Preface

Geotechnical engineering is that part of engineering that is concerned with the behavior of soils and rocks. It is a branch of civil engineering that deals with the application of the laws and principles of mechanics and hydraulics to engineering problems dealing with soil as an engineering material. Soil has many different meanings, depending on the field of study. From an engineering perspective, soils generally refer to sedimentary materials that have not been cemented and have not been subjected to high compressive stresses. It can include not only agronomic materials but also broken-up fragments of rock, volcanic ash, alluvium, Aeolian sand, glacial material, and any other residual or transported products of rock weathering. Difficulties naturally arise because there is no distinct dividing line between rock and soil. For example, to a geologist a given material may be classified as a formational rock because it belongs to a definite geologic environment, but to a geotechnical engineer it may be sufficiently weathered or friable that it could be classified as a soil.

Geotechnical engineering deals with the mechanical properties of the soil materials and with the application of the knowledge of these properties to engineering problems. In particular, it is concerned with the interaction of structures with their foundation material. This includes both conventional structures and also structures such as earth dams, embankments, and roads, which are themselves made of soils.

Like other branches of engineering, the major issues in geotechnical engineering are those of stability and serviceability. When a structure is built, it will apply a load to the underlying soil; if the load is too great, the strength of the soil will be exceeded and failure may ensue. It is important to realize that not only buildings are of concern; the failure of an earth dam can have catastrophic consequences, as can failures of natural and man-made slopes and excavations. Buildings or earth structures may be rendered unserviceable by excessive deformation of the ground, although it is usually differential settlement, where one side of a building settles more than the other, which is most damaging. Criteria for allowable settlement vary from case to case; for example, the settlement allowed in a factory that contains sensitive equipment is likely to be far more stringent than that for a warehouse. Another important aspect to be considered in geotechnical engineering practice is the effect of any construction on adjacent structures; for example, the excavation of a basement and construction of a large building will cause deformations in the surrounding ground and may have a detrimental effect on adjacent buildings or other structures such as railway tunnels.

Many of the problems arising in geotechnical engineering stem from the interaction of soil and water. For example, when a basement is excavated, water will tend to flow into the excavation. The question of how much water flows in needs to be answered so that suitable pumps can be obtained to keep the excavation dry. The flow of water can have detrimental effects on the stability of the excavation, and is often the initiator of landslides in natural and man-made slopes. Some of the effects associated with
the interaction of soil and water are quite subtle; for example, if an earthquake occurs, then a loose soil deposit will tend to compress causing the water pressures to rise. If the water pressures should increase so that they become greater than the stress due to the weight of the overlying soil, then a quicksand condition will develop and buildings founded on this soil may fail.

Geotechnical engineering differs from other branches of engineering in that generally there is little control over the material properties; we have to make do with the soil at the site and this is often highly variable. By taking samples at a few scattered locations, we have to determine the soil properties and their variability. And so knowledge of the site geology and geological processes is essential to successful geotechnical engineering practice.

The scope of geotechnical engineering is very broad. The subject has such a wide range of topics and concepts that no one textbook can possibly meet the needs of all students. Most of the existing books have been written solely either for engineering students or for students pursuing technology programs. Some books consequently stress the theory while others, particularly those used in the technology programs, which are more practice-oriented, lay more emphasis on the application of the principles. This book is an attempt to bridge the gap between these two extremes by arranging the available and appropriate sources in a comprehensive manner so as to meet the needs of students in both engineering and technology programs.

The word 'technology' in the title is to emphasize the knowledge, skills, and processes required in geotechnical engineering practice which the text aims to provide. The book is therefore suitable for use as a textbook for students in civil engineering in the universities and various engineering technology programs in the polytechnics and colleges of technology. The latter will include the 2-year National Diploma (ND), Associate Degree, and 4-year (HND) programs in civil engineering, building, and construction technology. In addition, it would be useful for students in other disciplines such as architecture, geology, geography, agriculture, and so on. Additionally, the book would also serve the needs of geotechnical and civil engineering practitioners, contractors, architects, and builders as a reference material.

The book is the outcome of several years of teaching soil mechanics, foundation engineering, and geotechnical engineering at both the university and polytechnics in Nigeria and abroad. Most of the materials have consequently been taken essentially from class notes, which have been developed from published literature and have been reviewed several times over the years in light of new information and changing technology. The book is intended to provide an accurate, representative, logical, and properly sequenced coverage of the subject of geotechnical engineering with emphasis on theory (the fundamentals of soil mechanics), technology, and practice. The theory aspect is focused primarily on an elementary treatment of the analysis of soil masses using classical elasticity and plasticity theories in recognition that analysis is a means and not an end in itself since the primary objective of the geotechnical engineer is to design and not just to analyze. The author believes that a student can never fully benefit from analytical thinking unless he correlates the thinking with a parallel study of engineering design and practice. By so doing, the student develops his judgement and perception, his imagination and creativity: in short, his ability to synthesize which is particularly important in geotechnical engineering. For geotechnical engineering, unlike most other engineering disciplines, requires a lot of educated judgement to apply the theories and associated equations to the evaluation of soils and foundation design. Much progress can be made when the principles and their limitations are learned together within the context of engineering application.

The text comprises of 12 chapters with illustrative example problems, sets of practice problems, and a number of appendices. The first three chapters deal with the genesis, morphology, index properties, and classification of soils. Chapter 1 traces the genesis of Geotechnical Engineering and its development,
practice, and importance as a subdivision of Civil Engineering. The chapter further explains the nature, origin, and types of soils, weathering and its agents and factors affecting it with particular emphasis on tropical weathering and laterization, and ends with a brief discussion of soil maps and geotechnical mapping of project sites. The types of map that may be prepared for engineering or environmental purposes are many and varied and can be categorized on the basis of purpose, content, and scale.

Chapter 2 deals mostly with engineering geology, which is especially helpful for readers who have not taken a geology course before and is a good review for those who have. Most civil engineering projects are built on soil or rock and are constructed solely or partly of these materials. This chapter provides engineers with a good knowledge of the type and characteristics of the terrain on which such projects are to be constructed in order to achieve optimum safety and economic performance. The earth’s crust, which is of interest to geotechnical engineers, is made up of rocks and the so-called unconsolidated sediments composed chiefly of solid mineral particles derived primarily from the physical and chemical weathering of rocks. The concepts of plate tectonics and geologic and soil structures are used to explain the geological processes in the earth. Mineralogy is the primary factor controlling the size, shape, and properties of soil particles. It also determines the possible ranges of physical and chemical properties of any given soil; therefore, a priori knowledge of what minerals are in a soil provides intuitive insight as to its behavior.

Chapter 3 is on identification and classification properties of soils. Soil texture and soil structure are both unique properties of soil that have profound effects on their behavior. The index properties commonly used for coarse-grained soils are grain size distribution and relative density. Index properties of fine-grained soils include consistency and sensitivity. These properties of a soil indicate the type and conditions of the soil and provide a relationship to its structural properties such as strength, compressibility, permeability, swelling potential, etc. Brief descriptions of some of these properties are given in this chapter. Towards the end, the chapter shows how these properties can be used for the classification of soils. The Soil Classification Systems considered include the following: Geological and Pedological Classification Systems (Classification by Origin and by Pedology), Morphological Classification Systems (Classification by Appearance and Textural Soil Classification System [USDA]), and Classification by Use (American Association of State Highway Transportation Officials System [AASHTO] and Unified Soil Classification System [USCS]).

Chapters 4 to 6 are on stress and strength analysis including the application of lateral pressure in the design of retaining walls, braced excavations, and flexible bulkheads. Chapter 4 is on stresses due to external loads. In this chapter, the mathematical definitions of stress and strain and the elasticity of an isotropic material are first treated. This is followed by the classical theory of Boussinesq for the stress in a semi-infinite, elastic, isotropic, and homogeneous continuum loaded normally on its upper plane surface by a concentrated load. The Boussinesq solution is later extended to analyze the stresses produced by a uniformly distributed load over a flexible circular foundation, rectangular loading, strip loading, line loading, triangular loading, and embankment loading. The case of irregular loading using the Newmark’s Chart is also considered. The settlement of a foundation under external loadings by the use of both the Boussinesq theory and the semi-empirical strain influence factor method proposed by Schmertmann et al. (1978) are considered.

Chapter 5 is on shear strength of soils. Strength theories which are used in geotechnical engineering derive essentially from the classical theories of elasticity and plasticity. Such theories are usually modified when used by soil engineers in recognition of the discrete and multi-phase nature of soil deposits. The generalized elasticity equations obtained in Chapter 4 are modified for a state of plane stress; and
the principal stresses and maximum shear stresses are determined by transformation of stresses either algebraically or graphically using Mohr’s circle. The Mohr-Coulomb theory is then used to analyze the strength characteristics of soils. The strength parameters (drained and undrained) can be measured in the laboratory using the Direct shear, the Triaxial, and the Unconfined Compression tests. In-situ methods for determining shear strength of soils include the Standard Penetration Test (SPT), the Dutch Cone, Vane Shear Test, the California Bearing Ratio (CBR) test. The typical behaviors of sand and clay in shear are analyzed. Skempton’s semi-empirical equation is used for calculating the pore water pressure change from axisymmetric total stress changes under undrained situations. The chapter introduces the critical state concept developed by Roscoe, Schofield, and Wroth (1958) in interpreting the Mohr-Coulumb failure criterion. The concept relates effective stresses and void ratio. The stress field is the surface where all effective stress paths reach or approach a line/surface called the “Critical State Line (CSL),” which is the ultimate condition of a soil in which the material deforms (plastic shearing) at constant volume under constant effective stresses. Finally the theory of creep is used in analyzing time-dependent deformation of soils. As an aid to understanding and visualizing rheological behavior, some viscoelastic models are introduced.

Chapter 6 deals with earth pressures and retaining structures. Retaining walls are structures used not only to retain earth but also water and other materials such as coal, ore, etc. where conditions do not permit the mass to assume its natural slope. In this chapter, after considering the types of retaining wall, earth pressure theories are developed in estimating the lateral pressure exerted by the soil on a retaining structure for at-rest, active, and passive cases. The effect of sloping backfill, wall friction, surcharge load, point loads, line loads, and strip loads are analyzed. Karl Culmann’s graphical method can be used for determining both active and passive earth pressures. The analysis of braced excavations, sheet piles, and anchored sheet pile walls are considered and practical considerations in the design of retaining walls are treated. They include saturated backfill, wall friction, stability both external and internal, bearing capacity, and proportioning the dimensions of the retaining wall. Finally, a brief treatment of earth pressure on underground structures is included.

Chapters 7 and 8 explain the process, theory, and associated volumetric changes of water migration (both steady state and transient) in soils. Chapter 7 is devoted to seepage and groundwater flow. Water in soil exists in a variety of forms, affects its engineering properties, and plays a very important role in all soil mechanics problems. The effects caused by the presence of water whether at rest or when moving through the pores of the soil must therefore be properly understood. Capillarity and both saturated and unsaturated flows are considered. Methods of measuring soil suction and the hydraulic conductivity of soils in the laboratory and in-situ are highlighted. The chapter considers the permeability of stratified deposits, effective stress, and seepage pressures. Using Darcy’s law and other assumptions, the basic flow equation is derived. Analytical and graphical (flow nets) methods for solving the Laplace equation are developed. Kozeny’s analysis of seepage through earth dam sections using the basic parabola is introduced and the Casagrande constructions are illustrated for some homogeneous earth dams with different discharge slopes. Seepage in soils with transverse isotropy and through soils with nonhomogeneous sections are analyzed. The chapter ends with a consideration of the mechanics of piping, filter, and its design.

Chapter 8 is on the compressibility and consolidation of soils. When stress is applied to a soil sample, its volume decreases due to either compression of the solid soil particles, or compression of water and air within the voids, or an escape of water and air from the voids. The solid particles and the pore water are relatively incompressible and therefore the decrease in volume of a saturated soil mass when subjected
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to stress increase is due almost entirely to an escape of water from the voids. The process is time-depen-
dent and is referred to as consolidation. The total compression of soil under load is composed of three
components (i.e. elastic settlement, primary consolidation settlement, and secondary compression). The
consolidation component is time-dependent and its analysis is usually based on Terzaghi’s theory. The
chapter considers the consolidation characteristics of a soil and their experimental determination. The
coefficient of consolidation can be determined by the Casagrande Logarithm-of-Time Fitting Method
or the Taylor Square-Root of Time Method. The concepts of preconsolidation and overconsolidation are
discussed while ways of determining the preconsolidation pressure, compression index, precompression
index, and the coefficient of volume compressibility are explained. Ways to compute the settlement
using coefficient of volume compressibility and e-σ methods for both normally consolidated and
overconsolidated soils are provided. The chapter also explains Schmertmann (1955) graphical procedure
for approximating the field compression index from the laboratory curve. It includes the derivation of
Terzaghi’s 1-D theory of consolidation and its solution using both analytical and graphical methods.
Finally, the phenomenon and way of computing the secondary compression index are treated.

Chapters 9, 10, and 11 are on stability of earth masses, slopes and embankments, and the improve-
ment of soils by both mechanical and chemical stabilization among other methods. Chapter 9 is on
stability of slopes. The design of open-cut slopes and embankments, foundations, levees, and earth-dam
cross-sections is based primarily on stability considerations. There are many causes and types of earth
instability. There are also many ways of analyzing the stability of slopes. The chapter considers the limit
equilibrium approach, which aims essentially to determine a factor of safety, F, that would ensure a slope
does not fail. The chapter considers the analysis of stability of infinite slopes based on translational type
of failure and the analysis of finite slopes using the Swedish Method, Method of Slices, Bishop Simplified
Method, Friction Circle Method, and the Translational Method. The solution of equations developed
for the analysis of stability of slopes can be tedious and time consuming. A way of reducing the amount
of calculation required in slope stability studies is by use of charts based on geometric similarity. The
chapter discusses how Taylor (1948) and Janbu (1964) charts are used in stability analysis of slopes.
Procedures for φ = 0 soils, soils with φ > 0, and for infinite slopes are provided. There are many ways
to reduce the risk of instability in slopes. The methods used can be divided into three main categories,
namely: Geometrical Methods, which involve a change in the geometrical conditions of the slope aimed
at reducing or removing some of the weight tending to cause slipping; Hydrological Methods, which
include lowering of the ground water table, reduction of the water content of the soil, and reforestation;
and Chemical and Mechanical Stabilization methods, which include compaction, chemical stabilization,
and grouting. The methods cause an increase in the average shear strength of the soil. These are
discussed more fully in Chapter 10.

Chapter 10 deals with soil improvement and stabilization. It is often necessary to improve the prop-
erties of the soil whether as a foundation material or as a construction material because it is not suitable
for its intended purpose. The fundamental techniques for improving the properties of natural materials
are compaction, modification, stabilization, drainage, precompression, vibrocompaction, soil reinforce-
ment, which includes soil nailing, and the use of geotextiles. The principles and methods of compaction
are discussed: compaction parameters like maximum dry density and the optimum moisture content,
zero-air-voids curve for different degrees of saturation, factors affecting compaction. The chapter further
discusses field compaction and compaction equipment and the use of (a) the sand cone method, (b) the
rubber balloon method, (c) the oil method, (d) the proctor’s penetration method, and (e) the nuclear
method for compaction control in the field. There are many methods of stabilizing soils; one of which
is the addition of chemical admixtures. The chapter discusses stabilization by cement, lime, bitumen, fly ash, and pozzolanas, and the construction of stabilized soils. Other methods of stabilization including drainage, electro-osmosis, precompression, vibrofloatation, geotextiles, and soil reinforcement are discussed. Finally, the chapter briefly considers pavement design. The types and requirements of a pavement are considered. There are essentially two methods of design, namely semi-empirical method and rational method of design. The semi-empirical methods in use include the AASHTO guide, the CBR method, and the asphalt institute design method. The rational method of pavement design is based on the multi-layered elastic theory which assumes that each layer of a pavement acts as a horizontally continuous, isotropic, homogeneous, and linearly elastic medium.

Chapter 11 is on foundations which are structural elements that transmit loads from structures to the underlying soil. There are two main classes of foundation, namely shallow foundations and deep foundations. In shallow foundations, the depth of the footing (D) is generally equal to or less than the width (B) of the footing. Deep foundations are foundations where the depth of the footing (D) is greater than the width (B) of the footing. The choice of the appropriate type of foundation is governed by some important factors such as the nature of the structure, the loads exerted by the structure, the subsoil characteristics, and the allotted cost of foundations. The primary design concerns of foundations are settlement and bearing capacity. The design must also take into consideration the requirements of safety, dependability, serviceability, functional utility, and economy. The chapter considers the modes of failure and the methods of determining the ultimate bearing capacity of foundations. The methods of computing the bearing capacity include the presumptive analysis, analytical methods (theories of Terzaghi, Meyerhof, Vesc, and Hansen), plate bearing test, penetration test, and centrifuge test. The procedure and considerations in the design of shallow foundation are discussed. The chapter examines the types, situations calling for the use, advantages and disadvantages, load-carrying capacity, and design of deep foundations. The efficiency of the group of deep foundations is discussed. The group capacity can be determined by the use of empirical formulas (efficiency method, field’s method) and by the rational (equivalent) method. Negative skin friction, its causes, capacity, and ways of reducing its effect are considered.

Chapter 12, the last chapter, is on site characterization and subsurface investigation. A good knowledge about a site including its subsurface conditions is very important in its safe and economical development. It is therefore an essential preliminary to the construction of any civil engineering works. This chapter outlines the objectives of site characterization and the general objectives of geotechnical investigation. Field investigation is usually performed in three phases: fact-finding and geological survey, reconnaissance exploration, and detailed subsurface investigation. The stages in a full exploratory program normally comprises of site exploration which includes desk study and site reconnaissance, preliminary exploration or sectioning (boring, sampling, and field tests), detailed exploration (undisturbed sampling and in-situ tests), laboratory measurements of soil properties, analysis of results, and soil exploration report. There could still be special exploration for large undisturbed samples should the need arise. Methods of sample recovery include test pits, continuous flight auger, split-spoon/SPT sampler, Shelby tube sampler, piston samplers, etc. The types of field tests and sampling methods should be based on the outcome of the desk study and site reconnaissance. The commonly used field testing methods for determining soil strength parameters during subsurface investigation include the penetrometer test, pressuremeter test, vane shear test, plate load test, etc. Geophysical techniques can contribute very greatly to the process of ground
investigation by allowing an assessment, in qualitative terms, of the lateral variability and vertical profiling of the near-surface materials beneath a site. Non-contacting techniques such as ground conductivity and gravity surveying as well as some surface techniques like electrical resistivity traversing are very useful in this regard. Some of these geophysical techniques are discussed in the chapter. Laboratory examination/verification and testing should be made of representative portions of the samples to establish appropriate soil parameters. Some soil parameters may be estimated by correlations. The results of the subsurface investigation and related testing, together with interpretations, discussions, and foundation recommendations, are usually presented in the form of a detailed soil report. Subsurface exploration is actually an exercise in reducing uncertainty/risk in a civil engineering project. It reduces the cost of the project. The more investigation and testing the less the total cost of the project.

In recognition of the trend towards the use of the International System of Units (SI), these units have been used throughout the book. However, since the imperial system of units is still being used extensively in many countries, some problems in the English units have been included in some chapters, and conversion tables are provided in the Appendix.

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