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# FOUNDATION DESIGN

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*Civil Engineering and*
*Engineering Mechanics Series*

*N. M. Newmark and W. J. Hall, Editors*

# PREFACE

This book is written primarily for two groups of men: practicing engineers who frequently or occasionally design and supervise the construction of foundations and advanced students preparing for engineering practice.

A wealth of information in theory of soil mechanics and in practice of foundation engineering has been developed. Such information has become a basic tool for engineers. At the present time, a practicing engineer can no longer be excused for unwarranted wastefulness or inadequacy of foundation design. Instead, he must be capable of dealing with soil and foundation problems under normal conditions with confidence. At the same time, he should be able to recognize the unusual conditions which require specialists' guidance.

The purpose of the book is to provide essential data for foundation design under ordinary circumstances. The material is presented for convenient application. The background theories are generally presented in concise forms of formulae or charts. Limitations of. these data are briefly pointed out to aid the student in recognizing the unusual conditions.

Since this book is a text on design and application, complicated and highly theoretical materials are excluded. For students desiring study of the theories, reference is made to texts of soil mechanics and the original articles.

The book is divided into three parts: Part 1, General Principles; Part 2, Foundations; Part 3, Retaining Structures. Part 1 contains the basic concepts and tools applicable to all foundations and retaining structures. For the convenience of practicing engineers, a brief review of some basic principles of soil mechanics is included. As a text book for the course of foundation design, some portion of Part 1 may be omitted.

Parts 2 and 3 deal with common types of foundations and retaining structures. All pertinent data pertaining to one type of foundations or retaining structures are presented in one chapter, and, generally, a complete design procedure is itemized near the beginning of the chapter. When considered helpful to the reader, numerical examples are given which are designated thus DE 8–2, indicating Design Example 2 in Chapter 8.

Although the material in this book generally covers the more commonly used foundation practice, exception has been taken in presenting the treatise on combined footings and mat foundations. In addition to the conventional methods of design, highly theoretical analyses are also included. The reason for this is that the conventional methods do not furnish all the necessary information regarding the internal stresses of the footings and mat foundations.

The author acknowledges the use of many materials from various technical publications. The source of information is acknowledged by a key thus: (Terzaghi, 1955), which denotes that the book or article can be found in the References under the author's name (Terzaghi) and the year of publication (1955).

Grateful appreciation is due to Dr. George E. Triandafilidis, who has reviewed the manuscript and offered constructive criticism. The author is deeply indebted to Dr. Ralph B. Peck whose teaching in foundation engineering has bestowed upon the author the basic philosophy in engineering practice. The manuscript was also reviewed by Dr. N. M. Newmark, Head of Civil Engineering Department, University of Illinois, and Dr. K. H. Chu, Professor of Civil Engineering, Illinois Institute of Technology.

The author also acknowledges the use of the illustrations for the following plates: Dr. D. U. Deere, University of Illinois, Plate 1; Mr. G. J. Higgins, Raymond Concrete Pile Co., Plates 2 and 8; Dr. J. Brinch Hansen, The Danish Geotechnical Institute, Plate 4; Moretrench Corp., Plate 5; Dr. G. E. Triandafilidis, University of Illinois, Plate 6; Commonwealth Edison Co., Plate 7; Calweld, Inc., Plate 9; *Engineering News-Record,* Plate 10; Messrs. E. E. White, Spencer, White, and Prentis, Plate 13.

The author is dedicating this book to his wife for her encouragement and assistance in preparing this work.

WAYNE C. TENG

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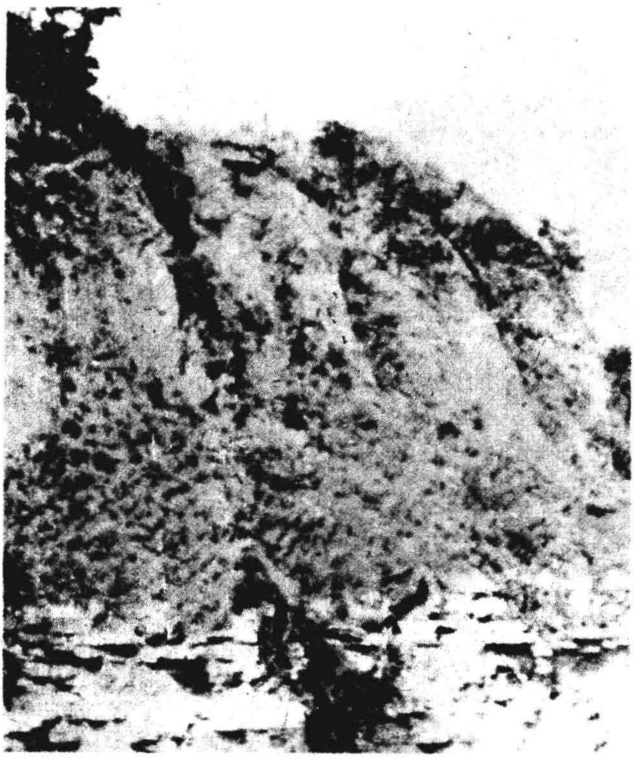
## PART ONE GENERAL PRINCIPLES

PART TWO FOUNDATIONS

# PART I
# GENERAL PRINCIPLES

*Plate One*



*A Profile of the Earth's Crust*

The earth's crust is made of natural materials ranging from loose and incoherent *soils* to massive and hard *rocks*. Within such a wide range there are innumerous varieties of earth materials, each of which differs from the others in different degrees. The physical properties of earth materials are further complicated by the presence of water. For a given job the pertinent engineeering properties of all earth materials encountered should be determined. This chapter summarizes the more significant properties involved in the common foundation practice.

# 1 SOILS, ROCKS, AND SOIL MOISTURE

## 1-1 Components of Soils

Soil contains three components, namely, air, water, and solid matter:

1. The air content of a soil has little engineering significance; therefore it is not commonly determined.
2. The water content (or moisture content) of a soil is defined as the ratio between the weight of water and the weight of the solid matter. The latter is equal to the weight of oven-dried soil. The water content influences the engineering properties of a soil.
3. The solid matter of a soil is primarily composed of mineral aggregates (soil grains). In some cases the soil also contains organic material. The mineral aggregates are derived from rocks as a result of rock weathering.

The intergranular space which is occupied by air and water (or water alone when saturated) is known as a void. The amount of voids in a soil is expressed by its *void ratio* which is the ratio between the volume of voids and the volume of solid matter. The term *porosity* (percentage of voids) is also used. It represents the ratio between the volume of voids and the total volume including solid matter and voids. The void ratio or porosity is an important soil property. For instance, a soil having an excessive amount of voids is weak, compressible, and pervious.

The relative amount of water in the voids is defined by the *degree of saturation* which is the ratio between the volume of water and the volume of voids. A soil is fully saturated, or at 100 per cent saturation, if all the voids are filled with water.

## 1-2 Relationships between Void Ratio, Water Content, and Unit Weight

Equations relating the void ratio, water content, unit weight, and other terms are very useful because in practice it is often necessary to compute one if the others are known. These relationships can be readily derived by definition of the terms. Notations to be used in the equations are:

$e$ = void ratio = volume of voids/volume of solid matter, expressed as a decimal;

$G$ = specific gravity of solid matter = 2.65 (average for common soil minerals);

$n$ = porosity = volume of voids/total volume, expressed as a decimal;

$w$ = water content = weight of water/weight of solid matter, expressed as a percentage;

$V$ = volume of soil sample;

$V_v$ = volume of voids in the soil sample;

$V_s$ = volume of solid matter in the soil sample;

$S$ = degree of saturation = volume of water/volume of voids, expressed as a percentage;

$\gamma_b$ = bulk unit weight = unit weight of soil plus the weight of water in the voids;

$\gamma_s$ = saturated unit weight of soil if water fills up all the voids;

$\gamma_d$ = dry unit weight = unit weight of oven-dried sample;

$\gamma_w$ = unit weight of water = 1 g/cc = 62.5 pcf (65 pcf for sea water);

$\gamma_G$ = unit weight of solid matter = $G\gamma_w$;

$\gamma'$ = buoyant weight, also known as effective weight, $\gamma_e = \gamma_s - \gamma_w$.

By definition,

$$e = \frac{V_v}{V_s} = \frac{V_v}{V - V_v} = \frac{V_v/V}{1 - V_v/V}$$

$$n = \frac{V_v}{V}$$

Therefore,

$$e = \frac{n}{1 - n} \tag{1-1a}$$

$$n = \frac{e}{1 + e} \tag{1-1b}$$

Referring to Fig. 1-1, if the volume of solid matter is unity, the volume of air plus water is $e$ by definition. The total volume of the sample is then $1 + e$.

The weight of the solid matter is equal to the volume of the solid matter × specific gravity × unit weight of water = $1 \times G \times \gamma_w = G\gamma_w$. By the same reasoning, the weight of water in the sample equals $eS\gamma_w$.

By definition again, water content is equal to the weight of water divided by the weight of solid matter. If the weight of solid matter is $G\gamma_w$, it follows that the weight of water is $wG\gamma_w$. From this, the following equations are derived.

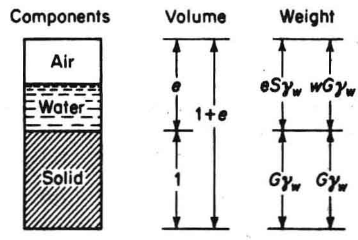


**Fig. 1-1** Components of soil.

$$eS = wG \tag{1-2}$$

Bulk unit weight
$$\gamma_b = \frac{eS + G}{1 + e}\gamma_w \tag{1-3}$$

$$= \frac{1 + w}{1 + e}G\gamma_w \tag{1-4}$$

Dry unit weight
$$\gamma_d = \frac{G\gamma_w}{1 + e} \tag{1-5}$$

Saturated unit weight
$$\gamma_s = \frac{G + e}{1 + e}\gamma_w \tag{1-6}$$

$$= \gamma_d(1 + w) \tag{1-7}$$

Buoyant unit weight
$$\gamma' = \gamma_s - \gamma_w$$

$$= \frac{G - 1}{1 + e}\gamma_w \tag{1-8}$$

## 1-3 Engineering Properties of Soils

The properties of soils are complex and variable. For a given engineering application, certain properties are more significant than others. The important engineering properties may be grouped into the following categories each of which is discussed in a separate section or sections.

| | |
|---|---|
| *Basic properties:* | Unit weight, void ratio, and water content (Sec. 1-1 & 1-2); Grain size distribution (Sec. 1-4) |
| *Strength:* | Shear strength (Sec. 1-5) |
| *Compressibility:* | Consolidation (Sec. 3-5) |
| *Seepage:* | Permeability (Sec. 1-6) |
| *Compaction characteristics:* | (Sec. 3-9) |

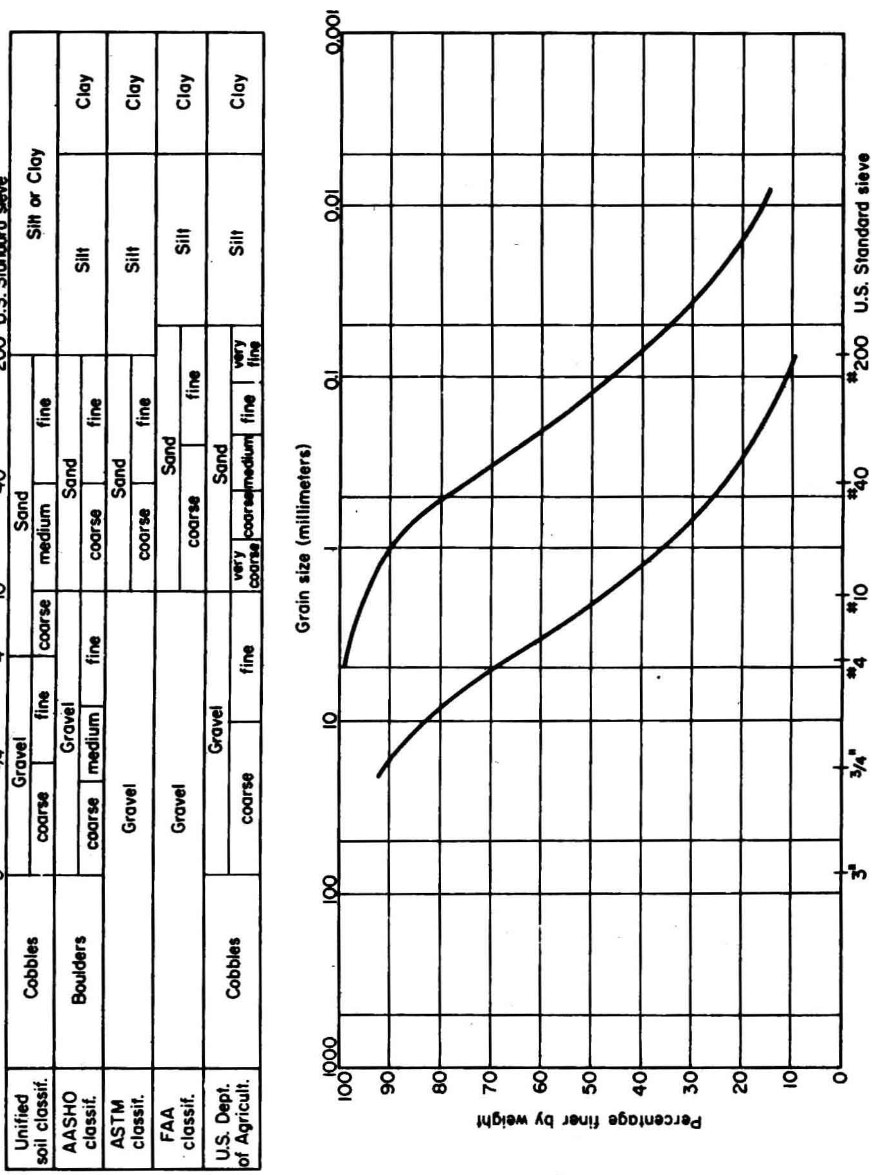



*Fig. 1-2* Grain size distribution.