普通高等教育“十一五”国家级规划教材

Structural Mechanics

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内容简介

本书是根据中国高等学校土木工程专业的教学计划、结构力学课程的教学大纲和课程基本要求，为中国高等学校土木工程专业结构力学课程“双语教学”编写的英文结构力学教材。全书共分14章，包括：绪论，结构的几何组成分析，静定梁，静定刚架，三铰拱，静定桁架和组合结构，静定结构总论，影响线，虚功原理和结构的位移，力法，位移法，渐进法和超静定结构的影响线，矩阵位移法和超静定结构总论。除第一章外，每章均有提要、小结、思考题和习题，书后附有答案。

本书与第一作者主编的中文结构力学(参考文献1)在章节次序和内容上基本上是对应的，便于中文与英文教学中交互使用。

本书可作为土木工程专业，即“大土木”的房建、路桥、水利等各类专门化方向的“双语”教材及参考用书，也可供工程技术人员学习专业外语之用。

Brief Introduction of the Book

The textbook, written in terms of the national education program, syllabus and requirement of the course—Structural Mechanics—for the undergraduates majoring in civil engineering in China, is intend to be a sort of bilingually teaching material. It includes 14 chapters, which are: introduction, geometric construction analysis of structures, statically determinate beams, plane statically determinate rigid frames, three-hinged arches, plane statically determinate trusses and composite structures, general remarks on statically determinate structures, influence lines, principle of virtual work and displacement of structures, force method, displacement method, method of successive approximations and influence lines for indeterminate structures, matrix displacement method, and general remarks on statically indeterminate structures. All chapters except for chapter 1 are arranged by abstract, text, summary, problems for reflecting, and problems for solution; the answers to selected problems are attached to the back as well.

It should be pointed out that the arrangement of the content and the order of the chapters for the book is almost the same as its Chinese counterpart (bibliography 1), so as to give an alternant usage for Chinese readers and teachers.

The book can be not only used as a textbook and/or reference book for the students majoring in civil engineering structures, but also employed as a specialized English book for the engineer and technicians interested in civil engineering and English.

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CHAPTER 1
INTRODUCTION

Abstract of the chapter

The chapter will introduce four questions such as the objective and learning method of structural mechanics, the analytical models of structures, the classification of framed structures and their loads. Among the four questions, the analytical models are the most significant since they will lay the foundations of the other chapters of the book.

1.1 Structures and Their Classification

In civil engineering project, the generic term *an engineering structure* or briefly named a structure is referred to as a frame or skeleton used to carry loads applied on it and composed by members of buildings or other constructions made of construction materials. The following figures show some photographs of engineering structures. Figure 1.1 is a tall building suspended structure, Fig. 1.2 is a bridge structure, Fig. 1.3 is the structure of a hydraulic power station, Fig. 1.4 is the structure of an industrial premises. Speaking in detail, the roof panel, the roof truss, the beams, the columns, the foundation and their combination of the one-storey workshop of a plant shown in Fig. 1.18 are all structures.

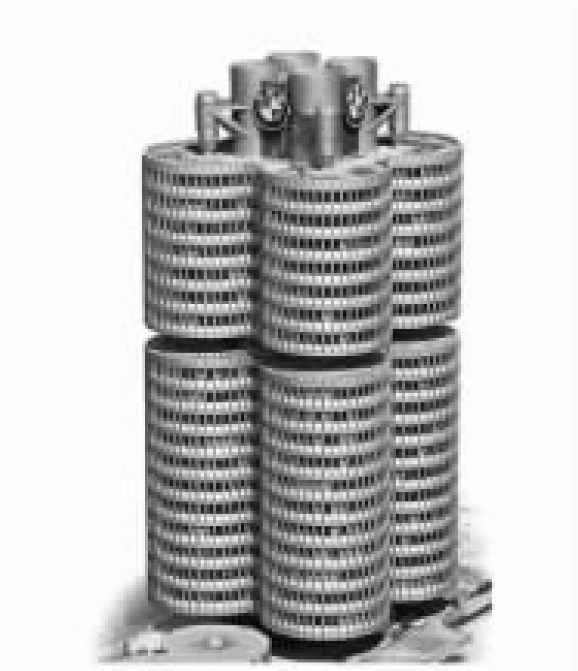

Fig. 1.1 Tall building suspended structure

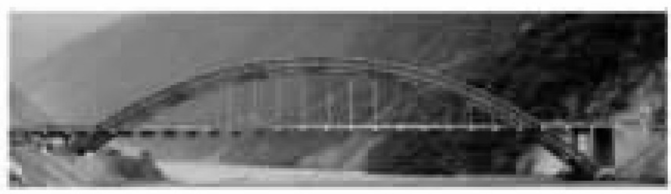

Fig. 1.2 Bridge structure

Fig. 1.3 Hydraulic power station

Fig. 1.4 Industrial premises

Structures can be classified into three categories by their geometric characteristics.

(1) Framed structure

A framed structure is comprised of members whose cross-sectional dimension (e. g. the width b and depth h of a rectangular cross section, the radius of a circular cross section, etc.) is much smaller than the length l as shown in Fig. 1. 5. The most commonly used types of structures in the structural engineering are framed structures which will be the main attention the book focuses on.

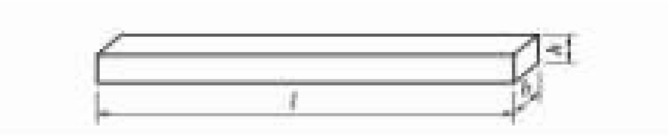

Fig. 1. 5 Bar

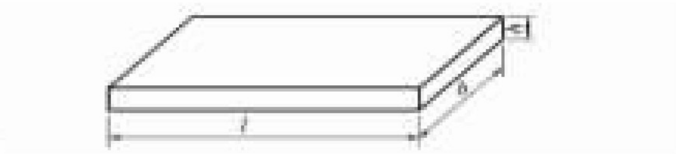

Fig. 1. 6 Plate

(2) Plate, slab and shell (or thin-walled structure)

When the thickness of the structure is very small in comparison with its other two dimensions (length and width), the structure is referred to as a thin-walled structure. The geometric characteristic of a thin-walled structure is that its thickness h is much smaller than its length l and width b. The plate shown in Fig. 1. 6 is one of instances of thin-walled structures. The combination of finite number of plates would develop a floded plate shown as in Fig. 1. 7 (a). Figure 1. 7 (b) shows a building with a roof structure composed of floded plates. If a structure has a curved middle surface, it is called a shell, as shown in Fig. 1. 8. In that context, a plate or a slab can be considered as a thin-walled structure with a plane middle surface.

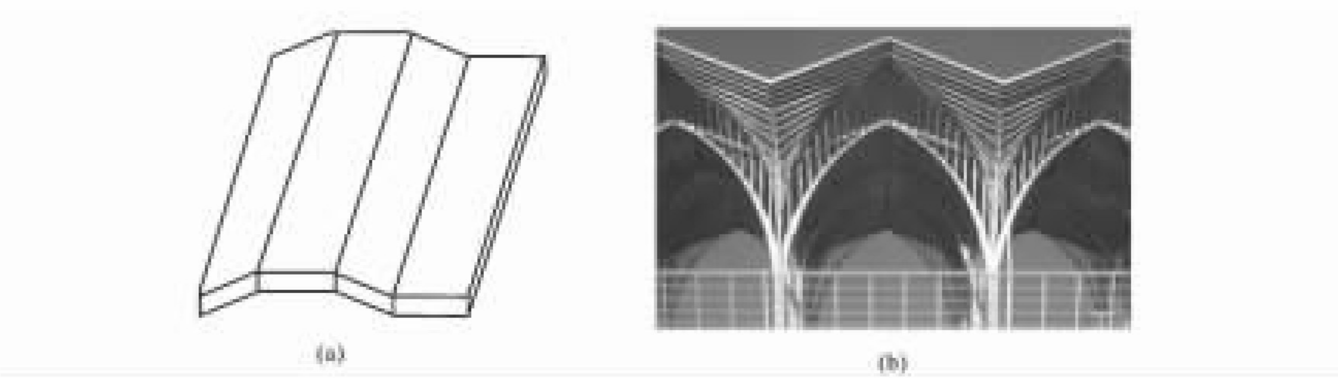

Fig. 1. 7 Floded plate structure

(a) floded plate; (b) floded plate roof

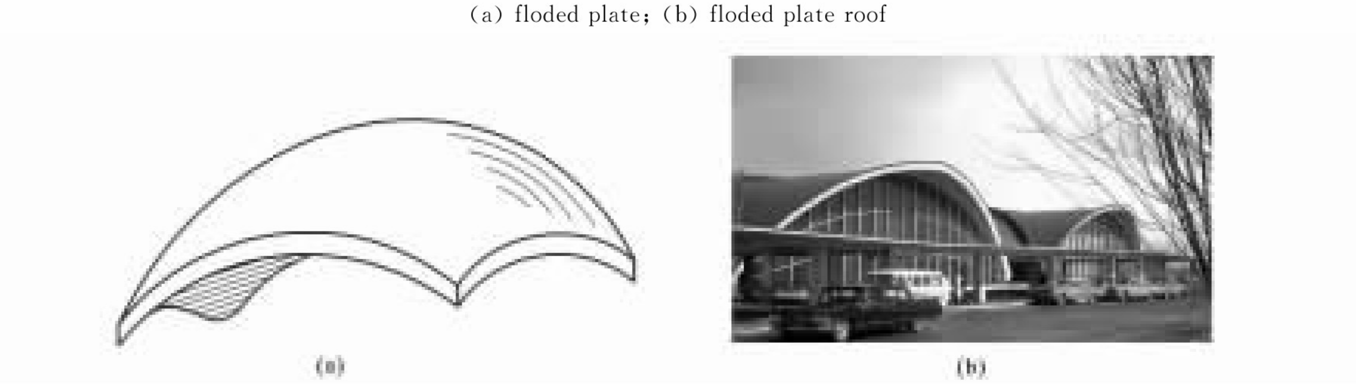

Fig. 1. 8 Shell structure

(a) shell; (b) shell roof

(3) Massive structure

The three dimensions (length l, width b and depth h) of a massive structure have the same order of magnitude. Consider, for example, the retaining wall shown in Fig. 1.9 and the dam shown in Fig. 1.10 are two of projects applying massive structures.

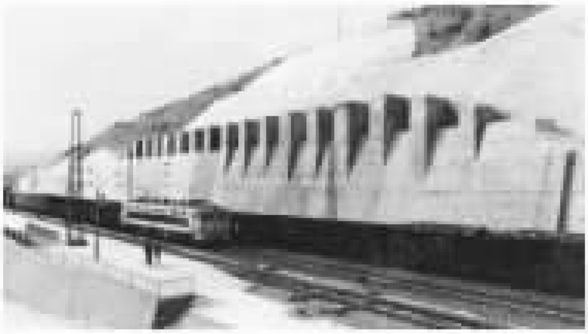

Fig. 1.9 Retaining wall

Fig. 1.10 Dam

1.2 Objective and Learning Method of Structural Mechanics

1.2.1 The relationship between Structural Mechanics and other curricula

In Structural Mechanics, the primary focus will be on the analysis of the structure. In this context, you can name the course as Mechanics of Framed Structure. For simplicity, Structural Mechanics is adopted.

Structural Mechanics belongs to one of technically fundamental courses, plays a very important role and is a connecting link between the preceding courses and the following (or subsequent) courses learned by the undergraduates majoring in the specialty pertinent to civil engineering.

Structural Mechanics is the following course of Theoretical Mechanics and Strength of Materials. The objective of Theoretical Mechanics is the investigation of essential rules and analysis of mechanical motion (including static state and equilibrium) of rigid bodies. The attention paid by Strength of Materials is the strength, stiffness and stability of a single member (or a bar). While the contents treated of in Structural Mechanics are the strength, stiffness and stability of framed structures, which are composed of many members. Therefore, Theoretical Mechanics and Strength of Materials would provide primary principles and basement of mechanical analysis for the studying of Structural Mechanics.

Structural Mechanics is meanwhile the preceding course of Theory of Elasticity (focusing on the strength, stiffness and stability of plate, shell and massive structures), Reinforced Concrete Design, Masonry Structure, Steel Structure and other specialized curricula associated with building construction, structural engineering, highway engineering, bridge engineering, water conservancy engineering and underground engineering. By this token, Structural Mechanics will provide basic mechanical knowledge for the studying of the subsequent courses and play a very important role in the specialty pertinent to civil engineering.

1.2.2 Objective and learning method of Structural Mechanics

The objective of Structural Mechanics comprises following aspects:

(1) Discuss principles for constructing structures, rational configurations of structures and selections of computing models for analyzing structures;

(2) Investigate the methods for analyzing internal forces and displacements of structures so as to check their strength and stiffness;

(3) Study structural stability and structural response induced by dynamic loading.

The analyzing problems involved in Structural Mechanics can be classified into two categories: the first category is statically determinate problems, which can be solved by means of force equilibrium conditions, the first fundamental condition listed in next paragraph; the second category is statically indeterminate problems, which can be figured out only by satisfying all of the following three types of fundamental conditions. The three types of fundamental conditions are:

(1) **Force equilibrium conditions** The entire structure or part of it must be balanced under the action of a system of forces.

(2) **Compatibility conditions or geometrical conditions of displacements** The continuity of a structure must be maintained after the structure has deformed under the action of the loadings applied on it. That is, there are no overlap and gap existing in the materials composing the structure, and meanwhile the deformation and displacement of the structure should satisfy the restraint conditions provided by the supports and the connecting joints.

(3) **Physical conditions** This is the physical performance condition linking stress and strain or forces and displacements yielding in a structure, i.e. physical or constitutive equation.

The all analyzing methods formulated in Structural Mechanics are permeated by aforementioned three types of fundamental conditions, i.e. every analyzing method discussed in the course has to utilize the three conditions in some kinds of degree and order.

During studying the course, we should focus our attention on the relationship between Structural Mechanics and other curricula. A necessary review about the knowledge associated with Theoretical Mechanics and Strength of Materials should be taken and the knowledge also should be consolidated and advanced during the study.

In the process of studying the course, we have to pay attention to the learning method and clue of solving problems. All of the analyzing methods discussed in the book are the concrete application of above-mentioned three types of fundamental conditions. How the three types of conditions are applied to the computing process of every analyzing method is the point we should focus on. During studying the course, the clues of solving problems must be mastered, especially the general method of analyzing problems should be held. For instance, the method of passing through known field to unknown field; the method of partitioning the entire structure into elements then integrating them into the very beginning structure; the method of contrasting pertinent problems between which some sort of relationship exist in some extent, etc.

Study should associate with practice. Doing exercises is a very important approach for learning Structural Mechanics. We will not predominate the primary concept, principle and method of Structural Mechanics without doing some amount of exercises. However, doing exercises should avoid silliness. The first silliness is only doing exercises without reading and reviewing the book. The second silliness is doing exercises fast and more without understanding them completely. The third silliness is doing exercises with referring to the answers but being not able to verify the exercises by self. The fourth silliness is doing exercises without rectifying fault happened in doing exercises and extracting lesson from them.

1.3 Analytical Models of Structures

1.3.1 The rules of developing analytical model

Real structures are usually too complex to perform a rational analysis in their real practical states. They have to be simplified or idealized, by throwing away some unimportant details, as analyzing models prior to computation. An analytical model is a simplified representation of sketch, or an ideal sketch, of a real structure for the purpose of analysis. The simplified representation of sketch of a structure is referred to as its analytical model. All the analysis of structures is performed in their analytical models. Therefore, the development of analytical model is the basement of structural analysis. Establishment of an analytical model is one of the most important steps of the analysis process; it requires experience and knowledge of design practices in addition to a thorough understanding of the behavior of structures. Remember that the structural response predicted from the analysis of the model is valid only to the extent that the model represents the actual structure.

Development of the analytical model should generally obey the following rules:

(1) The analytical model should reflect, as accurately as practically possible, the main stressed and strained characteristics of the structure of interest to the analyst;

(2) In order to facilitate the analysis, the analytical model should maintain principal factors and discard much of the detail about the members, connections, and so on, that is expected to have little effect on the desired characteristics.

It should be pointed out that the development of analytical model should meet the site and time conditions under the above rules. It should have alternative ways. For instance, a more precise analytical model should be developed for an important structure; while a less precise analytical model should be used for an unimportant structure. Furthermore, in schematic design stage we can develop a rough analytical model for a structure; while in technical design stage we can select a more precise analytical model for the same structure. For hand-oriented method, the simplest analytical models of structures should be used; while for computer-oriented method, complex models of structures might be selected.

1.3.2 Simplifying points of analytical model

(1) The simplification of structural system

Generally, the actual structures are space, or three-dimensional, structures, whose members are connected as a space frame to undergo the loadings likely acting on it in various sense. Fortunately, many actual three-dimensional structures can be subdivided, by discarding some subsidiary space restraints, into plane structures for simplifying analysis. If all the members of a structure as well as the applied loads lie in a single plane, the structure is called a plane structure. The book will mainly discuss the calculation problems of plane structures.

(2) The simplification of members

The main attention the book focuses on is the framed structures. A framed structure is comprised of members (or bars), whose cross-sectional dimensions (e. g. the width b and depth h of a rectangular cross section, the radius of a circular cross section, etc.) is much smaller than the length l. Also cross-sectional deformation of the members satisfies plane-section assumption, and stress acting on the cross sections of members can be determined by the stress resultants (i. e. internal forces, bending moment, shear force and axial force). The cross-sectional deformation can be also evaluated by the strain components of the centroidal axes of the members. In the circumstances, the analytical model of a two- or three-dimensional structure selected for analysis is represented by a line diagram. On this diagram, each member of the structure is represented by a line coinciding with its centroidal axis; each connection between the members is represented by a kind of joint; the length of each member is represented by the distance between joints to which the member be attached; the position of the loads acting upon members is also transmitted to their centroidal axes. However, the simplifying approach is only suitable for the members whose ratios between their longitudinal and lateral dimensions are greater than 4.

(3) The simplification of connections

The connections between members of a structure are commonly simplified into joints. Two types of joints are commonly used to join members of structures:

① Flexible, or hinged joint

A hinged joint prevents only relative translations of member ends connected to it; that is, all member ends connected to a hinged joint have the same translation but may have different rotations. Such joints are thus capable of transmitting forces but not moments between the connected members. Figure 1.11 (a) shows a roof structure, the relative translations of each member are restrained by the gussets, but slight rotation between members will exist. So the gussets or connections of the roof structure are idealized into hinges. Hinged joints are usually depicted by small circles at the intersections of members on the line diagram of the structure, as shown in Fig. 1.11(b).

② Rigid joint

A rigid joint prevents relative translations and rotations of the member ends connected

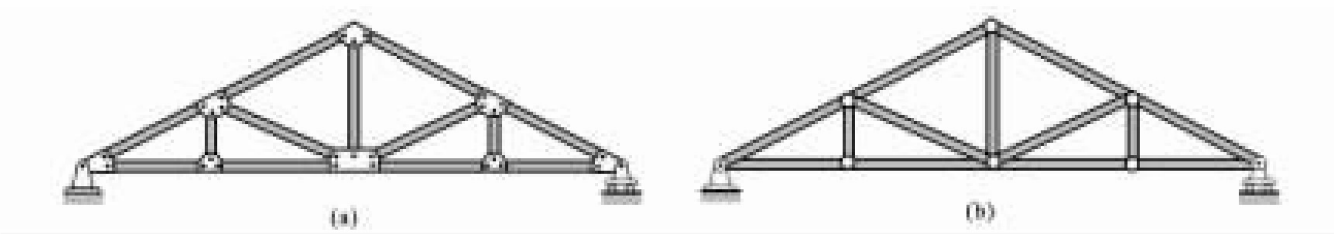

Fig. 1.11 Roof structure and its computing model

to it; that is, all member ends connected to a rigid joint have the same translations and rotation. In other words, the original angles between the members intersecting at a rigid joint are maintained after the structure has deformed under the action of loads. Such joints are, therefore, capable of transmitting forces as well as moments between the connected members. Figure 1.12 (a) shows a connection of a reinforced concrete side column and beam, the relative translations and rotation of the column and beam are restricted by the arrangement of the reinforcements which are cast into the whole body by the concrete. So the connection is simplified into a rigid joint. Rigid joints are usually represented by monolithic point at the intersections of members on the line diagram of the structure, as shown in Fig. 1.12 (b).

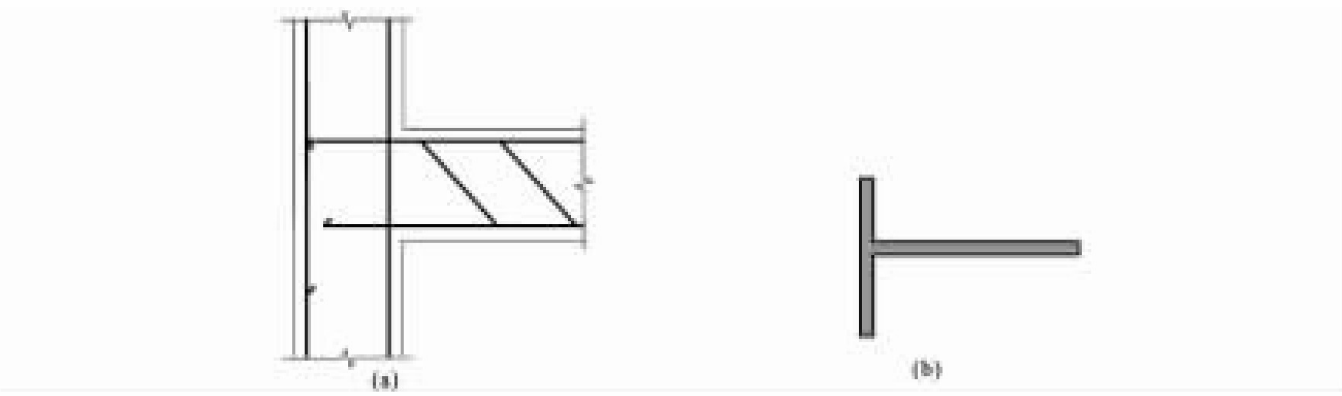

Fig. 1.12 Connection of reinforced concrete bars and its computing model

(4) The simplification of connections between structure and its foundation

Supports are used to attach structures to their foundations or other bodies, thereby restricting their movements under the action of applied loads. The loads tend to move the structures; but supports prevent the movements by exerting opposing forces, or reactions, to neutralize the effects of loads, thusly keeping the structures in equilibrium. The type of reaction depends on the type of supporting device used and the type of movement it prevents. A support that prevents translation of the structure in a particular direction exerts a reaction force on the structure in that direction. Similarly, a support that prevents rotation of the structure about a particular axis exerts a reaction couple on the structure about that axis.

The types of supports commonly used for plane structures are grouped into four categories, depending on the number of reactions (1, 2 or 3) they exert on the structures.

① Roller support

Figure 1.13 (a) shows a photo of the roller support of a bridge structure; Fig. 1.13 (b) and (c) depict the roller and rocker supports used in bridge structures. The supports only prevent translation perpendicular to the supporting surface. So the reaction force R_A acts perpendicular to the supporting surface and may be directed either into or away from the structure. The magnitude of R_A is the unknown. The support is thusly idealized, in according with its behavioral characteristics, as a roller-liked symbol shown as in Fig. 1. 13 (d) or a link shown as in Fig. 1. 13 (e).

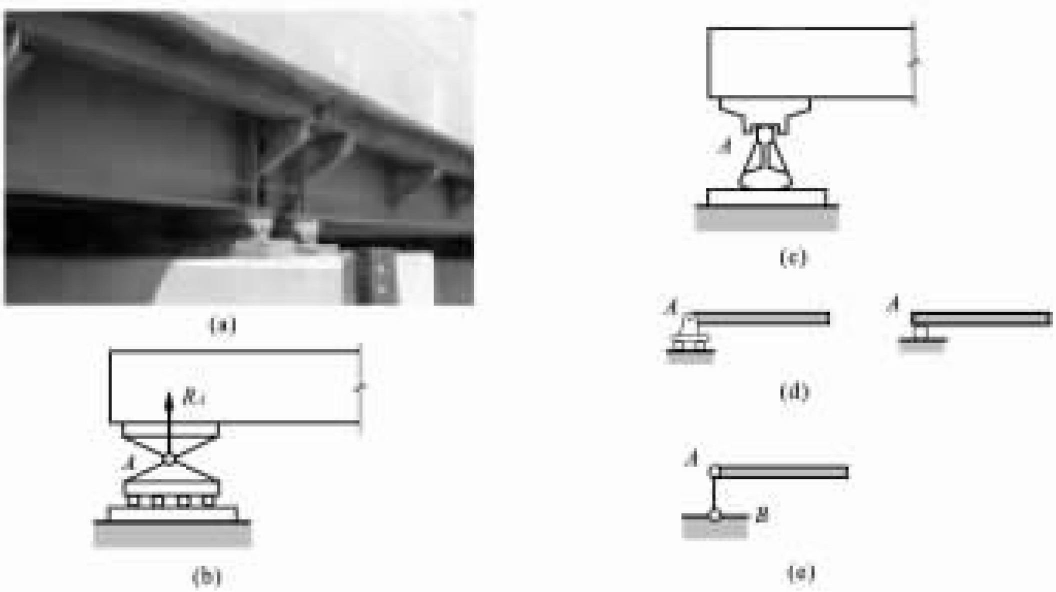

Fig. 1. 13 Roller support

(a) photo of the roller support of a bridge; (b)the roller support of a bridge; (c) the rocker support of a bridge; (d) computing models of roller support; (e) computing model of roller support

② Hinged support

The conformations of this kind of supports are depicted in Fig. 1. 14 (a) and (b), they are simply referred to as hinge. The supports are able to prevent translations in any direction. So the reaction force R_A may act in any direction. It is usually convenient to represent R_A by its rectangular components, X_A and Y_A. The magnitudes of X_A and Y_A are the two unknowns. The support is thusly idealized, in according with its behavioral characteristics, as a hinge-liked symbol shown as in Fig. 1. 14 (c) or two concurrent links shown as in Fig. 1. 14 (d) and (e).

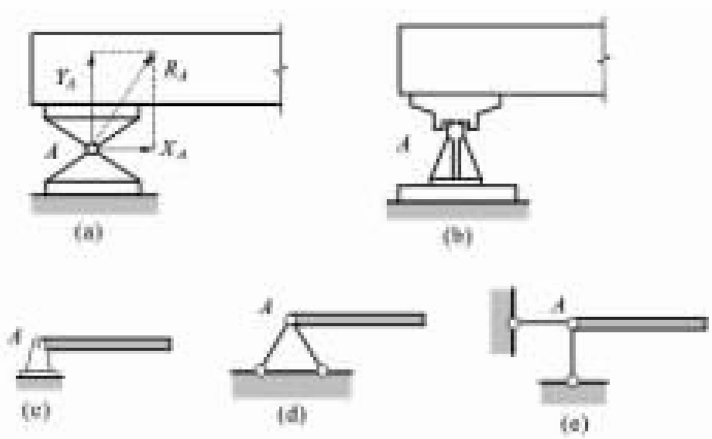

Fig. 1. 14 Hinged support

(a) and (b) conformations of hinged support; (c), (d) and (e) computing models of hinged support

Figure 1.15 (a) shows a precast reinforced concrete column embedded in cup-liked foundation and the interspace around the column bottom end is filled by asphaltum with jute fiber. In practice, there is slight rotation between the column and the foundation but no translations. So the attachment can be simplified as a hinge. Figure 1.15 (b) shows another example of hinged support, an arc-shaped sluice, there is a rotation about pin A when the sluice is being opened.

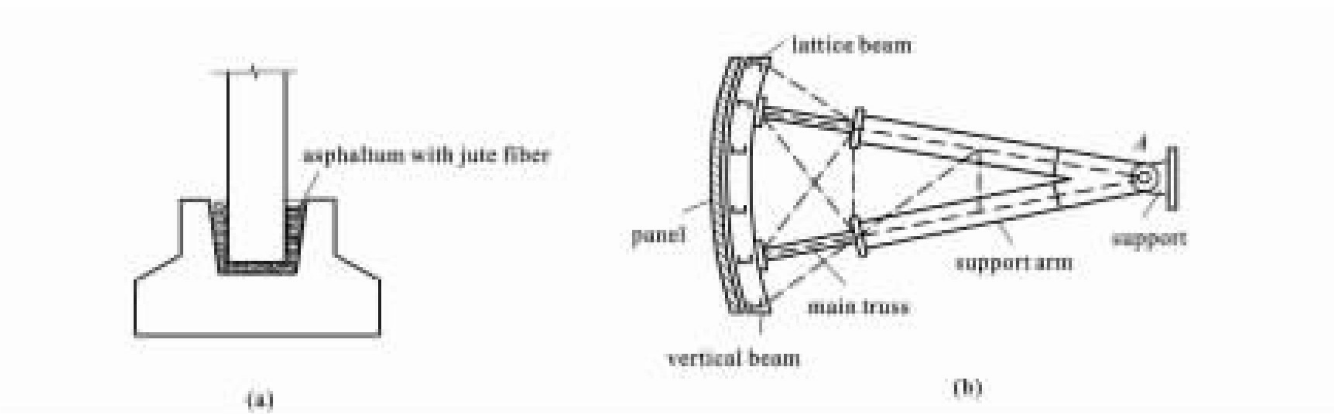

Fig. 1.15 Practical hinged supports

(a) precast reinforced concrete column embedded in cup-liked foundation; (b) arc-shaped sluice with hinged support

③ Fixed support

The fixed support can prevent both relative translations and rotation between structure and its foundation. So the reactions consist of two force components X_A, Y_A and a couple of moment M_A. The magnitude of X_A, Y_A and M_A are the three unknowns. The support is thusly idealized, in according with its behavioral characteristics, as a symbol shown as in Fig. 1.16 (b).

Figure 1.16 (c) shows a precast reinforced concrete column embedded in cup-liked foundation and the interspace around the column bottom end is filled by crushed stone concrete. In practice, there is no movement between the column and the foundation when the depth of embedment reaches some kind of degree. So the attachment generally is simplified as a fixed support.

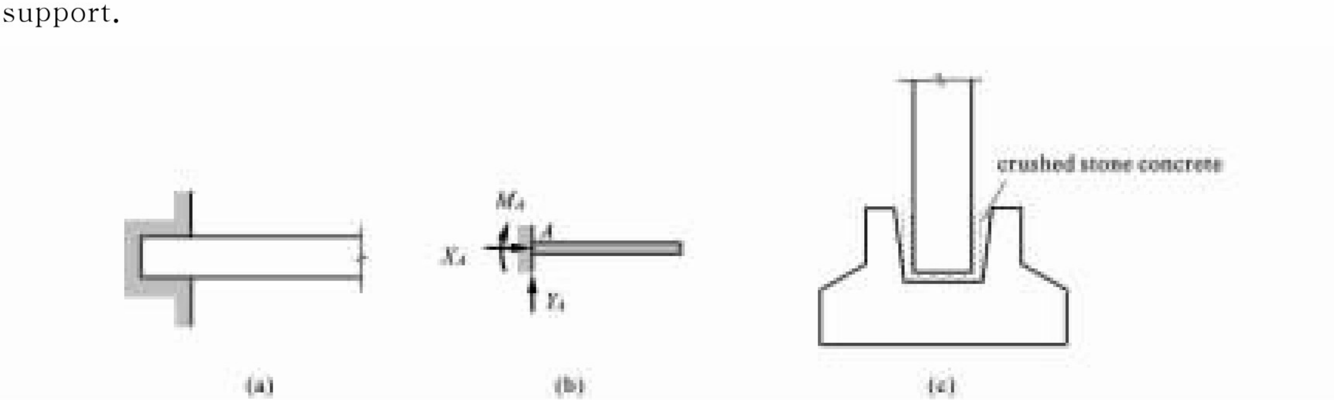

Fig. 1.16 Fixed support

(a) conformation of fixed support; (b) computing model of fixed support;

(c) precast reinforced concrete cup-liked foundation

④ Directional support

The directional support (or double-link support) restricts all relative movement between structure and its foundation but slides along its supporting surface. So the reactions consist of a force Y_A perpendicular to the supporting surface and a couple of moment M_A. The magnitudes of Y_A and M_A are the two unknowns. The support is thusly idealized, by its behavioral characteristics, as a symbol shown as in Fig. 1. 17 (b) or two parallel links shown as in Fig. 1. 17 (c).

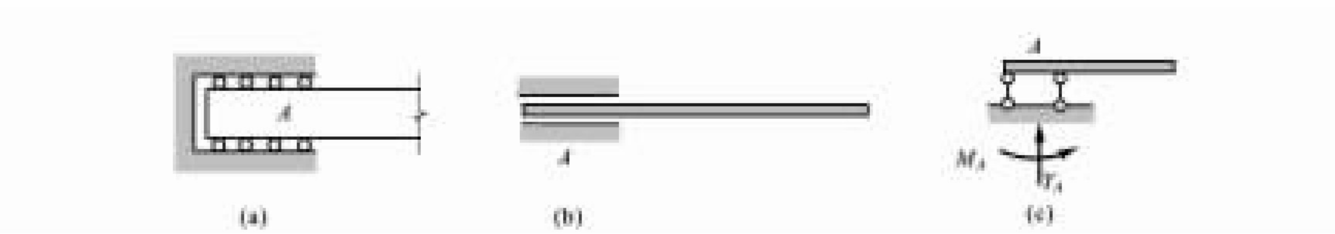

Fig. 1. 17 Directional support

(a) conformation of directional support; (b) schematic symbol of directional support; (c) computing model of directional support

(5) The simplification of property of material

Generally, the structures constructed in civil engineering are made of materials such as steel, concrete, bricks, stone, timber, and so on. However, in order to simplify the structural analysis, all materials composing structures are assumed to be continuous, homogeneous, isotropic, perfectly elastic or plastic.

Above assumption is suitable for metal within some stressing extent, but for concrete, reinforced concrete, bricks, stone and the like, the assumption will have some degree of approximation. As far as timber, because the property along the timber grain is quite different from that cross the timber grain, the attention should be paid when applying the assumption.

(6) The simplification of load

The loads applied on structures may be divided into two categories such as body force and surface force. The body force indicates the gravities and inertial forces of structures and the like; the surface force means the action upon structures transmitted by other bodies attached to them, for instance, the compression of soil and vehicular wheels and so on. In framed structures, the members are represented by lines coinciding with their centroidal axes, so both body force and surface force can be simplified as the forces acting on the lines. The loads can be simplified into concentrated loads and distributed loads according to their distribution. The simplification and determination of loads are of complexity. The special discussion about them will be given in latter section.

1.3.3 Illustration of analytical models of structures

Figure 1. 18 (a) shows an illustrative diagram of a workshop of a factory. Now its analytical models will be discussed.

(1) The simplification of structural system of the workshop

The structure of the workshop is, like clockwork along its longitudinal direction, collocated by a series of planar elements, composed by roof structure, columns and foundation