



# Soil Properties and Other Strange Things for Non- Geotechnical Engineers

An Online Continuing Education Course for Engineers

**Course Number: G-2005**

**Credit: 2 Hours / 2 PDH / 2 CPD**

# Soil Properties and Other Strange Things for Non-Geotechnical Engineers

## Introduction

Geotechnical engineering is a fascinating subject. Unlike many engineering disciplines, it is not a pure science but rather it is an art form that requires both judgment and experience to arrive at a satisfactory solution. Unlike steel or concrete for instance, soil is quite different. For instance, geotechnical engineers can arrive at different but equally satisfactory recommendations for bearing capacity or settlement even when given the same information. Acceptable solutions are dependent upon many soil variables and the methods were used to predict the result.

The purpose of this course then, is to acquaint primarily the non-geotechnical engineer with some common properties, correlations and other interesting information about soil. The topics discussed herein have been simplified and are not exhaustive but they serve to demonstrate several principles. The interested reader should consult one of many textbooks on the topics discussed herein.

## Arriving at Acceptable Solutions

For a moment, consider that the deformation of a steel member under a compressive load is equivalent to the settlement of a foundation under its design load. Calculating the deformation of short sections of steel under an applied load is relatively straightforward and depends upon the applied load, area of the section, original length of the member and the elastic modulus of steel. All of these variables are easily acquired and require no interpretation.

On the other hand, calculating the theoretical settlement of foundations requires a great deal of interpretation and judgment. Factors such as the complexity of the soil profile, the engineering properties of the soil itself, the previous load history of the soil and the variation in groundwater level all play an important role in the outcome.

Is it strange then that geotechnical engineers can arrive at a different set of equally correct solutions to a problem even if they are given identical information? Since judgment is required along virtually every step of geotechnical design, differences in experience, judgment and methods of analysis can affect the conclusion. Soil properties are not specified and the engineer must develop the soil properties by explorations, testing and using the engineer's own experience and judgment. Since it is unlikely that anyone would have all of the information associated with a site, the engineer is faced with choosing simple models based on the limited data that is economically feasible to retrieve in order to predict the outcome.

An interesting study was undertaken in 1988 by Thomas F. Wolff to explore how judgment plays a role in geotechnical engineering design. In this study, a group of experienced practitioners and students were asked to design a shallow foundation (i.e. specify the size of footing required to carry the specified load but not exceed tolerable limits of settlement). Each participant was given identical information regarding loads and subsurface conditions. It was up to each participant to study the data, select appropriate values and methods to derive their conclusion.

The results of the study showed wide variability in the geotechnical values selected. In addition, interesting information was revealed about how the participants formulated their conclusions regarding values that were derived from the same set of subsurface information. Among the findings:

1. N-values, derived from the soil test boring logs, resulted in a range of values used in design. Participants selected values that ranged from 14 blows per foot to 26 blows per foot.
2. The soil friction angle selected by the participants ranged from 30 degrees to 35 degrees. However, no designer used a friction angle greater than 35 degrees even when correlations suggested a greater value.
3. Practitioners tend to be more conservative than students.

The study also showed that the participants recommended a wide range of footing sizes for design. The recommended footings ranged from 5 feet to 9.75 feet wide to support the same given load. Although each conclusion is correct, it reflects the results of many factors such as interpretation and selection of soil values, methods of analysis and the participant's experience.

### **How Does the Bearing Capacity Solution Work?**

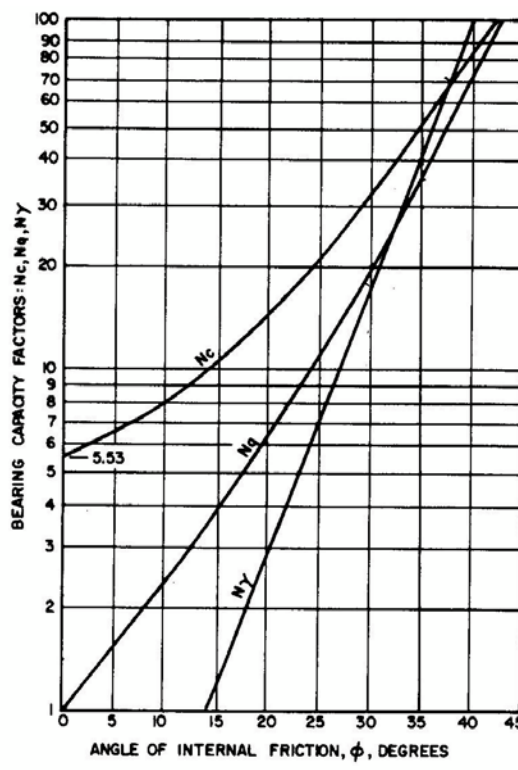
The discussion above revealed that there are many *correct* solutions to an assignment and the solution selected depends upon the practitioner. The method of analysis and selected values will change the results. Bearing capacity selection is a two phase approach. First the practitioner must select a safe bearing pressure to avoid catastrophic soil failure and second, the practitioner must select a bearing pressure that will not cause the foundation element to settle more than a tolerable amount. For shallow spread footings, total settlement is commonly limited to 1 inch although this depends upon the structure.

Bearing capacity is predicted based on commonly used bearing capacity equations. These methods vary from simple to complex. However, each are dependent upon the practitioner selecting soil values such as soil friction angle, soil cohesive strength and soil unit weight. The selection of soil values is also dependent upon the practitioners experience and how well the selected value represents actual conditions at the site.

Shallow footings can be described as square, rectangular, circular or continuous based on its shape. As an example of a simple equation, the ultimate bearing capacity ( $q_u$ ) of soil underlying a shallow strip footing can be calculated as:

$$q_u = 1/2\gamma B N_\gamma + c N_c + \gamma D N_q \quad (1.0)$$

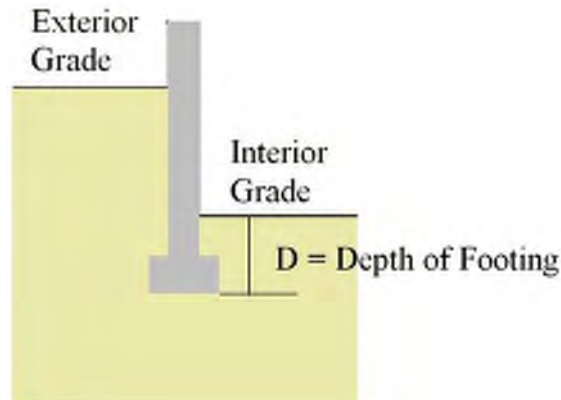
- $N_\gamma$ ,  $N_c$  and  $N_q$  are bearing capacity factors that depend only upon the soil friction angle ( $\phi$ ) as shown in Figure 1. The soil friction angle is commonly assigned by using charts or tables that correlate the penetration resistance obtained during the exploration program to the friction angle.



**Figure 1 – Bearing Capacity Factors**  
[Ref: NAVFAC DM-7]

- The cohesion term “ $c$ ” is obtained by laboratory or field-testing methods such as using a Torvane. Correlations using (Standard Penetration Test) SPT results are unreliable for assigning cohesion.
- The unit weight of the soil ( $\gamma$ ) is commonly based on a published correlation with soil classification.
- The value “ $B$ ” is the width of the footing and is the common symbol for the width.

- The value “D” is the depth of the footing below the lowest adjacent backfill. If the footing is backfilled equally on each side then D is the depth below grade. If the footing is backfilled unequally on each side as in a basement, then D is the lesser measurement.



**Figure 2 – Depth of Footing**

The original bearing capacity equation shown in Expression (1.0) applies to continuous footings where the length  $L$  is very much greater than the width  $B$ . Since many footings however are square, rectangular or circular, the equation for a continuous footing was modified to account for the shape of the footing. Semi-empirical shape factors have been applied to each of the three components of the bearing capacity equation resulting in the following modifications:

- Square Footing:  $q_u = 0.4\gamma B N_\gamma + 1.2c N_c + \gamma D N_q$
- Circular Footing:  $q_u = 0.3\gamma B N_\gamma + 1.2c N_c + \gamma D N_q$
- Rectangular Footing:  $q_u = 1/2(1 - 0.2B/L)\gamma B N_\gamma + 1.2c N_c + \gamma D N_q$

Later research improved the simple bearing capacity equations shown above by introducing a correction factor for shape of footing with load eccentricity, depth of footing, and inclination of load. Thus, the more complex *General Bearing Capacity Equation* has evolved as shown in Expression (2.0), which maintains the contribution from the three components identified earlier and incorporates appropriate correction factors for each term.

$$q_u = 1/2\gamma B N_\gamma (F_\gamma s F_\gamma d F_\gamma i) + c N_c (F_c s F_c d F_c i) + \gamma D N_q (F_q s F_q d F_q i) \quad (2.0)$$

The factors beginning with “F” are the correction factors for depth (d), shape (s) and inclination of load (i) applied to the original terms proposed in Expression (1.0).

Further refinements include correction factors for sloping ground and tilting of the foundation base.

The ultimate bearing capacity obtained when using the General Bearing Capacity Expression (2.0) gives a bearing pressure that is too large for footings having widths (B) greater than approximately 6 feet. Accordingly a correction factor can also be applied to the first term of the General Bearing Capacity equation.

The ultimate bearing capacity derived above is divided by a factor of safety, commonly 3, to arrive at an allowable bearing capacity. This value might be further refined when considering settlement.

The reader should also remember that no matter how simple or complex the method, the solution is also dependent upon the soil values selected by the practitioner, which is also subject to interpretation.

*The calculation of bearing capacity and correction factors can become quite involved. Since there is no clearly defined universal set of values and equations used by all practitioners, it would not be unusual for the calculated results to vary among practitioners even when given the same set of subsurface conditions.*

### **What's That Again?**

Water content (W<sub>c</sub>), sometimes referred to as moisture content (M<sub>c</sub>), can be greater than 100 percent. How is that? Does it seem unreal that water content could be greater than 100 percent especially when fully saturated soil is referred to as 100 percent saturated? Although it might be hard to visualize, you must first be aware that degree of saturation and water content are two completely different values and have different meaning. Thus, the correct answer is that it's all in the definition. Water content is defined as the weight of water divided by the weight of the solid particles. Percent saturation on the other hand is expressed as the volume of water divided by the volume of voids.

Since water content is not expressed in terms of total volume it is quite reasonable for the moisture content to be greater than 100 percent especially when considering an organic material such as peat. The weight of the vegetative particles (i.e. solids) in a unit volume of peat can be very much less than the weight of water included in that same unit volume. Peat can have a water content of several hundred percent.

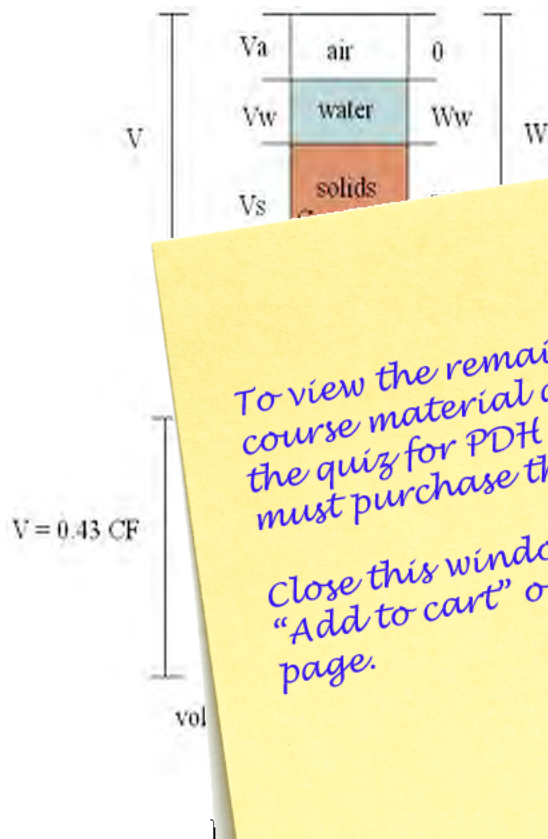
While water content is related to the weight of solid particles, the degree of saturation is related to volume. The volume of water can not be greater than the total available volume to hold the water (i.e. volume of voids). Therefore, degree of saturation is limited to 100 percent. Values such as water content and degree of saturation are discussed below.

## Weight-Volume Relationship of Soil

Soils are sediments and other unconsolidated material comprised of solid particles produced by disintegrations of rock and mixtures of such particles with organic substances. A volume of soil also contains liquid and gasses filling the void between the particles. Hence, a volume of soil is comprised of three phases: solid, liquid and gas.

Visualize for a moment a shovel full of soil. Likely, you will find solid particles such as sand of various sizes with voids between the particles. The voids are filled with air and quite possibly, some moisture. Imagine now that this sample is confined within a unit volume and all the solid particles are compressed together without any voids between the particles. Visualize that the water (moisture) contained in the sample collects on top of the solids and the air rides at the very top of the volume. This describes the three-phase diagram shown in Figure 3a. The diagram is presented in two dimensions rather than three.

In each of the definitions discussed, refer to the diagram shown in Figure 3a.



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