高校土木工程专业国际化人才培养英文系列教材

Basic Principles of Concrete Structures

混凝土结构基本原理

He Dongqing
贺东青

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This book not only presents the mechanical properties of reinforced concrete materials and methods for the design of individual members for bending, shearing, compression, tension and torsion, but also provides much detail referring to applications in the concrete structural members. An introduction to prestressed concrete is also included.

This book can serve as a textbook for the undergraduates majoring in civil engineering and related majors in colleges and universities, as well as a useful reference book for technicians of civil engineering. We also hope it can help Chinese undergraduate students with a language environment so that they can keep learning English continuously.

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Preface

Basic principles of concrete structures is a basic specialty course for undergraduates majoring in civil engineering. This textbook *Basic Principles of Concrete Structures* has three objectives: 1) to establish a firm understanding of the behavior of structural concrete; 2) to develop proficiency in the methods used in current design practice; 3) to help Chinese undergraduate students with a language environment so that they could keep learning English continuously.

The textbook is based on the current national standard *Code for Design of Concrete Structures* GB 50010. The main contents include mechanical properties of steel and concrete, which are very important to mechanical behavior of reinforced concrete structural members. Then step by step, methods for the design of individual members subjected to basic loading types (bending, shearing, compression, tension and torsion) and environment actions are provided. Finally, the knowledge of prestressed concrete structures is stated.

A feature of the textbook is that more emphasis has been laid on basic theories of concrete structures as well as on applications of basic theories both in designing new structures and in analyzing existing structures. The reader will find lots of examples, questions and problems in each chapter, which provide an entry into the literature for those wishing to increase their knowledge through independent study.

The editor in chief of this textbook is He Dongqing from Henan University. Some colleagues have taken part in the editorial work. He Dongqing prepared the draft for Chapters 1,2,5 and 6. Song Pengwei and Fu Xiaoyu prepared the draft for Chapters 3 and 4. Li Fengli prepared Chapter 8. Wu Min prepared Chapter 7 and Yu Mengmeng prepared Chapter 9. Song Pengwei drew all of the figures.

Due to the limited knowledge of the editor, some mistakes and errors in the book may exist. The suggestions for improvement will be gladly accepted.

He Dongqing

October, 2017

Contents

Chapter 1 Introduction

1.1 General Concepts of Concrete Structures

1.1.1 Definition and Classification of Concrete Structures

The structures mainly made of concrete are called concrete structures, which include plain concrete structure, reinforced concrete structure, prestressed concrete structure and so on. The concrete structures with no reinforcement or non-stressed steel bars are called plain concrete structures, while those with steel bars, steel mesh or steel cage embedded in concrete to carry loads are called reinforced concrete structures. The concrete structures prestressing in concrete by tendons are called prestressed concrete structures. The concrete structures are widely used in industrial and civil buildings, bridges, tunnels, mines, water harbor, etc.

1.1.2 Function and Demand of Reinforcement

Generally, concrete is strong in compression while weak in tension. However, steel is strong in both tension and compression. When the steel reinforcement bars are embedded at the tensile area in a concrete member, they can resist the tension instead of concrete after the concrete cracks. Then steel reinforcement bars and concrete can work cooperatively to provide the resistance of a member.

Taking beams as an example, a plain concrete beam under two concentrated loads is shown in Figure 1-1(a). When the external loads are increased to make the stress in the beam's bottom zone exceed the tensile strength of concrete, the concrete will crack, and the beam will rupture suddenly, indicating the load-carrying capacity of the plain concrete is very low and the failure is brittle. If an appropriate amount of steel bars is embedded at the bottom of the beam, the steel bars will help concrete to sustain the tension due to its good tension-resistant property after the concrete cracks (Figure 1-1b). Thus, the beam can continue to carry loads rather than rupture. The steel bars increase the load-carrying capacity of the beam and improve the beam's deformability, whereby the beam presents obvious warning before its final failure.

As shown in Figure 1-1(c), steels with higher compressive strength are also arranged in axial compression columns to help the concrete sustain compression. Thus, the cross-sectional dimension of the column can be smaller. In addition, the steels in column can also improve the failure load and can sustain the tension by the occasional factors.

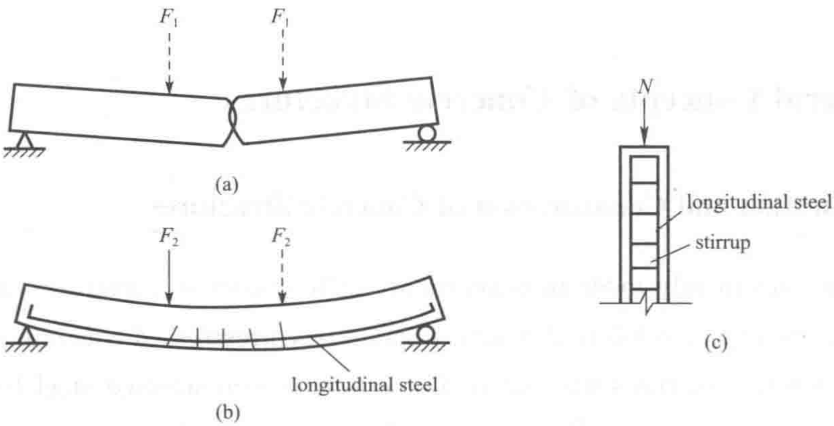

Figure 1-1 Mechanical performance of two beams and an axial compression column

(a) Plain concrete beam; (b) Reinforced concrete beam; (c) Reinforced concrete column

Steel bars can be well bonded to concrete. Thus, they can jointly resist external loads and deform together. The thermal expansion coefficients of concrete and steel are so close (1.2×10^{-5}/℃ for steel and $1.0\times10^{-5}\sim1.5\times10^{-5}$/℃ for concrete) that the thermal-stress-induced damage to the bond between the two materials can be prevented. At the same time, the arrangement and the number of steel bars should be determined based on correct calculation, detailing requirements and correct construction.

1.1.3 Advantages and Disadvantages of Concrete Structures

Concrete structures have following advantages:

Availability of materials: The materials of concrete used in the largest amount, i. e., sand and gravel are easy to purchase in local market, and industry wastes (e. g., blast furnace slag, and fly ash) can be utilized effectively.

Economy: Reinforced concrete structures take use of the properties of steel and concrete reasonably, and can reduce the cost of construction comparing with steel structure.

Durability: The dense concrete has a high strength. In addition, a thick enough concrete cover can protect the embedded steel from corrosion; thus, the frequent maintenance costs little. So the durability of reinforced concrete is better.

Fire resistance: The steel bar is wrapped in concrete so that it will not quickly reach the softening temperature which leads to structural damage. Compared with wood structure and steel structure, it is better in fire resistance.

Moldability: Concrete structures can be cast according to designed requirements into various shapes and sizes.

Integrity: The members of in situ cast concrete structure are firmly connected to effectively resist dynamic loads such as earthquakes, explosions and other impacts.

Concrete structures also have some disadvantages. Their larger self-weights are disadvantageous for the seismic performance of large span structures and high-rise building structures, and also bring difficulties to transport and construction lifting. In addition, the reinforced concrete structure crack resistance is poor, so most of tensile and bending members in service are behaving with cracks. When a crack is not allowed or there is a strict limit to the crack, prestressed concrete structure should be used. Furthermore, the concrete structures have complicated constructing processes and poor insulation performance.

1.2 Historical Development of Concrete Structures

The concrete structures have a long history of around 150 years. Compared with steel, wood and masonry structures, concrete structures have many advantages in physical mechanical properties, availability of materials, construction costs, etc. So the concrete structures have developed rapidly and have the widest range of applications.

In China, the concrete structure is mostly used in high-rise buildings and multi-storey frames. Concrete-masonry mixing structures are widely used in multi-storey houses. Those structures such as TV towers, water towers, pools, cooling towers, chimneys, tanks and silos are also commonly constructed into concrete and prestressed concrete structures. In addition, concrete structures are also common in large-span public buildings and industrial buildings.

At present, the tallest reinforced concrete building in the world is Khalifa Tower, with a height of 828m, located in Dubai, the United Arab Emirates. The prestressed concrete television tower in Toronto, Canada, with a height of 549m is a representative prestressed concrete structure. The world's tallest concrete gravity dam is Grande Dixence Dam in Switzerland, with a height of 285m and a width of 15m at the top of the dam, 225m at the bottom of the dam and 695m in length. China's Three Gorges Project of Yangtze River is the largest water conservancy project in the world. The concrete dam is 186m high and the amount of concrete is 15, 270, 000mm^3.

Waterlocks, hydroelectric dams, docks and wharves built with reinforced concrete are also very extensively applied in China.

In recent years, China has made a lot of new achievements in the research of concrete basic theory and design methods, structural reliability and load analysis, industrial building system, structural seismic and finite element analysis methods, and modern test technology. Advanced modern test technology ensures that experimental research is more accurate and systematic. The analysis method based on reliability theory is also gradually improved, and begins to use in the whole structure and during the whole process. At the same time, the period of structural design has been shortened by the popularity and multifunction of electronic computers, the development of CAD and other software systems.

In addition, we have made great progress in the design theory and methods of concrete structure. The current specification *Code for Design of Concrete Structures* GB 50010—2010, which has accumulated rich engineering practices and scientific achievements over the past more than half a century, and improved the design method of concrete structure in China to the present international level. And it plays a guiding role in engineering design.

With the development of high strength steel bars, high performance admixtures and hybrid materials, the high performance concrete has been used widely, and the research and the application of steel fiber concretes and polymer concretes have made great development. Besides, lightweight concrete, aerated concrete, ceramic concrete and green concrete using industrial waste slag not only improve the performance of concrete, but also have important significance for energy conservation and environmental protection. Concrete for special needs such as ray-resisting, hard-wearing, corrosion-resisting, anti-osmosis, heat preservation and intelligent concrete with its structure are also in development.

1.3 Function and Limit State of Structures

1.3.1 Function of Structures

In order to ensure that the structure of the design is safe and reliable, the building structure should meet the requirements of its function. The function of the structures includes three aspects: safety, applicability and durability. Safety refers to the reliability of the bearing capacity of building structures. The structure should be able to withstand all kinds of loads and deformations during the normal construction and service, and the overall stability of the structure can be maintained during and after an earthquake, explosion, etc. The applicability requires that the structure cannot produce too much deformation and cannot have wide cracks and vibrations during the normal service period. The durability requires that the structure will not have serious weathering, corrosion, peeling and carbonization in the normal maintenance condition, so as to achieve the expected life of the design.

1.3.2 Limit State of Structures

The entire structure or part of a structure exceeding a certain state will not meet the design requirements of a function and this state is called the limit state of this function. So the limit state of structures is the state of a boundary between reliability and failure.

The limit state of structures can be divided into the ultimate limit state and the serviceability limit state.

1. Ultimate limit state

The ultimate limit state is when the structure or member reaches the maximum carrying capacity or deformation is not suitable for the continuous bearing state. The structure under such conditions including damages by lack of material strength, the fatigue damage, too much plastic deformation to bear load, loss of stability or turning into mechanism system, is considered to exceed the ultimate limit state. The structure or member cannot meet the requirements of security after exceeding the capacity limit state.

2. Serviceability limit state

The structure or member reaches a specified limit in the service or durability of a structure or member is called serviceability limit state.

For example, when the structure or member appears excessive deformation, excessive cracks, local damage, and vibrations that affect normal use, it can be considered that the structure or member exceeds the serviceability limit state. Beyond the serviceability limit state, the structure or member cannot guarantee the applicability and durability of the functional requirements.

When structural design is carried out, the structure or member should be calculated according to the ultimate limit state, and also be checked according to the serviceability limit state. In other words, the structure or member should satisfy the requirements of the ultimate limit state while satisfying the serviceability limit state.

1.3.3 Load and Material Strength

The value of a load that does not change over time is called a permanent load or a constant load (expressed as G or g), such as the self-weight of the structure. The load that varies with time is called a variable load or a live load (expressed as Q or q), such as floor live load.

The standard value of a load is its basic representative value denoted by the subscript k, which are used to check the deformation and the crack width of the concrete structure. The design value of a load should be adopted in order to meet the reliability requirement of structures when calculating the load-carrying capacity of the section. The design value is equal to the standard value multiplied by the load factor. The load factor of a constant load γ_G is generally 1. 2. The load factor of a live load γ_Q is generally 1. 4.

The internal force obtained by the load standard value is called the standard value of internal force, such as the standard value of the bending moment M_k and the axial force standard value N_k. The internal force, which is calculated by load design value, is called the design value of internal force, such as the design value of bending moment M and the axial force design value N.

The standard value of material strength should be adopted when checking the structural deformation and crack width. When calculating the load-carrying capacity of the section, the design value of material strength should be used. The design value of material strength is equal to the standard value divided by the material sub-coefficient. For example, the design value of axial tensile strength of concrete (f_t) is equal to the standard value ($f_{t,k}$) divided by the material sub-coefficient (γ_c).

1. 4 Characteristics of Course and Learning Methods

This course is one of the fundamental specialized courses for undergraduate students majoring in civil engineering. From the study of this course, students should know the basic mechanical properties, computational analysis methods and detailing of structural members composed of concrete and reinforcement, understand the distinctions and similarities between this course and previous mechanics courses, acquire the ability of solving real engineering problems in structural design and assessment, and lay a solid foundation for future design courses. To study this course more effectively, students should do the following:

(1) Pay attention to the differences and similarities between this course and previous courses, especially that the basic principles of concrete structures are equivalent to the mechanics of reinforced concrete and prestressed concrete.

(2) Concrete structural theories are mostly based on the experimental research. There has not been a complete or generally accepted theoretical system up to now. Therefore, students should pay attention to the site visit and understand the actual projects.

(3) To ensure the safety and reliability of structures, only undertaking quantitative theoretical analysis is not enough. Qualitative detailing measures are necessary as well.

These measures are summaries of previous experiences. Although they cannot be explained quantitatively, profound principles are behind them. So in the study, students should understand the meaning of the detailing measures rather than just memorize them.

(4) Study fundamental theories with the goal of applying them in future engineering practice.

(5) Combining theory with practice is helpful in the study of this course.

Questions

1-1 What is reinforced concrete structure? What are the main roles and requirements of reinforcement?

1-2 What are the main advantages and major drawbacks of reinforced concrete structures?

1-3 What are the functional requirements of the structure? Briefly describe the concepts of the ultimate state and the serviceability limit state.

1-4 What are the main characteristics of this course? What are the issues that need to be addressed in this course?