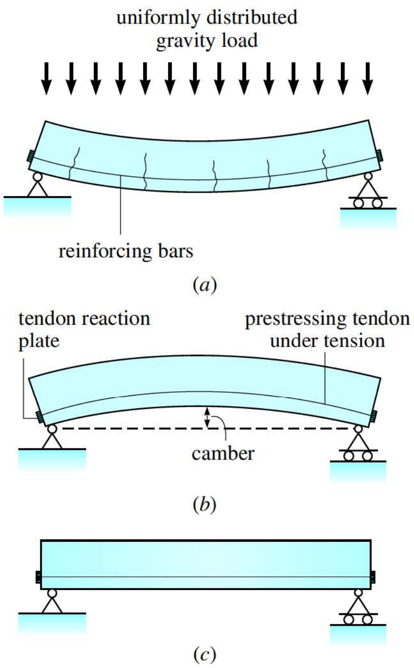

Figure 1.4: (*a*) Reinforced concrete beams utilize steel reinforcing bars to carry tensile bending stress, but small cracks will still occur; (*b*) a prestress concrete beam is provided with an axial compressive load using a tensioned steel cable, or tendon, before gravity loads are applied. Depending on the location of the tendon along the cross section, a camber, or initial upward beam deflection, may be introduced; (*c*) upon loading, the prestressed beam still undergoes tensile bending stress, but the prestressing compressive load counteracts it. Meanwhile, the beam experiences a reduced net downward deflection due to the cambering.

reinforced concrete systems are, nowadays, commonly *prestressed*. This construction method is used to overcome concrete's lack of tensile strength by including high-strength steel cables, or tendons, inside the structural members (Figure 1.4). After the concrete is cured, the tendons are tensioned and each end is fixed to the outside, creating a compressive stress on the concrete. This initial compressive stress is strategically located along the cross section and along the beam by the placement of the tendons. In Figure 1.4*b* the tendon is located on the bottom of the cross section to counteract the tensile bending stress caused by the uniform gravity loading (shown in Figure 1.4*c*). Afterward, the beam deflection is greatly reduced (Figure 1.4*c*). Prestressing allows engineers to design very thin slabs and long-span beams for building and bridge applications.

Until improved methods of indeterminate analysis enabled designers to predict the internal forces in reinforced concrete construction, design remained semi-empirical; that is, simplified computations were based on observed behavior and testing as well as on the principles of mechanics. With the introduction in the early 1930s of *moment distribution* by Hardy Cross, engineers acquired a relatively simple technique to analyze continuous structures. As designers became familiar with moment distribution, they were able to analyze indeterminate frames, and the use of reinforced concrete as a building material increased rapidly.

The introduction of welding in the late nineteenth century facilitated the joining of steel members—welding eliminated heavy plates and angles required by earlier riveting methods—and simplified the construction of rigid-jointed steel frames.

In recent years, the computer and research in materials science have produced major changes in the engineer's ability to construct special-purpose structures, such as space vehicles. The introduction of the computer and the subsequent development of the direct stiffness method for beams, plates, and shell elements permitted designers to analyze many complex structures rapidly and accurately. Structures that even in the 1950s took teams of engineers months to analyze can now be analyzed more accurately in minutes by one designer using a computer.

1.5 Basic Structural Elements

All structural systems are composed of a number of basic structural elements—beams, columns, hangers, trusses, and so forth. In this section we describe the main characteristics of these basic elements so that you will understand how to use them most effectively.

Hangers, Suspension Cables—Axially Loaded Members in Tension

Since all cross sections of axially loaded members are uniformly stressed, the material is used at optimum efficiency. The capacity of tension members is a direct function of the tensile strength of the material. When members are