PDH-Pro.com

Bearing Capacity of Soils II

Course Number: GE-02-302

PDH: 3

Approved for: AK, AL, AR, DE, FL, GA, IA, IL, IN, KS, KY, LA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, SC, SD, TN, TX, UT, VA, VT, WI, WV, and WY

State Board Approvals

Florida Provider # 0009553 License #868
Indiana Continuing Education Provider #CE21800088
Maryland Approved Provider of Continuing Professional Competency
New Jersey Professional Competency Approval #24GP00025600
North Carolina Approved Sponsor #S-0695
NYSED Sponsor #274

How Our Written Courses Work

This document is the course text. You may review this material at your leisure before or after you purchase the course.
After the course has been purchased, review the technical material and then complete the quiz at your convenience.
A Certificate of Completion is available once you pass the exam (70% or greater). If a passing grade is not obtained, you may take the quiz as many times as necessary until a passing grade is obtained).
If you have any questions or technical difficulties, please call (508) 298-4787 or email us at admin@PDH Pro.com.

DEEP FOUNDATIONS

5-1. **Basic Considerations.** Deep foundations transfer loads from structures to acceptable bearing strata at some distance below the ground surface. These foundations are used when the required bearing capacity of shallow foundations cannot be obtained, settlement of shallow foundations is excessive, and shallow foundations are not economical. Deep foundations are also used to anchor structures against uplift forces and to assist in resisting lateral and overturning forces. Deep foundations may also be required for special situations such as expansive or collapsible soil and soil subject to erosion or scour.

a. **Description.** Bearing capacity analyses are performed to determine the diameter or cross-section, length, and number of drilled shafts or driven piles required to support the structure.

(1) **Drilled Shafts.** Drilled shafts are nondisplacement reinforced concrete deep foundation elements constructed in dry, cased, or slurry-filled boreholes. A properly constructed drilled shaft will not cause any heave or loss of ground near the shaft and will minimize vibration and soil disturbance. Dry holes may often be bored within 30 minutes leading to a rapidly constructed, economical foundation. Single drilled shafts may be built with large diameters and can extend to deep depths to support large loads. Analysis of the bearing capacity of drilled shafts is given in Section I.

(a) Lateral expansion and rebound of adjacent soil into the bored hole may decrease pore pressures. Heavily overconsolidated clays and shales may weaken and transfer some load to the shaft base where pore pressures may be positive. Methods presented in Section I for calculating bearing capacity in clays may be slightly unconservative, but the FS’s should provide an adequate margin of safety against overload.

(b) Rebound of soil at the bottom of the excavation and water collecting at the bottom of an open bore hole may reduce end bearing capacity and may require construction using slurry.

(c) Drilled shafts tend to be preferred to driven piles as the soil becomes harder, pile driving becomes difficult, and driving vibrations affect nearby structures. Good information concerning rock is required when drilled shafts are carried to rock. Rock that is more weathered or of lesser quality than expected may require shaft bases to be placed deeper than expected. Cost overruns can be significant unless good information is available.

(2) **Driven Piles.** Driven piles are displacement deep foundation elements driven into the ground causing the soil to be displaced and disturbed or remolded. Driving often temporarily increases pore pressures and reduces short term bearing capacity, but may increase long term bearing capacity. Driven piles are often constructed in groups to provide adequate bearing capacity. Analysis of the bearing capacity of driven piles and groups of driven piles is given in Section II.

(a) Driven piles are frequently used to support hydraulic structures such as locks and retaining walls and to support bridges and highway overpasses. Piles are also useful in flood areas with unreliable soils.

(b) Pile driving causes vibration with considerable noise and may interfere with the performance of nearby structures and operations. A preconstruction survey of nearby structures may be required.

(c) The cross-section and length of individual piles are restricted by the capacity of equipment to drive piles into the ground.

(d) Driven piles tend to densify cohesionless soils and may cause settlement of the surface, particularly if the soil is loose.

(e) Heave may occur at the surface when piles are driven into clay, but a net settlement may occur over the longterm. Soil heave will be greater in the direction toward which piles are placed and driven. The lateral extent of ground heave is approximately equal to the depth of the bottom of the clay layer.

(3) **Structural capacity.** Stresses applied to deep foundations during driving or by structural loads should be compared with the allowable stresses of materials carrying the load.

b. **Design Responsibility.** Selection of appropriate design and construction methods requires geotechnical and structural engineering skills. Knowledge of how a deep foundation interacts with the superstructure is provided by the structural engineer with soil response information provided by the geotechnical engineer. Useful soil-structure interaction analyses can then be performed of the pile-soil support system.

c. **Load Conditions.** Mechanisms of load transfer from the deep foundation to the soil are not well understood and complicate the analysis of deep foundations. Methods available and presented below for evaluating ultimate bearing capacity are approximate. Consequently, load tests are routinely performed for most projects, large or small, to determine actual bearing capacity and to evaluate performance. Load tests are not usually performed on drilled shafts carried to bedrock because of the large required loads and high cost.

(1) **Representation of Loads.** The applied loads may be separated into vertical and horizontal components that can be evaluated by soil-structure interaction analyses and computer-aided methods. Deep foundations must be designed and constructed to resist both applied vertical and lateral loads, Figure 5-1. The applied vertical load Q is supported by soil-shaft side friction Q_{su} and base resistance Q_{bu}. The applied lateral load T is carried by the adjacent lateral soil and structural resistance of the pile or drilled shaft in bending, Figure 5-2.

(a) Applied loads should be sufficiently less than the ultimate bearing capacity to avoid excessive vertical and lateral displacements of the pile or drilled shaft. Displacements should be limited to 1 inch or less.

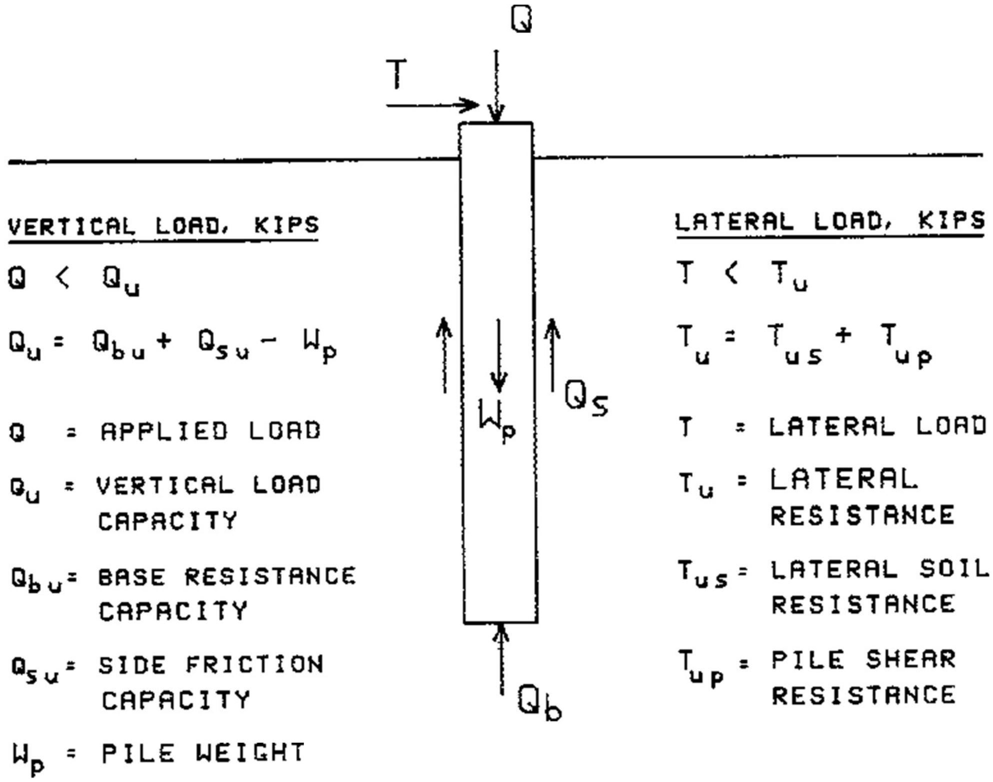

Figure 5-1. Support of deep foundations

(b) Factors of safety applied to the ultimate bearing capacity to obtain allowable loads are often 2 to 4. FS applied to estimations of the ultimate bearing capacity from static load test results should be 2.0. Otherwise, FS should be at least 3.0 for deep foundations in both clay and sand. FS should be 4 for deep foundations in multi-layer clay soils and clay with undrained shear strength $C_u > 6$ ksf.

(2) **Side Friction.** Development of soil-shaft side friction resisting vertical loads leads to relative movements between the soil and shaft. The maximum side friction is often developed after relative small displacements less than 0.5 inch. Side friction is limited by the adhesion between the shaft and the soil or else the shear strength of the adjacent soil, whichever is smaller.

(a) Side friction often contributes the most bearing capacity in practical situations unless the base is bearing on stiff shale or rock that is much stiffer and stronger than the overlying soil.

(b) Side friction is hard to accurately estimate, especially for foundations constructed in augered or partially jetted holes or foundations in stiff, fissured clays.

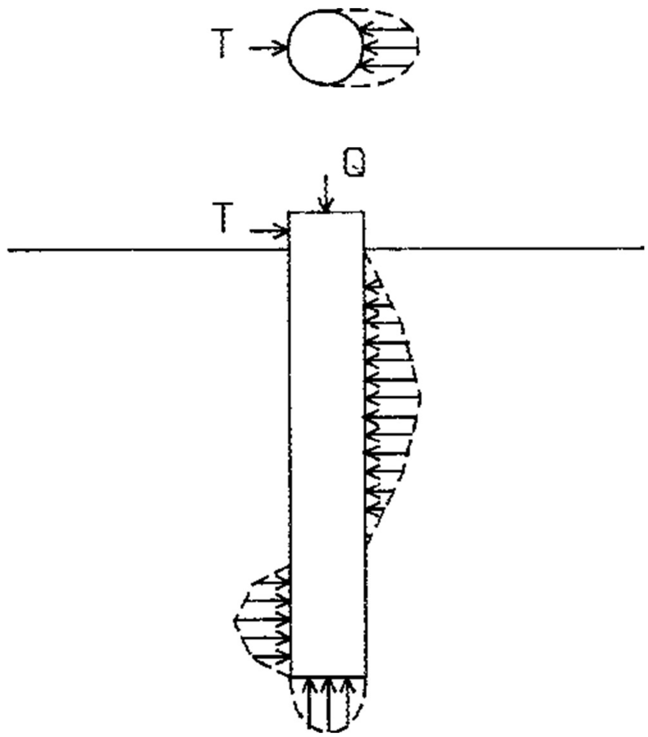

Figure 5-2. Earth pressure distribution T_{us} acting on a laterally loaded pile

(3) **Base Resistance.** Failure in end bearing normally consists of a punching shear at the tip. Applied vertical compressive loads may also lead to several inches of compression prior to a complete plunging failure. The full soil shear strength may not be mobilized beneath the pile tip and a well-defined failure load may not be observed when compression is significant.

Section I. Drilled Shafts

5-2. **Vertical Compressive Capacity of Single Shafts.** The approximate static load capacity of single drilled shafts from vertical applied compressive forces is

$$Q_u \approx Q_{bu} + Q_{su} - W_p \tag{5-1a}$$

$$Q_u \approx q_{bu} A_b + \sum_{i=1}^{n} Q_{sui} - W_p \tag{5-1b}$$

where

Q_u = ultimate drilled shaft or pile resistance, kips
Q_{bu} = ultimate end bearing resistance, kips
Q_{su} = ultimate skin friction, kips
q_{bu} = unit ultimate end bearing resistance, ksf
A_b = area of tip or base, ft^2
n = number of increments the pile is divided for analysis (referred to as a pile element, Figure C-1)

Q_{sui} = ultimate skin friction of pile element i, kips
W_p = pile weight, $\approx A_b \, L \, \gamma_p$ without enlarged base, kips
L = pile length, ft
γ_p = pile density, kips/ft^3

A pile may be visualized to consist of a number of elements as illustrated in Figure C-1, Appendix C, for the calculation of ultimate bearing capacity.

a. **End Bearing Capacity.** Ultimate end bearing resistance at the tip may be given as Equation 4-1 neglecting pile weight W_p

$$q_{bu} = c \cdot N_{cp} \cdot \zeta_{cp} + \sigma'_L \cdot N_{qp} \zeta_{qp} + \frac{B_b}{2} \cdot \gamma'_b \cdot N_{\gamma p} \cdot \zeta_{\gamma p} \qquad (5\text{-}2a)$$

where

c = cohesion of soil beneath the tip, ksf
σ'_L = effective soil vertical overburden pressure at pile base $\approx \gamma'_L \, L$, ksf
γ'_L = effective wet unit weight of soil along shaft length L, kips/ft^3
B_b = base diameter, ft
γ'_b = effective wet unit weight of soil in failure zone beneath base, kips/ft^3
$N_{cp}, N_{qp}, N_{\gamma p}$ = pile bearing capacity factors of cohesion, surcharge, and wedge components
$\zeta_{cp}, \zeta_{qp}, \zeta_{\gamma p}$ = pile soil and geometry correction factors of cohesion, surcharge, and wedge components

Methods for estimating end bearing capacity and correction factors of Equation 5-2a should consider that the bearing capacity reaches a limiting constant value after reaching a certain critical depth. Methods for estimating end bearing capacity from in situ tests are discussed in Section II on driven piles.

(1) **Critical Depth.** The effective vertical stress appears to become constant after some limiting or critical depth Lc, perhaps from arching of soil adjacent to the shaft length. The critical depth ratio Lc/B where B is the shaft diameter may be found from Figure 5-3. The critical depth applies to the Meyerhof and Nordlund methods for analysis of bearing capacity.

(2) **Straight Shafts.** Equation 5-2a may be simplified for deep foundations without enlarged tips by eliminating the $N_{\gamma p}$ term

$$q_{bu} = c \cdot N_{cp} \cdot \zeta_{cp} + \sigma'_L \cdot (N_{qp} - 1) \cdot \zeta_{qp} \qquad (5\text{-}2b)$$

or

$$q_{bu} = c \cdot N_{cp} \cdot \zeta_{cp} + \sigma'_L \cdot N_{qp} \cdot \zeta_{qp} \qquad (5\text{-}2c)$$

Equations 5-2b and 5-2c also compensates for pile weight W_p assuming $\gamma_p \approx \gamma'_L$. Equation 5-2c is usually used rather than Equation 5-2b because N_{qp} is usually large compared with "1" and $N_{qp}-1 \approx N_{qp}$. W_p in Equation 5-1 may be ignored when calculating Q_u.