Bearing Capacity of Soils II

Course Number: GE-02-302

PDH: 3

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Module 5: Deep Foundations

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** the technical and economic factors governing the selection between drilled shafts and driven piles for specific soil conditions.
- **Calculate** ultimate vertical and lateral bearing capacities for single deep foundation elements using standard analytical methods and in situ test data.
- **Identify** the impact of group effects, soil heave, and downdrag on foundation performance and structural integrity.

Executive Summary: Deep foundations are essential for transferring structural loads to stable strata when shallow options fail due to insufficient bearing capacity, excessive settlement, or special soil conditions like scour and expansiveness. Effective design requires integrating geotechnical response with structural capacity, often verified through load tests to mitigate the approximations inherent in static analysis.

Design Fundamentals

Deep foundations transfer loads to acceptable bearing strata at depth. They are utilized when shallow foundations are uneconomical or technically unfeasible.

Core Applications

- **Load Transfer:** Reaching competent strata at distance below ground surface.
- **Anchor Structures:** Resisting uplift, lateral, and overturning forces.
- **Special Soil Conditions:** Mitigating risks from expansive, collapsible, or erodible soils.

Drilled Shafts (Nondisplacement Elements)

Drilled shafts are reinforced concrete elements cast in boreholes (dry, cased, or slurry-filled).

- **Advantages:** Minimal vibration/soil disturbance, no ground heave, and the ability to build large diameters for massive loads.
- **Hard Ground Performance:** Preferred over driven piles as soil becomes harder or rock is encountered.
- **Design Risks:** Rebound at the excavation bottom and water collection can reduce end bearing capacity.

Driven Piles (Displacement Elements)

Driven piles are driven into the ground, displacing and remolding the soil.

- **Soil Interaction:** Driving increases pore pressures temporarily (reducing short-term capacity) but often increases long-term capacity through "soil freeze."
- **Densification:** In cohesionless soils, driving tends to densify the material.
- **Constraints:** Limited by equipment capacity; causes significant noise and vibration.

Design Responsibility and Load Conditions

Selection requires both geotechnical and structural engineering expertise. Because load transfer mechanisms are complex, **load tests** are routinely performed for project validation, except for shafts bearing on bedrock where costs are prohibitive.

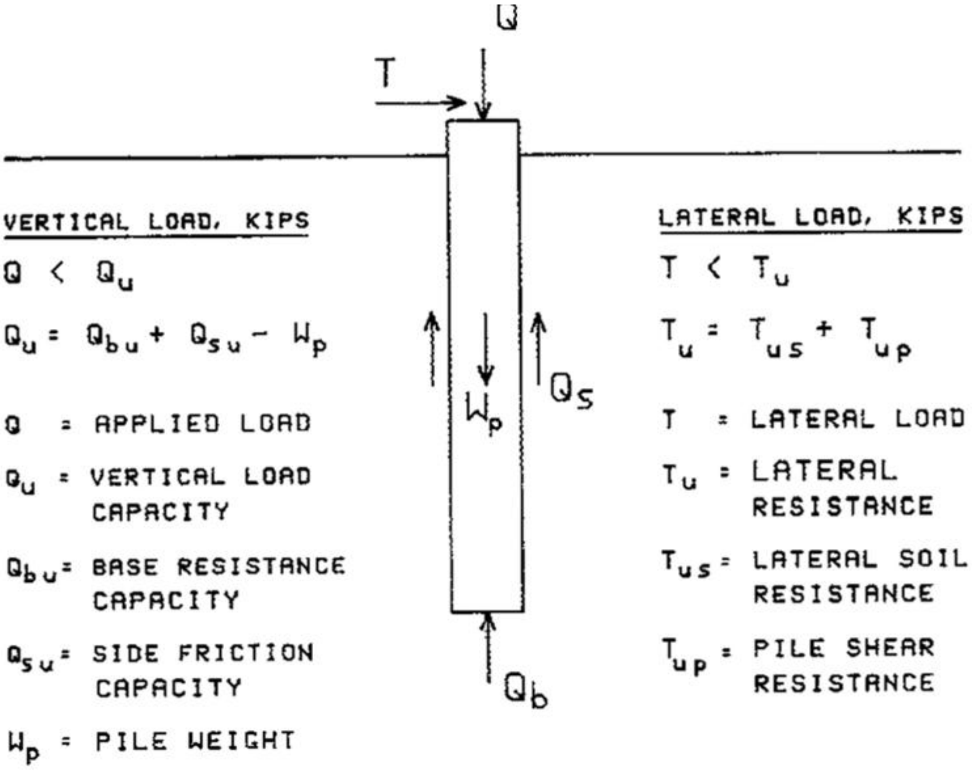

Figure 5-1. Support of deep foundations

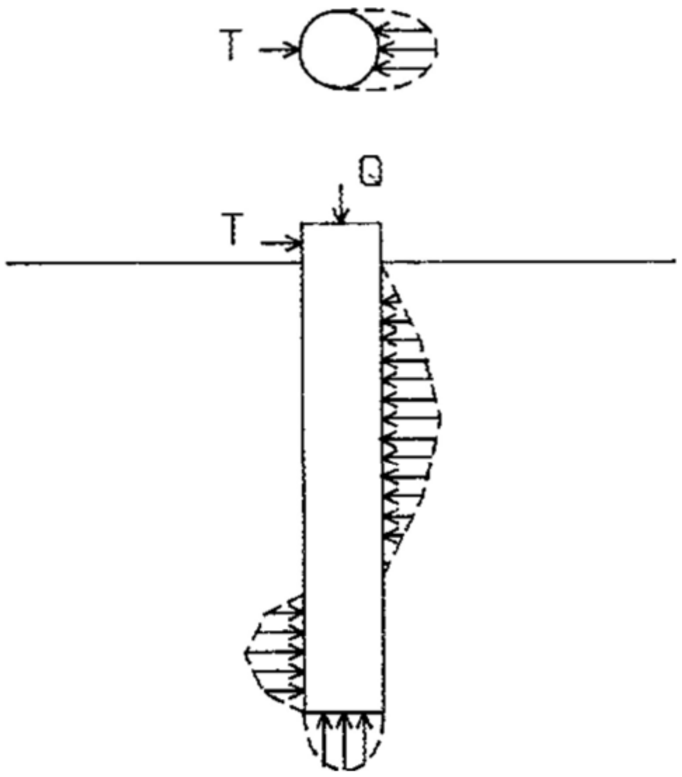

Figure 5-2. Earth pressure distribution Tus acting on a laterally loaded pile

Factor of Safety (FS) Requirements

- **Static Load Test Results:** FS = 2.0.
- **Standard Estimations (Clay/Sand):** FS = 3.0.
- **Multi-layer Clay or Stiff Clay (Cu > 6 ksf):** FS = 4.0.

Section I. Drilled Shafts

Vertical Compressive Capacity of Single Shafts

The ultimate capacity of a single shaft is calculated as:

Equation 5-1a:

$$Q_u = Q_{bu} + Q_{su} - W_p$$

Where:

- **Qu** = ultimate capacity of a single shaft
- **Qbu** = ultimate base (tip) capacity
- **Qsu** = ultimate side (skin) friction capacity
- **Wp** = weight of the plug or shaft (if accounting for self-weight)

Equation 5-1b:

$$Q_{bu} = q_{bu} A_b Q_{su} = \sum_{i=1}^{n} \quad Q_{sui}$$

Where:

- **Qu** = Ultimate resistance (kips)
- **Qbu** = Ultimate end bearing (kips)
- **Qsu** = Ultimate skin friction (kips)
- **qbu** = Unit end bearing (ksf)
- **Ab** = Area of base (ft2)
- **Wp** = Weight of pile (kips)

End Bearing Capacity

End bearing resistance at the tip is generally estimated by:

Equation 5-2a:

$$q_{bu} = cN_{cp}z_{cp} + \sigma'_L N_{qp} z_{qp} + 0.5 B_b \gamma'_b N_{gp} z_{gp}$$

Where:

- **c** = Cohesion (ksf)
- **σ'L** = Effective vertical overburden pressure at base (ksf)
- **Bb** = Base diameter (ft)
- **Ncp, Nqp, Ngp** = Bearing capacity factors
- **zcp, zqp, zgp** = Geometry correction factors

Simplified for Straight Shafts: Equation 5-2b:

$$q_{bu} = \sigma'_L N_{qp} z_{qp}$$

Where:

- **qbu** = Unit end bearing (ksf)
- **σ'L** = Effective vertical overburden pressure at base (ksf)
- **Nqp** = Bearing capacity factor
- **zqp** = Geometry correction factor
- **γp** ≈ γ'L (assuming gp is approximately g'L)

🧮 **Calculation Note:** Effective vertical stress becomes constant after a **critical depth (Lc)**. Refer to the critical depth ratio (Lc/B) in Figure 5-3 to prevent overestimating capacity at extreme depths.

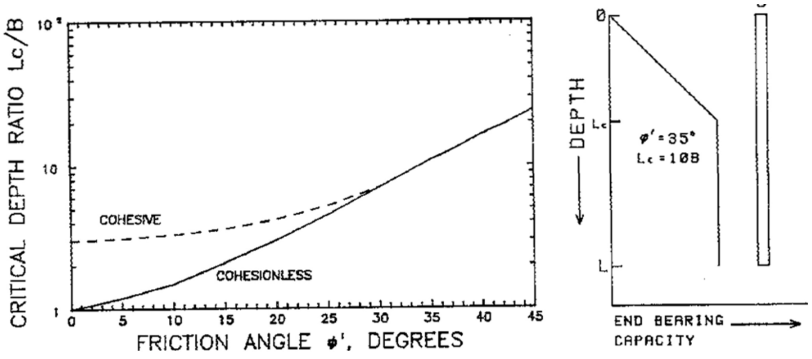

Figure 5-3. Critical depth ratio Lc/B (Data from Meyerhof 1976)

Cohesive Soil Analysis: For saturated clay ($\varphi = 0$): **Equation 5-3:**

$$q_{bu} = N_{cp} C_u \leq 80 \text{ ksf}$$

Where:

- **qbu** = Unit end bearing (ksf)
- **Ncp** = Bearing capacity factor
- **Cu** = Undrained shear strength (cohesion)

Skin Friction Capacity

Equation 5-4:

$$Q_{su} = \sum f_{si} A_{si}$$

Where:

- **fsi** = Skin friction at element i (ksf)
- **Asi** = Surface area of element i (ft2)

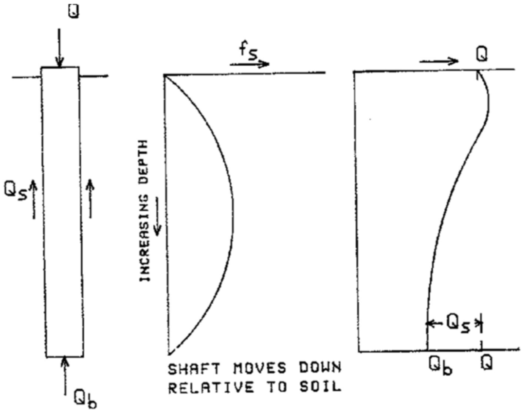

Figure 5-4. An example distribution of skin friction in a pile