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Bearing Capacity of Soils I

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CHAPTER 1

INTRODUCTION

1-1. **<u>Purpose and Scope.</u>** This course presents guidelines for calculation of the bearing capacity of soil under shallow and deep foundations supporting various types of structures and embankments. This information is generally applicable to foundation investigation and design conducted by Corps of Engineer agencies.

a. **Applicability.** Principles for evaluating bearing capacity presented in this course are applicable to numerous types of structures such as buildings and houses, towers and storage tanks, fills, embankments, and dams. These guidelines may be helpful in determining soils that will lead to bearing capacity failure or excessive settlements for given foundations and loads.

b. **Evaluation.** Bearing capacity evaluation is presented in Table 1-1. Consideration should be given to obtaining the services and advice of specialists and consultants in foundation design where foundation conditions are unusual or critical or structures are economically significant.

(1) Definitions, failure modes and factors that influence bearing capacity are given in Chapter 1.

(2) Evaluation of bearing capacity can be complicated by environmental and soil conditions. Some of these non-load related design considerations are given in Chapter 2.

(3) Laboratory and in situ methods of determining soil parameters required for analysis of bearing capacity are given in Chapter 3.

(4) Analysis of the bearing capacity of shallow foundations is given in Chapter 4 and of deep foundations is given in Chapter 5.

c. **Limitations.** This course presents estimates of obtaining the bearing capacity of shallow and deep foundations for certain soil and foundation conditions using well-established, approximate solutions of bearing capacity.

(1) This course excludes analysis of the bearing capacity of foundations in rock.

(2) This course excludes analysis of bearing capacity influenced by seismic forces.

d. **References.** Standard references pertaining to this course are listed in Appendix A, References. Each reference is identified in the text by the designated Government publication number or performing agency. Additional reading materials are listed in Appendix B, Bibliography.

TABLE 1-1

Bearing Capacity Evaluation

Step	Procedure
1	Evaluate the ultimate bearing capacity pressure q_u or bearing force Q_u using guidelines in this course and Equation 1-1.
2	Determine a reasonable factor of safety FS based on available subsurface surface information, variability of the soil, soil layering and strengths, type and importance of the structure and experience. FS will typically be between 2 and 4. Typical FS are given in Table 1-2.
3	Evaluate allowable bearing capacity q_a by dividing q_u by FS; i.e., $q_a = q_u/FS$, Equation 1-2a or $Q_a = Q_u/FS$, Equation 1-2b.
4	Perform settlement analysis when possible and adjust the bearing pressure until settlements are within tolerable limits. The resulting design bearing pressure q_d may be less than q_a. Settlement analysis is particularly needed when compressible layers are present beneath the depth of the zone of a potential bearing failure. Settlement analysis must be performed on important structures and those sensitive to settlement. Refer to EM 1110-1-1904 for settlement analysis of shallow foundations and embankments and EM 1110-2-2906, Reese, and O'Neill (1988) and Vanikar (1986) for settlement of deep foundations.

1-2. **Definitions.**

a. **Bearing Capacity.** Bearing capacity is the ability of soil to safely carry the pressure placed on the soil from any engineered structure without undergoing a shear failure with accompanying large settlements. Applying a bearing pressure which is safe with respect to failure does not ensure that settlement of the foundation will be within acceptable limits. Therefore, settlement analysis should generally be performed since most structures are sensitive to excessive settlement.

(1) **Ultimate Bearing Capacity.** The generally accepted method of bearing capacity analysis is to assume that the soil below the foundation along a critical plane of failure (slip path) is on the verge of failure and to calculate the bearing pressure applied by the foundation required to cause this failure condition. This is the ultimate bearing capacity q_u. The general equation is

$$q_u = cN_c\zeta_c + \frac{1}{2}B\gamma'_H N_\gamma \zeta_\gamma + \sigma'_D N_q \zeta_q \tag{1-1a}$$

$$Q_u = q_u BW \tag{1-1b}$$

where

q_u = ultimate bearing capacity pressure, kips per square foot (ksf)

Q_u = ultimate bearing capacity force, kips

c = soil cohesion (or undrained shear strength C_u), ksf B = foundation width, ft

W = foundation lateral length, ft

γ_H' = effective unit weight beneath foundation base within failure zone, kips/ft^3

σ_D' = effective soil or surcharge pressure at the foundation depth D, γ_D'D, ksf

γ_D' = effective unit weight of surcharge soil within depth D, kips/ft^3

N_c, N_γ, N_q = dimensionless bearing capacity factors for cohesion c, soil weight in the failure wedge, and surcharge q terms

$\zeta_c, \zeta_\gamma, \zeta_q$ = dimensionless correction factors for cohesion, soil weight in the failure wedge, and surcharge q terms accounting for foundation geometry and soil type

A description of factors that influence bearing capacity and calculation of γ_H' and γ_D' is given in section 1-4. Details for calculation of the dimensionless bearing capacity "N" and correction "ζ" factors are given in Chapter 4 for shallow foundations and in Chapter 5 for deep foundations.

(a) Bearing pressures exceeding the limiting shear resistance of the soil cause collapse of the structure which is usually accompanied by tilting. A bearing capacity failure results in very large downward movements of the structure, typically 0.5 ft to over 10 ft in magnitude. A bearing capacity failure of this type usually occurs within 1 day after the first full load is applied to the soil.

(b) Ultimate shear failure is seldom a controlling factor in design because few structures are able to tolerate the rather large deformations that occur in soil prior to failure. Excessive settlement and differential movement can cause distortion and cracking in structures, loss of freeboard and water retaining capacity of embankments and dams, misalignment of operating equipment, discomfort to occupants, and eventually structural failure. Therefore, settlement analyses must frequently be performed to establish the expected foundation settlement. Both total and differential settlement between critical parts of the structure must be compared with allowable values. Refer to EM 1110-1-1904 for further details.

(c) Calculation of the bearing pressure required for ultimate shear failure is useful where sufficient data are not available to perform a settlement analysis. A suitable safety factor can be applied to the calculated ultimate bearing pressure where sufficient experience and practice have established appropriate safety factors. Structures such as embankments and uniformly loaded tanks, silos, and mats founded on soft soils and designed to tolerate large settlements all may be susceptible to a base shear failure.

(2) **Allowable Bearing Capacity.** The allowable bearing capacity q_a is the ultimate bearing capacity q_u divided by an appropriate factor of safety FS,

$$q_a = \frac{q_u}{FS} \tag{1-2a}$$

$$Q_a = \frac{Q_u}{FS} \tag{1-2b}$$

FS is often determined to limit settlements to less than 1 inch and it is often in the range of 2 to 4.

(a) Settlement analysis should be performed to determine the maximum vertical foundation pressures which will keep settlements within the predetermined safe value for the given structure. The recommended design bearing pressure q_d or design bearing force Q_d could be less than q_a or Q_a due to settlement limitations.

(b) When practical, vertical pressures applied to supporting foundation soils which are pre-consolidated should be kept less than the maximum past pressure (pre-consolidation load) applied to the soil. This avoids the higher rate of settlement per unit pressure that occurs on the virgin consolidation settlement portion of the e-log p curve past the pre-consolidation pressure. The e-log p curve and pre-consolidation pressure are determined by performing laboratory consolidation tests, EM 1110-2-1906.

(3) **Factors of Safety.** Table 1-2 illustrates some factors of safety. These FS's are conservative and will generally limit settlement to acceptable values, but economy may be sacrificed in some cases.

(a) FS selected for design depends on the extent of information available on subsoil characteristics and their variability. A thorough and extensive subsoil investigation may permit use of smaller FS.

(b) FS should generally be $\geq$ 2.5 and never less than 2.

(c) FS in Table 1-2 for deep foundations are consistent with usual compression loads. Refer to EM 1110-2-2906 for FS to be used with other loads.

b. **Soil.** Soil is a mixture of irregularly shaped mineral particles of various sizes containing voids between particles. These voids may contain water if the soil is saturated, water and air if partly saturated, and air if dry. Under unusual conditions, such as sanitary landfills, gases other than air may be in the voids. The particles are a by-product of mechanical and chemical weathering of rock and described as gravels, sands, silts, and clays. Bearing capacity analysis requires a distinction between cohesive and cohesionless soils.

(1) **Cohesive Soil.** Cohesive soils are fine-grained materials consisting of silts, clays, and/or organic material. These soils exhibit low to high strength when unconfined and when air-dried depending on specific characteristics. Most cohesive soils are relatively impermeable compared with cohesionless soils. Some silts may have bonding agents between particles such as soluble salts or clay aggregates. Wetting of soluble agents bonding silt particles may cause settlement.

(2) **Cohesionless Soil.** Cohesionless soil is composed of granular or coarse- grained materials with visually detectable particle sizes and with little cohesion or adhesion between particles. These soils have little or no strength, particularly when dry, when unconfined and little or no cohesion when submerged. Strength occurs from internal friction when the material is confined. Apparent adhesion between particles in cohesionless soil may occur from capillary tension in the pore water. Cohesionless soils are usually relatively free draining compared with cohesive soils.

Purchase this course to see the remainder of the technical materials.