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土木工程材料

第2版 改编版

Civil Engineering Materials

Second Edition

原著 SHAN SOMAYAJI
改编 阎培渝

高等教育出版社
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出版说明

本书为高等教育出版社"世界优秀教材中国版"系列教材之一。为了更好地优化、整合世界优秀教育资源，并通过本土化使其最大程度地发挥作用，丰富我国的教育资源，促进我国的教学改革，提高我国高等教育的教学质量，高等教育出版社决定出版"世界优秀教材中国版"系列教材。"世界优秀教材中国版"系列教材具有以下特征：

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希望该系列教材的出版能为我国高等学校教学改革和教育资源建设作出贡献。

高等教育出版社

2005年5月

改编者的话

建筑材料是人类建造活动所用一切材料的总称。人类社会的基本活动——衣食住行，无一不是直接或间接地与建筑材料密切相关。土木工程结构体系和施工技术的进步，无一不是以建筑材料的进步为基础。熟悉建筑材料的基本知识、掌握各种新材料的特性，是进行结构设计和工程项目管理所必需的基本条件。如果不能正确使用建筑材料，轻则影响结构物的外观和使用功能，重则危害结构的安全性，造成重大事故。

“建筑材料”课程是土木工程类学生接触的第一门专业基础课，通过本课程的学习，使学生了解建筑材料科学知识，同时为后续课程和以后实际工作中正确使用建筑材料提供必要的基本知识。

本书是在美国加州理工大学 Shan Somayaji 教授编著的 Civil Engineering Materials（第 2 版）的基础上改编的。原版是一本在世界范围内非常有影响的教材，反映了近年来建筑材料科学技术领域的进展，及其对结构设计和施工工艺进步的促进作用，内容与我国现行教学体系比较接近，包括许多背景知识，可供学生拓展眼界。改编版删减了一些与我国的规范标准、现实情况及专业课程培养目标要求出入较大的内容，增加了一些必要但原书未讲授的内容。全书分为 7 章，在简要介绍建筑材料的基本力学性能的基础上，讲述了骨料、混凝土和其他水泥基材料混凝土、砌体材料、木材、沥青混合料及钢铁的组成、结构、性能和生产加工方法，并讨论了它们的相互关系。

本教材可以作为大学本科土木工程、水利工程、环境工程、工程管理和建筑学等专业的专业基础课程“建筑材料”或专业外语课程的教科书，也可作为建筑工程类设计、科研及施工技术人员的参考书。

由于改编者水平所限，不妥之处在所难免，谨请广大读者与同行专家批评指正。

阎培渝

2006 年 5 月于清华园

Preface to the rewritten Edition

This text was written originally by Mr. Shan Somayaji of California Polytechnic State University in San Luis Obispo and published by Prentice Hall, USA. Higher Education Press of China would offer Chinese students some texts written in English to spread their knowledge. This book is recommended because it is a very practical text for the students in the junior year. The text is rewritten based on the standards and practice in China.

Although a great deal of care is taken to see that the details are current, noncontroversial, and free of error, it is natural to expect errors and omissions due to the vastness in scope and breadth of this material. The author would be very grateful if these are brought to his notice at the following address:

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Beijing 100084

The author also wishes to acknowledge the valuable contributions of Prof. Wang Lijiu of Dalian University of Technology, whose insightful comments in reviewing this manuscript are greatly appreciated.

YAN Peiyu

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Chapter 1
Introduction

Civil engineering consists of the design, construction, maintenance, inspection, and management of characteristically diverse public works projects, from railroads to high-rise buildings to sewage treatment centers. Their construction may be under or above ground, offshore or inland, over mile-deep valleys or flat terrains, and upon rocky mountains or clayey soils. The thought that all these creative efforts are made possible through the marvelous innovative spirits of civil engineers is in itself comforting and appealing, as well as challenging for prospective civil and construction engineers. The gigantic achievements of the past stand as a flashing beacon to promote the potential of civil engineering.

Although the profession of civil engineering per se is of fairly recent origin—the American Society of Civil Engineers (ASCE), the oldest national engineering society in the United States, was founded in 1852—the work of civil engineering is as old as humankind. The most ambitious and historically significant projects throughout the history of civilization were accomplished to satisfy the fundamental human needs for transportation, water, shelter, and disaster control. Nonetheless, the systematic approach to planning for the community's future, by training young minds professionally in all facets of civil engineering, is quite new.

1.1 MATERIALS AND METHODS—A HISTORICAL PERSPECTIVE

At the core of civil engineering rests the investigation of materials and methods that can satisfy the needs of the community. For example, shelter is provided for through housing; dwellings are built in accordance with a *method* that is appropriate for the *material* selected, the method of construction changing with the material.

Remnants of the methods and materials of civil engineering can be found in plenty among the records of ancient civilizations. In addition to Fighting wars and conquering other kingdoms, rulers all over the world were involved in constructing facilities and building programs that catered to the public spirit. The first Babylonian dynasty of King Hammurabi (c. 1800 B. C.) initiated sweeping reforms and construction programs that were documented in contemporary manuscripts. King Sennacherib of Assyria (c. 700 B. C.), who was called a great engineer-king, built a dam across the river Tebitu, and from the reservoir thus created constructed many canals. The canal walls were built from cubes of stone and the canal floor had a layer of concrete or mortar under a top course of stone to prevent leakage. Nearly all Mesopotamian cities around that time were paved with slabs of stone and brick. The first emperor of the Chin dynasty in China, between 259 and 210 B. C. , started the building of the Great Wall for protection from the Huns. The great Roman emperor Constantine I, after his conversion to Christianity, built the city of Constantinople and dedicated it as his capital (A. D. 330).

The handling of materials in construction necessitated proper tools. Stones had to be cut to proper size and shape before they could be used to build masonry. Trees had to be felled, cut, and shaped before they could be used in construction. Soil and mineral deposits had to be dug up prior to making bricks and cement. Metals provided the base material from which tools could be fashioned, making it possible to advance public work facilities with relative ease and safety.

The use of metals came in before 4000 B. C. with the advent of native copper— which was naturally occurring—for ornaments and utensils. During this period, it was learned that heat softens metals, promoting the technique of forming. The period 3000-1000 B. C. is known as the Bronze Age, due to the increased use of bronze, the first manmade alloy, formed by mixing molten copper and tin. Around the same time, elaborate techniques were developed for forming gold and silver jewelry. Following the Bronze Age came the Iron Age. Iron ore—mostly iron oxide—was heated in a charcoal hearth. The carbon in the charcoal reacted with the iron oxide, releasing carbon dioxide and producing a spongy mass of iron. Pure iron has a high melting temperature of around 1600°C. Though facilities for melting at this high temperature were not yet available, iron containing large amounts of carbon could be melted and cast into shapes, marking the origin of *cast iron*.

History shows us that ancient engineers were innovative and efficient in terms of the materials they chose and the methods of construction they employed. Sumerians, for example, around 3000 B. C. , built houses with mud bricks joined by locally available bitumen. They are supposed to have constructed 5. 4 m thick walls along a circumference of about 9. 6 km to provide refuge for people and cattle. Mesopotamians built mud-brick huts without windows to keep out the sizzling heat of the summer sun. People in south India and Sri Lanka had houses made of wooden frames and removable reed mat for walls. Such houses, which are cheap and practical, are still being built.

Historical sites and ruins show us the skills of ancient builders. During the period of the Eastern Chou Dynasty in China, 770-250 B. C. , a number of cities were built, usually rectangular or square in a north-south axis, surrounded by double walls and a moat. At Harappa and Mohenjo Daro in Pakistan, along the rich alluvial banks of the Indus river, are the remains of two large and expertly constructed cities dating back to 3000-1500 B. C. The cities were planned around a central citadel and constructed of good quality burned bricks. Elaborate municipal drainage and complex irrigation systems were without parallel during ancient times. Remains of domestic utensils and jewelry made from carved ivory, silver, copper, bronze, and earthenware indicate a well-developed technology of metals.

The Assyrians of Mesopotamia around 1100-750 B. C. knew how to construct buildings that could not be destroyed by fire. The building walls were made of stone, so that the fire burned off only the roof. One of the most important technological discoveries of ancient engineers—which brought revolutionary changes to twentieth-century civil engineering construction—was the introduction of hydraulic cement by the Romans, around 145 B. C. They discovered that the local sandy volcanic ash, when added to lime mortar, made a material that became as strong as rock when dried. They called this mortar *pulvis puteolanus*, and used it for gigantic endeavors like the Colosseum, and to build aqueducts, bridges, and roads, some of which are still in use. Their standard roads were 4. 5 m wide and had a 1. 2-m deep foundation formed of layers of stone, rubble, and concrete, and were topped with a surface of concrete, stone, and powdered gravel. Underground sewage facilities were installed because their cities were located in valleys between sharp hills. The walls of their buildings had thin facings of brick, stone, or marble. They built apartment houses of five or more stories, and provided public latrines that were flushed with water delivered from baths and industrial establishments. The Romans are also credited with building semicircular arch bridges using stones.

In Patiliputra, India, the houses around 300 B. C. were constructed of wood, and to protect them from fire an elaborate system of fire protection was enforced. Records show the construction of suspension bridges held by iron chains. Ingots of steel made in India were taken to Damascus, where they were converted into sword blades.

The historical records available all over the globe show us that the basic materials used in construction were either derived from the earth or made from plants. Every continent of the world possesses three basic types of surface characteristics: hard crystalline rocks, such as granite; mountainous belts of folded sedimentary rocks; and plainland basins filled with sediments. This means that the core of civil engineering construction or material technology is the same in every part of the world, though different materials have been used in different places, depending on the local availability and need.

In Mesopotamia, for example, the most abundant natural resource of the land was mud. Hence the city walls were made of clayey mud. Molding the clay into bricks made it possible to build straight walls without visible weak spots. The brick mold is believed to have been a Sumerian invention—around 3000 B. C.—and the use of molds made it possible to manufacture bricks that were flat on all six sides. The bricks were dried from a few days up to 5 years depending on the strength required. But independent of the extent of the drying period, the bricks softened and crumbled when they became wet. This led to the discovery of a new kind of brick— burned brick. The chemical changes in the clay during burning resulted in strong and durable bricks. But these bricks were costly due to the scarcity of fuel, and thus were employed only for the outside of important buildings.

Egyptian temple buildings had stone-paved floors supporting colossal (hollow) stone columns, holding up the loads from massive stone lintels. Stones were used exclusively in temple buildings and for tombs, for the Egyptians considered a tomb a house of eternity and a temple a house of a million years. In contrast, the houses for people—mortals—were built of mud and wood, and thus were not durable. The vast cedar forests of Lebanon supplied timber to Egypt and Mesopotamia, which had little good building timber of their own. Assyrians made use of swamp reeds as structural material for house construction. A bundle of reeds tied together served as a pillar to hold up a house of light construction. In building construction, the post-and-beam framing technique using timber owes its development to the Greeks. Into the Mediterranean basin they brought a tradition of using wood, featuring a sloping and pitched roof.

In the Babylon of King Nabopolassar, around 600 B. C. , double city walls were built, the space between outer and inner filled with rubble, generally up to ground level. The Ishtar Gate of Babylon, built during the rule of King Nebuchadrezzar, around 580 B. C. , was finished with enameled bricks, of blue for the towers, and green and pink for the connecting walls. The Babylonian roads were paved with massive stone blocks set in asphalt. Geologists have identified a 12-km stretch of road paved with slabs of sandstone and limestone, about 69 km southwest of Cairo, Egypt, that may have been the world's first paved road, built roughly 4600 years ago, and used to transport heavy stones for the building of the pyramids.

This brief historical perspective on materials and methods of civil engineering shows that construction materials were, for the most part, of native origin and satisfied environmental compatibility as well as financial constraints. This statement applies to most (but not all) of the basic materials used in today's civil engineering facilities. Advances in engineering techniques, resource constraints, and cost-cutting measures are responsible for the introduction of a significant number of new materials into today's construction market. Although it is beyond the scope of this basic textbook on the properties and use of materials in civil engineering or construction, the aspect of material selection, is central in importance. The choice of a construction material should be made only after a detailed review of its long-term performance, its potential to effect the durability of other materials in the structure, and its environmental compatibility. For example, asbestos may appeal as a good construction material due to one or more favorable properties—fire resistance, in this case—as well as for financial reasons, but its long-term potential to cause environmental hazards and human discomfort must outweigh the immediate utility and financial dividends.

1.2 CIVIL ENGINEERING MATERIALS

The basic materials used in civil engineering applications or in construction projects are:

- Wood
- Cement and concrete
- Bitumens and bituminous materials
- Structural clay and concrete units

• Reinforcing and structural steels

These are sometimes called *structural materials*. Added to these are plastics, soils, and aluminum. All these materials are employed in a variety of civil engineering structures such as dams, bridges, roads, foundations, liquid-retaining structures, waterfront construction, buildings, and retaining walls. The basic materials most common to highway construction are soils, aggregates, bituminous binders, lime, and cement.

Wood is derived from trees, and can be put to use directly, as pieces of lumber cut from a log, or as a raw material in the manufacture of various wood products or manufactured components. Plywood, glue-laminated timber, and oriented strand-board are some of the wood products most commonly found in the construction of buildings and bridges.

Concrete is one of the most common construction materials, in which Portland cement is the essential ingredient. Portland cement (and other types of hydraulic cement) is also a key ingredient in the manufacture of many other cementitious products, such as masonry blocks, soil-cement bricks, and plaster. In combination with other materials, such as reinforcing bars, polypropylene fibers, and high-strength strands or wires, different types of concrete are produced, such as reinforced, fiber, and prestressed concrete.

Bitumen, which comes in a variety of forms, is mixed with other raw materials for the construction of pavements, roof shingles, waterproofing compounds, and many other materials. Structural clay and concrete masonry units, commonly called bricks and blocks, are the principal elements in the construction of masonry walls. Structural steel, which is fabricated in many forms and shapes, is employed in the construction of railroad ties, high-rise buildings, roof trusses, and many more structural elements.

These basic materials or products are selected for their properties, performance, availability, aesthetics, and cost. Knowledge of all these aspects is essential in selecting a suitable material for a particular situation.

In addition to the materials mentioned above, there are a significant number of secondary construction materials common to engineering projects. Sealants, adhesives, floor and wall coverings, fasteners, and doors and windows fall into this category. Most of these, also called nonstructural materials, are chosen based on quality guidelines and aesthetic considerations.

1.3 PROPERTIES OF ENGINEERING MATERIALS

Materials for engineering applications are selected so as to perform satisfactorily during service. The material for a highway bridge should possess adequate strength, rough surface, and sufficient rigidity. A water-retaining structure would be built with a material that is impermeable, crack-free, strong, and does not react with water. A road surface needs such materials that show little movement under the impact of loads, are water-resistant, and are easy to repair.

Performance requirements, or property specifications, are not the same for all structures or