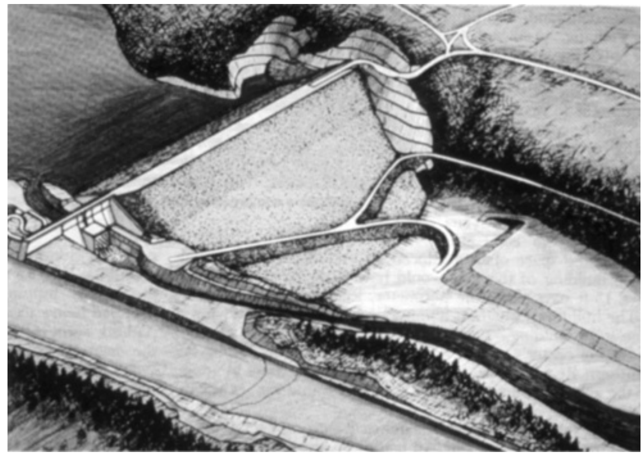
CHAPTER 1

Introduction



1.1 SOIL BEHAVIOR IN CIVIL AND ENVIRONMENTAL ENGINEERING

Civil and environmental engineering includes the conception, analysis, design, construction, operation, and maintenance of a diversity of structures, facilities, and systems. All are built on, in, or with soil or rock. The properties and behavior of these materials have major influences on the success, economy, and safety of the work. Geoengineers play a vital role in these projects and are also concerned with virtually all aspects of environmental control, including water resources, water pollution control, waste disposal and containment, and the mitigation of such natural disasters as floods, earthquakes, landslides, and volcanoes. Soils and their interactions with the environment are major considerations. Furthermore, detailed understanding of the behavior of earth materials is essential for mining, for energy resources development and recovery, and for scientific studies in virtually all the geosciences.

To deal properly with the earth materials associated with any problem and project requires knowledge, understanding, and appreciation of the importance of geology, materials science, materials testing, and mechanics. Geotechnical engineering is concerned with all of these. Environmental concerns—especially those related to groundwater, the safe disposal and containment of wastes, and the cleanup of contaminated sites—has spawned yet another area of specialization; namely, environmental geotechnics, wherein chemistry and biological science are important. Geochemical and microbiological phenomena impact the composition, properties, and stability of soils and rocks to degrees only recently beginning to be appreciated.

Students in civil engineering are often quite surprised, and sometimes quite confused, by their first course in engineering with soils. After studying statics, mechanics, and structural analysis and design, wherein problems are usually quite clear-cut and well defined, they are suddenly confronted with situations where this is no longer the case. A first course in soil mechanics may not, at least for the first half to two-thirds of the course, be mechanics at all. The reason for this is simple: Analyses and designs are useless if the boundary conditions and material properties are improperly defined.

Acquisition of the data needed for analysis and design on, in, and with soils and rocks can be far more difficult and uncertain than when dealing with other engineering materials and aboveground construction. There are at least three important reasons for this.

1. *No Clearly Defined Boundaries.* An embankment resting on a soil foundation is shown in Fig. 1.1*a*, and a cantilever beam fixed at one end is shown in Fig. 1.1*b*. The free body of the cantilever beam, Fig. 1.1*c*, is readily analyzed for reactions, shears, moments, and deflections using standard methods of structural analysis. However, what are the boundary conditions, and what is the free body for the embankment foundation?
2. *Variable and Unknown Material Properties.* The properties of most construction materials (e.g., steel, plastics, concrete, aluminum, and wood) are ordinarily known within rather narrow limits and usually can be specified to meet certain needs. Although this may be the case in construction using earth and rock fills, at least part of every geotechnical problem involves interactions with in situ soil and rock. No matter how extensive (and expensive) any boring and sampling program, only a very small percentage of the subsurface material is available for observation and testing. In most cases, more than one stratum is

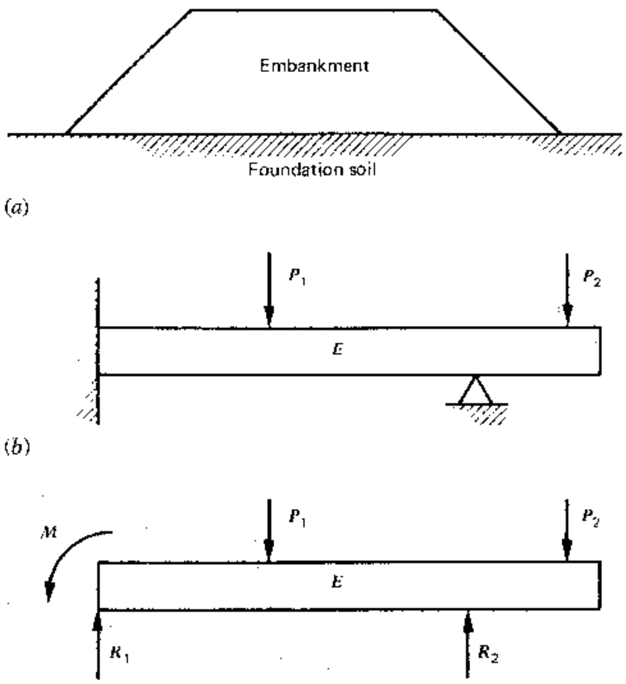


Figure 1.1 The problem of boundary conditions in geotechnical problems: (*a*) embankment on soil foundation, (*b*) cantilever beam, and (*c*) free body diagram for analysis of propped cantilever beam.

present, and conditions are nonhomogeneous and anisotropic.

3. *Stress and Time-Dependent Material Properties.* Soils, and also some rocks, have mechanical properties that depend on both the stress history and the present stress state. This is because the volume change, stress–strain, and strength properties depend on stress transmission between particles and particle groups. These stresses are, for the most part, generated by body forces and boundary stresses and not by internal forces of cohesion, as is the case for many other materials. In addition, the properties of most soils change with time after placement, exposure, and loading. Because of these stress and time dependencies, any given geotechnical problem may involve not just one or two but an almost infinite number of different materials.

Add to the above three factors the facts that soil and rock properties may be susceptible to influences from changes in temperature, pressure, water availability, and chemical and biological environment, and one might conclude that successful application of mechanics to earth materials is an almost hopeless proposition. It has been amply demonstrated, of course, that such is not the case; in fact, it is for these very reasons that geotechnical engineering offers such a great challenge for imaginative and creative work.

Modern theories of soil mechanics, the capabilities of modern computers and numerical analysis methods, and our improved knowledge of soil physics and chemistry make possible the solution of a great diversity of static and dynamic problems of stress deformation and stability, the transient and steady-state flow of fluids through the ground, and the long-term performance of earth systems. Nonetheless, our ability to analyze and compute often exceeds considerably our ability to understand, measure, and characterize a problem or process. Thus, understanding and the ability to conceptualize soil and rock behavior become all the more important.

The objectives of this book are to provide a basis for the understanding of the engineering properties and behavior of soils and the factors controlling changes with time and to indicate why this knowledge is important and how it is used in the solution of geotechnical and geoenvironmental problems.

It is easier to state what this book is not, rather than what it is. It is not a book on soil or rock mechanics; it is not a book on soil exploration or testing; it is not a book that teaches analysis or design; and it is not a book on geotechnical engineering practice. Excellent books and references dealing with each of these important areas are available. It is a book on the composition, structure, and behavior of soils as engineering materials. It is intended for students, researchers, and practicing engineers who seek a more in-depth knowledge of the nature and behavior of soils than is provided by classical and conventional treatments of soil mechanics and geotechnical engineering.

Here are some examples of the types of questions that are addressed in this book:

- What are soils composed of? Why?
- How does geological history influence soil properties?
- How are engineering properties and behavior related to composition?
- What is clay?
- Why are clays plastic?
- What are friction and cohesion?
- What is *effective* stress? Why is it important?
- Why do soils creep and exhibit stress relaxation?
- Why do some soils swell while others do not?
- Why does stability failure sometimes occur at stresses less than the measured strength?
- Why and how are soil properties changed by disturbance?

- How do changes in environmental conditions change properties?
- What are some practical consequences of the prolonged exposure of clay containment barriers to waste chemicals?
- What controls the rate of flow of water, heat, chemicals, and electricity through soils?
- How are the different types of flows through soil interrelated?
- Why is the residual strength of a soil often much less than its peak strength?
- How do soil properties change with time after deposition or densification and why?
- How do temperature changes influence the mechanical properties of soils?
- What is soil liquefaction, and why is it important?
- What causes frost heave, and how can it be prevented?
- What clay types are best suited for sealing waste repositories?
- What biological processes can occur in soils and why are they important in engineering problems?

Developing answers to questions such as these requires application of concepts from chemistry, geology, biology, materials science, and physics. Principles from these disciplines are introduced as necessary to develop background for the phenomena under study. It is assumed that the reader has a basic knowledge of applied mechanics and soil mechanics, as well as a general familiarity with the commonly used engineering properties of soils and their determination.

1.2 SCOPE AND ORGANIZATION

The topics covered in this book begin with consideration of soil formation in Chapter 2 and soil mineralogy and compositional analysis of soil in Chapter 3. Relationships between soil composition and engineering properties are developed in Chapter 4. Soil composition by itself is insufficient for quantification of soil properties for specific situations, because the soil fabric, that is, the arrangements of particles, particle groups, and pores, may play an equally important role. This topic is covered in Chapter 5.

Water may make up more than half the volume of a soil mass, it is attracted to soil particles, and the interactions between water and the soil surfaces influence the behavior. In addition, owing to the colloidal nature of clay particles, the types and concentrations of chemicals in a soil can influence significantly its behavior in a variety of ways. Soil water and the clay–water–electrolyte system are then analyzed in Chapter 6. An analysis of interparticle forces and total and effective stresses, with a discussion of why they are important, is given in Chapter 7.

The remaining chapters draw on the preceding developments for explanations of phenomena and soil properties of interest in geotechnical and geoenvironmental engineering. The formation of soil deposits, their resulting structures and relationships to geotechnical properties and stability are covered in Chapter 8. The next three chapters deal with those soil properties that are of primary importance to the solution of most geoengineering problems: the flows of fluids, chemicals, electricity, and heat and their consequences in Chapter 9; volume change behavior in Chapter 10; and deformation and strength and deformation behavior in Chapter 11. Finally, Chapter 12 on time effects on strength and deformation recognizes that soils are not inert, static materials, but rather how a given soil responds under different rates of loading or at some time in the future may be quite different than how it responds today.

1.3 GETTING STARTED

Find an article about a problem, a project, or issue that involves some aspect of geotechnical soil behavior as an important component. The article can be from the popular press, from a technical journal or magazine, such as the *Journal of Geotechnical and Geoenvironmental Engineering* of the American Society of Civil Engineers, *Géotechnique, The Canadian Geotechnical Journal, Soils and Foundations, ENR,* or elsewhere.

1. Read the article and prepare a one-page *informative abstract.* (An informative abstract summarizes the important ideas and conclusions. A *descriptive abstract,* on the other hand, simply states the article contents.)
2. Summarize the important geotechnical issues that are found in the article and write down what you believe you should know about to understand them well enough to solve the problem, resolve the issue, advise a client, and the like. In other words, what is in the article that you believe the subject matter in this book should prepare you to deal with? Do not exceed two pages.