SETTLEMENT OF GROUP PILE AND BLOCK FAILURE
Types of settlement

• Similar to any cases of settlement, it can be classified into 2 types:
  a. Elastic settlement
  b. Consolidation settlement.
The simplest relation for settlement of groups piles is given by Vesic (1969):

\[ S_g(e) = \sqrt{\frac{B_g}{D_s}} \]

Where  
- \( B_g \) = Width or pile group section  
- \( D \) = Width or diameter of each pile in group  
- \( s \) = elastic settlement of each pile at comparable working load.
For pile group in sand and gravel, Meyerhof (1976) suggested:

\[
S_{g(e)} (\text{mm}) = \frac{0.92q \sqrt{B_g}}{N_{\text{cor}}} I
\]

Where \( q (\text{kN/m}^2) = \frac{Q_g}{(L_g B_g)} \)

\( L_g \) and \( B_g \) : Length and width of the pile group section in m
\( N_{\text{cor}} \) : Average corrected SPT within seat of settlement (\( \sim B_g \) deep below the tip of the piles).

\( I = \text{Influence factor} = 1 - \frac{L}{8B_g} \geq 0.5 \)

\( L = \text{Length of pile embedment} \)
In similar manner, the pile group settlement can be related to the cone penetration resistance as:

\[ S_g(e) = \frac{q_B g l}{2q_c} \]

Where \( q_c \) = average cone resistance within the seat of settlement.
Elastic Settlement of Piles Under Working Load

- Caused by three factors:

\[ s = s_1 + s_2 + s_3 \]

Where

- \( s \): Total pile settlement
- \( s_1 \): Settlement of pile shaft
- \( s_2 \): settlement of pile caused by the load at pile point.
- \( s_3 \): settlement of pile caused by the load transmitted along the pile shaft.
\[ S_1 = \left( \frac{Q_{wp} + \zeta Q_{ws}}{A_pE_p} \right) L \]

Where:
- \( Q_{wp} \) = load carried at the pile point under working load condition.
- \( Q_{ws} \) : load carried by skin resistance under working load condition
- \( A_p \) = Area of pile cross section
- \( L \) = Length of pile
- \( E_p \) = Young Modulus of the pile material.
• Magnitude of $\xi$ depend on the skin resistance distribution as below:

$\xi = 0.5$

$\xi = 0.67$

$\xi = 0.5$
\[ s_2 = \frac{q_{wp}D}{E_s} \left(1 - \mu_s^2 \right) I_{wp} \]

- Where:-

\(D\) = width or pile diameter

\(q_{wp}\) = point load per unit area at the pile point \(= Q_{wp}/A_p\)

\(E_s\) = Young Modulus of soil

\(\mu_s\) = Poisson’s ratio of soil

\(I_{wp}\) = Influence factor

\(I_{wp}\) can be taken as shown while \(\mu_s\) is obtained from table given.
Values of $\alpha$, $\alpha_{av}$, and $\alpha_r$.

For circular foundation:

$\alpha = 1$

$\alpha_{av} = 0.85$

$\alpha_r = 0.88$
<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Young's modulus, $E$, MN/m$^2$</th>
<th>Young's modulus, $E$, lb/in.$^2$</th>
<th>Poisson's ratio, $\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose sand</td>
<td>10.35– 24.15</td>
<td>1,500– 3,500</td>
<td>0.20– 0.40</td>
</tr>
<tr>
<td>Medium dense sand</td>
<td>17.25– 27.60</td>
<td>2,500– 4,000</td>
<td>0.25– 0.40</td>
</tr>
<tr>
<td>Dense sand</td>
<td>34.50– 55.20</td>
<td>5,000– 8,000</td>
<td>0.30– 0.45</td>
</tr>
<tr>
<td>Silty sand</td>
<td>10.35– 17.25</td>
<td>1,500– 2,500</td>
<td>0.20– 0.40</td>
</tr>
<tr>
<td>Sand and gravel</td>
<td>69.00–172.50</td>
<td>10,000–25,000</td>
<td>0.15– 0.35</td>
</tr>
<tr>
<td>Soft clay</td>
<td>2.07– 5.18</td>
<td>300– 750</td>
<td>0.20– 0.50</td>
</tr>
<tr>
<td>Medium clay</td>
<td>5.18– 10.35</td>
<td>750– 1,500</td>
<td>0.20– 0.50</td>
</tr>
<tr>
<td>Stiff clay</td>
<td>10.35– 24.15</td>
<td>1,500– 3,500</td>
<td>0.20– 0.50</td>
</tr>
</tbody>
</table>
Vesic also proposed semiempirical method to obtain $s_2$ as:

$$s_2 = \frac{Q_{wp}C_p}{D_{qp}}$$

Where

$q_p$ = ultimate point resistance of pile
$C_p$ = empirical coefficient.

$C_p$ is as given below (Vesic-1977)

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Driven Pile</th>
<th>Bored Pile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (Dense to Loose)</td>
<td>0.02-0.04</td>
<td>0.09-0.18</td>
</tr>
<tr>
<td>Clay (Stiff to Soft)</td>
<td>0.02-0.03</td>
<td>0.03-0.06</td>
</tr>
<tr>
<td>Silt (Dense to Loose)</td>
<td>0.03-0.05</td>
<td>0.09-0.12</td>
</tr>
</tbody>
</table>
• $S_3$

$$s_3 = \left(\frac{Q_{ws}}{pL}\right) \frac{D}{E_s} \left(1 - \mu_s^2\right) I_{ws}$$

Where

$P$: perimeter of pile

$L$: embedded length of pile

$I_{ws}$: Influence factor

Vesic (1977) proposed simple empirical relation for $s_3$ as:

$$I_{ws} = 2 + 0.35 \sqrt{\frac{L}{D}}$$

Example

$$s_3 = \frac{Q_{ws}C_s}{Lq_p}$$

where

$$C_s = \left(0.93 + 0.16 \sqrt{\frac{L}{D}}\right) C_p$$
Consolidation Settlement of Group Pile.
General Consolidation Settlement of Group Piles.
Estimation can be made using a 2:1 stress distribution methods as shown.

**Step 1:** Let depth of embedment as $L$ with the pile group subjected to load $Q_g$. If pile cap is below the OGL, then $Q_g = \text{Load from superstructure} - \text{effective weight of soil remove.}$

**Step 2:** Assuming load $Q_g$ is transfer to the soil beginning at a depth of $2L/3$ from the top of the pile. This is considered as depth $z = 0$. From then $Q_g$ is spreaded out in 1:2 direction to the below of the pile tip.
Step 3: Calculate the stress increase cause at the middle of each soil layer cause by load $Q_g$:

$$
\Delta \sigma_i' = \frac{Q_g}{(B_g + z_i)(L_g + z_i)}
$$

Step 4: Calculate the settlement of each layer caused by the stress increase

$$
\Delta S_{c(i)} = \left[ \frac{\Delta e_{(i)}}{1 + e_{o(i)}} \right] H_i
$$

Step 5: Total Consolidation of pile settlement is calculated by

$$
\Delta S_{c(g)} = \Sigma \Delta S_{c(i)}
$$

It should also be noted that the settlement can be initiated by fills nearby, adjacent floor load and lowering of water table.