SOILS AND FOUNDATIONS
Lesson 08
Chapter 8 – Shallow Foundations
Topics

- **Topic 1 (Section 8.0, 8.1, 8.2, 8.3, 8.4)**
  - General and Bearing Capacity

- **Topic 2 (Section 8.5, 8.6, 8.7, 8.8, 8.9)**
  - Settlement
  - Spread footings on embankments, IGMs, rocks
  - Effect of deformations on bridge structures

- **Topic 3 (Section 8.10)**
  - Construction
Shallow Foundations

Lesson 08 - Topic 1
General and Bearing Capacity
Section 8.0 to 8.4
Learning Outcomes

At the end of this session, the participant will be able to:

- **Identify different types of shallow foundations**
- **Recall foundation design procedure**
- **Contrast factors that influence bearing capacity in sand and clay**
- **Compute bearing capacity in sand and clay**
- **Describe allowable bearing pressure for rock foundations**
Abutment and piers may have shallow or deep foundations
General Approach to Foundation Design

- **Duty of Foundation Designer**
  - Establish the most economical design that safely conforms to prescribed structural criteria and properly accounts for the intended function of the structure

- **Rational method of design**
  - Evaluate various foundation types
Recommended Foundation Design Approach

Step 1:

Determine:
- Direction, type and magnitude of foundation loads
- Tolerable deformations
- Special constraints
  - Underclearance requirements
  - Structure type, span lengths
  - Time constraints on construction
  - Extreme event loading
  - Construction load requirements
Recommended Foundation Design Approach

Step 2:
Evaluate subsurface investigation and laboratory testing data for reliability and completeness

Choose design method consistent with quality and quantity of subsurface data
Recommended Foundation Design Approach

Step 3:

Consider alternate foundation types
Foundation Alternatives

- Shallow Foundations
- Deep Foundations
  - Piles, shafts
Foundation Cost

- Express foundation capacity in terms of $

- TOTAL cost of foundation system divided by the load supported by the foundation in tons

- TOTAL cost of a foundation must include ALL costs associated with the foundations
  - Need for excavation support system, pile caps, etc.
  - Environmental restrictions
  - All other factors as applicable
Foundation Cost

- If estimated costs of alternative foundation systems during design are within 15%, the alternate foundation designs should be considered for inclusion in contract documents.
Loads and Limit States

- **Loads**
  - Permanent and Transient
  - Codes specify load combinations

- **Foundation limit states**
  - Ultimate
    - Bearing capacity, eccentricity, sliding, global stability, structural capacity
  - Serviceability
    - Excessive settlement, excessive lateral displacement, structural deterioration of foundation
Types of Shallow Foundations

- **Isolated Spread Footings**
  - Length (L) to width (B) ratio, $L/B < 10$
Types of Shallow Foundations

- **Combined Strip Spread Footings**
  - Length (L) to width (B) ratio, $L/B \geq 10$
Shallow Foundations for Bridge Abutments
Shallow Foundations for Retaining Walls
Combined Footings

- Combined Footings
- Abutment Fill
- Toe of Side Slope
- Toe of End Slope
- Original Ground
Mat Foundations

REINFORCED CONCRETE MAT
Spread Footing Design Procedure

Geotechnical design of spread footing is a two part process

First Part:
- Establish an allowable stress to prevent shear failure in soil

Second Part:
- Estimate the settlement under the applied stress
Allowable Bearing Capacity

Allowable bearing capacity is lesser of:

Applied stress that will result in shear failure divided by FS
- Ultimate limit criterion

OR

Applied stress that results in a specified amount of settlement of the structure
- Serviceability criterion
Bearing Capacity Chart

Ultimate Bearing Capacity, $q_{ult}$

Allowable Bearing Capacity,

$$q_{all} = \frac{q_{ult}}{FS}$$

Contours of Allowable Bearing Capacity for a given settlement

FS > 1 against shear failure

shear controls

settlement controls

S1
S2
S3

Allowable Bearing Capacity, $q_{all}$

Effective Footing Width, ft (m)

Allowable Bearing Capacity, ksf (kPa)

Contours of Allowable Bearing Capacity for a given settlement
Design Process Flow Chart

Figure 8-10
Bearing Capacity

- Bearing capacity failure occurs when the shear strength of foundation soil is exceeded.
- Similar to slope stability failure.
Bearing Capacity Failure Mechanisms

- General shear
- Local shear
- Punching shear
Footing Dimension Terminology

- $B_f = \text{Width of footing}$
  - Least lateral dimension

- $L_f = \text{Length of footing}$

- $D_f = \text{Depth of embedment of footing}$
Basic Bearing Capacity Equation

**Equation 8-8**

\[
q_{ult} = c \left(N_c\right) + q \left(N_q\right) + 0.5 \left(\gamma\right)\left(B_f\right)\left(N_\gamma\right)
\]

c = cohesion
q = surcharge at footing base
\(N_c, N_q, N_\gamma\) = Bearing capacity factors
\(\gamma\) = unit weight of foundation soil
Assumptions of Basic Bearing Capacity Equation (Section 8.4.3)

- Strip (continuous) footing
- Rigid footing
- General shear
- Concentric loading (i.e., loading through the centroid of the footing)
- Footing bearing on level surface of homogeneous soil
- No impact of groundwater
Bearing Capacity Factors

Figure 8-15

Table 8-1
Example 8-1

\[ \gamma_{\text{sub}} = 63 \text{ pcf} \]

\[ d = D = 5' \]

\[ B = 6' \]

\[ \gamma_T = 125 \text{ pcf} \]

\[ \phi = 20^\circ \]

\[ c = 500 \text{ psf} \]
Example 8-1

Solution
## Effect of Variation of Soil Properties and Footing Dimensions (Table 8-2)

<table>
<thead>
<tr>
<th>Properties and Dimensions</th>
<th>Cohesive Soil</th>
<th>Cohesionless Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma = \gamma_a =$ effective unit weight</td>
<td>$\phi = 0$</td>
<td>$\phi = 30^\circ$</td>
</tr>
<tr>
<td>$\gamma_b =$ submerged unit weight</td>
<td>$c = 1000$ psf</td>
<td>$c = 0$</td>
</tr>
<tr>
<td>$D_f =$ embedment depth</td>
<td>$q_{ult}$ (psf)</td>
<td>$q_{ult}$ (psf)</td>
</tr>
<tr>
<td>$B_f =$ footing width (assume strip footing)</td>
<td>5140</td>
<td>6720</td>
</tr>
</tbody>
</table>

A. **Initial situation**: $\gamma = 120$ pcf, $D_f = 0'$, $B_f = 5'$, deep water table

B. **Effect of embedment**: $D_f = 5'$, $\gamma = 120$ pcf, $B_f = 5'$, deep water table

C. **Effect of width**: $B_f = 10'$ $\gamma = 120$ pcf, $D_f = 0'$, deep water table

D. **Effect of water table at surface**: $\gamma = 57.6$ pcf, $D_f = 0'$, $B_f = 5'$
### Effect of Variation of Soil Properties and Footing Dimensions (Table 8-2)

<table>
<thead>
<tr>
<th>Properties and Dimensions</th>
<th>Cohesive Soil</th>
<th>Cohesionless Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$ = $\gamma_a$ = effective unit weight</td>
<td>$\phi = 0$</td>
<td>$\phi = 30^\circ$</td>
</tr>
<tr>
<td>$\gamma_b$ = submerged unit weight</td>
<td>$c = 1000$ psf</td>
<td>$c = 0$</td>
</tr>
<tr>
<td>$D_f =$ embedment depth</td>
<td>$q_{ult}$ (psf)</td>
<td>$q_{ult}$ (psf)</td>
</tr>
<tr>
<td>$B_f =$ footing width (assume strip footing)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### A. Initial situation: $\gamma = 120$ pcf, $D_f = 0'$, $B_f = 5'$, deep water table
5140 | 6720 |

#### B. Effect of embedment: $D_f = 5'$, $\gamma=120$ pcf, $B_f = 5'$, deep water table
5740 | 17760 |

#### C. Effect of width: $B_f = 10'$ $\gamma = 120$ pcf, $D_f = 0'$, deep water table
5140 | 13440 |

#### D. Effect of water table at surface: $\gamma = 57.6$ pcf, $D_f = 0'$, $B_f = 5'$
5140 | 3226 |
Find the allowable bearing capacity assuming a FS=3 for the condition shown below for a 10’x50’ footing with rough base.

- Final Grade
- Sand
  - \( \gamma = 115 \text{ pcf} \)
  - \( \phi = 35^\circ \)
  - \( C = 0 \)
Bearing Capacity Correction Factors

- Footing shape
  - Adjusted for eccentricity
- Depth of water table
- Embedment depth
- Sloping ground surface
- Inclined base
- Inclined loading
Student Exercise 5

Solution
Modified Bearing Capacity Equation
Equation 8-11

\[ q_{ult} = cN_c s_c b_c + qN_q C_{w_q} s_q b_q d_q + 0.5 \gamma B_f N_\gamma C_{w_\gamma} s_\gamma b_\gamma \]

- \( s_c, s_\gamma, s_q \) \textit{shape correction factors}
- \( b_c, b_\gamma, b_q \) \textit{base inclination correction factors}
- \( C_{w_q}, C_{w_\gamma} \) \textit{groundwater correction factors}
- \( d_q \) \textit{embedment correction factor}
- \( N_c, N_\gamma, N_q \) \textit{bearing capacity factors as function of } \phi
### Estimation of $\phi$ for Bearing Capacity Factors (Table 8-3)

<table>
<thead>
<tr>
<th>Description</th>
<th>Very Loose</th>
<th>Loose</th>
<th>Medium</th>
<th>Dense</th>
<th>Very Dense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected N-value $N_{160}$</td>
<td>0</td>
<td>4</td>
<td>10</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Friction angle $\phi$ Degrees</td>
<td>25 – 30</td>
<td>27 – 32</td>
<td>30 – 35</td>
<td>35 – 40</td>
<td>38 – 43</td>
</tr>
<tr>
<td>Moist unit weight ($\gamma$) pcf</td>
<td>70 – 100</td>
<td>90 – 115</td>
<td>110 – 130</td>
<td>120 – 140</td>
<td>130 – 150</td>
</tr>
</tbody>
</table>
Shape Correction Factors

- Basic equation assumes strip footing which means $L_f/B_f \geq 10$

- For footings with $L_f/B_f < 10$ apply shape correction factors

- Compute the effective shape of the footing based on eccentricity
Effective Footing Dimensions

\[ B'_f = B_f - 2e_B \quad ; \quad L'_f = L_f - 2e_L \quad ; \quad A' = B'_f L'_f \]
Pressure Distributions

**Structural design**

- $q_{\text{min}}$
- $B_f$
- $e_B$
- $p$
- $q_{\text{max}}$

**Sizing the footing**

- $q_{\text{eq}}$
- $B_f$
- $B_f - 2e_B$
### Shape Correction Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Friction Angle</th>
<th>Cohesion Term ($s_c$)</th>
<th>Unit Weight Term ($s_γ$)</th>
<th>Surcharge Term ($s_q$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape Factors, $s_c$, $s_γ$, $s_q$</td>
<td>$\phi = 0$</td>
<td>$1 + \left( \frac{B_f}{5L_f} \right)$</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>$\phi &gt; 0$</td>
<td>$1 + \left( \frac{B_f}{L_f} \frac{N_q}{N_c} \right)$</td>
<td>$1 - 0.4 \left( \frac{B_f}{L_f} \right)$</td>
<td>$1 + \left( \frac{B_f}{L_f} \tan \phi \right)$</td>
</tr>
</tbody>
</table>

**In routine foundation design, use of effective dimensions in shape factors is not practical**
**Location of Groundwater table**

*To correct the unit weight*

<table>
<thead>
<tr>
<th>$D_W$</th>
<th>$C_{W}\gamma$</th>
<th>$C_{W}q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$D_f$</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>$&gt; 1.5B_f + D_f$</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*Note:* For intermediate positions of the groundwater table, interpolate between the values shown above.
Embedment Depth

To account for the shearing resistance in the soil above the footing base

<table>
<thead>
<tr>
<th>Friction Angle, $\phi$ (degrees)</th>
<th>$D_f/B_f$</th>
<th>$d_q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>1</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.40</td>
</tr>
<tr>
<td>37</td>
<td>1</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.35</td>
</tr>
<tr>
<td>42</td>
<td>1</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.30</td>
</tr>
</tbody>
</table>

See Note

Note: The depth correction factor should be used only when the soils above the footing bearing elevation are as competent as the soils beneath the footing level; otherwise, the depth correction factor should be taken as 1.0.
Modify the bearing capacity equation as follows:

\[ q_{ult} = c \left( N_{cq} \right) + 0.5 (\gamma)(B_f)(N_{\gamma q}) \]

Useful in designing footings constructed within bridge approach fills.
Footing in Slope

\[ N_s = \begin{cases} 0 & \text{FOR } B_f < H_s \\ \frac{1}{c}H_s & \text{FOR } B_f \geq H_s \end{cases} \]

(a) Geometry

(b) Cohesive Soil (\(\phi = 0\))

(c) Cohesionless Soil (\(c = 0\))
Footing Near Slope

\[ N_s = 0 \text{ (for } B_f < H_s) \]
\[ N_s = \frac{1}{c} H_s \text{ (for } B_f \geq H_s) \]

(d) Geometry  
(e) Cohesive Soil (\( \phi = 0 \))  
(f) Cohesionless Soil (c = 0)
**Inclined Base**

- Footings with inclined base should be avoided or limited to angles less than 8-10°
- Sliding may be an issue for inclined bases

<table>
<thead>
<tr>
<th>Factor</th>
<th>Friction Angle</th>
<th>Cohesion Term (c)</th>
<th>Unit Weight Term (γ)</th>
<th>Surcharge Term (q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Inclination Factors, b_c, b_γ, b_q</td>
<td>φ = 0</td>
<td>b_c</td>
<td>b_γ</td>
<td>b_q</td>
</tr>
<tr>
<td></td>
<td>φ &gt; 0</td>
<td></td>
<td>(1-0.017α tanφ)^2</td>
<td>(1-0.017α tanφ)^2</td>
</tr>
</tbody>
</table>

φ = friction angle, degrees;  
α = footing inclination from horizontal, upward +, degrees
Inclined Loading

- If shear (horizontal) component is checked for sliding resistance, the inclination correction factor is omitted.
- Use effective footing dimensions in evaluation of the vertical component of the load.
Comments on Use of Bearing Capacity Correction Factors

- For settlement-controlled allowable bearing capacity, the effect application of correction factors may be negligible.

- Application of correction factors is secondary to the adequate assessment of the shear strength characteristics of the foundation soil through correctly performed subsurface exploration.
Local or Punching Shear

\[ c^* = 0.67c \]
\[ \phi^* = \tan^{-1}(0.67\tan\phi) \]

- Loose sands
- Sensitive clays
- Collapsible soils
- Brittle clays

\[ B_f^* = B_f \text{ for a square or circular footing} \]
\[ B_f^* = B_f L_f / (2(B_f + L_f)) \text{ for a rectangular footing} \]
Bearing Capacity Factors of Safety

\[ q_{all} = \frac{q_{ult}}{FS} \]

- \( q_{all} \) = allowable bearing capacity
- \( q_{ult} \) = ultimate bearing capacity
- Typical FS = 2.5 to 3.5
- FS is a function of
  - Confidence in shear strength parameter, c and \( \phi \)
  - Importance of structure
  - Consequences of failure
Overstress Allowances

For short-duration infrequently occurring loads, an overstress of 25 to 50 % may be allowed for allowable bearing capacity
Presumptive Allowable Bearing Capacity

- NOT recommended for soils
- See Tables 8-8, 8-9 and 8-10 for rocks
Learning Outcomes

At the end of this session, the participant will be able to:

- Identify different types of shallow foundations
- Recall foundation design procedure
- Contrast factors that influence bearing capacity in sand and clay
- Compute bearing capacity in sand and clay
- Describe allowable bearing pressure for rock foundations
Any Questions?

THE ROAD TO UNDERSTANDING SOILS AND FOUNDATIONS
Shallow Foundations

Lesson 08 - Topic 2
Settlement, footings on embankments, IGMs, rocks, effect of deformations on bridge structures
Section 8.5 to 8.9
Learning Outcomes

At the end of this session, the participant will be able to:

- Calculate immediate settlements in granular soils
- Calculate consolidation settlements in saturated fine-grained soils
- Describe tolerances and consequences of deformations on bridge structures
Settlement of Spread Footings

- Immediate (short-term)
- Consolidation (long-term)
Immediate Settlement

- **Hough’s method**
  - Conservative by a factor of 2 (FHWA, 1987)

- **Schmertmann’s method**
  - More rational
  - Based on nonlinear theory of elasticity and measurements
Charts
Figure 2-11

- \( D_s = 4B \) to \( 6B \) for continuous footings where \( \frac{L_f}{B_f} \geq 10 \)

- \( D_s = 1.5B \) to \( 2B \) for square footings where \( \frac{L_f}{B_f} = 1 \)
Legend:

- - - - -

**Square footings**
where \( L_f/B_f = 1 \)

---

**Continuous footings**
where \( L_f/B_f \geq 10 \)
Schmertmann Method

\[
S_i = C_1 C_2 \Delta p \sum_{i=1}^{n} \Delta H_i \\
\Delta H_i = H_c \left( \frac{I_z}{X E} \right) \\
C_1 = 1 - 0.5 \left( \frac{p_0}{\Delta p} \right) \geq 0.5 \\
C_2 = 1 + 0.2 \log_{10} \left( \frac{t(\text{years})}{0.1} \right)
\]

- \( I_z \) Strain Influence Factor
- \( E \) Elastic Modulus, Table 5-20
- \( X \) Modification factor for \( E \)
- \( C_1 \) Correction factor for strain relief
- \( C_2 \) Correction factor for creep deformation
Rigid footing vertical strain influence factor, $I_z$

\[ I_{zp} = 0.5 + 0.1 \left( \frac{\Delta p}{p_{op}} \right)^{0.5} \]

see (b) below

$L_f$ = Length of footing

$B_f$ = least width of footing

axisymmetric $L_f/B_f = 1$

plane strain $L_f/B_f \geq 10$

Depth to Peak Strain Influence Factor, $I_{zp}$
**Example 8-2**

Given: 6’x24’ footing on soil profile shown below. Determine settlement at end of construction and 10 years after construction.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Depth</th>
<th>SPT N-value</th>
<th>Unit Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayey Silt</td>
<td>3 ft</td>
<td>8</td>
<td>115 pcf</td>
</tr>
<tr>
<td>Sandy Silt</td>
<td>3 ft</td>
<td>25</td>
<td>125 pcf</td>
</tr>
<tr>
<td>Coarse Sand</td>
<td>5 ft</td>
<td>30</td>
<td>120 pcf</td>
</tr>
<tr>
<td>Sandy Gravel</td>
<td>25 ft</td>
<td>68</td>
<td>128 pcf</td>
</tr>
</tbody>
</table>

Ground Surface

- **B_f = 6 ft**
Draw Strain Influence Diagram

**Calculate peak \( I_z = 0.64 \)**
Determine Elastic Modulus, $E_s$

- **Use Table 5-20, Page 5-90**

Layer 1: Sandy Silt: $E = 4N1_{60}$ tsf
Layer 2: Coarse Sand: $E = 10N1_{60}$ tsf
Layer 3: Coarse Sand: $E = 10N1_{60}$ tsf
Layer 4: Sandy Gravel: $E = 12N1_{60}$ tsf

- **Calculate X-factor, $X = 1.42$**
### Setup Table for Settlement Computation

<table>
<thead>
<tr>
<th>Layer</th>
<th>$H_c$ (inches)</th>
<th>$N_{160}$ (tsf)</th>
<th>$E$ (tsf)</th>
<th>$XE$ (tsf)</th>
<th>$Z_1$ (ft)</th>
<th>$I_Z$ at $Z_i$</th>
<th>$H_i = \frac{I_Z}{XE} H_c$ (in/tsf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>25</td>
<td>100</td>
<td>142</td>
<td>1.5</td>
<td>0.31</td>
<td>0.0759</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>30</td>
<td>300</td>
<td>426</td>
<td>3.5</td>
<td>0.56</td>
<td>0.0152</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>30</td>
<td>300</td>
<td>426</td>
<td>6</td>
<td>0.55</td>
<td>0.0599</td>
</tr>
<tr>
<td>4</td>
<td>96</td>
<td>68</td>
<td>816</td>
<td>1,159</td>
<td>12</td>
<td>0.22</td>
<td>0.0176</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\sum H_i = 0.1686$</td>
</tr>
</tbody>
</table>
**Compute Correction Factors** $C_1, C_2$

\[
C_1 = 1 - 0.5 \left( \frac{p_o}{\Delta p} \right) = 1 - 0.5 \left( \frac{3 \text{ ft} \times 115 \text{ pcf}}{1655 \text{ psf}} \right) = 0.896
\]

\[
C_2 = 1 + 0.2 \log_{10} \left( \frac{t(\text{years})}{0.1} \right)
\]

- **At end of construction, $t=0.1$ year**

\[
C_2 = 1 + 0.2 \log_{10} \left( \frac{0.1}{0.1} \right) = 1.0
\]

- **At $t=10$ years**

\[
C_2 = 1 + 0.2 \log_{10} \left( \frac{10}{0.1} \right) = 1.4
\]
Determine Immediate Settlement

- **At end of construction, \( t = 0.1 \) year**

\[
S_i = C_1 C_2 \Delta p \sum H_i
\]

\[
S_i = (0.896)(1.0) \left( \frac{1655 \text{psf}}{2000 \text{psf/tsf}} \right) \left( 0.1686 \frac{\text{in}}{\text{tsf}} \right)
\]

\[
S_i = 0.125 \text{ inches}
\]

- **At \( t = 10 \) years**

\[
S_i = 0.125 \text{ inches} \left( \frac{1.4}{1.0} \right) = 0.175 \text{ inches}
\]
Consolidation Settlement

- Same procedures as in Chapter 7 (Approach Roadway Deformations)
Example 8-3

Calculate consolidation settlement for following case:

130 kips

4'

10'

10'

Gravel
\( \gamma_T = 130 \text{ pcf} \)

Normally consolidated clay
\( \gamma_{\text{sub}} = 65 \text{ pcf}, e_0 = 0.75, C_c = 0.4 \)

Rock
Example 8-3

\[ p_0 = (14' \times 130 \text{ pcf}) + (5' \times 65 \text{ pcf}) = 2,145 \text{ psf} \]

\[ \Delta p = \frac{130 \text{kips}}{(10 \text{ ft} + 15 \text{ ft})^2} = \frac{130 \text{kips}}{625 \text{ ft}} = 0.208 \text{ksf} = 208 \text{psf} \]

\[ \Delta H = H \frac{C_c}{1 + e_0} \log_{10} \left( \frac{p_0 + \Delta p}{p_0} \right) \]

\[ \Delta H = 10 \text{ft} \left( \frac{0.4}{1 + 0.75} \right) \log_{10} \left( \frac{2145 \text{ psf} + 208 \text{ psf}}{2145 \text{ psf}} \right) \]

\[ \Delta H = 0.09' = 1.1'' \]
Find footing settlement (immediate + consolidation) for the following case

Sand and Gravel
Avg. \( N' = 40 \)

Clayey Silt
\( C_c = 0.25 \)
\( e_0 = 0.90 \)

(Normally Consolidated)
Student Exercise 6

Pressure - psf

Depth - ft.
If spread footings are placed on embankments, structural fills that include sand and gravel sized particles should be used that are compacted properly (minimum 95% of standard Proctor energy)
Settlement of Footings on Structural Fills

In absence of other data, use $N_{160} = 32$ for the structural to estimate settlement of footings on compacted structural fill.
Vertical Stress Distribution

- Bridge Pier
- Earth Embankment

Depth

Vertical Stress

h=20'
h=40'
Use theory of elasticity

\[ \delta_v = \frac{C_d \Delta p B_f (1 - \nu^2)}{E_m} \]

where:
- \( \delta_v \) = vertical settlement at surface
- \( C_d \) = shape and rigidity factors (Table 8-12)
- \( \Delta p \) = change in stress at top of rock surface due to applied footing load
- \( B_f \) = footing width or diameter
- \( \nu \) = Poisson’s ratio (refer to Table 5-23 in Chapter 5)
- \( E_m \) = Young’s modulus of rock mass (see Section 5.12.3 in Chapter 5)
Effect of Deformations on Bridge Structures

Section 8.9

- Tilt (Rotation)
- Differential Settlement

Uniform settlement

Regular pattern of settlement

Irregular pattern of settlement

\[ A = \frac{\text{Difference in Settlement Between Foundations}}{\text{Distance Between Foundations}} = \frac{\delta}{s} \]
<table>
<thead>
<tr>
<th>Limiting Angular Distortion, $\delta/S$</th>
<th>Type of Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.004</td>
<td>Multiple-span (continuous span) bridges</td>
</tr>
<tr>
<td>0.005</td>
<td>Single-span bridges</td>
</tr>
</tbody>
</table>

Note:
$\delta$ is differential settlement, $S$ is the span length. The quantity, $\delta/S$, is dimensionless and is applicable when the same units are used for $\delta$ and $S$, i.e., if $\delta$ is expressed in inches then $S$ should also be expressed in inches.
Construction Point Concept for Evaluation of Settlements

- Divide the loadings based on sequence of construction
- Key construction point is when the final load bearing member is constructed, e.g., when a bridge deck is constructed

- Table 8-14 - Put in a slide
Learning Outcomes

At the end of this session, the participant will be able to:

- Calculate immediate settlements in granular soils
- Calculate consolidation settlements in saturated fine-grained soils
- Describe tolerances and consequences of deformations on bridge structures
Any Questions?

THE ROAD TO UNDERSTANDING SOILS AND FOUNDATIONS
Shallow Foundations

Lesson 08 - Topic 3
Construction
Section 8.10
Learning Outcomes

At the end of this session, the participant will be able to:

- Discuss elements of shallow foundation construction/inspection
Key Elements of Shallow Foundation Construction

- Table 8-15
- Contractor set-up
- Excavation
- Shallow foundation
- Post installation
  - Monitoring
Tests for gradation and durability of fill at sufficient frequency to ensure that the material meets the specification

Compaction tests

If surcharge fill is used for pre-loading verify the unit weight of surcharge
Monitoring

- Check elevations of footing, particularly when footings are on embankment fills.
- Periodic surveying during the service life of the footing, particularly if the subsurface has soft soils within the depth of influence.
- Impacts on neighboring facilities.
- Use instrumentation as necessary.
Learning Outcomes

At the end of this session, the participant will be able to:

- Discuss elements of shallow foundation construction/inspection
Any Questions?

THE ROAD TO UNDERSTANDING SOILS AND FOUNDATIONS
Interstate 0 – Apple Freeway
Note: Scale shown in Station Form

Baseline Stationing

Interstate 0

Existing Ground Surface

Proposed Final Grade

Proposed Abutment

Proposed Toe of Slope
## Subsurface Investigations
- Terrain reconnaissance
- Site inspection
- Subsurface borings

## Basic Soil Properties
- Visual description
- Classification tests
- Soil profile

## Laboratory Testing
- $P_o$ diagram
- Test request
- Consolidation results
- Strength results

## Slope Stability
- Design soil profile
- Circular arc analysis
- Sliding block analysis
- Lateral squeeze analysis

## Approach Roadway Settlement
- Design soil profile
- Magnitude and rate of settlement
- Surcharge
- Vertical drains

### Spread Footing Design
- Design soil profile
- Pier bearing capacity
- Pier settlement
- Abutment settlement
- Surcharge
- Vertical drains

## Driven Pile Design
- Design soil profile
- Static analysis – pier
  - Pipe pile
  - H – pile
- Static analysis – abutment
  - Pipe pile
  - H – pile
- Driving resistance
- Lateral movement - abutment

## Construction Monitoring
- Wave equation
- Hammer approval
- Embankment instrumentation
Assumptions:

- Footing embeded 4′ below ground
- Footing width = 1/3 pier height = 7′
- Footing length = 100′
  \[ L/W = 100/7 > 10 \] \( \therefore \) Continuous
Compute $N_{160}$ values

<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>$p_0$ (psf)</th>
<th>$p_0$ (tsf)</th>
<th>$N$ (bpf)</th>
<th>Hammer Efficiency ($E_f$)</th>
<th>$E_f / 60$</th>
<th>$N_{60}$ (bpf)</th>
<th>$C_n$</th>
<th>$N_{160}$ (bpf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>550</td>
<td>0.275</td>
<td>11</td>
<td>65</td>
<td>1.083</td>
<td>12</td>
<td>1.43</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>770</td>
<td>0.385</td>
<td>21</td>
<td>65</td>
<td>1.083</td>
<td>23</td>
<td>1.32</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>880</td>
<td>0.440</td>
<td>22</td>
<td>65</td>
<td>1.083</td>
<td>24</td>
<td>1.28</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>1100</td>
<td>0.550</td>
<td>40</td>
<td>65</td>
<td>1.083</td>
<td>43</td>
<td>1.20</td>
<td>52</td>
</tr>
<tr>
<td>12</td>
<td>1195</td>
<td>0.598</td>
<td>37</td>
<td>65</td>
<td>1.083</td>
<td>40</td>
<td>1.17</td>
<td>47</td>
</tr>
<tr>
<td>14</td>
<td>1290</td>
<td>0.645</td>
<td>33</td>
<td>65</td>
<td>1.083</td>
<td>36</td>
<td>1.15</td>
<td>41</td>
</tr>
</tbody>
</table>

Average corrected blow count = 36
APPLE FREEWAY PIER SETTLEMENT

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>ΔH</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1&quot;</td>
</tr>
<tr>
<td>100</td>
<td>2&quot;</td>
</tr>
<tr>
<td>150</td>
<td>3&quot;</td>
</tr>
<tr>
<td>200</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td></td>
</tr>
</tbody>
</table>

ΔH = 2.85"
APPLE FREEWAY

EAST ABUTMENT SETTLEMENT

Pressure (psf)

0
1000 2000 3000 4000 5000 6000

Depth (ft)

0 10′ 20′ 30′ 40′

Gravel Layer

Time (days)

0 100 200 300 400 500

ΔH

ΔH = 2.59″

Sand $P_f$

Clay $P_o$

$P_{abut}$

$P_c$

4470 5550

4920 5850

5650 6200
APPLE FREEWAY

EAST ABUTMENT SETTLEMENT TREATMENT

Assume Wick Drains Installed

*0.25" Δ Remaining 30 days after abutment loaded

Begin Abutment Footing Construction

12.66" emb. Δ

ΔH_{abut}

15.25" Emb. + Abut

Time – days

0 100 200 300 400

15" 10" 5"

ΔH

30' Fill to 10' Surcharge

13.7" t90

15.25" Total ΔH

Time – Days

0 100 200 300 400 500

0.83" 5" 10"

ΔH - Total

240 days 400 days

*Assume 10' Surcharge Used

*Assume 10' Surcharge Used

0.83" 5" 10"

ΔH - Total

240 days 400 days

*Assume 10' Surcharge Used

0.83" 5" 10"

ΔH - Total

240 days 400 days

*Assume 10' Surcharge Used
Design Soil Profile

Strength and consolidation values selected for all soil layers. Footing elevation and width chosen.

Pier Bearing Capacity

\[ Q_{allowable} = 3 \text{ tons/sq.ft.} \]

Pier Settlement

Settlement = 2.8", \( t_{90} = 220 \) days.

Abutment Settlement

Settlement - 2.6", \( t_{90} = 433 \) days.

Vertical Drains

\( t_{90} = 60 \) days - could reduce settlement to 0.25" after abutment constructed and loaded.

Surcharge

10' surcharge: \( t_{90} = 240 \) days before abutment constructed.
Any Questions?

THE ROAD TO UNDERSTANDING SOILS AND FOUNDATIONS