Effect of soil Mechanics in foundation engineering

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Abstract: The practice of foundation engineering was largely empirical until 1925, when K. Terzaghi, often called the "father of soil mechanics" published his book "Erdbaumechanik auf bodenphysikalischer Grundlage." From this point onward, and with the years from 1950 onward being especially fruitful, foundation engineering has developed into a more rational approach. This is not to say that there is not still a large element of "art" and empiricism in the practice, but the currency tendency is to rely much more on laboratory testing and recognized principles of the behavior of elastoplastic solids than was done earlier. Much laboratory work in the area of soil behavior has been done and reported in geotechnical literature jr. recent years. Most of this work has been done on samples prepared under ideal conditions in the boratory. This tends to produce samples which are rather homogeneous, uniform, and generally lacking in geological aging so that those properties of anisotropy and cementation are often not produced. A few laboratories attempt to reproduce anisotropy, but the practice does not seem to be widespread at present. Reproducing aging and environmental processes in the laboratory to obtain natural cementation effects is generally too time-consuming to be practical. Tests on laboratory samples, however, constitute a large part of the data base on which empirical correlations and field predictions are made. When one takes into account the actual soil makeup, its geologically obtained properties, and the difficulties of obtaining samples which have sufficiently small amounts of disturbance that the resulting test data are reliable, test data on laboratory prepared samples may bear little resemblance to field performance.

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1- Introduction

No construction material has both engineering and physical properties which are more variable than the ground. These properties vary both laterally and vertically and often by large orders of magnitude. Those properties of particular interest to the foundation engineer include:

1- Strength parameters (stress-strain modulus, shear modulus, Poisson's cohesion, and angle of internal friction)
2- Compressibility indexes (for deformation/settlement)
3- Permeability
4- Gravimetric-volumetric data (unit weight, specific gravity, void ratio, water content, etc.)

Some knowledge about these properties allows the engineer to make esti mates for:

1. Bearing capacity
2. Settlements including both the amount and rate
3. Earth pressures (both vertical and lateral)
4. Pore pressures and dewatering quantities

Not all engineering properties of the soil are of equal importance in the design and construction of a given foundation. This review chapter will emphasize those soil mechanics principles most applicable for the analysis and design of foundations.

2- Review of study

Several problems are involved with laboratory testing or field samples, including:

1. Recovery of undisturbed samples
2. Small quantity of samples relative to the volume of soil involved
3. Limitations on laboratory test equipment (and sometimes of qualified personnel)

It is not difficult to see that "engineering judgment" will play a significant role in the practice of foundation engineering. The term engineering judgment is not being used in this context to give dignity to a "guess," regardless of how it may appear to the casual observer.

The proper application of engineering judgment requires that the foundation engineer have available a site profile, soil property data, and sufficient geological information to arrive at a safe, economical, and practical decision. In cases such as one-story load-bearing wall construction used for buildings of the department store, office, and service station type where the soil is relatively homogeneous, the necessary information may comprise only the boring logs from four or five relatively shallow exploratory borings. For a 10-story building the necessary information would normally have to be more. Where a 100-story building is involved, the amount of information would be very considerable and might cost on the order of 0.5 to 1 percent of the total construction cost. It should be obvious-that in any of the examples cited it would be helpful if the foundation engineer had provided recommendations and/or designs for previous projects near the current site[1].

3- Foundation Materials

The foundation engineer is concerned with the construction of some type of engineered structure on earth, generally above any water surface-but it may be below as for marine structures located under bodies of water, or rock. The earth is composed of a mixture of rock and soil, the latter being weathered or degraded rock. Water in varying amounts is found in the pores, or voids, of the soil and in more limited quantities in the cracks and pores of the rock. Air is also present in many of the void spaces but usually is not a significant factor in foundation design.

Rock will be defined as that naturally occurring material composed of mineral particles so firmly bonded together that relatively great effort is required to separate them (ie., blasting, heavy crushing, or ripping forces). Soil is defined as naturally occurring mineral aggregations which can be readily separated into elemental particles and in mass form contains numerous voids. These voids contain air, water, or organic materials in varying quantities. The elemental soil particles are formed from the decomposition of rock by mechanical (air, ice, wind, and water) and chemical processes.

Soil deposits can be described as residual or transported formations. A residual soil formation is one which has been formed at the current location by decomposition of the parent rock. A transported soil is one which has formed at one location and "as since been transported by wind, water, ice, or gravity to the current site. The terms residual and transported must be taken in the proper context, since many of the current residual soils are formed (or are being formed) from transported soil deposits of earlier geological periods. In many cases these earlier deposits have indurated to become rocks, and later uplifts have exposed this material (both rock and compressed soil) to a new onset of weathering. Areas in which these processes are ongoing include the Appalachian mountains, Piedmont regions, and much of the Plains area of the United States. Similar areas exist on other continents.

The initial reason for classifying soil deposits as transported or residual was that the latter soils tended (but not always) to have better engineering properties of strength and deformation. In this context it may be preferable to apply the classification of "transported soil" to a deposit of relative recent (geologically speaking) age and produced from the activity of recent glacial, windborne (loess), and (including ongoing) water action. A number of geological survey maps are available to locate areas where there is a high likelihood of encountering a transported soil deposit.

4- Soil Volume And Density Relationships

The more common soil definitions and mathematical relationships are presented in the following sections. Figure 2-1 illustrates and defines a number of the terms used in the following relationships.[3]

Void ratio e. The ratio of the volume of voids V. to the volume of soilds VS in a given volume of material, usually expressed as a decimal.

$$e = \frac{V_\nu}{V_s} \qquad (2\text{-}1)$$

Porosity n. The ratio of the volume of voids to the total volume V of a soil mass; may be expressed as a percentage or a decimal.

$$n = \frac{V_\upsilon}{V_t} \qquad (2\text{-}2)$$

Water content w. The ratio of the weight of water WW in a given soil mass to the
weight of sail solids WS in the same mass and expressed as a percentage.

$$w = \frac{W_W}{W_S} \times 100 \qquad (2\text{-}3)$$

Unit density p. The ratio of mass per unit of volume. In the Fps system the values are the same as unit weight following. The SI system gives units of kg/m3, but preferred usage units are g/cm^3 or kg/cm^3.

Unit weight y (as distinct from density). The ratio of the weight of soil to the corresponding volume with Units of force per unit volume. The general expression is

$$\gamma = \frac{W_t}{V_t} \qquad (2\text{-}4)$$

Commonly used units are pcf, kcf, or kN/m3. Dry unit weight is based on using the weight of soil solids WS in Eq. (2-4).

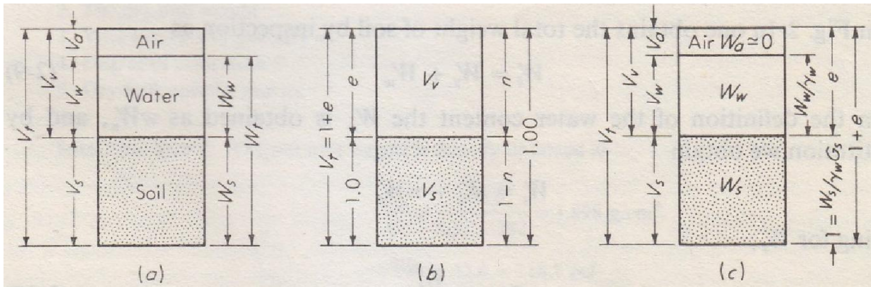

Figure 2-1 (a) Weight/volume relationships for a soil mass; (b) volume/void relationships; (c) volumes expressed in terms of weights and specific gravity.

The saturated unit weight is obtained when W, is based on a state when all the soil voids are filled with water.

Degree of saturation S. The ratio of the volume of water to the total volume of soil voids and expressed as a percentage.

$$S = \frac{V_w}{V_\upsilon} \times 100 \quad (2\text{-}5)$$

A "saturated" soil as obtained from beneath the water table may have a computed S of 95 to 100 percent.

Specific gravity G. The ratio of the unit weight of a material in air to the unit weight of distilled water at 4°C. No serious error in soils work is introduced at the usual laboratory temperature ranges of 15 to 25°C. The average specific gravity of a mass of soil grains GS is computed as

$$G_s = \frac{W_s / V_s}{W_w / V_w} = \frac{W_s / V_s}{\gamma_w} = \frac{\gamma_s}{\gamma_w} \quad (2\text{-}6)$$

In this equation yW = unit weight of water, usually taken as 1.00 g/cm^3.

These six basic definitions/equations are sufficient to develop any needed volumetric-gravimetric relationships for soil mechanics problems[2]. For example, a useful relationship between the void ratio e and porosity n can be obtained as follows (see Fig. 2-1b).

Since the volume values are symbolically given, let the volume of solids V_s = 1.00 and from Eq. (2-1) directly obtain e = V_υ, Placing these values on the left side of Fig. 2-1b gives V_t = 1 + e. Making the indicated substitutions into Eq. (2-2), obtain.

$$n = \frac{V_v}{V_t} = \frac{e}{1+e} \quad (2\text{-}7)$$

This equation can be directly solved for e to obtain

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

From Fig. 2-la one obtains the total weight of soil by inspection as

W_t=W_s+W_w (2-9)

From the definition of the water content the W„, is obtained as wW_s, and by substitution we obtain

W_t=W_s+wW_s

Solving for W_S,

$$W_s = \frac{W_t}{1+w} \quad (2\text{-}10)$$

Now dividing through by the total volume V and using the unit weight definition of Eq. (2-4) obtain the very useful relationship for dry unit weight as

$$\gamma_{dry} = \frac{\gamma_{wet}}{1+w}$$

A useful relationship for a saturated soil (S = 100 percent) can be obtained:

From Eq. (2-6): $W_w = V_w \gamma_w G_w$

From $V_t = 1 + \ell$ we have V_s=1.00 and $V_w = V_r = \ell$

Substitution: $W_w = e\gamma_w G_w$

Obtain from Eq. (2-6): $W_s = V_s \gamma_w G_s$

Take G_w. = 1.00 (negligible error), γ_W = 1.00, and use Eq. (2-3) to obtain

$\ell = wG_s$ (for S = 100 percent) (2-12)

With some additional manipulations one can obtain

$$\ell = \frac{w}{S} G_s$$

and

$$\gamma_{dry} = \frac{\gamma_w G_s}{1+e} \quad (2\text{-}13)$$

$$\gamma_{wet} = \frac{G_s \gamma_w (1+w)}{1+e} \quad (2\text{-}14)$$

Example 2-1 A cohesive soil specimen (from a split spoon; see Chap. 3 for method) was subjected to laboratory tests to obtain the following data: The moisture content w was 22.5 percent; Gs = 2.60; and to determine the approximate unit weight, a sample weighing 224.0 g was placed in a 500-cm^3 container with 382 cm^3 of water required to fill the container. The reader should note the use of nonstandard SI laboratory units.

5- Required

1. The wet unit weight
2. The dry unit weight

3. Void ratio ℓ and porosity n
4. Degree of saturation S
5. Dry-bulk specific gravity

SOLUTION Sten1 The wet unit weight is directly obtained as

$$\gamma_{wet} = \frac{\gamma_{wet}}{V_t} = \frac{224.0}{500-382} = 1.898\,g/cm^3$$
$$= 1.898 \times 62.4 = 118.5\,pcf$$
$$= 1.898 \times 9.807 = 18.61\,kN/m^3$$

Step 2 The dry unit weight is obtained using Eq. (2-11):

$$\gamma_{dry} = \frac{118.5}{1+0.225} = 96.7\,pcf$$
$$= \frac{18.61}{1.225} = 15.19\,kN/m^3$$

Step 3 The void ratio e and porosity n require some volume computations as follows:

$$V_s = \frac{W_s}{G_s\gamma_w} = \frac{1.898/1.225}{2.60(1.0)} = 0.596\,cm^3\,(or\,ft^3, m^3)$$
$$V_v = V_t - V_s = 1.000 - 0.596 = 0.404\,cm^3$$
$$e = \frac{V_v}{V_s} = \frac{0.404}{0.596} = 0.677$$
$$n = \frac{V_v}{V_t} = \frac{0.404}{1.00} = 0.404 \text{ (or 40.4 percent)}$$

Step 4 To find the degree of saturation S it will be necessary to find the volume of water in the voids. The weight of water W_w is the difference between the dry and wet weights; therefore,

$$W_W = 1.898 - \frac{1.898}{1.225} = 0.349 \text{ (in 1 cm}^3\text{ of soil)}$$

1.225

From Eq. (2-6) obtain V_w = W_W when using g and cm^3; therefore,

$$S = \frac{V_W}{V\nu} \times 100 = \frac{0.349}{0.404} \times 100 = 86.4 \text{ percent}$$

Step 5 The dry bulk specific gravity is obtained as (dimensionless)

$$G_b = \frac{\gamma_{dry}}{\gamma_w} = \frac{1.898/1.225}{1.00} = 1.549$$

6- Conclusion

1. To differentiate between gravel and sand, samples of each type of material can be prepared to include jars of fine, medium, and coarse sizes if the material is to be further subdivided and can be kept in the laboratory. The engineer simply makes a visual comparison.
2. To differentiate between fine sand and silt, both materials may appear as dust when dry. By placing a spoonful of the soil in a test tube of water and shaking, sand or silt can be detected, since the sand settles out in lZ min or less, whereas the silt takes 5 or more minutes to settle (i.e., water clears). One can observe relative thickness of the sediments for subclassification, as silty sand, etc.

U.S.		British (B.S.)		German DIN		French	
Sieve no.	mm	Sieve no.	mm	Sieve no.	mm	Sieve no.	mm
4	4.76	—		—		—	
10*	2.00	8*	2.057	—		34*	2.000
20	0.841	16	1.003	—		31	1.000
30	0.595	30	0.500	500	0.500	28	0.500
		36†	0.422	400†	0.400	27†	0.400
40†	0.420	—		—		—	
50	0.297	52	0.295	—		—	
60	0.250	60	0.251	250	0.250	25	0.250
80	0.177	85	0.178	160	0.160	23	0.160
100	0.149	100	0.152	125	0.125	22	0.125
200	0.074	200	0.076	80	0.080	20	0.080
270	0.053	300	0.053	50	0.050	18	0.050

* Breakpoint between sand and gravel.
† Use for Atterberg Limits.

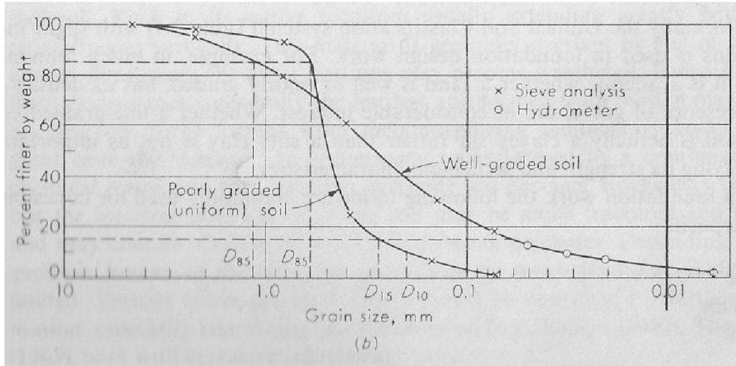

Figure 2-3 (a) Various standard sieve numbers and screen openings; Ih) grain-size-distribution curves.

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