METHOD OF REMOVING SECONDARY COMPRESSION ON CLAY USING PRELOADING

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**INTRODUCTION**

Mesri (1973)

\[ S_s = \frac{C\alpha'}{H \log \left( \frac{t_2}{t_1} \right)} \]

where \( C\alpha' = \frac{C\alpha}{1+e_p} \)

Alihudien & Mochtar (2009)

\[ C\alpha' = (0.013 e_0 - 0.00062 \text{ LL} - 0.003) P' \]

The Secondary Compression Index \( (C\alpha') \) is affected by the Effective Consolidation Stress \( (P') \). The greater the Effective Consolidation Stress is, the greater the Secondary Compression Index will become.

Preloading + Prefabricated Vertical Drain (PVD)
# MATERIALS AND RESEARCH METHODS

Table 1. Soil consistencies for soil that dominant of clay and silt, Mochtar (2012)

<table>
<thead>
<tr>
<th>Soil Consistencies</th>
<th>Undrained Shear Strength, Cu (kPa)</th>
<th>ton/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft</td>
<td>0 - 12.5</td>
<td>0 - 1.25</td>
</tr>
<tr>
<td>Soft</td>
<td>12.5 - 25</td>
<td>1.25 - 2.5</td>
</tr>
<tr>
<td>Medium</td>
<td>25 - 50</td>
<td>2.5 - 5</td>
</tr>
<tr>
<td>Stiff</td>
<td>50 - 100</td>
<td>5.0 - 10</td>
</tr>
<tr>
<td>Very Stiff</td>
<td>100 - 200</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Hard</td>
<td>&gt; 200</td>
<td>&gt; 20.0</td>
</tr>
</tbody>
</table>

Table 2. Consistencies of tested soil samples

<table>
<thead>
<tr>
<th>Soil Consistencies</th>
<th>Undrained Shear Strength (Cu) (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft</td>
<td>6</td>
</tr>
<tr>
<td>Soft</td>
<td>14.8</td>
</tr>
<tr>
<td>Medium</td>
<td>36.5</td>
</tr>
</tbody>
</table>

- **Atterberg Limits Test**
- **Remolded Sample**
- **Volumetric and Gravimetric Test**
- **Oedometer Test**
- **Statistical Analysis with Regression**
- **Calculation of Soil Settlement**
RESULTS AND DISCUSSION
Empirical correlation of the secondary compression index as function of void ratio and the effective consolidation stress

Fig. 1. The relationship between the initial void ratio and $C\alpha'/P'$

Fig. 2. The relationship between the void ratio at the end of primary consolidation and $C\alpha'/P'$

Fig. 3. The relationship between the initial void ratio and the void ratio at the end of primary consolidation

Table 4. The correlation between the secondary compression index ($C\alpha'$), the void ratio ($e$), and the effective consolidation stress ($P'$)

<table>
<thead>
<tr>
<th>Correlation</th>
<th>R</th>
<th>Regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C\alpha' = (0.0072 \ e_0 - 0.0067) \ P'$</td>
<td>0.888</td>
<td>Linear    (Eq. 1)</td>
</tr>
<tr>
<td>$C\alpha' = (0.0003 \ exp^{1.6116 \ e_0}) \ P'$</td>
<td>0.873</td>
<td>Exponential</td>
</tr>
<tr>
<td>$C\alpha' = (0.0077 \ e_p - 0.006) \ P'$</td>
<td>0.914</td>
<td>Linear    (Eq. 2)</td>
</tr>
<tr>
<td>$C\alpha' = (0.0003 \ exp^{1.8191 \ e_p}) \ P'$</td>
<td>0.910</td>
<td>Exponential</td>
</tr>
</tbody>
</table>
Empirical correlation of the secondary compression index as function of void ratio and the effective consolidation stress

Equation 1
Equation 2
Alihudien & Mochtar (2009)
Laboratory

Fig. 4. Comparison of empirical correlation value to data obtained from laboratory
Method of removing secondary compression

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>H (m)</th>
<th>Consistency</th>
<th>Gs</th>
<th>Unit Weight</th>
<th>Atterberg’s Limit</th>
<th>Consolidation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y&lt;sub&gt;s&lt;/sub&gt;</td>
<td>LL (%)</td>
<td>PL (%)</td>
</tr>
<tr>
<td>0.0 - 2.0</td>
<td>2</td>
<td>Medium</td>
<td>2.616</td>
<td>1.700</td>
<td>1.063</td>
<td>100</td>
</tr>
<tr>
<td>2.0 - 5.0</td>
<td>3</td>
<td>Very Soft</td>
<td>2.616</td>
<td>1.426</td>
<td>0.705</td>
<td>100</td>
</tr>
<tr>
<td>5.0 - 10.0</td>
<td>5</td>
<td>Soft</td>
<td>2.616</td>
<td>1.483</td>
<td>0.771</td>
<td>100</td>
</tr>
<tr>
<td>10.0 - 15.0</td>
<td>5</td>
<td>Medium</td>
<td>2.616</td>
<td>1.700</td>
<td>1.063</td>
<td>100</td>
</tr>
</tbody>
</table>

\[ \gamma_{sat} = \gamma_t = 1.9 \text{ t/m}^3 \]

Primary Consolidation - normally consolidated (NC-Soil):

\[ Sc = \left( \frac{C_c}{1 + e_0} \right) \log \left( \frac{P_o + \Delta P}{P_o} \right) H \]

\[ H_{initial} = \frac{q_{final} + Sc(y_{embankment} - y'_{embankment})}{y_{embankment}} \]

\[ H_{final} = H_{initial} - Sc \]

Secondary Compression (Ss):

\[ Ss = Cα'H \log \left( \frac{t_2}{t_1} \right) \]

where:

\[ Cα' = (0.0072 e_0 - 0.0067) \text{ P}^4 \]

or

\[ Cα' = (0.0077 e_p - 0.0060) \text{ P}^4 \]

\[ t_1 = 0.5 \text{ years}, \ t_2 = 25 \text{ years} \]

Table 5. Soil Parameters
Method of removing secondary compression

- Total of primary and secondary compression, $S_{total}$
  $$S_{total} = 3.52 \text{ m}$$

- New final load of embankment, $q_{final2}$
  $$y = 1.899x^2 - 4.755x + 6.670 = 1.899(3.52)^2 - 4.755(3.52) + 6.670 = 13.46 \text{ t/m}^2$$

- Extra load of embankment to remove the secondary compression, $\Delta q$
  $$q_{final1} = 10 \text{ t/m}^2$$
  $$\Delta q = q_{final2} - q_{final1} = 13.46 - 10 = 3.46 \text{ t/m}^2$$

- Initial height of embankment before primary and secondary compression occurs, $H_{initial(p+s)}$
  $$y = -0.0019x^2 + 0.6482x + 0.553 = -0.0019(13.46)^2 + 0.6482(13.46) + 0.553 = 8.93 \text{ m}$$

- Final height of embankment after primary and secondary compression occurs, $H_{final(p+s)}$
  $$y = 0.0093x^2 + 0.6131x - 0.7952 = 0.0093(8.93)^2 + 0.6131(8.93) - 0.7952 = 5.42 \text{ m}$$

- Final height of embankment in the field after unloaded, $H_{final-field}$
  $$Y_{timbunan} = 1.9 \text{ t/m}^3$$
  $$H_{final-field} = H_{final(p+s)} - \frac{\Delta q}{Y_{embankment}} = 5.42 - 3.46 / 1.9 = 3.6 \text{ m}$$
Method of removing secondary compression

Table 6. The value of $H_{\text{initial}}$ dan $H_{\text{final-field}}$

<table>
<thead>
<tr>
<th>$q_{\text{final1}}$ (t/m$^3$)</th>
<th>$S_{\text{total}}$ (m)</th>
<th>$q_{\text{final2}}$ (t/m$^3$)</th>
<th>$\Delta q$ (t/m$^3$)</th>
<th>$H_{\text{initial(p+s)}}$ (m)</th>
<th>$H_{\text{final(p+s)}}$ (m)</th>
<th>$H_{\text{final-field}}$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.33</td>
<td>5.89</td>
<td>0.89</td>
<td>4.31</td>
<td>2.02</td>
<td>1.55</td>
</tr>
<tr>
<td>10</td>
<td>3.52</td>
<td>13.46</td>
<td>3.46</td>
<td>8.93</td>
<td>5.42</td>
<td>3.60</td>
</tr>
<tr>
<td>15</td>
<td>4.40</td>
<td>22.53</td>
<td>7.53</td>
<td>14.19</td>
<td>9.78</td>
<td>5.82</td>
</tr>
<tr>
<td>20</td>
<td>5.13</td>
<td>32.26</td>
<td>12.26</td>
<td>19.48</td>
<td>14.68</td>
<td>8.23</td>
</tr>
<tr>
<td>25</td>
<td>5.76</td>
<td>42.36</td>
<td>17.36</td>
<td>24.60</td>
<td>19.92</td>
<td>10.78</td>
</tr>
</tbody>
</table>

Fig. 8. The relationship between $H_{\text{final-field}}$ and $H_{\text{initial(p+s)}}$

$y = -0.022x^2 + 2.490x + 0.420$

$R^2 = 1$
CONCLUSION

1. Based on laboratory experimental studies and statistical analysis, there are empirical correlations between the secondary compression index \((Cα')\) with the initial void ratio \((e_0)\), the void ratio at the end of primary consolidation \((e_p)\), and the effective consolidation stress \((P')\).

2. Regression between \(Cα' - e_0 - P'\) and \(Cα' - e_p - P'\) shows a strong correlation between these parameters. Based on the linear regression, the relationship of \(Cα' - e_0 - P'\) has the coefficient of determination is \(R = 0.888\), while for the relation \(Cα' - e_p - P'\) has \(R = 0.914\). With a fairly high R value of close to 1, this empirical correlation can be used in predicting the secondary compression index. The correlations obtained from this study are as follows:

\[
Cα' = (0.0072 e_0 - 0.0067) P' \quad \text{and} \quad Cα' = (0.0077 e_p - 0.006) P'
\]

where \(Cα'\) is the secondary compression index, \(e_0\) is the initial void ratio, \(e_p\) is the void ratio at the end of primary consolidation, and \(P'\) is the effective consolidation stress which is the magnitude of the addition of stress due to the external load \((ΔP)\), \(P' = ΔP\).

3. The value of the secondary compression index \((Cα')\) is influenced by the effective consolidation stress \((P')\). The greater the effective consolidation stress \((P')\) is, then the greater the secondary compression index \((Cα')\) will become. So that the secondary compression can be removed along with preloading at the time of removal of the primary consolidation. Secondary compression can be removed by giving an extra load \((Δq)\) that causes additional compression to the primary consolidation where the magnitude equals to the expected secondary compression. Then, this \(Δq\) could be removed at the end of the primary consolidation. So that after soil improvement with preloading is completed, there is no more settlement caused by primary consolidation and secondary compression. The extra load \((Δq)\) during preloading will make the soil become more compressive such that increases undrained shear strength value \((Cu)\). The increasing value of \(Cu\) causes the secondary compression index \((Cα')\) to be smaller. So that the extra load \((Δq)\) at the time of preloading can eliminate the secondary compression at a certain time period.
REFERENCES


Q and A?
MATERIALS AND RESEARCH METHODS
### Soil parameters obtained from laboratory tests

<table>
<thead>
<tr>
<th></th>
<th>Very Soft</th>
<th>Soft</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{\text{sat}}$ (g/cm³)</td>
<td>1.426</td>
<td>1.483</td>
<td>1.700</td>
</tr>
<tr>
<td>$\gamma_{d}$ (g/cm³)</td>
<td>0.705</td>
<td>0.771</td>
<td>1.063</td>
</tr>
<tr>
<td>$e_0$</td>
<td>1.380</td>
<td>1.265</td>
<td>1.050</td>
</tr>
<tr>
<td>Wc (%)</td>
<td>102.25</td>
<td>92.46</td>
<td>60</td>
</tr>
<tr>
<td>Gs</td>
<td>2.616</td>
<td>2.616</td>
<td>2.616</td>
</tr>
<tr>
<td>Cu (kPa)</td>
<td>6.0</td>
<td>14.8</td>
<td>36.5</td>
</tr>
<tr>
<td><strong>Atterberg Limits</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL (%)</td>
<td>107.51</td>
<td>107.51</td>
<td>107.51</td>
</tr>
<tr>
<td>PL (%)</td>
<td>42.63</td>
<td>42.63</td>
<td>42.63</td>
</tr>
<tr>
<td>PI (%)</td>
<td>64.88</td>
<td>64.88</td>
<td>64.88</td>
</tr>
<tr>
<td><strong>Consolidation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cc</td>
<td>0.763</td>
<td>0.723</td>
<td>0.658</td>
</tr>
<tr>
<td>Cs</td>
<td>0.203</td>
<td>0.197</td>
<td>0.187</td>
</tr>
<tr>
<td>$C_v$ (cm²/s)</td>
<td>0.000108</td>
<td>0.000159</td>
<td>0.000181</td>
</tr>
<tr>
<td>Cα</td>
<td>0.0301</td>
<td>0.0284</td>
<td>0.0191</td>
</tr>
</tbody>
</table>

Table 3. Soil parameters
Method of removing secondary compression

\[ C\alpha' = (0.0072 \, e_0 - 0.0067) \, P' \] (eq.1)
\[ C\alpha' = (0.0077 \, e_p - 0.006) \, P' \] (eq.2)

The value of \( C\alpha' \) is influenced by the effective consolidation stress (\( P' \)).


The secondary compression is significantly reduced when soils are over consolidated to moderate levels, indicating that the use of preload is greater than the final embankment/structural load, this is an effective method of reducing secondary compression.

Alonso, Gens, & Lloret (2000)

The secondary compression coefficient (\( C\alpha \)) decreased significantly with an increase in the over consolidation ratio (OCR), so pre-consolidation is an effective method of removing secondary compression.

Secondary compression can be removed along with preloading at the time of removal of the primary consolidation. Secondary compression can be removed by giving an extra load (\( \Delta q \)) that causes additional compression to the primary consolidation with the magnitude equals to the expected secondary compression. Then, this \( \Delta q \) could be removed at the end of the primary consolidation. So that after soil improvement with preloading is completed, there is no more settlement caused by primary consolidation and secondary compression.