STRUCTURAL
结构力学
MECHANICS

主编：赵章焰
主审：张　氢

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STRUCTURAL MECHANICS
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前　言

随着我国重型装备制造国际化程度的不断提高，机械设计、制造领域里的企业越来越多地参与到国际竞争，毕业生负责或参与国际重型装备设计、技术服务和技术交流的机会越来越多。多角度培养学生的国际化能力是社会和行业的需求。

本教材是编者结合十多年的“结构力学”双语教学经验编写而成的。它既可以作为高等学校机械类学生的教材，也可作为机械工程技术人员的参考用书。本教材采用全英文编写，使读者在学习结构力学的同时，掌握结构力学的英语表达，增强读者对外技术交流的能力；同时，还在教材中融入了较多的工程实际案例。多年来，编写人员主持和参与了大量与机械结构研究、设计和分析相关的科研课题，并将这些素材融入到教材中，提高教材的适应性和可读性。在每章的结尾附有少量生词解释。

本教材由武汉理工大学赵章焰（第一、四、七章）、李郁（第二、五、六章）和王贡献（第三章）编写，由赵章焰担任主编。

本教材承蒙同济大学机械学院张氢教授担任主审。主审提出了许多宝贵的意见和建议，对提高本教材质量帮助很大，编者对此表示由衷的感谢。

由于编者水平有限，教材中的缺点、错误在所难免，恳请使用本教材的教师和学生及工程技术人员批评指正。

编　者

2014 年 1 月

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Chapter 1 Introduction

1.1 The Research Object and Task of Structural Mechanics and Its Relationship with Construction Machinery

In engineering technology, the structure we generally refers to is a supportive system, which is consisted according to certain conditions, laws and supports the load combination, such as the jib, slewing platform and the structure of portal. As shown in Fig. 1. 1.

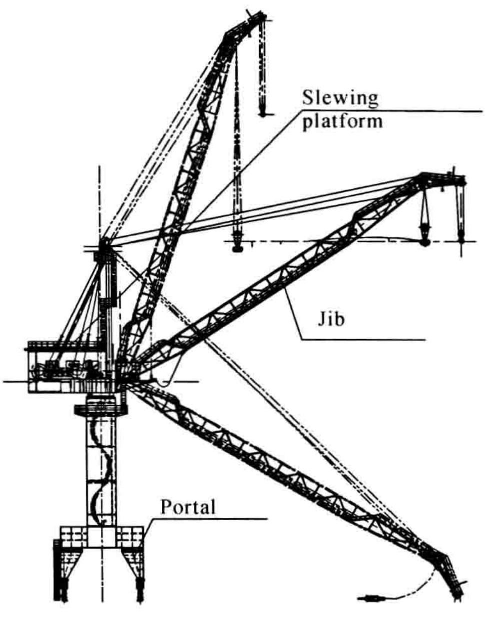


Fig. 1. 1

The classification of structural mechanics will be described following in details.

In material mechanics we have mainly dealt with the single load-bearing component's (such as link, beam, shaft), stiffness and stability under loading effect. However, the structural mechanics will focus on the following aspects of the system of structure composed by a rod:

① We study how to calculate the internal forces and displacements of structure under loading effect. On this basis, we can use the knowledge of subsequent courses to begin to structural design and structural checking.

②We study the stable calculations of the structure and dynamic analysis of structures under loading effect.

③We study the composition rules, reasonable forms of structure and so on.

The metal structure of hoisting machinery and engineering machinery is a major component of the whole machinery. In order to design strong, stable, lightweight and flexible metal construction, we should choose the metal structure of the structure properly; determine the size of structure correctly, which is vital to improve the quality and economy of the whole machinery. In order to design the metal structure properly, we must master the formation rules, the inner force, deformation and stability calculation of structure under loading effect. In other words, structural mechanics is the fundamental theory for us to design metal structure.

Structural mechanics is an important technically based course of hoisting machinery and engineering machinery majors. During the learning process, we should not only master the basic theory of structural mechanics, but also do a lot of exercises, link theory with practice and ponder often, so as to cultivate proficient calculating ability and analytical ability.

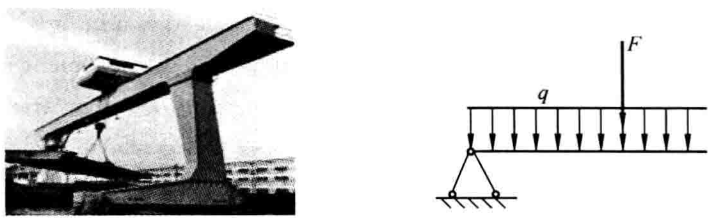
1.2 The Developmental History of Structural Mechanics

In ancient times, people could make a lot of things such as the bow and arrow, houses, wooden boats and musical instruments. Of course, all of these are simple structures. With the development of society, people gradually understood the rules of structural design and the strength and stiffness of structure, and then accumulated experience, which is reflected in the brilliant achievements of ancient buildings, such as the Egyptian pyramids, the Great Wall in China, Anji bridge in Zhaozhou, Imperial Palace of Beijing and so on. Although these structures implied knowledge of mechanics, they did not form a discipline. In terms of basic principles and methods, structural mechanics developed with theoretical mechanics, mechanics of materials simultaneously. So in the early period of development, structural mechanics mixed with theoretical mechanics and introduce the basic knowledge of truss structures, in the later chapters, from the directions of force method and displacement method; It will make a detailed explanation for solving the practical problems of structural mechanics.

1.3 Computing Model

For the actual structure, such as a crane boom, slewing platform, steel truss bridge and some buildings are very complex. If we study the actual situation of this structure, it would be very complicated. Therefore, we should make the actual model simplification before doing computational analysis. The computing model strikes a balance between the reality of structure and the simplicity of the computation. Computing model may differ in degree of detail. basically, the model is a simplified picture of the main factors governing the behavior of the structure.

For example:



(a) (b)

Fig. 1.2

Fig. 1.2(a) shows a gantry crane, a heavy weight is suspended from the beam.

If we analyses according to reality, we can't determine the reaction forces because we don't know the distribution of the reaction forces. So we must simplify it so that we can study it better.

To make simplification, the following factors should be taken into account:

① the width of the walls is very small comparison with the length of the beam.

② The beam can't move in horizontal direction because of friction between the beam and walls, but it can extend or shrink due to change of temperature.

③ the beam is represented by a line.

So the Fig. 1.1(a) can be simplified as Fig. 1.2(b). Fig. 1.2(b) is referred to as computing model. Using the computing model, we can study the situation well. q is refer to the heavy weight as is shown in fig. 1.2(b), and F is refer to the dead mechanics of materials. In the early 19th century, due to industrial development, people began to design a variety of large-scale engineering structures.

However, as for the design of these structures, more precise analysis and calculations should be made. Therefore, the analytic theory and method of engineering structures began to be independent. And in the mid-19th century, structural mechanics became an independent discipline. At that time, there were many calculating theory and methods about structural mechanics. In 1826, a French scholar, Navier proposed the general methods to solve the problems about structural mechanics. From the 1830s onwards, in order to pass train on the bridge, engineers needed not only consider the bridge's withstood of static load, but also needed consider the dynamic load. But due to the growth of the span of bridge, the metal truss structure formed. In the decades after 1847, scholars adopted the graphical method and the analytical method to study the stress analysis of statically determinate truss structure, which laid a foundation for the theory of truss. In 1864, Britain's Maxwell founded the unit load method and theorem of reciprocal displacements, and calculated the displacement of truss with the unit load method, scholars finally got to understand a systematic approach to the problem of structural mechanics. After establishing the basic theory, these scholars solved the previous problems of structure, at the same time, they also constantly developed new structures and the corresponding theories.

From late 19th to early 20th century, scholars did a lot of research about the ship's structure mechanics, and studied the kinetic theory of beam under movable loading effect, the problems of the free vibration and the forced vibration. In the early of 20th century, the development of aeronautical engineering promoted the analysis for thin-walled shell structure stiffening stress and deformation, as well as stability problems. At the same time, the extensive concrete began to be used in building bridges and buildings, which required scientists to studied steel structure Symmetrical. In 1914, German Bendixen founded the angle displacement method, which is used to solve problems of frame and continuous beam. Later, in the 20th to 30th decade of 20th century, he put forward several simple calculating methods for the complex truss structure (statically indeterminate structure), so that the ordinary designers could master and use these methods.

With the development of structural mechanics, the problems of fatigue, fracture and the structural problems of composite material entered the research field of structural mechanics. In this book, the previous chapters will mainly load of the structure.

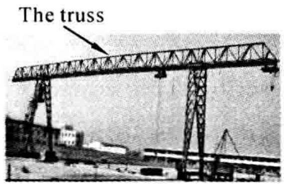


Fig. 1. 3

As is shown in fig. 1. 3, there is a truss gantry crane, the truss of the crane can be simplified as is shown in Fig. 1. 4, so that we can have a better study in line with the actual situation.

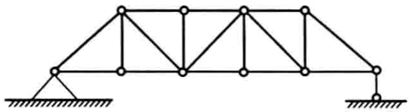


Fig. 1. 4

How to simplify is a very important problem. We can do it from three aspects as following:

1. 3. 1 Simplification of Members

In analysis we have the following requirements:

① we use the center line to represent a member ignoring its lateral dimension, as is shown in Fig. 1. 5(a).

② Small bending beam can be expressed for center line, as is shown in Fig. 1. 5(b).

③Beam column which has small inclined angle can be drawn with vertical or horizontal line, as is shown in Fig. 1. 5(c).

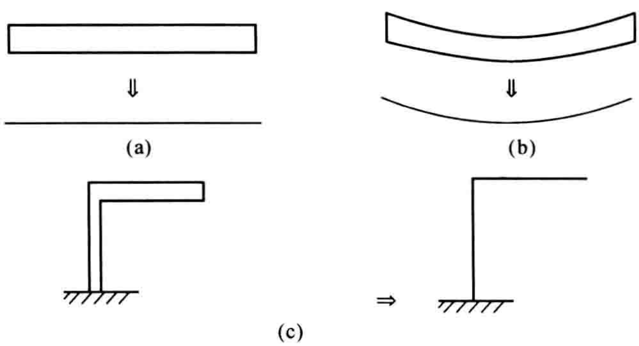


Fig. 1. 5

1.3.2 Simplification of Joints

When the members are connected together, the mutual displacements of the members are restrained. The connection point is called joint.

The following we will describe three common connection point that are the hinge joint and the rigid joint。

(1) Hinge Joint

Hinge joint have the feature of small resistance in bending.

A hinge joint restrains the translation of one member relative to the others, the members can have independent free rotations about the centre of the hinge. Such joints are thus capable of transmitting forces but not moments between the connected members. as is shown in Fig. 1. 6.

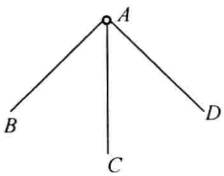


Fig. 1. 6

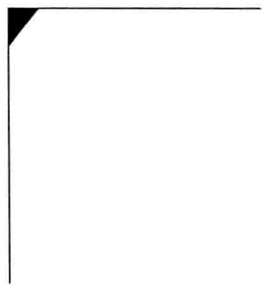


Fig. 1. 7

(2) Rigid Joint

A rigid joint prevent relative translations and rotations of the member ends connected to it. All member ends connected to a rigid joint have the same translations and rotation. In other word, the members from a monolithic body, they can move and translate as a group, but can not move with respect to each other.

When the deformation of the structure was taken place, the Included angle between members can't change (invariable). In practical engineering structure, the rigid joint can be simplified that which is shown in Fig. 1. 7.

In order to understand this concept better, the following will discuss the actual application situation of crane. as is shown in fig. 1. 8.

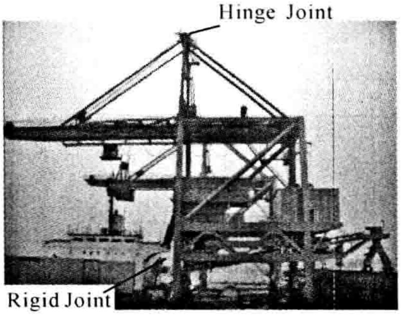


Fig. 1. 8

1. 3. 3 Simplification of Supports

The member that connects structure to some stationary foundation is called support. The loads tend to move the structures, but supports prevent the movement by exerting opposing forces or reactions to neutralize the effect of loads, thusly keeping the structure in equilibrium.

In simple words, supports have the following function:

① Prevent translation of the structure in a particular direction exerts a reaction force on the structure in that direction.

② Prevent rotation of the structure axis exerts a reaction moment couple on the structures about that axis.

There are many forms of support structure, but in the computing model usually including the following situations.

(1) Link support

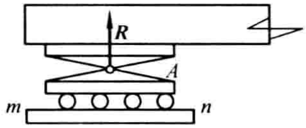


Fig. 1. 9

As is shown in Fig. 1. 9, it is depict the link support of a structure. The support only prevent translation perpendicular to the supporting surface. So the reaction force **R** acts perpendicular to the supporting surface and may be directed either into or away from the structure. What is more, the link support can be moved horizontally along the direction of mn. The support is thusly idealized, in according with its behavioral characteristic, we can simplify it to the model of Fig. 1. 10.

In a word, in such support, only the motion in a direction perpendicular to the support surface beneath the roller is restricted.

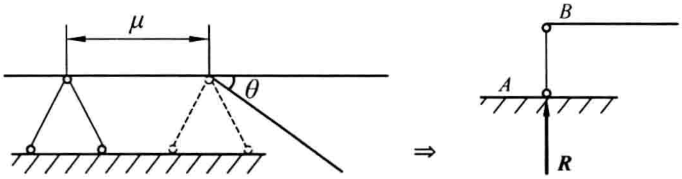


Fig. 1. 10

(2) Hinge Support

First let us know this kind of support. As is shown in Fig. 1. 11.

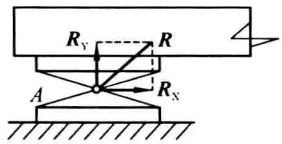


Fig. 1. 11

It reflect that the support are able to prevent translations in any direction, so the reaction force $\boldsymbol{R}$ may act in any direction, it is usually convenient to represent $\boldsymbol{R}$ by its rectangular components, $\boldsymbol{R}_X$ and $\boldsymbol{R}_Y$, both acting through the center of the hinge pin. The support is thusly idealized, we can simply it as the Fig. 1. 12 shown.

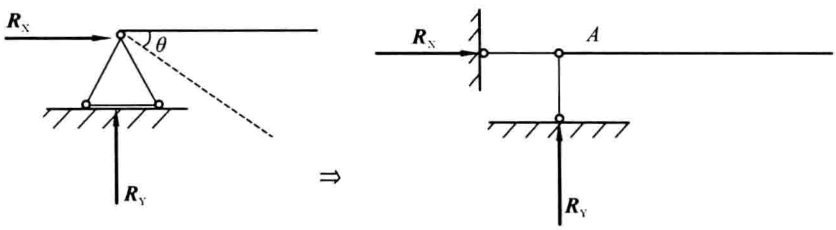


Fig. 1. 12

We will summarize its characteristics. The hinge support have the following features:

- The supports are able to prevent any translation in any direction.
- Two reaction forces pass through the same hinge point A.

(3) Fixed support

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.

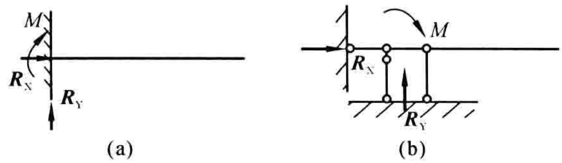


Fig. 1. 13

This support prevents motions, which both translation and rotation between structure and its foundation and the supports have the following features:

①The reactions of the fixed support consist of two force components $\boldsymbol{R}_X$ and $\boldsymbol{R}_Y$ and a couple of moment.

② There are three reaction forces. It also be represented by three link supports, as is shown in Fig. 1. 13.

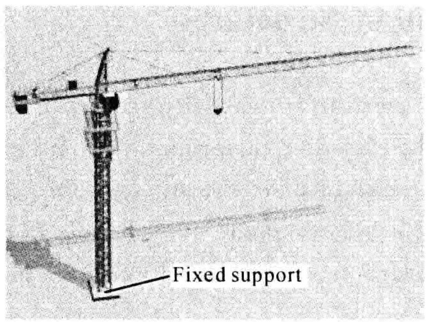


Fig. 1. 14

In practice, we can see many fixed support. As is shown in fig. 1. 14.

(2)Fixed direction support

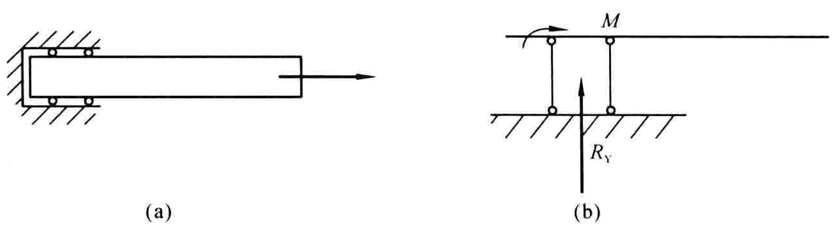


Fig. 1. 15

The support permits the member's translation in only one direction. The directional support restricts all relative movement between structure and its foundation but slides along its supporting surface. So the reactions consist of a force $\boldsymbol{R}_Y$ perpendicular to the supporting surface and a couple of moment M. the magnitudes of $\boldsymbol{R}_Y$ and M are the two unknowns. The support is thusly idealized, according the fixed direction support behavioral characteristics, we can have a symbol shown in Fig. 1. 15(b).

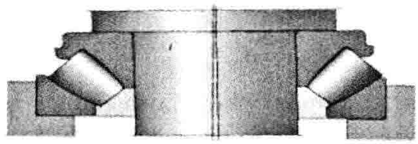


Fig. 1. 16

In the fig. 1. 16, we can see a thrust bearing and we can take it as an example of fixed direction support.

1. 4 Classification of Structures

The types of structures can be classified from different perspectives, in other words, structures may be classified in various ways, for example, according to the number and type of restraint, structures may be classified into statically determinate and statically indeterminate system, and so on. The following I will introduce same ways of structure's classification. Structure may be classified into the following forms primarily.

1. 4. 1 Classify by the Spatial Position of Axis and the Force

According to the spatial position of the axis and the force, Structures can be classified into plane structure and space structure. If members of the structure and its loads are in the same plane, then it is called plane structure. If members are not in a plane or its loads are not lie in the same plane, then the structure is called space structure. As is shown in Fig. 1. 17(plane structure) and Fig. 1. 18 (space structure).

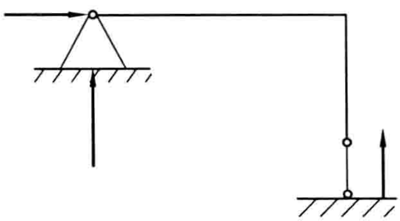


Fig. 1. 17

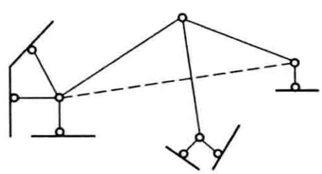


Fig. 1. 18

1. 4. 2 Classify by Restraints

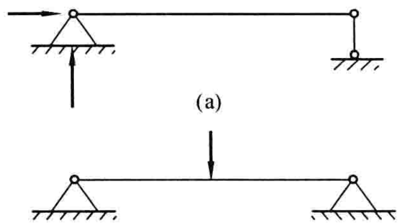
In accordance with whether the internal forces statically indeterminate or not, structure can divided with statically determinate structure and statically indeterminate structure. Fig. 1. 19 depict the structure clearly.

(1)Statically determinate structure.

All reaction forces and internal forces can be determined by statically equilibrium equations. As is shown in Fig. 1. 19(a).

(2)Statically indeterminate structure.

All reaction forces and internal forces can't be determined by statically equilibrium equations. As is shown in Fig. 1. 19(b).



(a)

(b)

Fig. 1. 19

1.4.3 Classify by Geometry

Classifying by geometry, we can divided structure into rod-type structure, thin-wall structure and massive structure.

①Rod-type Structure

A rod-type structure is comprised of bars, of which the length scales much larger than the other two.

②Thin-wall Structure

When the thickness of the structure is very small in comparison with its overall dimension, it can named the thin-wall structure. As is depicted in Fig. 1. 20 is a plate, then there is a shell in Fig. 1. 21.

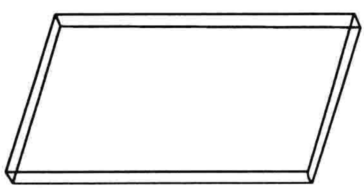


Fig. 1. 20

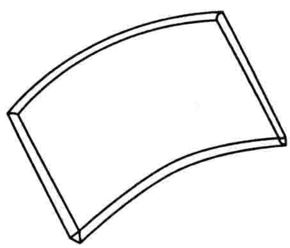


Fig. 1. 21

③Massive Structure

The three dimensions of magnitude and have similar size in three dimensions. For