SOILS AND FOUNDATIONS

THIRD EDITION

CHENG LIU · JACK B. EVETT

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To Kimmie, Jonathan, and Michele Liu
and
Linda, Susan, Scott, Sarah, and Sallie Evett

Preface

We have attempted to prepare an introductory, practical textbook for soil mechanics and foundations, which emphasizes design and practical applications that are supported by basic theory. Written in a simple and direct style that should make it very easy to read, understand, and grasp the subject matter, this book contains an abundance of both example problems in each chapter and work problems at the end of each chapter. Additionally, there are ample diagrams, charts, and illustrations throughout to help explain the subject matter better. In summary, we have tried to extract the salient and essential aspects of soils and foundations and to present these in a simple and straightforward manner.

The preceding paragraph, slightly modified, began the preface of both the first and second editions of *Soils and Foundations*, and we feel that it aptly relates to our basic philosophy in preparing this, the third edition. We have, however, updated material where applicable and added substantial amounts of new and essential material to the third edition. We believe the result is a much stronger, more comprehensive, and therefore better book.

The major feature of the third edition is the addition of substantial new material. Most significantly, we have included a totally new Chapter 5, entitled "Water in Soil." This much-needed chapter was suggested by a number of users of our first and second editions and covers flow of water in soils, capillary rise in soils, frost action in soils, and flow nets and seepage. We feel that this new chapter truly makes our book comprehensive in its coverage of soils and foundations.

We urge students using this book to review each illustration as it is cited and especially, to study each example problem very carefully. Believing that example problems are an extremely effective means of learning a subject such as soils and foundations, we have included an abundance of example problems, and we believe they will be very useful in mastering the material in the book.

We wish to express our sincere appreciation to Carlos G. Bell, formerly of The University of North Carolina at Charlotte, and to W. Kenneth Humphries, Dean of Engineering at the University of South Carolina, who read our original manuscript and offered many helpful suggestions. Also, we thank Donald Steila of the Department of Geography and Earth Science at The University of North Carolina at Charlotte, who reviewed Chapter 1. Finally, we thank those users of the previous editions of our book who communicated suggestions for improvements in the new edition.

We hope you will enjoy using the book. We would be pleased to receive your comments, suggestions, and/or criticisms.

Cheng Liu
Jack B. Evett
Charlotte, North Carolina

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Formation of Natural Soil Deposits

1-1 INTRODUCTION

Soil is more or less taken for granted by the average person. It makes up the ground on which we live, it is for growing crops, and it makes us dirty. Beyond these observations, most people are not overly concerned with soil. There are, however, some people who *are* deeply concerned. These include certain engineers as well as geologists, contractors, hydrologists, farmers, agronomists, soil chemists, and others.

Most structures of all types rest either directly or indirectly upon soil, and proper analysis of the soil and design of the structure's foundation are necessary to ensure a safe structure free of undue settling and/or collapse. A comprehensive knowledge of the soil in a specific location is also important in many other contexts. Thus study of soils should be an important component in the education of civil engineers.

Chapter 1 relates the formation of natural soil deposits; it describes the sources of soil. Chapter 2 introduces and defines various engineering properties of soils. Subsequent chapters deal with evaluation of these properties and with essential interrelationships of soil with structures of various types.

1-2 ROCKS—THE SOURCES OF SOILS

Soil is comprised of particles, large and small, and it may be necessary to include as "soil" not only solid matter but also air and water. Normally, the particles are the result of weathering (disintegration and decomposition) of rocks and decay of vegetation. Some soil particles may, over a period of time, become consolidated under the weight of overlying material and become rock. Even cycles of rock disintegrating to form soil, soil being consolidated under great pressure and heat to form rock, rock disintegrating to form soil, and so on, have occurred repeatedly throughout geologic time. The differentiation between soil and rock is not sharp; but from an engineering perspective, if material can be removed without blasting, it is usually considered to be "soil," whereas if blasting is required, it might be regarded as "rock."

Rocks can be classified into three basic groups that reflect their origin and/or method of formation: *igneous, sedimentary,* and *metamorphic.*

Igneous Rocks

Igneous rocks form when magma (molten matter) such as that produced by erupting volcanoes cools sufficiently to solidify. Volcanic action, normally referred to as *volcanism,* can occur beneath or upon the earth's surface. Volcanoes probably produced the minority of earth's igneous rocks, however. During the earth's formative stages, its surface may well have been largely molten, thus not requiring magma to move to the surface from great depths. It is likely that great amounts of Precambrian rock formed in this fashion.

Igneous rocks can be coarse-grained or fine-grained depending on whether cooling occurred slowly or rapidly. Relatively slow cooling occurs when magma is trapped in the crust below the earth's surface (such as at the core of a mountain range), while more rapid cooling occurs if the magma reaches the surface while molten (e.g., lava flow).

Of coarse-grained igneous rocks, the most common is *granite,* a hard rock rich in quartz, widely used as a construction material and for monuments. Others are *syenites, diorites,* and *gabbros.* Most common of the fined-grained igneous rocks is *basalt,* a hard, dark-colored rock rich in ferromagnesian minerals and often used in road construction. Others are *rhyolites* and *andesites.*

Being generally hard, dense, and durable, igneous rocks often make good construction materials. Also, they typically have high bearing capacities and therefore make good foundation material.

Sedimentary Rocks

Sedimentary rocks comprise the great majority of rocks found on the earth's surface. They are formed when mineral particles, fragmented rock particles, and remains of certain organisms are transported by wind, water, and ice (with water being the predominant transporting agent) and deposited, typically in layers, to form sediments. Over a period of time as layers accumulate at a site, pressure on lower layers resulting from the weight of overlying strata hardens the deposits, forming sedimentary rocks. Additionally, deposits may be solidified and cemented by certain minerals (e.g., silica, iron oxides, calcium carbonate). Sedimentary rocks can be identified easily when their layered appearance is observable. The most common sedimentary rocks are *shale, sandstone, limestone,* and *dolomite.*

Shale, the most abundant of the sedimentary rocks, is formed by consolidation of clays or silts. Organic matter or lime may also be present. Shales have a laminated structure and often exhibit a tendency to split along laminations. They can become soft and revert to clayey or silty material if soaked in water for a period of time. Shales vary in strength from soft (may be scratched with a fingernail and easily excavated) to hard (requiring explosives to excavate). Shales are sometimes referred to as "claystone" or "siltstone," depending on whether they were formed from clays or silts, respectively.

Sandstone, consisting primarily of quartz, is formed by pressure and the cementing action of silica (SiO_2), calcite (calcium carbonate, $CaCO_3$), iron oxide, or clay. Strength and durability of sandstones vary widely depending on the kind of cementing material and degree of cementation as well as the amount of pressure involved.

Limestone is sedimentary rock comprised primarily of calcium carbonate hardened underwater by cementing action (rather than pressure); it may contain some clays or organic materials within fissures or cavities. Like shales and sandstones, the strength of limestones varies considerably from soft to hard (and therefore durable), with actual strength depending largely on the rock's texture and degree of cementation. (A porous texture means lower strength.) Limestones occasionally have thin layers of sandstone and often contain fissures, cavities, and caverns, which may be empty or partly or fully filled with clay.

Dolomites are similar in grain structure and color to limestones and are, in fact, limestones in which the calcite ($CaCO_3$) interbonded with magnesium. Hence, the principal ingredient of dolomites is calcium magnesium carbonate [$CaMg(CO_3)_2$]. Dolomites and limestones can be differentiated by placing a drop of dilute hydrochloric acid on the rock. A quick reaction forming small white bubbles is indicative of limestone; no reaction, or a very slow one, means that the rock is dolomite.

As indicated above, the degrees of strength and hardness of sedimentary rocks are variable, and engineering usage of such rocks varies accordingly. Relatively hard shale makes a good foundation material. Sandstones are generally good construction materials. Limestone and dolomite, if strong, can be both good foundation and construction materials.

Metamorphic Rocks

Metamorphic rocks are much less common at the earth's surface than sedimentary ones. They are produced when sedimentary or igneous rocks literally change their texture and structure as well as mineral and chemical composition, as a result of heat, pressure, and shear. Granite metamorphoses to *gneiss,* a coarse-grained, banded rock. *Schist,* a medium- to coarse-grained rock, results from high-grade metamorphism of both basalt and shale. Low-grade metamorphism of shale produces *slate,* a fine-textured rock that splits into sheets. Sandstone is transformed to *quartzite,* a highly weather-resistant rock; and limestone and dolomite change to *marble,* a hard rock capable of being highly polished. Gneiss, schist, and slate are *foliated* (layered); quartzite and marble are *nonfoliated.*

Metamorphic rocks can be hard and strong if unweathered. They can be good construction materials—marble is often used for buildings and monuments—but foliated metamorphic rocks often contain planes of weakness that can diminish strength. Metamorphic rocks sometimes contain weak layers between very hard ones.

1-3 ROCK WEATHERING AND SOIL FORMATION

As related in the preceding section, soil particles are the result of weathering of rocks and organic decomposition. Weathering is achieved by *mechanical* (*physical*) and *chemical* means.

Mechanical weathering disintegrates rocks into small particles by temperature changes, frost action, rainfall, running water, wind, ice, abrasion, and other physical phenomena. These cause rock disintegration by breaking, grinding, crushing, and so on. The effect of temperature change is especially important. Rocks subjected to large temperature variations expand and contract like other materials, possibly causing structural deterioration and eventual breakdown of rock material. When temperatures drop below the freezing point, water trapped in rock crevices freezes, expands, and can thereby break rock apart. Smaller particles produced by mechanical weathering maintain the same chemical composition as the original rock.

Chemical weathering causes chemical decomposition of rock, which can drastically change its physical and chemical characteristics. This type of weathering results from reactions of rock minerals with oxygen, water, acids, salts, and so on. It may include such processes as oxidation, solution (strictly speaking, "solution" is a physical process), carbonation, leaching, and hydrolysis. These cause chemical weathering actions that can (1) increase volume of material, thereby causing subsequent material breakdown, (2) dissolve parts of rock matter, yielding voids that make remaining matter more susceptible to breaking, and (3) react with the cementing material, thereby loosening particles.

The type of soil produced by rock weathering is largely dependent on rock type. Of igneous rocks, granites tend to decompose to silty sands and sandy silts with some clays. Basalts and other rocks containing ferromagnesian minerals (but little or no silica) decompose primarily to clayey soils. With regard to sedimentary rocks, decomposed shales will produce clays and silts, while sandstones again become sandy soils. Weathered limestones can produce a variety of soil types, with fine-grained ones being common. Of metamorphic rocks, gneiss and schist generally decompose to form silt-sand soils, while slate tends more to clayey soils. Weathered marble often produces fine-grained soils; quartzite decomposes to more coarse-grained soils, including both sands and gravels.

1-4 SOIL DEPOSITS

Soils produced by rock weathering can be categorized according to where they are ultimately deposited relative to the location of the parent rock. Some soils remain where they were formed simply overlying the rock from which they came. These are known as *residual soils.* Others are transported from their place of origin and deposited elsewhere. They are called *transported soils.*

Residual soils have general characteristics that depend in part on the type of rock from which they came. Particle sizes, shapes, and composition can vary widely, as do depths of residual soil deposits—all depending on amount and type of weathering. The actual depth of a residual soil deposit depends on the rate at which rock weathering has occurred at the location and the presence or absence of any erosive agents that would have carried soil away.

Transported soils are formed when rock weathers at one site and the particles are moved to another location. Some common transporting agents for particles are (1) gravity, (2) running water, (3) glaciers, and (4) wind. Transported soils can therefore be categorized with regard to these agents as *gravity deposits, alluvial deposits, glacial deposits,* and *wind deposits.*

Gravity Deposits

Gravity deposits are soil deposits transported by the effect of gravity. A common example is the landslide. Gravity deposits, which are not generally carried very far, tend to be loosely compacted and otherwise exhibit little change in the general character of soil material as a result of being transported.

Alluvial Deposits

Alluvial deposits, having been transported by moving water, are found in the vicinity of rivers. Rainwater falling on land areas runs overland, eroding and transporting soil and rock particles as it goes, and eventually enters a creek or river. Continuously moving water can carry particles and deposit them a considerable distance from their former location. All soils carried and deposited by flowing water are called *alluvial deposits.* Lack of vegetation may allow enormous amounts of erosion leading to vast alluvial deposits (e.g., the Mississippi Delta).

Rivers are capable of transporting particles of all sizes, ranging from very fine silts in suspension to, in some cases, large boulders. The greater the velocity of river flow, the larger will be the size of particles that can be carried.

Hence, a sluggish creek may carry only fine-grained sediment while a flooding river transports all particle sizes, including large rocks. The relationship between river velocity and size of particle carried also affects the manner in which particles are deposited. As river velocity decreases, relatively larger particles settle and are deposited first. If the velocity decreases further, the next-larger-size particles settle out.

Alluvial deposits are often comprised of various soil types because different types of soil tend to mix as they are carried downstream. They do, however, tend to be layered, since settling rates are proportional to particle size.

The nature of soil can be greatly influenced by past alluvial transport and deposits. For example, at a location where a river's velocity decreases, such as when the channel widens significantly or its slope decreases substantially, coarser soil particles settle, forming submerged, flat, triangular deposits, known as *alluvial fans.* When flooding rivers, which normally carry heavy sediment load, overflow their banks, the overflowing water experiences a decrease in velocity. Larger particles, such as sands and gravels, tend to settle more quickly; their deposits can form *natural levees* along river banks (see Fig. 1-1). (These natural levees may someday be washed away by a more severe flood.) Smaller particles, such as silts and clays, settle less quickly, forming *floodplain deposits* in areas beyond the levees (Fig. 1-1). (However, smaller rivers can have floodplain deposits without forming levees.)

Another type of alluvial deposit occurs when rivers meander (i.e., follow a winding and turning course). As water moves through a channel bend, velocity along the inside edge decreases while that along the outer one increases. Consequently, particle erosion may occur along the outer edge with deposition along the inner edge. This action can, over a period of time, increase the amount of bend and significantly alter the river channel and adjacent land area. Eventually, the river may cut across a large bend, as shown in Fig. 1-2, leaving the old channel bend isolated. Water remaining in the isolated bend forms an *oxbow lake,* which can eventually fill in with floodplain deposits (usually silty and organic materials). Ultimately, the entire filled-in oxbow lake may be covered by additional floodplain deposits, leaving a hidden deposit of undesirable, high-plastic and/or organic silt, silty clay, and peat.

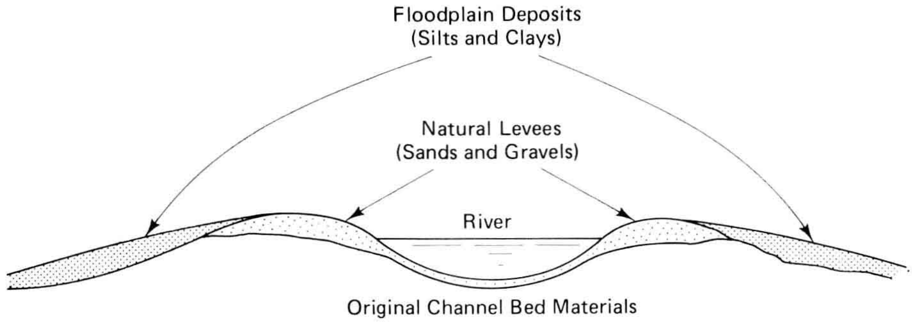

FIGURE 1-1 Natural levees and floodplain deposits.