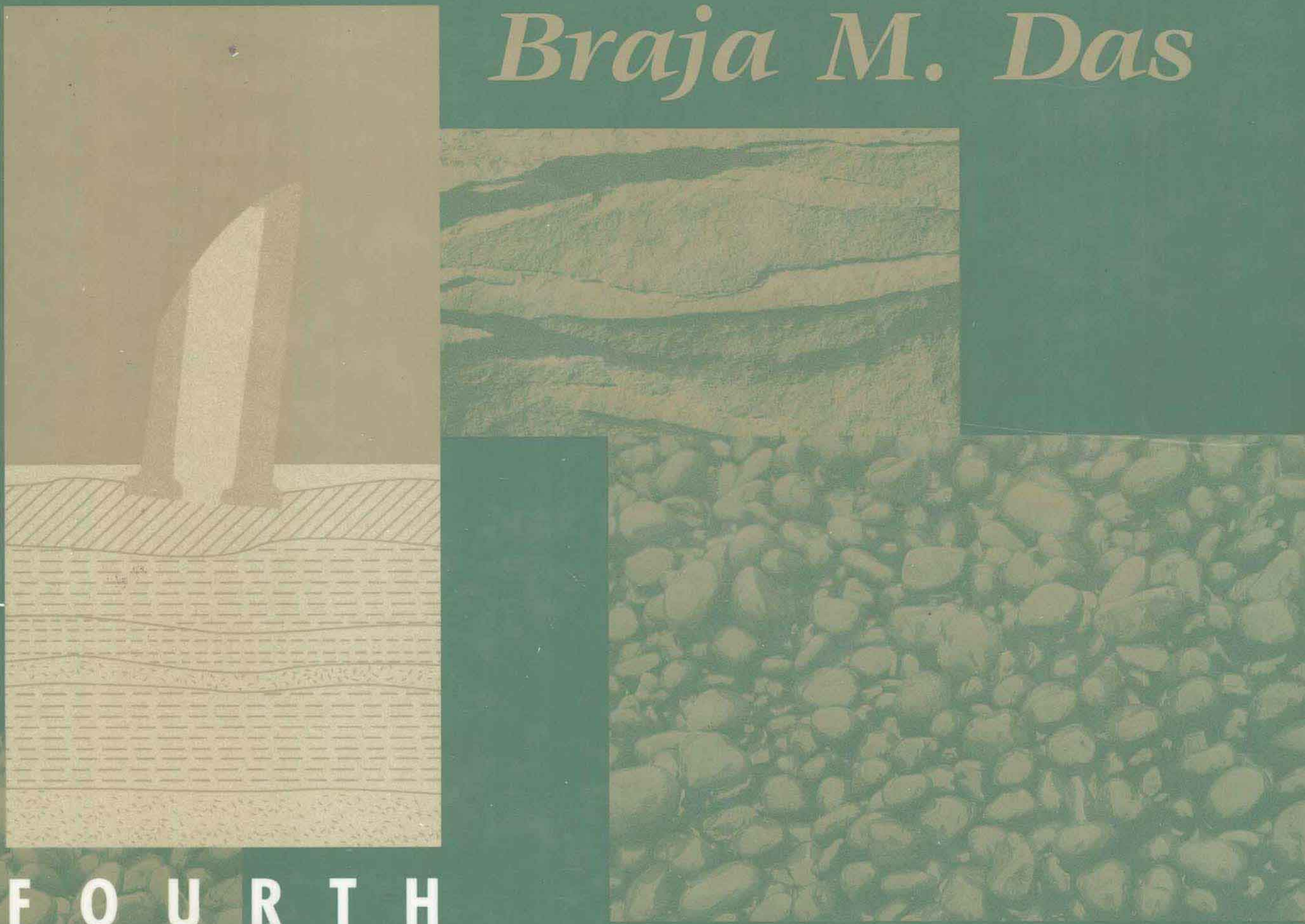
Braja M. Das



FOURTH EDITION

Principles of Geotechnical Engineering

PRINCIPLES OF GEOTECHNICAL ENGINEERING

Fourth Edition

BRAJA M. DAS
California State University, Sacramento

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PREFACE

Principles of Geotechnical Engineering, Fourth Edition, is intended for introductory courses in soils and geotechnical engineering taken by virtually all civil engineering majors. It is also useful for professionals and other readers wanting a general introduction to this important aspect of engineering. As in the first three editions of the book (1985, 1990, and 1994), the new edition offers an overview of soil properties and mechanics, together with coverage of field practices and basic engineering procedures. *Principles of Foundation Engineering,* Third Edition (1995), by the same author, goes on to apply these general concepts and procedures to earth, earth-supported, and earth-retaining structures, with an emphasis on design. *Principles of Geotechnical Engineering,* Fourth Edition, provides the background information needed to support study in later design-oriented courses or in professional practice.

CHANGES IN THE FOURTH EDITION

The Fourth Edition, consisting of 15 chapters, includes a number of new features that were incorporated in response to suggestions made by professors, students, and professionals familiar with the earlier versions of the book. The major changes are the following:

- To acquaint readers with the overall content of the text, Chapter 1 provides a preview of all chapters.
- The title of Chapter 2 has been changed to "Weight-Volume Relationships, Plasticity, and Structure of Soil."
- Chapter 3 provides modified and improved tables for systematic determination of group symbols and group names of soil.
- Chapter 4 provides additional case histories on soil compaction, requirements to achieve desired field compaction, and details regarding compaction of organic soil and waste materials.

- Experimental results for the directional variation of hydraulic conductivity, considerations for hydraulic conductivity of clayey soils in field compaction, and moisture content–unit weight criteria for construction of clay liners have been incorporated into Chapter 5.
- Chapter 6 contains several improved tables for calculation of vertical stress below loaded areas.
- Chapter 10 now contains the solutions of Caquot and Kerisel for determination of passive pressure behind retaining walls.
- Chapter 11 is a new chapter on dynamic lateral earth pressure.
- Chapter 12 now uses Meyerhof's bearing capacity, shape, depth, and inclination factors to calculate the ultimate bearing capacity of shallow foundations.
- The factor of safety determination for the rapid drawdown condition has been added in Chapter 13.
- To better reflect the content of the material incorporated in Chapter 14, the title has been changed to "Landfill Liners and Geosynthetics."
- Most of the example problems and homework problems have been changed.

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Sacramento, California

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CHAPTER ONE

SOILS AND ROCKS

For engineering purposes, *soil* is defined as an uncemented aggregate of mineral grains and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles. Soil is used as a construction material in various civil engineering projects, and it supports structural foundations. Thus, civil engineers must study the properties of soil, such as its origin, grain-size distribution, ability to drain water, compressibility, shear strength, and load-bearing capacity. *Soil mechanics* is the branch of science that deals with the study of the physical properties of soil and the behavior of soil masses subjected to various types of forces. *Soils engineering* is the application of the principles of soil mechanics to practical problems.

The record of a person's first use of soil as a construction material is lost in antiquity. For years, the art of soils engineering was based on only past experience. With the growth of science and technology, the need for better and more economical structural design and construction became critical. During the early part of the twentieth century, this need led to a detailed study of the nature and properties of soil as they related to engineering. The publication of *Erdbaumechanik* by Karl Terzaghi in 1925 gave birth to modern soil mechanics. This book presents the fundamental principles of soil mechanics on which more advanced studies are based.

Geotechnical engineering is defined as the subdiscipline of civil engineering that involves natural materials found close to the surface of the earth. It includes the application of the principles of soil mechanics and rock mechanics to the design of foundations, retaining structures, and earth structures.

1.1 PREVIEW

Soil is a unique natural material, and its properties are governed not only by the particle-size distribution, particle shapes, and density of particle packing, but also by the presence of water and air in the voids. Construction on and with soil and the problems associated with such construction have been with us for as long as history has been recorded. For example, the Leaning Tower of Pisa, which was completed in A.D. 1350, is now more than $16\frac{1}{2}$ ft (5 m) out of plumb in a 179-ft (54-m) height. This displacement has occurred gradually during the past 647 years, and the tower continues to shift slightly with each passing year. In the Panama Canal, landslides still occur many years after its construction. The Grand Teton Dam, which failed on June 5, 1976, resulted in the loss of 11 lives and the destruction of property worth more than $1 billion. To analyze and determine the cause of these problems and many others, one must have a thorough understanding of the physical and mechanical properties of various types of soil, which is the subject of this text. Following is a chapter-by-chapter preview of the contents presented:

- **Chapter 1.** This chapter (from Section 1.2 onward) presents the *origin of soil* from weathering of various types of rocks and subsequent transportation by such natural agents as wind, water, and ice. This chapter also provides an overview of clay minerals and their contribution to the plasticity in a soil when mixed with water. Methods of determining the *grain-size distribution* of solids in a given soil mass are discussed.
- **Chapter 2.** Soil is a three-phase system consisting of soil solids, water, and/or air. This chapter discusses the *weight-volume relationships* of soil and the *consistency* (plasticity) of fine-grained soils in which clay minerals are present.
- **Chapter 3.** In this chapter, the *classification* of various soils into groups and subgroups according to their engineering behavior is discussed. These classifications are based on the grain-size distribution and plasticity.
- **Chapter 4.** Soil must be *compacted* for construction of various structures. Different methods of soil compaction and the physical and mechanical properties of compacted soils are the subject of this chapter.
- **Chapter 5.** This chapter includes a discussion of the *hydraulic conductivity* of various soils. Hydraulic conductivity is a measure of ease by which water can flow through the void spaces. Methods of calculation of seepage through soil under structures are developed.
- **Chapter 6.** In a saturated soil, stress is carried by the solid particles at their points of contact (*effective stress*) and by the water present in the void spaces (*pore water pressure*). Procedures to calculate effective stress and pore water pressure are the subject of this chapter.
- **Chapter 7.** This chapter presents relationships to calculate the *stress transferred* into a soil mass due to various types of applied loads. The soil is assumed to be homogeneous, elastic, and isotropic.
- **Chapter 8.** Construction of structures results in some settlement of soil. The components of the settlement may be divided into two parts — *elastic* and *consolidation*. *Consolidation settlement* occurs in submerged clay layers and is time dependent, primarily because of the low hydraulic conductivity. The theories for estimation of settlement have been augmented in this chapter.
- **Chapter 9.** Unlike other materials, most of the failures in soil are controlled by its *shear strength*. This chapter expands upon the theories and measurement techniques of the shear strength of soils.

- **Chapter 10.** This chapter is primarily devoted to the calculation of *lateral earth pressure* on retaining walls, braced cuts, and other earth-retaining structures. It uses the shear strength parameters developed in Chapter 9.
- **Chapter 11.** This chapter is an extension of Chapter 10. The methods for estimating *lateral earth pressure due to earthquake loading* are discussed.
- **Chapter 12.** On the basis of the shear strength parameters developed in Chapter 9, this chapter describes the theories for calculating the *bearing capacity* of soil for construction of *shallow foundations.*
- **Chapter 13.** *Stability of various types of slopes* is the subject of this chapter. The concept of shear strength of soil developed in Chapter 9 is also utilized in this chapter.
- **Chapter 14.** Disposal of solid waste is a major problem in present-day society. Preparation of *clay liners* and the use of *geosynthetics* in the preparation of solid waste disposal sites are presented in this chapter.
- **Chapter 15.** Various techniques for *field exploration of soil* at proposed construction sites are described in this chapter. Such field exploration is a major prerequisite for the safe design and construction of various structures.

1.2 ROCK CYCLE AND THE ORIGIN OF SOIL

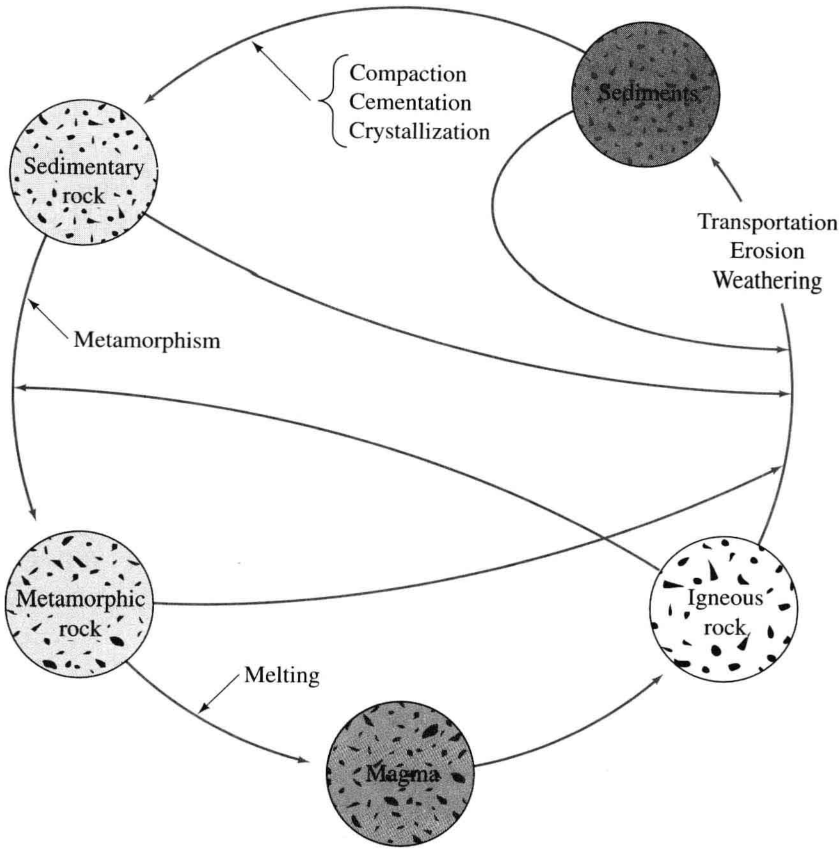
The mineral grains that form the solid phase of a soil aggregate are the product of rock weathering. The size of the individual grains varies over a wide range. Many of the physical properties of soil are dictated by the size, shape, and chemical composition of the grains. To better understand these factors, one must be familiar with the basic types of rock that form the earth's crust, the rock-forming minerals, and the weathering process.

On the basis of their mode of origin, rocks can be divided into three basic types: *igneous, sedimentary,* and *metamorphic.* Figure 1.1 shows a diagram of the formation cycle of different types of rock and the processes associated with them. This is called the *rock cycle.* Brief discussions of each element of the rock cycle follow.

Igneous Rock

Igneous rocks are formed by the solidification of molten *magma* ejected from deep within the earth's mantle. After ejection by either *fissure eruption* or *volcanic eruption,* some of the molten magma cools on the surface of the earth. Sometimes magma ceases its mobility below the earth's surface and cools to form intrusive igneous rocks that are called *plutons.* Intrusive rocks formed in the past may be exposed at the surface as a result of the continuous process of erosion of the materials that once covered them.

The types of igneous rock formed by the cooling of magma depend on factors



▼ **FIGURE 1.1** Rock cycle

such as the composition of the magma and the rate of cooling associated with it. After conducting several laboratory tests, Bowen (1922) was able to explain the relation of the rate of magma cooling to the formation of different types of rock. This explanation — known as *Bowen's reaction principle* — describes the sequence by which new minerals are formed as magma cools. The mineral crystals grow larger and some of them settle. The crystals that remain suspended in the liquid react with the remaining melt to form a new mineral at a lower temperature. This process continues until the entire body of melt is solidified. Bowen classified these reactions into two groups: (1) *discontinuous ferromagnesian reaction series,* in which the minerals formed are different in their chemical composition and crystalline structure, and (2) *continuous plagioclase feldspar reaction series,* in which the minerals formed have different chemical compositions with similar crystalline structures. Figure 1.2 shows Bowen's reaction series. The chemical compositions of the minerals are given in Table 1.1.