



Bearing Capacity of Shallow Footings

An Online Continuing Education Course for Engineers

Course Number: G-3003

Credit: 3 Hours / 3 PDH / 3 CPD

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Introduction

A foundation is that part of a structure which transmits a load directly into the underlying soil. If the soil conditions immediately below the structure are sufficiently strong and capable of supporting the required load, then shallow spread footings can be used to transmit the load. On the other hand, if the soil conditions are weak, then piles or piers are used to carry the loads into deeper, more suitable soil. This course is limited to the former and discusses the bearing capacity of shallow footings. Shallow footings are foundations where the depth of the footing is generally less than the width (B) of the footing.

Geotechnical engineering is the discipline that works with soil properties to establish the allowable bearing capacity of shallow footings. Geotechnical engineers are members of the design team who provide this information to those responsible for design. Often it is stated that geotechnical engineering is an “art form” rather than a science. Much of the geotechnical engineer’s guidance results from an interpretation of subsurface conditions based on an economically reasonable number of explorations. Based on experience and supported by theory, the geotechnical engineer interprets the information in order to predict foundation performance. The prediction usually ends up in a recommendation made by the geotechnical engineer in a report. Architects and structural engineers are probably most familiar with statements such as “The recommended allowable bearing pressure for shallow spread footings at this site is 4000 psf.” Where does this value come from and what was considered when establishing this value?

In this course, you will learn that there are two considerations for determining the allowable soil bearing pressure:

- Calculated theoretical bearing capacity and
- Magnitude of settlement

Thus, the magnitude of settlement that a footing might experience under the design load is an equally important criterion for establishing the allowable soil bearing pressure. In fact, for footings wider than 3 feet, settlement consideration often controls the magnitude of pressure applied to the soil.

At the end of this course you will have learned:

- How basic engineering values of soil are obtained and used in establishing bearing capacity.
- How the strength of soil determines bearing capacity.
- How settlement considerations determine bearing capacity.

Subsurface Explorations

Civil engineering projects such as buildings, bridges, earthen dams, and roadways require detailed subsurface information as part of the design process. The ground below us ultimately supports all structures and to be successful, the ground must not fail under the applied structural load.

The geotechnical engineer's task then is to explore the subsurface conditions at a project site and determine the capacity of the soil to carry the load without collapsing or experiencing intolerable movement.

Explorations are used to obtain samples of the soil for classification and testing purposes. Common forms of exploration methods include:

- Soil test borings with standard penetration testing.
- Cone penetrometer soundings with cone penetration testing.
- Test pit excavations.

Testing can be conducted in the laboratory with special samples retrieved for testing purposes. Testing completed as part of the exploration program with methods such as the Standard Penetration Test (SPT) or the Cone Penetration Test (CPT) is used to develop foundation design values. There is a wealth of published information that correlates the test results obtained from the SPT or CPT to certain applicable engineering properties and values. The results of field testing and laboratory testing, coupled with the geotechnical engineer's assessment and experience is usually sufficient to provide sound advice for a successful project.

Test pit excavations are useful for viewing soil type and stratification but have severe drawbacks. Test pits are limited to the depth that the machine can extend, they are impractical to use for explorations below the groundwater level and they produce a large disturbed area, often times within the proposed building footprint. Most importantly, they do not provide penetration test results like the SPT and CPT, which are often used as the basis for making bearing capacity recommendations.

The geotechnical engineer is interested in primarily two pieces of information from the exploration program that can be used to develop foundation recommendations. This information includes:

- Type of material encountered.
- Engineering values.

The type of soil is important because it provides an indication of how the material will react under load and whether or not the material is even sufficient to support shallow foundations. For instance, clay reacts quite differently than sand while peat or loose miscellaneous fill lying below the foundation is not suitable for supporting foundations.

Engineering properties of the soil are important because they provide information on the shear strength of the soil or the ability of the soil to carry the load as well as the settlement characteristics of the soil. Much of the information that the engineer uses is based on published values, results of past testing, empirical relationships and if necessary, the results of project specific testing.

When explorations are conducted, the information is recorded on a log. The log is a collection of pertinent information such as depth, description of the soil encountered, stratification of material and penetration resistance of the soil. By reviewing all of the logs from a particular site, the geotechnical engineer can formulate a three-dimensional picture of the subsurface conditions. Of course, this is based on taking individual explorations at specific locations on a site and interpreting soil conditions between the explorations. This is sometimes difficult because it involves interpreting what “Mother Nature” or others did without seeing the actual soil conditions between the exploration locations.

In short, the purpose of the exploration program is to provide sufficient site-specific information to enable the engineer to develop a picture of the subsurface conditions and select appropriate soil values applicable to the soils encountered. Often, the subsurface conditions are presented in a graphical geologic profile, which shows information from the log, soil strata and soil description.

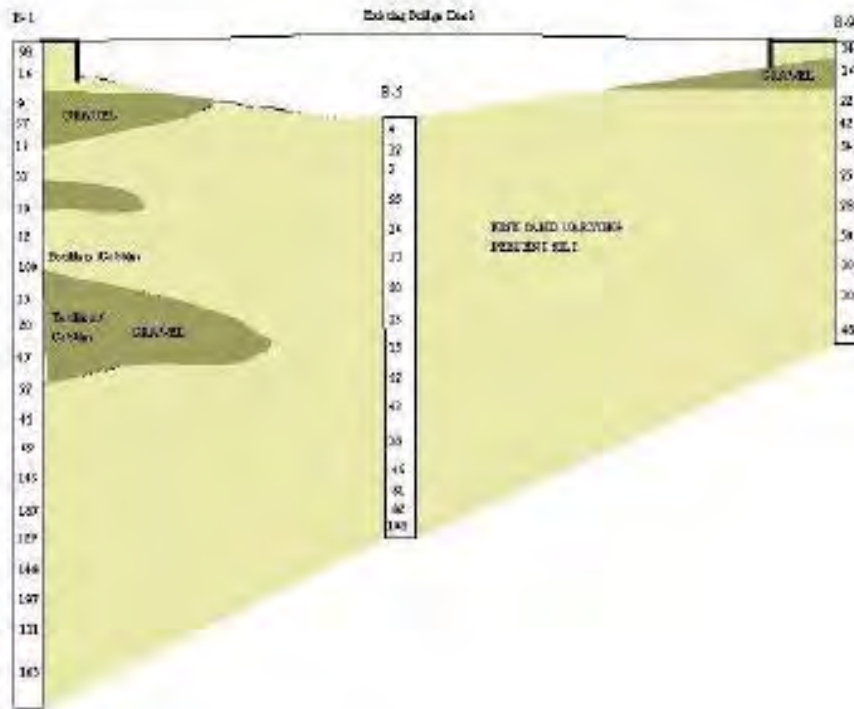


Figure 1 - Geologic Profile

The ability of soil to safely support a structure is of paramount importance. If the capacity of the soil is not sufficient then failure will occur. Failure can be defined as:

- A sudden, catastrophic movement where the ground below the structure collapses because its resistance to the load is less than the applied load. This relates to the capacity of the soil to safely carry the load (Criterion 1)
- Movement that is too great for the structure to accommodate. For instance, if the structure settles too much, cracks can develop in the frame and floor, windows and doors may not operate and the structure can become unsafe. This relates to the settlement potential of the soil under the applied load (Criterion 2).

Bearing capacity analysis is a two-part method used to determine the ability of the soil to support the required load in a safe manner without gross distortion resulting from objectionable settlement. The ultimate bearing capacity (q_u) is defined as that pressure causing a shear failure of the supporting soil lying immediately below and adjacent to the footing. The geotechnical engineer's task is to explore the subsurface conditions at a project site and determine the allowable capacity that the soil can carry without collapsing or experiencing intolerable movement. These precepts apply equally to deep

foundations as well as shallow foundations. However, in this course, we will focus only on shallow foundations.

Modes of Failure

Generally, three modes of failure have been identified:

- General Shear Failure: A continuous failure surface develops between the edge of the footing and the ground surface. This type of failure is characterized by heaving at the ground surface accompanied by tilting of the footing. It occurs in soil of low compressibility such as dense sand or stiff clay.
- Local Shear Failure: A condition where significant compression of the soil occurs but only slight heave occurs at the ground surface. Tilting of the foundation is not expected. This type of failure occurs in highly compressible soil and the ultimate bearing capacity is not well defined.
- Punching Shear Failure: A condition that occurs where there is relatively high compression of the soil underlying the footing with neither heaving at the ground surface nor tilting of the foundation. Large settlement is expected without a clearly defined ultimate bearing capacity. Punching will occur in low compressible soil if the foundation is located at a considerable depth below ground surface.

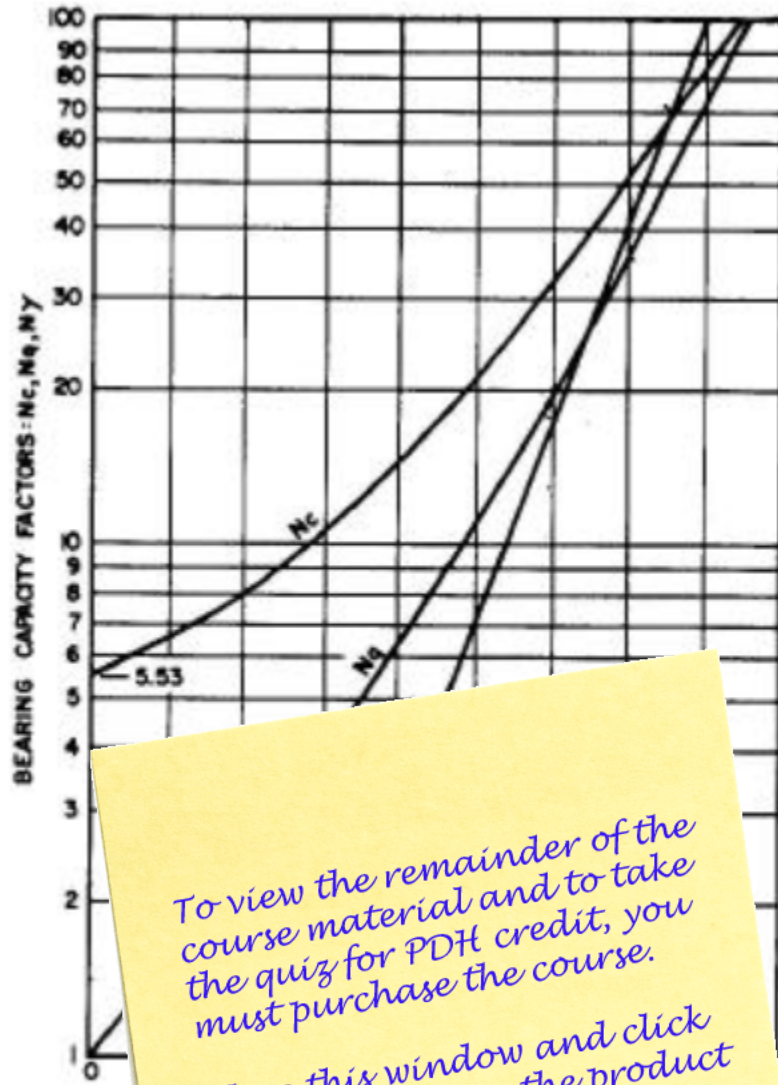
Bearing Capacity for Continuous Footings

First, we will discuss calculating the bearing capacity for continuous footings using the original equation developed for bearing capacity analysis and then we will expand this to discuss other shapes and conditions.

The failure mechanism for a narrow, continuous footing (length is \gg than width) assumes that a wedge of soil below the footing is pushed downward by the applied load thereby displacing soil adjacent to the wedge both laterally and upward. The ultimate bearing capacity therefore, is a function of the shear strength of the soil and the magnitude of the overlying surcharge due to the depth of footing (D). 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_y , N_c and N_q are bearing capacity factors that depend only upon the soil friction angle (ϕ) as shown in Figure 2. 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.



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- The cohesion term “c” is commonly assigned by using a Torvane. Correlations between penetration resistance and cohesion are also available.