Deep Foundation – Axial Load Capacity
- Static Load Tests
- Analytic Methods
- Dynamic methods

Pile Foundation vs. Shallow Foundation
- Soil property unknown after driving
- Excessive pore water pressure during driving of piles
- Integrity of pile

Load distribution along pile
$Q_u - Q_s = Q_p$
- Sand: $Q_s = 50\%$, $Q_p = 50\%$
- Clay: $Q_s = 90\%$, $Q_p = 10\%$

Pile load as function of pile displacement
Load, $Q$
- Driven pile
- Cast-in-place pile
- With bell
- Sand
- Stiff clay
- Soft clay

Displacement, $s$
Load deformation relationship of piles

Direction of pile loading

Determining Axial Capacity of Piles
- Load Test
- Static Analysis – Based on estimated strength and stress
- Dynamic Analysis – based on energy or wave equation

Static Load Test
Static pile load test

Definition of pile failure load

Types of pile loading tests

Static Load Tests
- Most reliable method to determine capacity
- Very expensive & takes a lot of time
- Lower FS can be used
- Most effective when
  - Large project with many pile (Lower FS)
  - Erratic soil conditions
  - Pile in soft clay
  - Structure sensitive to settlement
  - Uplift Capacity
- Before construction- test pile program
- Proof testing during construction
Analytic Methods

Bearing Capacity of Piles in sand

End Bearing of Piles (Sand)

According to Meyerhof (sand)
Bearing capacity factor of piles (Sand)

Comparison of cone resistance and pile point resistance (Sand)

Failure mechanism at pile point (Sand)

Comparison of SPTN-value and pile point resistance (Sand)
Critical depth of pile end bearing (Sand)

\[ \frac{Q}{Q_0} = \frac{N}{N_0} \]

friction angle \( \phi \)

\( Q_0 = \text{constant} \)

at \( L < L_e \)

at \( L \geq L_e \)

Lateral pressure against pile shaft (sand)

\[ K = K_0 \]

\[ \frac{K'}{K_0} \]

Bored pile

Small displacement pile

Large displacement pile

Lateral pressure against pile shaft (Sand)

\[ Q_s = K_0 \]

\( 5 \text{ to } 20D \)

\( 20 \text{ to } 100kPa \)

\( K' = \text{tapered} \)

Mansur & Hunter (1970)

- H-piles: 1.4-1.9
- Pipe piles: 1.2-1.3
- Precast concrete piles (square): 1.45-1.6
- Timber piles: 1.25
- Tension piles: 0.4-0.9

Tavenas (1971)

- H-piles: 0.5
- Prestressed concrete piles: 0.7
- Timber piles (tapered): 1.25

Ireland (1957)

- Step taper piles (Raymond): 1.11-3.64

Pile shaft capacity (sand)

\( Q_s \)

Sand
Critical depth of pile shaft resistance (Sand)

- Similar to end bearing, there is a critical depth for shaft resistance. A conservative estimate is $L_c = 15D$.

Bearing capacity of piles in clay

- Failure surface at pile point in clay (Clay)

- Skin friction resistance along pile shaft (Clay)
Beta Method  
(Effective stress analysis in clay)

Pile driving $\rightarrow$ $\Delta u \uparrow$ ($\approx 4 \sim 6$ Cu), the soil becomes remolded after $\Delta u$ dissipated

$$ f_s = \beta \sigma'_v $$

$$ \beta = (1 - \sin \phi_r) \sqrt{OCR} \tan(\phi) $$

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Alpha method  
(Total stress analysis in clay)

$$ f_s = \alpha c_u $$

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Lambda-method (clay)

Displacement of soil caused by pile driving results in a passive lateral earth pressure

(Vijayvergiya & Focht, 1972)

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Bearing Capacity of Drilled Shafts

- Bearing capacity of drilled shaft is less than that of pile
  1. The previous methods are usually calibrated using load test results
  2. Empirical formulas using in situ tests are developed from load test
Load transfer from pile to soil as function of pile displacement

Negative skin friction along piles

Dynamic Methods

Pile driving equipment

- Drop hammers (Height of fall governs the maximum concrete stress)
- Diesel hammers
- Vibratory hammers
- Steam hammers (Single and double acting)
- Air (pneumatic) hammers
Dynamic pile test

Stress wave analysis, rigid base

Stress wave analysis, soft base

Detection of pile defect by dynamic test
Determination of dynamic pile bearing capacity

Engineering News Formula

\[ Q_a = \frac{Wh}{F_s(S + c)} \]

- C=1.0 for single acting hammer
- Work poor, but used a lot because of convenient
- We can run a pile test at the site and relate to this formula

Elastic compression of pile

Pile driving formulae (definition)

\[ Q_hg = \frac{R}{0.5Re_{\text{soil}}} + 0.5Re_{\text{cushion}} + 0.5Re_{\text{pile}} \]

\[ \text{Effective height of fall} \]

\[ \text{Elastic compression of soil, cushion and soil} \]

\[ \frac{Q_hgQ_p(1-\epsilon)}{Q_h + Q_p} \]

\[ \text{Coefficient of restitution} \]

\[ \frac{\text{Mass of hammer}}{\text{Mass of pile}} \]
Pile driving formulae

Wave Equation

- Consider
  - Complete hammer system
  - Pile characteristics
  - Soil Characteristics
- Estimate
  - Pile stress during driving
  - Bearing capacity as a function of blow per count

Pile Dynamic Analyzer (PDA)

- Measure strain and velocity in pile during driving
- Case method analyses:
  - Simplification of true dynamics of pile driving & associated response of soil
  - Determine the pile capacity from wave trace data
  - The method include an empirical damping factor Jc, that can be determined from an on-site static load test

CAPWAP (Case Pile Wave Analysis Program)

- Case method is a simplification with an empirical factor
- Wave equation is more precise but suffers from weak estimates of the actual energy delivered by hammer
- The hammer & accessories are replaced with force-time & velocity-time data obtained from PDA
- The analysis produces Ru (ultimate resistance in the soil “springs” and q (the quake), and Jc.
Failure modes of horizontally loaded piles

Lateral pile resistance in sand

Lateral pile resistance in clay (rotational mode)

Lateral pile resistance in clay (pile failure mode)