



海外土建学科优秀教材
Oversea Excellent Textbooks on Civil Engineering

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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
Higher Education Press



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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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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

Contents

Chapter 1 Introduction 1

1.1 Materials and Methods—A Historical Perspective 1

1.2 Civil Engineering Materials 4

1.3 Properties of Engineering Materials 5

1.3.1 Forces, Loads, and Stresses 7

1.3.2 Strain 11

1.3.3 Stiffness 12

1.3.4 Ductile and Brittle Materials 16

1.4 Selection of Materials 19

1.5 Standards 21

Problems 23

Chapter 2 Aggregates 24

2.1 Types of Aggregates 24

2.1.1 Based on Source or Method of Manufacture 25

2.1.2 Based on Size 27

2.1.3 Based on Density 27

2.2 Properties of Aggregates 30

2.2.1 Specific Gravity and Moisture Content 31

2.2.2 Bulk Density and Voids 36

2.2.3 Modulus of Elasticity and Strength 37

2.2.4 Gradation and Fineness Modulus 38

2.2.5 Other Properties 43

Problems 46

Chapter 3 Concrete and Other Cementitious Materials 47

3.1 Introduction 47

3.1.1 Various Cementitious Materials 47

3.1.2 Uses of Concrete 48

3.2 Cement 50

3.2.1 Hydraulic Cement 51

3.2.2 Nonhydraulic Cement 52

3.3 Portland Cement 54

3.3.1 Manufacture 54

3.3.2 Cement Chemistry 56

3.3.3 Fineness 58

3.3.4 Strength of Cement 58

3.3.5 Consistency of Cement 59

3.4 Hydration 60

3.4.1 Setting 60

3.4.2 Hardening 61

3.5 Properties of Concrete 63

3.5.1 Properties of Fresh Concrete 65

3.5.2 Factors Affecting Consistency and Workability 69

3.5.3 Segregation and Bleeding 70

3.6 Mixing, Placing and Curing 71

3.6.1 Pumping and Placing 74

3.6.2 Finishing and Types of Finishes 76

3.6.3 Curing 77

3.7 Properties of Hardened Concrete 83

3.7.1 Compressive Strength 84

3.7.2 Tensile Strength 92

3.7.3 Flexural Strength 93

3.7.4 Stress-Strain Diagram and Modulus of Elasticity 94

3.7.5 Shrinkage 97

3.7.6 Creep 106

3.7.7 Carbonation 107

3.8 Durability 107

3.8.1 Alkali-aggregate Reaction 108

3.8.2 Sulfate Attack 109

3.8.3	Freeze-thaw Cycle	110			
3.8.4	Corrosion	110			
3.9	Mix Proportioning and Design	112	Chapter 5	Wood	169
3.9.1	Mix Design	113	5.1	Structure of Wood	169
3.9.2	Mix Design Procedure	115	5.2	Types of Wood	170
3.10	Admixtures	120	5.3	Physical Properties of Wood	171
3.10.1	Chemical Admixtures	120	5.3.1	Moisture Content	172
3.10.2	Mineral Admixtures or Pozzolans	125	5.3.2	Density and Specific Gravity	173
3.11	Types of Concrete	130	5.4	Shrinkage and Seasoning	175
3.11.1	Reinforced Concrete	130	5.4.1	Shrinkage	175
3.11.2	Prestressed and Precast Concrete	131	5.4.2	Seasoning	177
3.11.3	Fiber-reinforced Concrete	133	5.5	Treatment and Durability	177
3.11.4	Lightweight Concrete	135	5.5.1	Decay and Destruction	179
3.11.5	High-strength and High-perform- ance Concrete	137	5.6	Mechanical Properties and Allowable Values	180
3.12	Other Cementitious Materials	139	5.7	Wood Products	184
3.12.1	Plaster and Stucco	139	5.7.1	Glulam	186
3.12.2	Mortar	141	5.7.2	Plywood	188
3.12.3	Grout	142	5.7.3	Other Panel Products	190
3.12.4	Shotcrete	142	5.8	Creep	192
3.12.5	Soil Cement	143	Problems	193	
3.12.6	Pervious Concrete and Cement- bonded Particleboard	144	Chapter 6	Bituminous Materials and Mix- tures	195
Problems		144	6.1	Tars and Pitches	196
Chapter 4	Masonry	146	6.2	Asphalts	197
4.1	Masonry Units	149	6.3	Petroleum Asphalts	197
4.1.1	Clay Bricks and their Manufa- cture	150	6.3.1	Asphalt Cement	199
4.1.2	Sizes of Bricks	153	6.3.2	Cutback Asphalts	199
4.1.3	Properties of Bricks	153	6.3.3	Emulsified and Blown Asphalt	200
4.1.4	Concrete Masonry Units	155	6.4	Properties of Asphalt	201
4.2	Mortar, Grout and Plaster	157	6.4.1	Consistency	201
4.2.1	Lime Mortar	158	6.4.2	Specific Gravity	204
4.2.2	Mixing and Properties of Mortar	159	6.4.3	Durability	204
4.2.3	Grout and Its Uses	162	6.4.4	Rate of Curing	205
4.2.4	Plaster	163	6.4.5	Resistance to Action of Water	205
			6.4.6	Ductility and Adhesion	205
			6.4.7	Temperature Susceptibility	206
			6.4.8	Hardening and Aging	208
			6.5	Asphalt Grades	208
			6.5.1	Viscosity and Penetration	

Grading	209
6.5.2 Performance-based Grading	211
6.5.3 Cutback Asphalt Grades	212
6.6 Asphalt Concrete	213
6.6.1 Aggregates	214
6.6.2 Types of Asphalt Concrete	216
6.7 Asphalt Pavement	218
6.7.1 Elements of Flexible Pavement	219
6.7.2 Stabilization	221
6.8 Spray Applications	222

6.9 Testing	224
Problems	229
Chapter 7 Iron and Steel	230
7.1 Cast Iron and Wrought Iron	231
7.2 Steel Products	234
7.3 Properties of Steel	236
7.4 Structural Steel	239
7.5 Reinforcing Steel	242
7.6 Welded Wire Fabric	244
Problems	246

目录

第1章 引言 1

- 1.1 材料和方法——历史的观察 1
- 1.2 土木工程材料 4
- 1.3 工程材料的性能 5
 - 1.3.1 力、荷载和应力 7
 - 1.3.2 应变 11
 - 1.3.3 刚度 12
 - 1.3.4 塑性和脆性材料 16
- 1.4 材料的选择 19
- 1.5 标准 21
- 问题 23

第2章 骨料 24

- 2.1 骨料的种类 24
 - 2.1.1 按照来源和制备方法分类 25
 - 2.1.2 按照粒径分类 27
 - 2.1.3 按照密度分类 27
- 2.2 骨料的性质 30
 - 2.2.1 比重和含湿量 31
 - 2.2.2 堆积密度和空隙 36
 - 2.2.3 弹性模量和强度 37
 - 2.2.4 粒级和细度模数 38
 - 2.2.5 其他性能 43
- 问题 46

第3章 混凝土和其他水泥基材料 47

- 3.1 引言 47
 - 3.1.1 各种水泥基材料 47
 - 3.1.2 混凝土的用途 48
- 3.2 水泥 50
 - 3.2.1 水硬性胶凝材料 51
 - 3.2.2 气硬性胶凝材料 52
- 3.3 硅酸盐水泥 54
 - 3.3.1 制造过程 54

- 3.3.2 水泥化学 56
- 3.3.3 细度 58
- 3.3.4 水泥的强度 58
- 3.3.5 水泥的稠度 59
- 3.4 水化反应 60
 - 3.4.1 凝结 60
 - 3.4.2 硬化 61
- 3.5 混凝土的性能 63
 - 3.5.1 新拌混凝土的性能 65
 - 3.5.2 影响新拌混凝土的稠度和工作性的因素 69
 - 3.5.3 离析和泌水 70
- 3.6 拌和、浇筑和养护 71
 - 3.6.1 泵送和浇筑 74
 - 3.6.2 抹面工序与类型 76
 - 3.6.3 养护 77
- 3.7 硬化混凝土的性能 83
 - 3.7.1 抗压强度 84
 - 3.7.2 拉伸强度 92
 - 3.7.3 抗折强度 93
 - 3.7.4 应力-应变关系和弹性模量 94
 - 3.7.5 收缩 97
 - 3.7.6 徐变 106
 - 3.7.7 碳化 107
- 3.8 耐久性 107
 - 3.8.1 碱-骨料反应 108
 - 3.8.2 硫酸盐侵蚀 109
 - 3.8.3 冻融循环 110
 - 3.8.4 钢筋锈蚀 110
- 3.9 混凝土配合比设计 112
 - 3.9.1 配合比设计 113
 - 3.9.2 配合比设计流程 115

3.10	外加剂	120	5.4.1	收缩	175
3.10.1	化学外加剂	120	5.4.2	风干	177
3.10.2	矿物外加剂或火山灰材料	125	5.5	加工和耐久性	177
3.11	混凝土的类型	130	5.5.1	腐烂和劣化	179
3.11.1	钢筋混凝土	130	5.6	力学性质和允许值	180
3.11.2	预应力混凝土和预拌混凝土	131	5.7	木材制品	184
3.11.3	纤维增强混凝土	133	5.7.1	胶合板	186
3.11.4	轻混凝土	135	5.7.2	层压板	188
3.11.5	高强和高性能混凝土	137	5.7.3	其他板材	190
3.12	其他水泥基材料	139	5.8	徐变	192
3.12.1	胶泥和腻子	139	问题	193	
3.12.2	砂浆	141	第 6 章 沥青材料与沥青混合料	195	
3.12.3	灌浆料	141	6.1	焦油和热解沥青	196
3.12.4	喷射混凝土	142	6.2	沥青	197
3.12.5	土壤固化剂	143	6.3	石油沥青	197
3.12.6	无砂混凝土和水泥固化胶合板	144	6.3.1	粘稠沥青	199
问题	144		6.3.2	稀释沥青	199
第 4 章 砌体材料	146		6.3.3	乳化沥青和氧化沥青	200
4.1	墙体材料	149	6.4	沥青的性质	201
4.1.1	粘土砖及其制造过程	150	6.4.1	稠度	201
4.1.2	砖的尺寸	153	6.4.2	比重	204
4.1.3	砖的性质	153	6.4.3	耐久性	204
4.1.4	混凝土砌块	155	6.4.4	热损失率	205
4.2	砂浆、胶泥和腻子	157	6.4.5	水稳性	205
4.2.1	石灰砂浆	158	6.4.6	延性和粘附性	205
4.2.2	砂浆的拌和及性质	159	6.4.7	温度稳定性	206
4.2.3	灌浆料及其用途	162	6.4.8	硬化与老化	208
4.2.4	腻子	163	6.5	沥青的分级	208
4.3	砌体的性质	164	6.5.1	粘性和针入度	209
问题	168		6.5.2	基于性能的分级	211
第 5 章 木材	169		6.5.3	稀释沥青的分级	212
5.1	木材的结构	169	6.6	沥青混合料	213
5.2	木材的种类	170	6.6.1	骨料	214
5.3	木材的物理性质	171	6.6.2	沥青混合料的种类	216
5.3.1	含湿量	172	6.7	沥青路面	218
5.3.2	密度和比重	173	6.7.1	柔性路面的组成	219
5.4	收缩和风干	175	6.7.2	稳定性	221
			6.8	喷涂	222
			6.9	试验	224

问题	229	7.4	结构用钢	239	
第7章	钢铁	230	7.5	钢筋	242
7.1	铸铁和熟铁	231	7.6	焊接钢筋网	244
7.2	钢材	234	问题	246	
7.3	钢的性质	236			

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 engi-

neer-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 col-

umns, 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 Nebuchadnezzar, 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