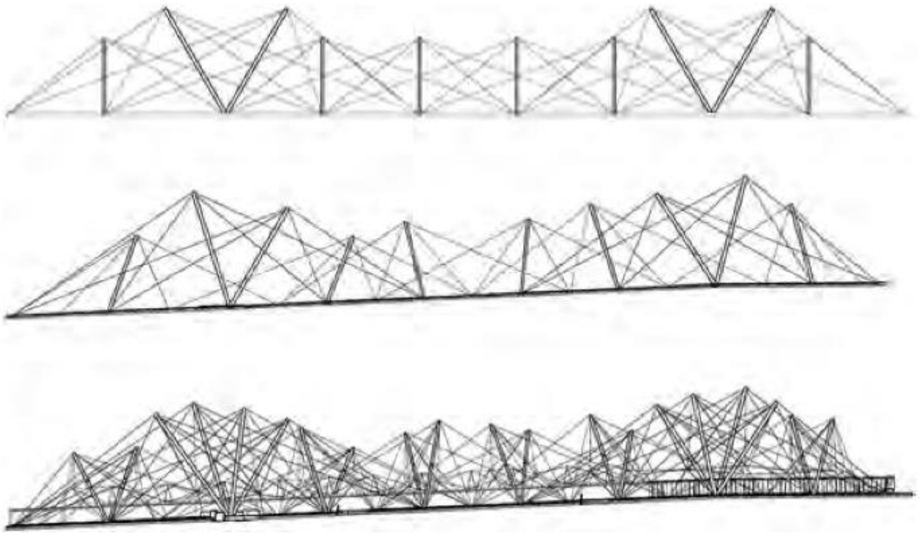
APPLICATION: STRUTS AND TIES, KURILPA BRIDGE

(SEE PHOTOGRAPHS OVER PAGE)

The Kurilpa pedestrian and cycle bridge in Brisbane, Australia, is a very large scale application of 'tensegrity' (tensional integrity), a structural idea developed by Kenneth Snelson and Buckminster Fuller in the 1940's and '50's. Major and minor masts (steel tubes up to 30 m × 905 mm × 19.1 mm wall thickness) are offset from the perpendicular both longitudinally and transversely. The 'flying spars' are pure tensegrity elements and introduce further apparent randomness into the structure. The main cables are spiral wound galvanised wire rope 30–80 mm diameter. The cable system serves to suspend the deck and canopy, stabilise the masts, and resist twisting and lateral movements of the superstructure.

Wind tunnel studies were carried out to check the system's aeroelastic stability. Three 3.2 tonne tuned mass dampers are suspended under the main span of the deck to control the risk of 'synchronous lateral excitation' from large crowds of pedestrians. Fittingly, the bridge provides a major access way to the Queensland Gallery of Modern Art, on the Brisbane South Bank.

Project: Kurilpa Bridge, Brisbane, Queensland, Australia; Architect: Cox Rayner Architects; Structural Engineer: Arup; Contractor: Baulderstone; Photos: David Sandison



Normal stress

A stress can be classified according to the internal reaction that produces it. As shown in Figures 5.8 and 5.9, axial tensile or compressive forces produce tensile or compressive stress, respectively. This type of stress is classified as a *normal stress*, because the stressed surface is normal (perpendicular) to the load direction.

The stressed area *a-a*, is perpendicular to the load.

In normal compressive stress,

$$f_c = \frac{P}{A}$$

where

P = applied load
A = resisting surface normal (perpendicular) to P

In normal tensile stress,

$$f_t = \frac{P}{A}$$

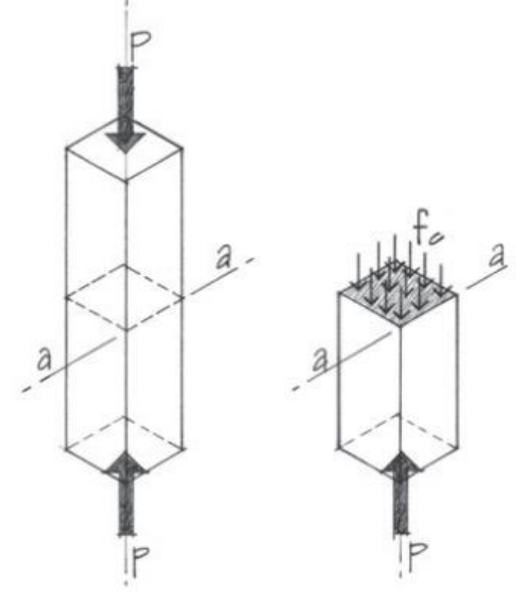


Figure 5.8 Normal compressive stress across section a-a.

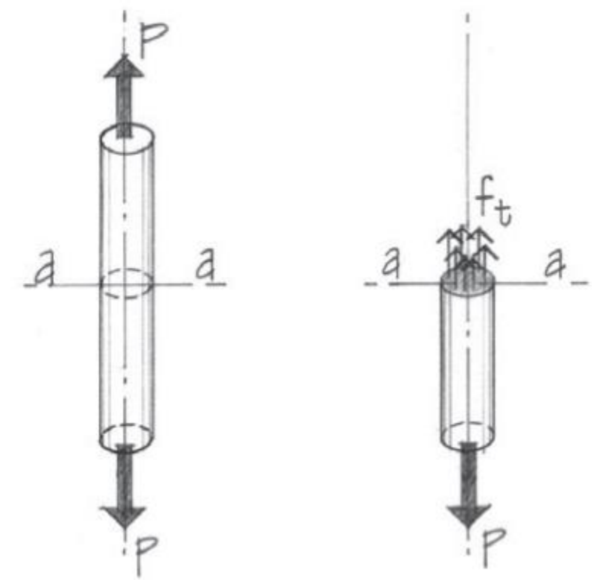


Figure 5.9 Normal tensile stress through section a-a.

Bearing stress

The third fundamental type of stress, *bearing stress* (Figure 5.13), is actually a type of normal stress, but it represents the intensity of force between a body and another body (i.e., the contact between beam and column, column and footing, footing and ground). The stressed surface is perpendicular to the direction of the applied load, the same as normal stress. Like the previous two stresses, the average bearing stress is defined in terms of a force per unit area

$$f_p = \frac{P}{A}$$

where

f_p = unit-bearing stress (psi, ksi, or psf; N/mm^2 or N/m^2)

P = applied load (# or k, N or kN)

A = bearing contact area ($in.^2$ or $ft.^2$, mm^2 or m^2)

Both the column and footing may be assumed to be separate structural members, and the bearing surface is the contact area between them. There also exists a bearing surface between the footing and the ground.

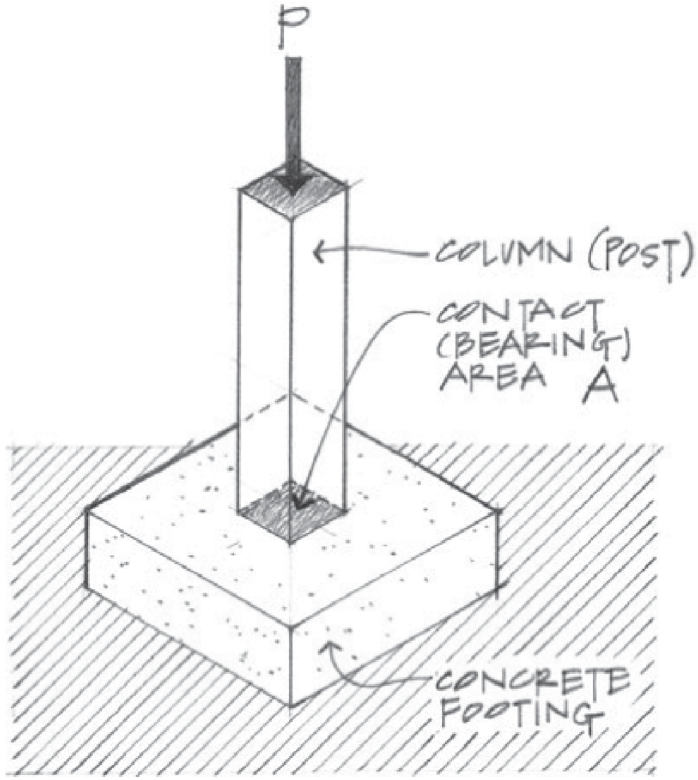


Figure 5.13 Bearing stress—post/footing/ground.

NORMAL STRAIN UNDER AXIAL LOADING

$$\epsilon = \frac{\delta}{L}$$

L: original length
δ: elongation
ε: strain

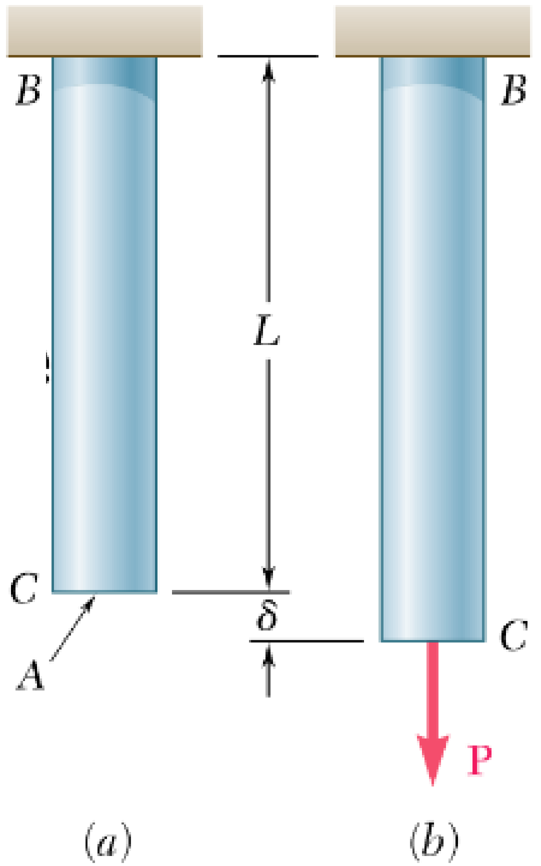


Fig. 2.1 Deformation of axially-loaded rod.

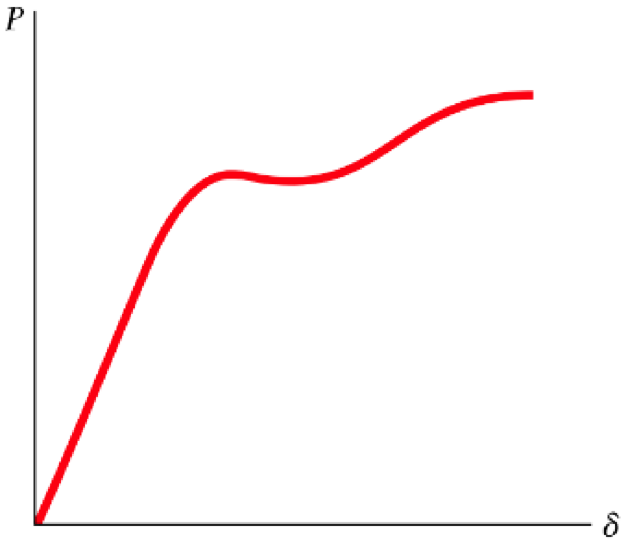


Fig. 2.2 Load-deformation diagram.

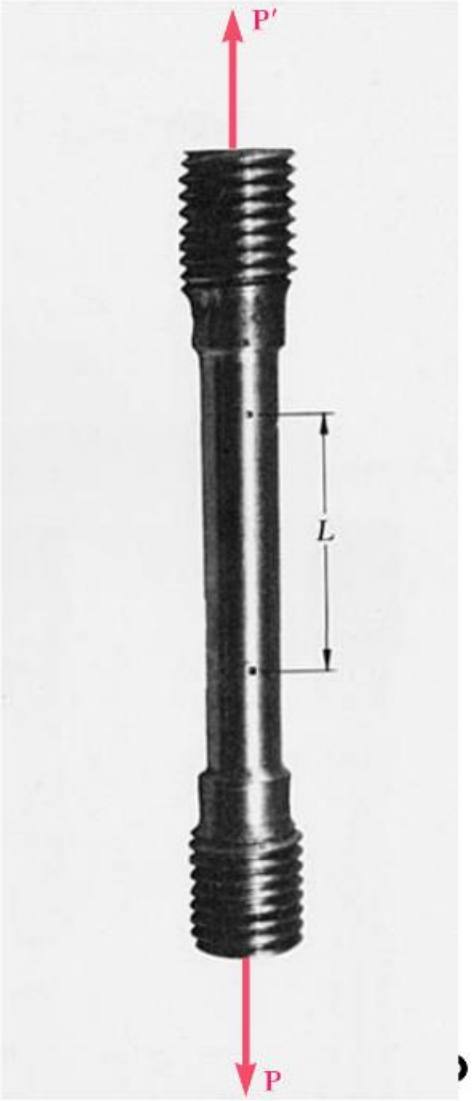


Photo 2.3 Test specimen with tensile load.

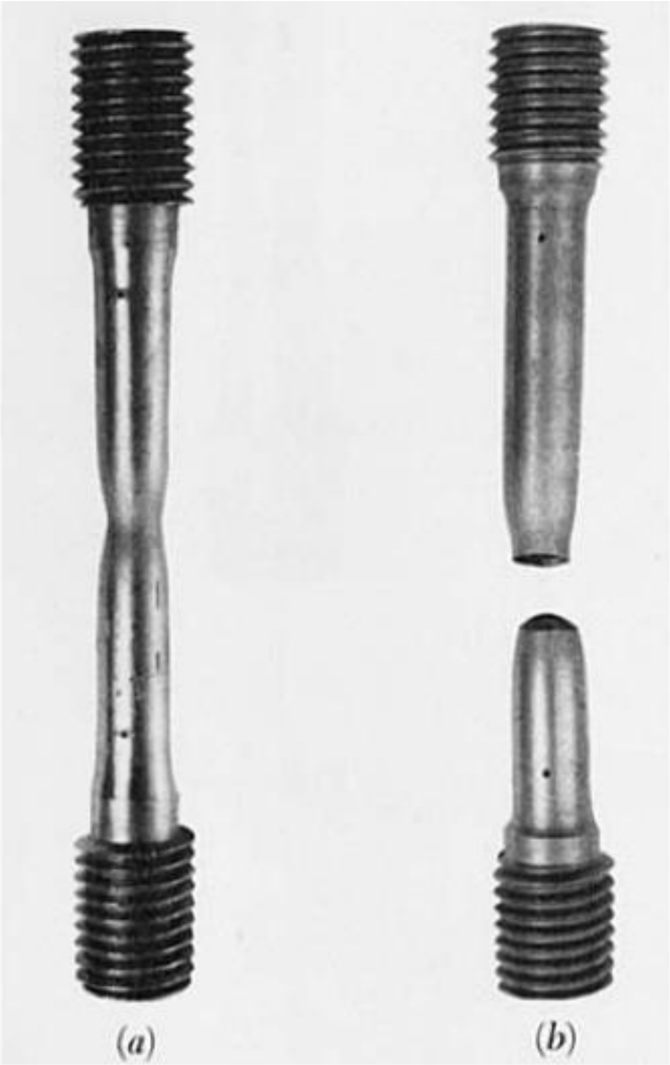


Photo 2.4 Tested specimen of a ductile material.

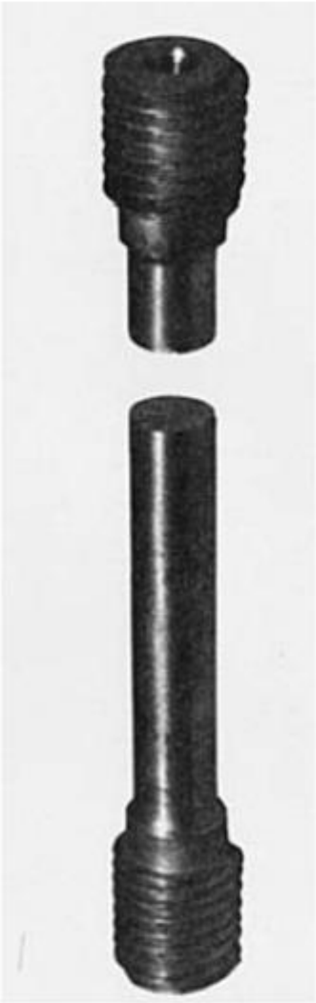


Photo 2.5 Tested specimen of a brittle material.

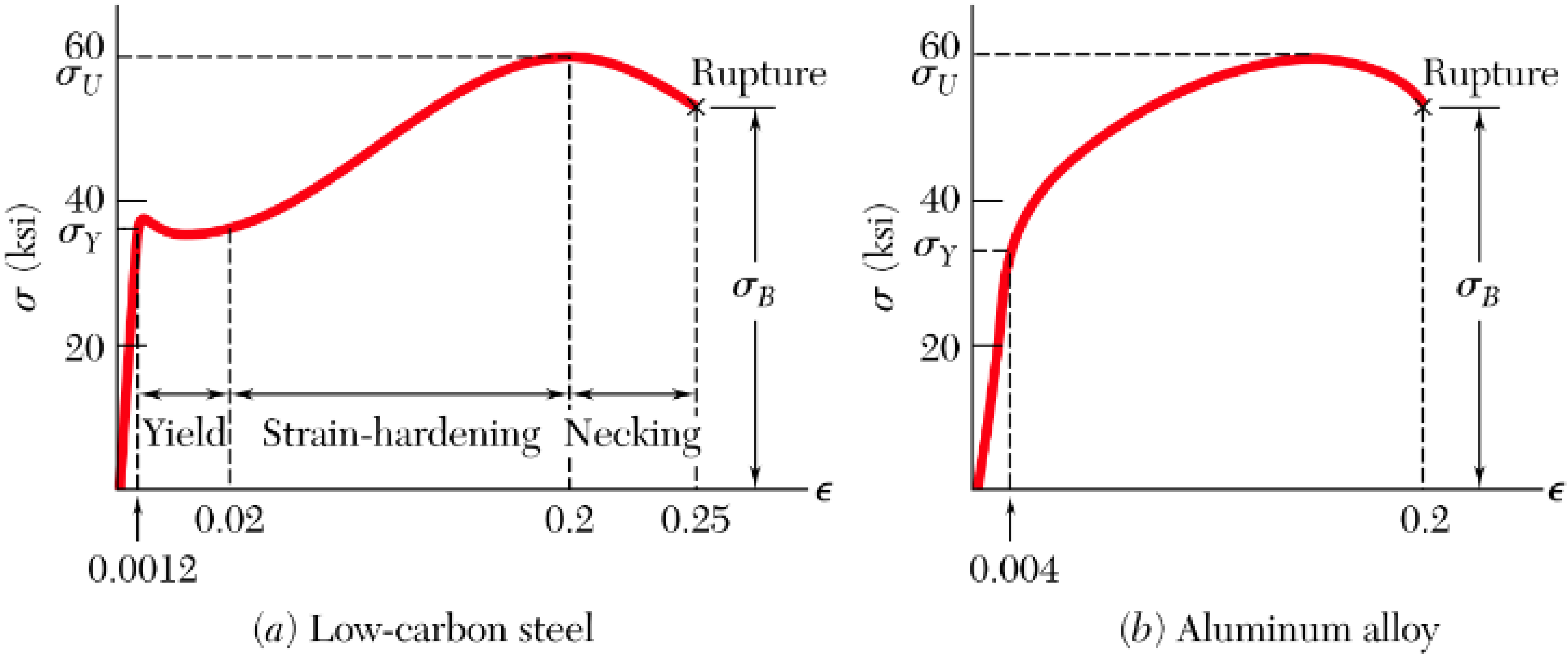


Fig. 2.6 Stress-strain diagrams of two typical ductile materials.

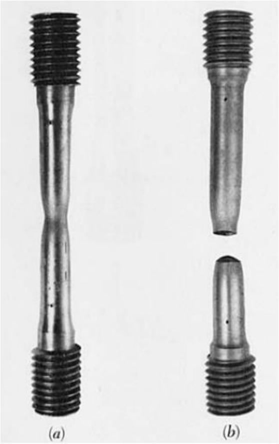


Photo 2.4 Tested specimen of a ductile material.

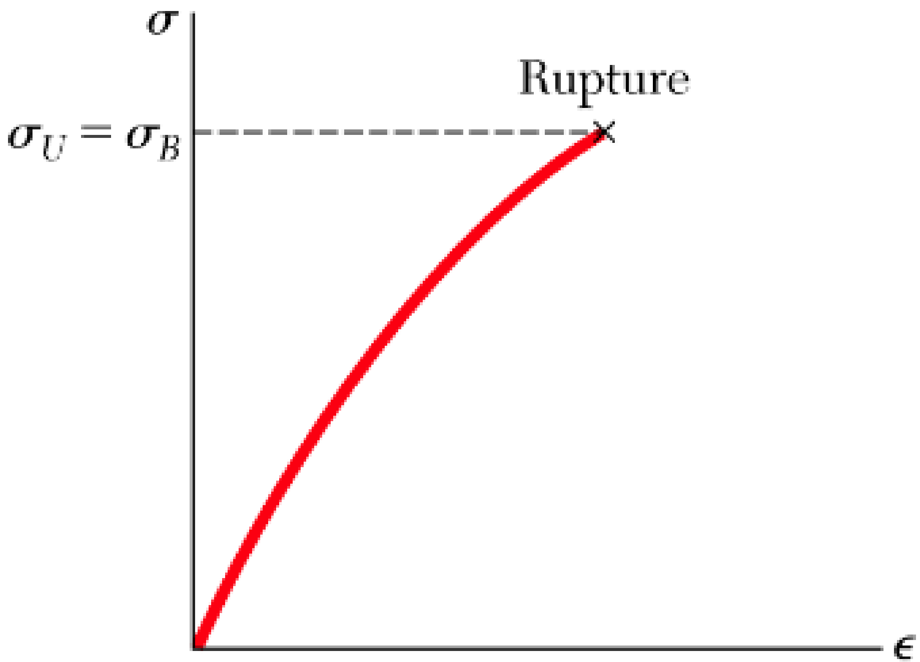


Fig. 2.7 Stress-strain diagram for a typical brittle material.

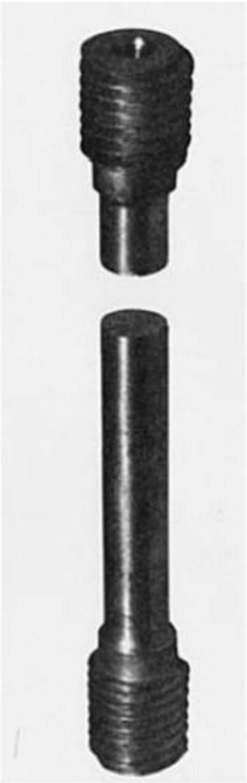


Photo 2.5 Tested specimen of a brittle material.

DEFORMATIONS OF MEMBERS UNDER AXIAL LOADING

Consider a homogeneous rod BC of length L and uniform cross section of area A subjected to a centric axial load **P** (Fig. 2.17). If the resulting axial stress $\sigma = P/A$ does not exceed the proportional limit of the material, we may apply Hooke's law and write

$$\sigma = E\epsilon \qquad (2.4)$$

from which it follows that

$$\epsilon = \frac{\sigma}{E} = \frac{P}{AE} \qquad (2.5)$$

Recalling that the strain ϵ was defined in Sec. 2.2 as $\epsilon = \delta/L$, we have

$$\delta = \epsilon L \qquad (2.6)$$

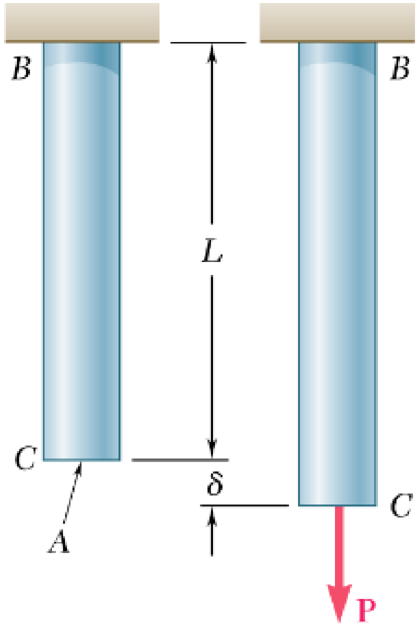


Fig. 2.17 Deformation of axially loaded rod.

and, substituting for ϵ from (2.5) into (2.6):

$$\delta = \frac{PL}{AE} \qquad (2.7)$$

STATICALLY INDETERMINATE MEMBERS

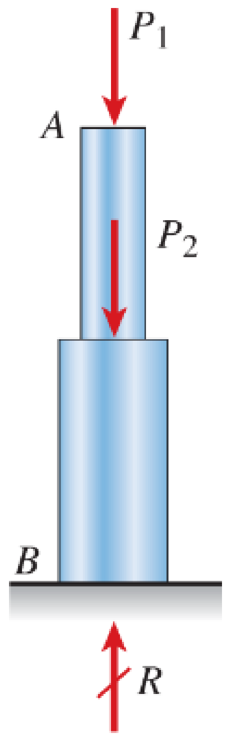


FIG. 2-14 Statically determinate bar

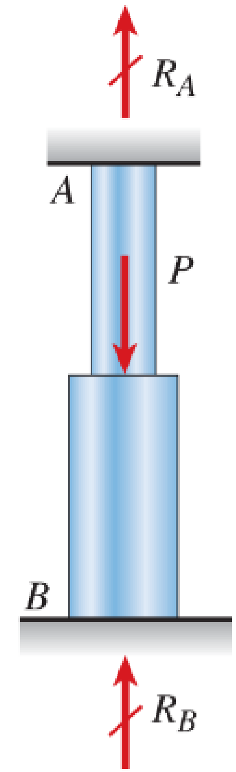


FIG. 2-15 Statically indeterminate bar

point C. As already discussed, the reactions R_A and R_B cannot be found by statics alone, because only one **equation of equilibrium** is available:

$$\sum F_{vert} = 0 \qquad R_A - P + R_B = 0 \tag{a}$$

STATICALLY INDETERMINATE MEMBERS

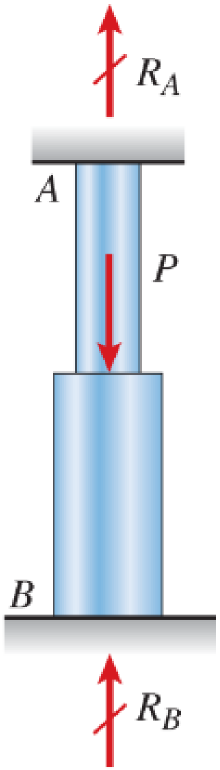


FIG. 2-15 Statically indeterminate bar

As already discussed, the reactions R_A and R_B cannot be found by statics alone, because only one **equation of equilibrium** is available:

$$\sum F_{vert} = 0 \qquad R_A - P + R_B = 0 \tag{a}$$

$$\delta_{AB} = 0 \tag{b}$$

This equation, called an **equation of compatibility**, expresses the fact that the change in length of the bar must be compatible with the conditions at the supports.