8.0 Syllabus

1. Settlement Analysis, Data for settlement analysis
2. Computation of settlement
3. Concept, Immediate, Consolidation and Secondary settlements (no derivation)
4. Tolerance, BIS Specifications for total and differential settlements of footings and rafts. (5 Hours)

8.1 Definitions

Settlement is the vertically downward movement of structure due to the compression of underlying soil because of increased load.

**Fig. 8.1 : Concepts of uniform and differential settlement**

Maximum Settlement: It is the absolute maximum downward movement of any part of building element.
Maximum Settlement = \( S_{\text{max}} \)
**Differential Settlement**: It is the maximum difference between two points in a building element.

\[
\text{Differential Settlement} = S_{\text{max}} - S_{\text{min}}
\]

**Angular Distortion**: It is another method of expressing differential settlement.

\[
\text{Angular Distortion} = \frac{\text{Differential Settlement}}{\text{Length of element}} = \frac{(S_{\text{max}} - S_{\text{min}})}{L}
\]

Fig. 8.2 represents soil movement under different circumstances at the ground level. The fluctuation in the elevation of ground level depends on seasonal changes in expansive (Indian Black Cotton) soils and

![Fig.8.2 : Soil movement in different situations](image)

Table 8.1 presents the different types of movements experienced by various soils. It can be noticed that only few soils such as clay can experience swell. Further, consolidation settlement and creep settlement are more pronounced in clay. Immediate or elastic settlement is observed in each and every soil. First three, namely Immediate, Consolidation and Creep settlement cause downward movement of ground while swell causes upward movement of ground.
Table 8.1: Types of Movement in different soils

<table>
<thead>
<tr>
<th>Principal Soil Type</th>
<th>Immediate</th>
<th>Consolidation</th>
<th>Creep</th>
<th>Swell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Some</td>
</tr>
<tr>
<td>Gravel</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Sand</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Silt</td>
<td>Yes</td>
<td>Minor</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Clay</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Organic</td>
<td>Yes</td>
<td>Minor</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

8.2 Extract from IS 1904-1986: General Requirements for Design & Construction of Foundation

IS 1904-1986 presents Table 1 which gives details about the permissible settlement in steel structures, reinforced concrete structures, multi-storeyed buildings and water towers and silos in two different types of soils, namely (1) Sand and hard clay and (2) Plastic clay. The settlements considered are maximum settlement, differential settlement and angular distortion or tilt. The details in this table can be followed in the absence of more precise settlement suggested by the user. In case of multi storeyed buildings both RC frames and load bearing wall structures are considered. Load bearing structures with L/H 2 and 7 are dealt with. Two types of foundations considered are isolated footing and raft foundation. Table 8.2 gives the extract of IS code and Table 8.3 presents the same table in different form for steel and RC structures. A maximum settlement of 75 mm, differential settlement of 0.0015L and angular distortion of 1 in 666 is permitted for isolated footings.
Table 8.2: Permissible uniform and differential settlement and tilt for shallow foundations

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Type of Structure</th>
<th>Sand &amp; Hard Clay</th>
<th>Plastic Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Max. Settlement</td>
<td>Diff. Settlement</td>
</tr>
<tr>
<td>1</td>
<td>Isolated foundation</td>
<td>50mm</td>
<td>0.0033L</td>
</tr>
<tr>
<td>i)</td>
<td>Steel</td>
<td>50mm</td>
<td>0.0015L</td>
</tr>
<tr>
<td>ii)</td>
<td>RCC</td>
<td>75mm</td>
<td>0.0033L</td>
</tr>
<tr>
<td>Raft foundation</td>
<td>75mm</td>
<td>0.002L</td>
<td>1/500</td>
</tr>
<tr>
<td>i)</td>
<td>Steel</td>
<td>75mm</td>
<td>0.0033L</td>
</tr>
<tr>
<td>ii)</td>
<td>RCC</td>
<td>75mm</td>
<td>0.002L</td>
</tr>
</tbody>
</table>

Not - The values given in the table may be taken only as a guide and the permissible total settlement/differential settlement/tilt (angular distortion) in each case should be decided as per requirements of the designer.

L denotes the length of deflected part of wall/raft or centre-to-centre distance between columns.
H denotes the height of wall from foundation footing.
*= For intermediate ratios of L/H, the values can be interpolated.
### Table 8.4: Limiting Values of movement for Geotechnical Structures

<table>
<thead>
<tr>
<th>Design Application</th>
<th>Parameter</th>
<th>Typical Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Foundation</td>
<td>Allowable Bearing Pressure</td>
<td>25 mm for buildings</td>
</tr>
<tr>
<td>Deep Foundation</td>
<td>Skin Friction</td>
<td>10 mm for skin friction to mobilize</td>
</tr>
<tr>
<td>Retaining Wall</td>
<td>Active &amp; Passive earth pressure</td>
<td>0.1% H for Ka &amp; 1% H for Kp to mobilize in dense sand</td>
</tr>
<tr>
<td>Reinforced Earth wall</td>
<td>Friction &amp; Dilatancy to load transfer in soil &amp; reinforcement</td>
<td>25 to 50 mm for geogrid 50 to 100 mm for geotextile</td>
</tr>
<tr>
<td>Pavement</td>
<td>Rut depth based on strain due to no. of repetitions</td>
<td>20 mm rut depth in major roads &amp; 100 mm rut depth in minor roads</td>
</tr>
<tr>
<td>Embankment</td>
<td>Self weight settlement</td>
<td>0.1% height of embankment</td>
</tr>
<tr>
<td>Drainage</td>
<td>Total settlement</td>
<td>100 to 500 mm</td>
</tr>
</tbody>
</table>

### 8.3 Total Settlement

Total foundation settlement can be divided into three different components, namely Immediate or elastic settlement, consolidation settlement and secondary or creep settlement as given below.

\[ S = S_I + S_C + S_S \]

Here, 
- \( S = \) Total Settlement
- \( S_I = \) Immediate / Elastic Settlement
- \( S_C = \) Consolidation Settlement
- \( S_S = \) Secondary Settlement

### 8.4 Immediate Settlement
• Immediate settlement is also called elastic settlement.
• It is determined from elastic theory.
• It occurs in all types of soil due to elastic compression.
• It occurs immediately after the application of load
• It depends on the elastic properties of foundation soil, rigidity, size and shape of foundation.

Immediate settlement is calculated by the equation mentioned below.

\[ S_I = \left( \frac{1-\mu^2}{E} \right) qBI_s \]

Here,
- \( S_I \) = Immediate settlement
- \( \mu \) = Poisson’s Ratio of foundation soil
- \( E \) = Young’s modulus of Foundation Soil
- \( q \) = Contact pressure at the base of foundation
- \( B \) = Width of foundation
- \( I_s \) = Influence Factor

Table 8.5 presents the typical values of Poisson’s ratio in different soils. Table 8.6 represents the ranges of soil modulus in clayey soil of different consistencies in undrained state. In the absence of more accurate data, the values in tables can be used. The influence factor \( I_s \) depends on the shape and flexibility of footing. Further, in flexible footing \( I_s \) is not constant. Table 8.7 presents the different values of \( I_s \).

Table 8.5: Typical Range of Poisson’s Ratio for different soils

<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>Poisson’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated Clay</td>
<td>0.5</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>0.3 – 0.4</td>
</tr>
<tr>
<td>Unsaturated Clay</td>
<td>0.35 – 0.4</td>
</tr>
<tr>
<td>Loess</td>
<td>0.44</td>
</tr>
<tr>
<td>Silt</td>
<td>0.3 – 0.35</td>
</tr>
<tr>
<td>Sand</td>
<td>0.15 – 0.3</td>
</tr>
</tbody>
</table>
Table 8.6: Typical Range of Soil Modulus in undrained state

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Soil Modulus (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft Clay</td>
<td>400 – 3000</td>
</tr>
<tr>
<td>Soft Clay</td>
<td>1500 – 4000</td>
</tr>
<tr>
<td>Medium Clay</td>
<td>3000 – 8500</td>
</tr>
<tr>
<td>Hard Clay</td>
<td>7000 – 17000</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>28000 – 42000</td>
</tr>
</tbody>
</table>

Table 8.7: Typical Values of Influence Factors $I_p$

<table>
<thead>
<tr>
<th>Shape of Footing</th>
<th>Flexible</th>
<th>Rigid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Center</td>
<td>Corner</td>
</tr>
<tr>
<td>Circle</td>
<td>1.00</td>
<td>0.64</td>
</tr>
<tr>
<td>Rectangle L/B = 1</td>
<td>1.12</td>
<td>0.56</td>
</tr>
<tr>
<td>Rectangle L/B = 1.5</td>
<td>1.36</td>
<td>0.68</td>
</tr>
<tr>
<td>Rectangle L/B = 2</td>
<td>1.52</td>
<td>0.77</td>
</tr>
<tr>
<td>Rectangle L/B = 5</td>
<td>2.10</td>
<td>1.05</td>
</tr>
<tr>
<td>Rectangle L/B = 10</td>
<td>2.52</td>
<td>1.26</td>
</tr>
<tr>
<td>Rectangle L/B = 100</td>
<td>3.38</td>
<td>1.69</td>
</tr>
</tbody>
</table>

**Problem 1**

Determine the elastic settlement of a footing 3 m X 3 m resting on sandy soil given $E_s = 45000$ kPa and $\mu = 0.3$. Footing carries a load of 2000 kN. Take $I_p = 0.82$ (Feb 2002)
\( q = \frac{2000}{3^2} = 222.22 \text{ kPa} \)

\( B = 3 \text{ m} \)

\( I_p = 0.82 \)

\( E = 45000 \text{ k Pa} \)

\( \mu = 0.3 \)

\( S_t = 0.011 \text{ m} = 11 \text{ mm} \)

**Problem 2**

Estimate the immediate settlement of a concrete footing 1 m X 1.5 m in size, if it is founded at a depth of 1 m in silty soil whose compression modulus is 9000 kPa. Footing is expected to transmit unit pressure of 200 kPa. Assume \( I_p = 1.06, \mu = 0.3 \)

**Data**

\( E = 9000 \text{ kPa} \)

\( \mu = 0.3 \)

\( q = 200 \text{ kPa} \)

\( B = 1 \text{ m} \)

\( I_p = 1.06 \)

\( S_t = 0.214 \text{ m} \)

**Problem 3**

A series of plate load tests was conducted on three plates 300 mm, 450 mm and 600 mm square plates. The loads and corresponding settlements in the linear portions of P – \( \Delta \) curves are as follows at a site. Find the immediate settlement of a footing 2 m X 2 m subjected to a load of 1000 kN.

<table>
<thead>
<tr>
<th>Plate size (mm)</th>
<th>Load (kN)</th>
<th>Settlement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 X 300</td>
<td>4.50</td>
<td>1.00</td>
</tr>
<tr>
<td>450 X 450</td>
<td>8.71</td>
<td>1.50</td>
</tr>
<tr>
<td>600 X 600</td>
<td>14.40</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Table 8.8 : Details of Load settlement for different plate sizes
Table 8.9: Variation of $qB$ with settlement for different plate sizes

<table>
<thead>
<tr>
<th>$B$ (m)</th>
<th>$P$ (kN)</th>
<th>$q$ (kPa)</th>
<th>$S$ (m)</th>
<th>$qB$ (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>4.50</td>
<td>50.00</td>
<td>0.0010</td>
<td>15.00</td>
</tr>
<tr>
<td>0.45</td>
<td>8.71</td>
<td>43.01</td>
<td>0.0015</td>
<td>19.36</td>
</tr>
<tr>
<td>0.60</td>
<td>14.40</td>
<td>40.00</td>
<td>0.0020</td>
<td>24.00</td>
</tr>
</tbody>
</table>

\[
S_t = \left(\frac{1-\mu^2}{E}\right)qBI_p
\]

\[
\therefore \frac{S_t}{qB} = \left(\frac{1-\mu^2}{E}\right)I_p
\]

\[
\left(\frac{1-\mu^2}{E}\right)I_p = 0.000111(kPa)^{-1}
\]

Fig. 8.3: Variation of $qB$ with settlement for different plate sizes

Data
B = 2 m
$q = \frac{1000}{(2*2)} = 250 kPa$
Problem 4

The following are the results of plate load test on granular soil. Find the allowable bearing pressure if $B = 2\text{ m}$, $B_p = 0.3\text{ m}$, permissible settlement in field = 12 mm.

Table 8.10 : Values of Load Settlement from Plate Load Test

<table>
<thead>
<tr>
<th>P (kN)</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ (mm)</td>
<td>0.14</td>
<td>0.31</td>
<td>0.63</td>
<td>0.91</td>
<td>1.24</td>
<td>2.50</td>
<td>8.07</td>
</tr>
</tbody>
</table>

Fig. 8.4 : Load – Settlement curve for Plate Load Test data

\[ s_f = \left[ \frac{1 - \mu^2}{E} I_p \right] qB \]

$s_i = 0.0555 \text{ m}$

\[ S_i = \left[ \frac{1 - \mu^2}{E} I_p \right] qB \]

\[ P_f = 50 \text{ kN}; \quad q_f = 555.6 \text{ kPa} \]

\[ \frac{s_p}{s_f} = \left[ \frac{B_f (B_f + 0.3)}{B_f (B_p + 0.3)} \right]^2 \]

\[ = \left[ \frac{0.3(2 + 0.3)}{2(0.3 + 0.3)} \right]^2 \]

\[ \therefore s_p = 1 \text{ mm} \]
Based on settlement
Permissible plate settlement ~ 1 mm
ABP     = 32 kN/(0.3X0.3) = 355.6 kPa

**Problem 5**

The following results were obtained from a plate load test conducted on dry sandy stratum using square plate of 0.3 m width. Determine the settlement of square footing 1.5 m wide when the intensity of loading is 120 kPa.

Table 8.11 : Values of Load Settlement from Plate Load Test

<table>
<thead>
<tr>
<th>Pressure (kPa)</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
</tr>
</thead>
<tbody>
<tr>
<td>Settlement (mm)</td>
<td>1.2</td>
<td>2.4</td>
<td>4.8</td>
<td>9.6</td>
<td>32.0</td>
</tr>
</tbody>
</table>

**Data**

Sandy stratum  
B_F = 1.5 m  
B_P = 0.3 m  
S_P = 3.2 mm
8.5 Consolidation Settlement

1. It occurs due to the process of consolidation.
2. Clay and Organic soil are most prone to consolidation settlement.
3. Consolidation is the process of reduction in volume due to expulsion of water under an increased load.
4. It is a time related process occurring in saturated soil by draining water from void.
5. It is often confused with Compaction.
6. Consolidation theory is required to predict both rate and magnitude of settlement.
7. Since water flows out in any direction, the process is three dimensional.
8. But, soil is confined laterally. Hence, vertical one dimensional consolidation theory is acceptable.

\[
\frac{S_r}{S_f} = \left[ \frac{B_p(B_p + 0.3)}{B_f(B_f + 0.3)} \right]^2
\]

<table>
<thead>
<tr>
<th>COMPACTION</th>
<th>CONSOLIDATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Man made</td>
<td>1. Natural</td>
</tr>
<tr>
<td>2. Volume reduction due to expulsion of air</td>
<td>2. Volume reduction due to expulsion of water</td>
</tr>
<tr>
<td>3. Sudden (Short duration)</td>
<td>3. Gradual</td>
</tr>
<tr>
<td>4. Dry density increases water content does not change</td>
<td>4. Dry density increases water content decreases</td>
</tr>
<tr>
<td>5. Applicable for unsaturated soils</td>
<td>5. Applicable for saturated soils</td>
</tr>
</tbody>
</table>

Table 8.12: Compaction Vs Consolidation
8.5.1: Oedometer Test

1. Oedometer test is also called consolidometer test.
2. It is a laboratory test to determine one dimensional consolidation properties of soil.
3. Compression index and Coefficient of consolidation are the important properties determined from this test.
4. At a given sustained pressure, rate of compression of saturated specimen with time is measured.
5. The pressure level is gradually increased with loading and decreased with unloading.

Consolidation Settlement in normally consolidated clayey soil is given by the expression,

$$ S_c = \left( \frac{C_c}{1 + e_o} \right) H \log_{10} \left( \frac{\sigma_o + \Delta \sigma}{\sigma_o} \right) $$

$S_c$ = Consolidation Settlement  
$C_c$ = Compression Index  
$e_o$ = Initial Void Ratio  
$H$ = Thickness of clay layer  
$\sigma_o$ = Initial overburden pressure at the middle of clay layer  
$\Delta \sigma$ = Extra pressure due to the new construction

8.5.2 : Computation of time taken for consolidation settlement in field

At any degree of consolidation, comparison in time taken for consolidation between laboratory & field with respect to drainage path is

$$ \frac{t_{lab}}{t_{field}} = \left( \frac{d_{lab}}{d_{field}} \right)^2 $$

t = Time taken  
d = Drainage path

Empirical equation for Compression Index based on Skempton’s work (1944) is given by,

$$ C_c = 0.009(\omega_L - 10\%) $$

Here, $\omega_L$ is the Liquid Limit in %. Compression index has no unit.

Initial void ratio in saturated soil is obtained from the equation,

$$ \omega G = S e $$
$$ \therefore e_o = \frac{\omega G}{S} $$
Here, \( \omega \) = Water content

\( G \) = Specific Gravity of Soil Solids (assume 2.7)

\( S \) = Degree of Saturation (=1 for soil experiencing consolidation)

### 8.5.3 : Load dispersion in particulate soil medium

\[
\sigma_o = \gamma_{sat} \frac{H}{2}
\]

\[
\Delta \sigma = \frac{P}{\left(\frac{H}{2} + B\right)^2}
\]

![Fig. 8.8 : Concept of Load dispersion](image)

### 8.5.4 : Coefficient of Consolidation

It is one of the important properties of consolidation theory that helps in evaluating consolidation settlement. It is determined from oedometer test. The below mentioned formula is used to determine coefficient of consolidation.

\[
C_v = \frac{T_v d^2}{t}
\]

Here, \( T_v \) is the time factor, \( d \) is the drainage path and \( t \) is time taken for consolidation.

### 8.5.5 : Time Factor
Time factor is obtained from the formulae shown below. It depends on the degree of consolidation.

\[ T_v = \frac{\pi}{4} \left( \frac{U}{100} \right) \]

\[ T_v = 1.7813 - 0.9332 \log_{10}(100 - U\%) \]

Commonly time factor at 50% and 90% degrees of consolidation are used and are as mentioned below.

\( (T_v)_{50} = 0.197 \)
\( (T_v)_{90} = 0.848 \)

**Problem 6**

The total time taken for 50% consolidation of clay layer is 4 years. What will be the time taken for 90% consolidation? (Aug 2001)

\( (T_v)_{50} = 0.197 \)
\( (T_v)_{90} = 0.848 \)

\[ C_v = \frac{(T_v)_{90} d^2}{t_{90}} = \frac{(T_v)_{50} d^2}{t_{50}} \]

\[ \frac{0.848d^2}{t_{90}} = \frac{0.197d^2}{4} \]

\[ \therefore t_{90} = 17.22 \text{ years} \]

**Problem 7**

A layer of clay 8 m thick underlies a proposed new building. The existing overburden pressure at the center of layer is 290 kPa and the load due to new building increases the pressure by 100 kPa. \( C_c = 0.45, \omega = 50 \%, G = 2.71. \) Estimate the consolidation settlement. (Aug 2002)

**Data**

\( C_c = 0.45 \)
\( e_o = 1.355 \)
\( H = 8 \text{ m} \)
\( \sigma_o = 290 \text{ kPa} \)
\( \Delta\sigma = 100 \text{ kPa} \)
Problem 8

A normally consolidated clay layer is 18 m thick. Natural water content is 45 %, saturated unit weight is 18 kN/m$^3$, grain specific gravity is 2.7 and liquid limit is 63 %. The vertical stress increment at the center of clay layer due to foundation load is 9 kPa. Ground water table is at the surface. Determine the settlement.  

(Aug 2003)

Data

$C_c = 0.477$
$e_o = 1.215$
$H = 18 \text{ m}$
$\sigma_o = 162 \text{ kPa}$
$\Delta\sigma = 9 \text{ kPa}$
\[ C_c = 0.009(\omega - 10\%) = 0.477 \]
\[ e_o = \omega G = 1.215 \]
\[ \sigma_o = \gamma_{sat} Z = 18 \times \frac{18}{2} = 162 \text{kPa} \]
\[ \Delta \sigma = 9 \text{kPa} \]
\[ S_c = \left( \frac{C_c}{1 + e_o} \right) H \log_{10} \left( \frac{\sigma_o + \Delta \sigma}{\sigma_o} \right) \]
\[ = 0.091 \text{m} \]

**Problem 9**

A square footing 1.2 m X 1.2 m rests on a saturated clay layer 4 m deep. \( \omega_L = 30\% \), \( \gamma_{sat} = 17.8 \text{kN/m}^3 \), \( \omega = 28\% \) and \( G = 2.68 \). Determine the settlement if the footing carries a load of 300 kN.

\[ \sigma_o = \gamma_{sat} Z = 17.8 \times \frac{4}{2} = 35.6 \text{kPa} \]
\[ \Delta \sigma = \frac{300}{(2 + 1.2 + 2)^3} = 11.095 \text{kPa} \]
\[ C_c = 0.009(\omega - 10\%) = 0.18 \]
\[ e_o = \omega G = 0.28 \times 2.68 = 0.75041 \]
\[ H = 4 \text{m} \]
\[ S_c = \left( \frac{C_c}{1 + e_o} \right) H \log_{10} \left( \frac{\sigma_o + \Delta \sigma}{\sigma_o} \right) \]
\[ = 0.0485 \text{m} \]

**Problem 10**

A test on undisturbed sample of clay showed 90% consolidation in 10 minutes. The thickness of sample was 25 mm with drainage at both top and bottom. Find the time required for 90% consolidation of footing resting on 5
m thick compressible layer sandwiched between two sand layers. (Aug 2007)

Data

\[ D_{\text{lab}} = \frac{25}{2} = 12.5 \text{ mm} \]
\[ D_{\text{field}} = \frac{5000}{2} = 2500 \text{ mm} \]
\[ t_{\text{lab}} = \frac{10}{(60 \times 24 \times 365)} \text{ years} \]

\[
\frac{t_{\text{lab}}}{t_{\text{field}}} = \left[ \frac{d_{\text{lab}}}{d_{\text{field}}} \right]^2
\]
\[
\frac{t_{\text{lab}}}{t_{\text{field}}} = \left[ \frac{d_{\text{lab}}}{d_{\text{field}}} \right]^2
\]
\[ \therefore t_{\text{field}} = 0.761 \text{ years} \]

Fig. 8.10 : Soil profile in the field and details of oedometer test

8.6 Secondary Compression

1. This settlement starts after the primary consolidation is completely over.
2. During this settlement, excess pore water pressure is zero.
3. The reasons for secondary settlement are not clear.
4. This is creep settlement occurring due to the readjustment of particles to a stable equilibrium under sustained loading over a long time.
5. This settlement is common in very sensitive clay, organic soils and loose sand with clay binders.

\[
S_S = C \alpha H \log_{10} \left[ \frac{t_{\text{sec}} - t_{\text{prim}}}{t_{\text{prim}}} \right]
\]
\( C_a \) = Coefficient of secondary compression  
\( H \) = Thickness of clay layer  
\( t_{sec} \) = Time taken for secondary compression (usually life span of structure)  
\( t_{prim} \) = Time taken for primary consolidation to complete (EPWP to become zero)

8.6.1 Coefficient of Secondary Compression

Table 8.13: Typical values of Coefficient of Consolidation in different soils

<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>( C_a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. C. Clay</td>
<td>0.005 – 0.02</td>
</tr>
<tr>
<td>Organic Clay</td>
<td>&gt; 0.03</td>
</tr>
<tr>
<td>O. C. Clay (OCR &gt; 2)</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Fig. 8.11: Time Vs Settlement curve representing coefficient of secondary settlement

Problem 11
Determine the creep settlement in a sensitive clay of thickness 6 m given $C_a = 0.01$ when the laboratory sample 20 mm thick with double drainage experienced complete consolidation in 10 minutes. The life span of structure is 100 years.

**Data**

$t_{sec} = 100$ yrs  
$H = 6$ m  
$C_a = 0.01$

\[
\frac{t_{lab}}{t_{field}} = \left[ \frac{d_{lab}}{d_{field}} \right]^2
\]

\[
t_{field} = 10 \left[ \frac{6000}{20/2} \right]^2
\]

\[
= 36 \times 10^5 \text{ mnts}
\]

\[
\therefore t_{prim} = t_{field} = 6.85 \text{ yrs}
\]

\[
S = C_a H \log_{10} \left[ \frac{t_{sec} - t_{prim}}{t_{prim}} \right] = 0.068 \text{ m}
\]

**Problem 12**

A 2 m X 2 m footing carrying a load of 1600 kN rests on a normally consolidated saturated clay layer 10 m thick below which hard rock exists. The life span of the structure is 150 years. Time taken for the completion of primary consolidation of 20 mm thick laboratory specimen with double drainage facility is 20 minutes. Find the total settlement, if the soil properties are as follows. Soil modulus 20 MPa, Poisson’s ratio 0.45, Influence factor 0.9, Liquid Limit 50 %, Natural water content 25 %, Specific Gravity of
grains 2.7, saturated density 20 kN/m\(^3\) and coefficient of secondary compression 0.001.

**Total Settlement, \(S = S_I + S_C + S_S\)**

**Data for Immediate Settlement**

\[ E = 20000 \text{ kPa} \]
\[ \mu = 0.45 \]
\[ q = 1600/2^2 = 400 \text{ kPa} \]
\[ B = 2 \text{ m} \]
\[ I_ρ = 0.9 \]

\[ S_I = \left(\frac{1 - \mu^2}{E}\right)qBI_ρ \]

\[ S_I = 0.02871 \text{ m} = 28.71 \text{ mm} \]

**Data for Consolidation Settlement**

\[ \omega_L = 50 \% \]
\[ \omega = 25 \% \]
\[ G = 2.7 \]
\[ C_c = 0.36 \]
\[ e_o = 0.675 \]
\[ H = 10 \text{ m} \]
\[ \sigma_o = 100 \text{ kPa} \]
\[ \Delta \sigma = 11.11 \text{ kPa} \]

\[ C_c = 0.009(\omega_L - 10\%) = 0.36 \]
\[ e_o = \frac{\omega G}{S} = \frac{0.25 \times 2.7}{1} = 0.675 \]

\[ \sigma_o = \gamma_{sat} \frac{H}{2} = 100 \text{ kPa} \]

\[ \Delta \sigma = \frac{P}{\left(\frac{2H}{2} + B\right)^2} = 11.11 \text{ kPa} \]

\[ S_c = \left(\frac{C_c}{1 + e_o}\right)H \log_{10}\left(\frac{\sigma_o + \Delta \sigma}{\sigma_o}\right) \]
Data for Secondary Settlement

- $t_{sec} = 150$ yrs
- $H = d_{field} = 10$ m
- $C_a = 0.001$
- $d_{lab} = 10$ mm
- $t_{lab} = 20$ mnts

\[
\frac{t_{lab}}{t_{field}} = \left[ \frac{d_{lab}}{d_{field}} \right]^2
\]

$\therefore t_{prim} = t_{field} = 38.05$ yrs

\[
S_s = C_a H \log_{10} \left[ \frac{t_{sec} - t_{prim}}{t_{prim}} \right]
\]

$= 0.0047 = 4.7$ mm

Total Settlement, $S = S_1 + S_C + S_S$

$= 28.71 + 98.30 + 4.70$

$= 131.71$ mm

8.7 Factors Influencing Settlement

Many factors influence the settlement of foundation soil when a structure is built on it. The following are a few important factors to be considered in the evaluation of settlement.

1. Elastic properties of soil
2. Shape of footing
3. Rigidity of footing
4. Contact pressure
5. Width of footing
6. Compressibility characteristics of soil
7. Initial conditions of soil (Density, void ratio etc.)
8. Degree of saturation
9. Over Consolidation Ratio
10. Time available for settlement
11. Thickness of soil layer
12. Load dispersion angle

8.8 Modulus of Subgrade Reaction

1. Modulus of subgrade reaction is defined as the ratio of contact pressure to the corresponding settlement
2. Its units are in kN/m$^3$
3. It depends on shape, rigidity and size of footing, depth of embedment and type of soil

8.9 Probable Questions

1. Distinguish between
   1. Consolidation Settlement and Immediate settlement
   2. Consolidation settlement and Secondary settlement
   3. Uniform settlement and Differential settlement

2. Explain the concept of elastic settlement.

3. What is influence factor? What factors influence it?

4. What is contact pressure? What factors influence the same?

5. How are soil modulus and poisson’s ratio determined in laboratory? Explain.

6. Explain the concept of consolidation theory.

7. What is consolidation settlement? How is it determined?

8. Explain the use of laboratory consolidation settlement in finding settlement of soil.

9. List the factors influencing settlement.

10. Explain the concept of creep / secondary consolidation settlement

11. Define the terms
   - Coefficient of secondary compression
   - Compression Index
   - Coefficient of Consolidation
- Influence factor
- Contact Pressure

12. What are the ill effects of total and differential settlement of soil on buildings?
13. What are the different types of settlements of footings?
14. Mention the relations used to compute elastic and consolidation settlements.
15. Write a note on BIS specifications for different types of settlements.
16. Explain the use of plate load test in estimating the probable settlement of footing.
17. Define modulus of subgrade reaction and indicate the factors affecting it.

8.10: References

4. IS6403-1981
5. IS 1904-1986: General Requirements for Design & Construction of Foundation