Chapter 1　Overview

1

1.1　Objectives and Tasks of Structural Mechanics

The part of a building or a structure responsible for bearing loads and serving as a framework is referred to as an engineering structure, or simply a structure. Figure 1-1 (a) shows a simply supported beam as an example, and Figure 1-1 (b) depicts a cantilever beam, which is another type of structure.

1.1.1　Classification of Structures

1.1

From a geometric perspective, structures can be classified into three categories: framed structures, shell structures, and solid structures.

1. Framed Structures

Framed structures consist of members where one dimension (length) is much greater than the other two dimensions (width, and height). Examples of framed structures include beams and columns (Figure 1-2).

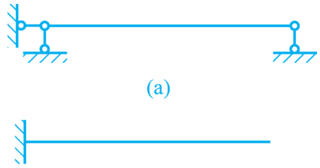


Figure 1-1

(a) simply supported beam; (b) cantilever beam

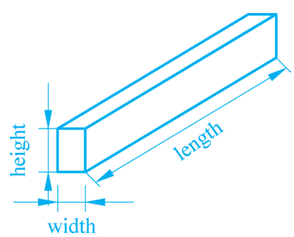


Figure 1-2

2. Shell Structures

Shell structures have one dimension (thickness) much smaller than the other two dimensions (length, and width). Both plates and shells belong to the shell structures, as shown in Figures 1-3 (a) and (b).

3. Solid Structures

Solid structures are characterized by all three dimensions of comparable magnitude. Examples of solid structures include dams (Figure 1-4) and retaining walls, which belong to the category of solid structures.

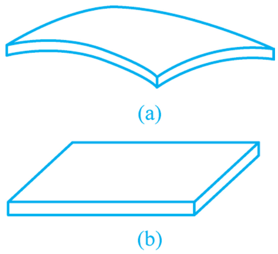


Figure 1-3

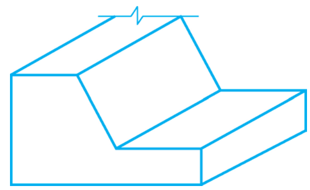


Figure 1-4

1.1.2 Objectives and Tasks of Structural Mechanics

The objectives and tasks of structural mechanics include studying the principles and methods for calculating the strength, stiffness, and stability of framed structures.

1.1.3 Relationship Between Structural Mechanics and Other Courses

Theoretical mechanics is a scientific discipline that studies the laws governing the mechanical motion of rigid bodies.

Materials mechanics is a scientific discipline that studies the principles and methods for calculating the strength, stiffness, and stability of individual components.

Structural mechanics is a scientific discipline that examines the principles and methods for determining the strength, stiffness, and stability of framed structures, as well as the rules governing the geometric composition.

Elastic mechanics is a scientific discipline that studies the stress, strain, and displacement in deformable solids under external factors such as loads and temperature changes.

Structural mechanics is a foundational course that occupies a crucial position in the field of civil engineering. On the one hand, it is closely connected to prerequisite courses; on the other hand, it establishes the necessary foundations for subsequent courses. Structural mechanics is also a highly practical discipline. While studying it, one should not only grasp the concepts and interconnections of structural mechanics but also establish a theoretical connection with practical applications and gradually enhance analytical and computational skills.

1.2 Analytical Models of Structures

1.2

During structural calculations, the actual conditions of the structure are complex, making it impossible to fully account for all stress characteristics. Hence, to establish calculation theories and methods, it becomes necessary to disregard minor factors and concentrate on the primary ones. An analytical model of the structure, a simplified representation, is then employed for calculations.

1.2.1 Principles for Determining the Analytical Model of a Structure

(1) Reflect the stress characteristics of the actual structure as accurately as possible.

(2) The section of an analytical model for a structure should prioritize computational convenience. Choosing the appropriate analytical model is fundamental to mechanical calculations and holds significant importance. Established engineering structures often have well-developed analytical models that can be directly applied. However, for new types of structures, the designers should determine the specific analytical models.

1.2.2 Key Points of Simplification for the Analytical Model

1. Simplification of Structural Systems

Actual structures are generally space structures, but in most cases, they can be simplified into planar structures.

2. Simplification of Members

Actual members have dimensions in three directions: length, width, and height. By neglecting the influence of width and height, members can be represented by their axial lines.

3. Simplification of Joints

Joints are points where two or more members are connected.

(1) Hinged joints: These joints allow connected members to freely rotate and are referred to as hinged joints, as shown in Figure 1-5 (a). Hinged joints cannot withstand bending moments.

Figure 1-5

(2) Rigid joints: These joints, where connected members cannot rotate are referred to as rigid joints, as shown in Figure 1-5 (b). Rigid joints can withstand bending moments.

4. Simplification of Supports

Supports are devices that connect the structure to the foundation or other supports. In the analytical model of structures, supports are generally simplified into the following types:

(1) Pin supports, as shown in Figure 1-6 (a). End A of the member can freely move horizontally but cannot move vertically. It can rotate freely around point A generating reaction forces only in the vertical direction.

(2) Hinged supports, as shown in Figure 1-6 (b). End A of the member can rotate freely around point A but cannot move in the horizontal or vertical directions.

Therefore, it generates reaction forces in both horizontal and vertical directions.

(3) Fixed supports, as shown in Figure 1-6 (c). End A of the member cannot rotate around point A and cannot move in horizontal and vertical directions. It generates reaction forces in both horizontal and vertical directions and a moment that restricts the rotation of the member.

(4) Directional supports, as shown in Figure 1-6 (d). Directional supports allow the end of the member to move freely in a specific direction while restricting movement and rotation in other directions. There are no reaction forces in the direction of free movement, but there are reaction forces perpendicular to the direction of free movement and a moment that restricts the rotation of the member.

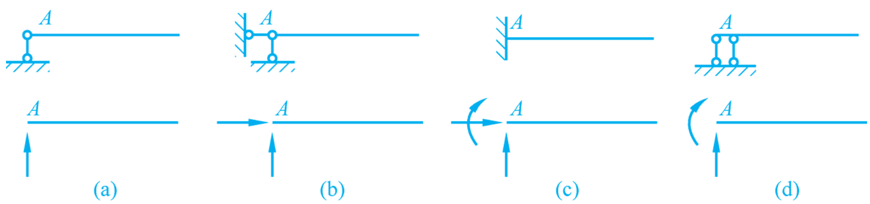


Figure 1-6

5. Simplification of Loads

When simplifying the structure by representing members with their axial lines, it is necessary to simplify the loads as forces acting along these axial lines. If the variation in load distribution is minimal, it can be simplified as a uniformly distributed load, as shown in Figure 1-7 (a). If the load is applied within a small area relative to the size of the structure, it can be simplified as a concentrated load, as shown in Figure 1-7 (b).

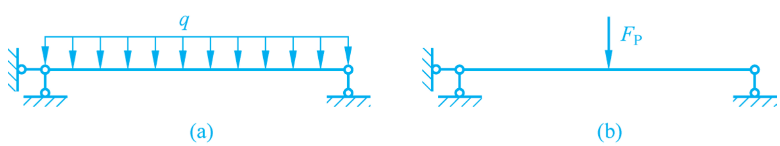


Figure 1-7

Example 1-1

Choose the column-end support for the industrial plant shown in Figure 1-8 (a) and establish an analytical model of the structure.

Due to the firm soil and the extensive foundation, the column is embedded in a cup-shaped foundation and filled with fine aggregate concrete at the mouth of the cup. Consequently, the analytical model of the structure for the connection between the column and the cup-shaped foundation can be considered as a fixed support [Figure 1-8 (b)]. This is because the cup-shaped foundation and the column exhibit minimal linear displacement and rotation, enabling the column to withstand greater bending moments. If asphalt felt is employed to fill the mouth of the cup, the analytical model for the connection between the column and the cup-shaped foundation can be regarded as a hinged support [Figure 1-8 (c)]. This is due to the relatively low restraining force of the asphalt felt on the rotation of the column end.

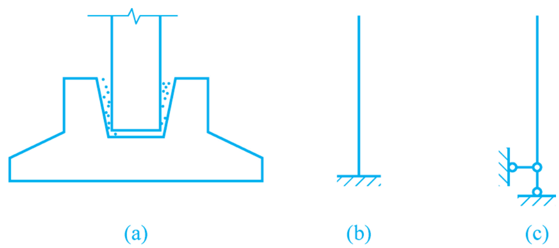


Figure 1-8

Example 1-2

Choose the crane beam in the industrial plant shown in Figure 1-9 (a) and establish an analytical model for calculation.

Figure 1-9 (a) shows a type of crane beam used in industrial plants, consisting of a reinforced concrete crossbeam *AB* and a vertical rod *CD*. However, the cross-sectional area of the vertical rod *CD* is significantly smaller than that of the beam *AB*. The diagonal rods *AD* and *BD* are constructed from manganese steel, and the crane beam's ends are supported by embedded steel plates on the plant's columns.

(1) Simplification of supports: Given that the ends of the crane beam are welded to the embedded steel plates on the columns with short weld lengths, this connection type provides limited constraint on the rotation of the crane beam ends. Considering the stress characteristics of the beam and the principle of computational convenience for the analytical model, the beam can be simplified as a simply supported beam with one end as a hinged support and the other end as a pin support.

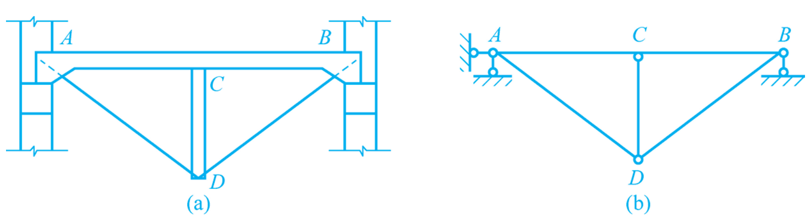


Figure 1-9

(2) Simplification of joints: Given that beam AB is a solid reinforced concrete beam with a larger cross-sectional area compared to members *CD*, *AD*, and *BD*, which primarily carry axial forces. Joints *A*, *D*, and *B* can be simplified as hinges. Joint *C* can be simplified as a semi-hinge because beam *AB* is continuous at point *C*, while the member *CD* is hinged at point *C*.

By representing the members with their axial lines, the analytical model for the structure is shown in Figure 1-9 (b), where *A*, *B*, and *D* are hinged joints, and *C* is a semi-hinge joint. This analytical model reflects the primary load-carrying characteristics (bending moment, shear force, axial force) of the main member *AB*. For the structure, the primary internal forces (axial forces) in members *AD*, *CD*, and *DB* are retained, while the influence of bending moment and shear force is neglected. Regarding the supports, the primary internal force (vertical support force) is retained while the rotational constraint is ignored. Practical experience has shown that this analytical model is reasonable as it reflects the primary deformation and load characteristics of the structure and is convenient for calculations.

1.3

1.3 Classification of Structures

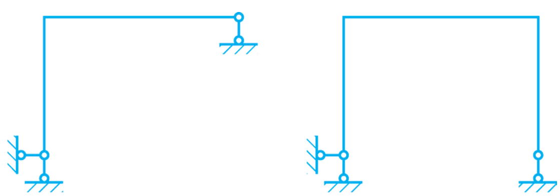
1.3.1 Beam

A beam is a bending member (Figure 1-10).

Figure 1-10

1.3.2 Rigid Frame

A structure composed of straight members, with predominantly rigid joints, is called a rigid frame [Figures 1-11 (a) and (b)].



(a) (b)

Figure 1-11

1.3.3 Arch

A curved structure that generates horizontal thrust under vertical loads is known as an arch (Figure 1-12).

1.3.4 Truss

A structure composed of axial members connected by ideal hinges at both ends is known as a truss (Figure 1-13). When loads are applied to the joints, the members only experience axial forces.

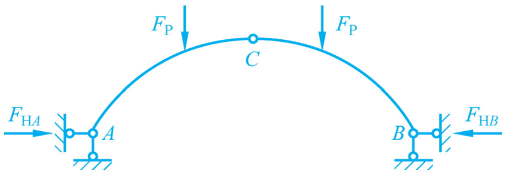


Figure 1-12

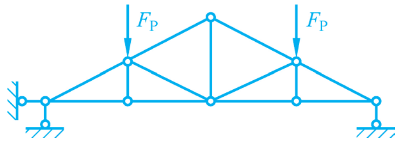


Figure 1-13

1.3.5 Mixed Structure

A mixed structure, shown in Figure 1-14, consists of both beam-type members and axial members. Besides the mentioned classifications, framed structures can be further categorized into statically determinate structures and statically indeterminate structures based on their computational characteristics. A structure in which all support reactions and internal forces can be determined using equilibrium equations is termed a statically determinate structure [Figure 1-15 (a)]. A structure in which equilibrium equations alone cannot determine all support reactions and internal forces is known as a statically indeterminate structure [Figure 1-15 (b)].

Figure 1-14

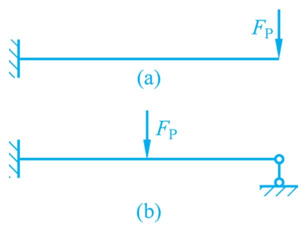


Figure 1-15

1.4 Classification of Loads

1.4

1.4.1 Classification Based on the Duration of Load Application

Loads acting on a structure can be classified based on the duration of their application as dead loads and live loads. Live loads can further be classified as stationary loads and moving loads.

(1) Dead load: Dead load refers to a load that permanently acts on the structure without any change in magnitude or position. Examples include self-weight.

(2) Live load: Live load refers to a load that temporarily acts on the structure. Examples include wind load, snow load, crowd load, and crane load.

(3) Stationary load: Stationary load refers to a load that can occupy any position on the structure. Examples include wind load and snow load.

(4) Moving load: Moving load refers to a series of parallel loads with constant

spacing that can move on the structure. An example is a crane load.

1.4.2 Classification Based on the Nature of Load Application

Based on the nature of load application, loads can be classified as static loads and dynamic loads.

(1) Static load: Static load refers to a load where the magnitude, direction, and position do not change with time or change slowly. It does not cause significant vibration in the structure, and inertial forces can be neglected during calculations.

(2) Dynamic load: Dynamic load refers to a load where the magnitude, direction, and position change with time, causing significant vibration in the structure. Inertial forces cannot be neglected during calculations.

It is important to note that factors such as temperature changes, support movements, and material shrinkage can also induce internal forces in the structure during the analysis of statically indeterminate structures. These internal forces can sometimes be significant and should not be neglected in structural design.

Chapter 2 Geometric Construction Analysis of Planer System

2

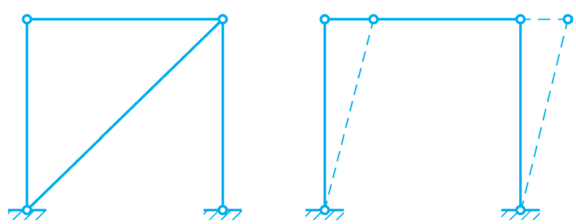
Geometric construction analysis is also known as geometric composition analysis or kinematic analysis. In engineering structures, the geometric shape and spatial position are needed to be stable when the structures are subjected to various loads. If the geometric shape of the structure is unstable, it cannot resist any load. Therefore, from the perspective of geometric construction, a structure should be geometrically stable, and this type of structure is referred to a geometrically stable system. Conversely, it is called a geometrically unstable system.

2.1 Basic Concepts in Geometric Construction Analysis

2.1.1 Geometrically Stable and Unstable Variant Systems

2.1.1

A geometrically stable system refers to a system, in which the shape of the structure and the relative positions of its members remain unchanged under the action of any load, when the material strains are neglected. Figure 2-1 (a) shows a geometrically stable system.



(a) (b)

Figure 2-1

A geometrically unstable system refers to a system, in which either the shape of the structure or the relative positions of its members are changed under the action of any load, when the material strains are neglected. The system as shown in Figure 2-1 (b) is unstable as the parallelogram system is an unstable shape.

The main objective of geometric construction analysis is to determine whether a system is a geometrically stable system. Based on this, the system is determined whether it is suitability for use as a structure.

2.1.2

2. 1. 2 Degrees of Freedom

Degrees of freedom are the numbers of independent coordinate parameters which are required to determine the position of a system. In Figure 2-2 (a), point A in a plane can be determined by two independent coordinates. Hence, a point in a plane possesses two degrees of freedom. In Figure 2-2 (b), a rigid body AB in a plane can be determined by three independent coordinates. Hence, a rigid body in a plane possesses three degrees of freedom.

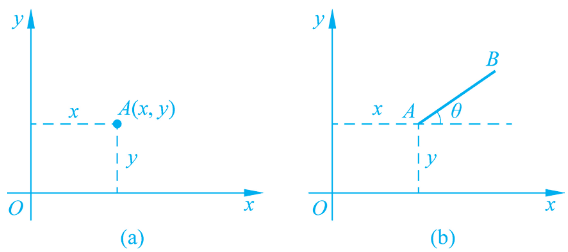


Figure 2-2

2.1.3

2. 1. 3 Restraints

Restraints, also named connections, are devices which can reduce the degrees of freedom. They exist between members of a system or between the system and its foundation. If a device or connection reduces one degree of freedom, it is called a single restraint. If devices or connections reduce two degrees of freedom, it is called a double restraint. The common restraints include links, hinges, and rigid connections (also known as rigid joints).

A link is equivalent to a single restraint as shown in Figure 2-3 (a).

A hinge is equivalent to two restraints as shown in Figure 2-3 (b).

A rigid joint is equivalent to three restraints as shown in Figure 2-3 (c).

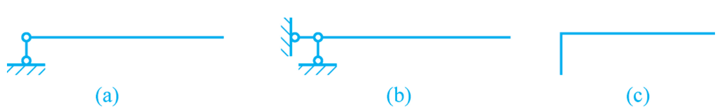


Figure 2-3

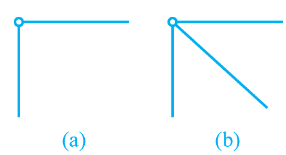


Figure 2-4

Restraints can be further classified as single restraints and multiple restraints. The connection of two rigid bodies is called a single restraint, while the connection of three rigid bodies is equivalent to two single restraints. The connection of more than three rigid bodies is called a multiple restraint. In general, a multiple hinge of n rigid bodies is equivalent to (n-1) single hinges. Figure 2-4 (a) is a single restraint, while Figure 2-4 (b) is a multiple restraint.