COMPRESSION BEHAVIOUR OF NATURAL SOILS


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ABSTRACT

Compressibility is an important characteristic feature of soils to evaluate magnitude of deformation under a given loading. It is observed that compression behaviour of natural soils is characterized initially by rigid response and rapid compression at greater stress levels. Marked breaking point is noticed at the point of transition which is usually termed as yield stress. Compression is relatively low if the applied stress level is within the yield point and the stress levels are noticeable when the applied stress level is greater than the yield value. Initial and final slopes of the compression curve represent the sample disturbance which is an important parameter to estimate the quality of sample obtained in the field. Availability of reliable engineering parameters for geotechnical design depends on careful testing. Testing may be carried out in the laboratory or in the field, but in either case the most important factor controlling the quality of the end result is likely to be the avoidance of soil disturbance. The present paper deals with determining the compression index before yield and post yield for evaluating settlements as also to quantify the degree of sample disturbance.

Keywords: Residual soil, compression index, consolidation, sample disturbance.

1. INTRODUCTION

Compressibility characteristics of natural soils are often the most important parameters for settlement evaluation. The compression behaviour of a natural clay can be classified into three regimes: the pre-yield regime characterised by small compressibility up to the consolidation yield stress with soil structure restraining the deformation; the transitional regime with gradual loss of soil structure when the effective stress is between the
consolidation yield stress and the transitional stress; and the post-transitional regime characterised by the same change law in compression behaviour as a reconstituted clay when the effective stress is higher than the transitional stress. Pre and post yield slopes of the compression curve represent the sample disturbance which is an important parameter to estimate the quality of sample obtained in the field.

Sample disturbance is the most significant issue affecting the quality and reliability of laboratory test data. All key design parameters such as compressibility, yield stress and undrained shear strength are adversely influenced by sample disturbance. A carefully planned experimental investigation has been carried out on soil samples extracted from different depths from various locations of Tirupati region. The properties of these soil samples represent wide spectrum of soils normally encountered in this region. One-dimensional compression test have been conducted apart from classification and identification tests. Based on test results, a framework for analyzing the compression index at pre and post yield and also degree of sample disturbance has been developed.

2. BACKGROUND INFORMATION

Researches were carried out to characterize the engineering properties of residual soils (Hight & Leroueil, 2002), to investigate the effects of soil structure on the engineering properties and analyse the compressibility behaviour (Nagaraj et al., 1998), and also to evaluate the collapse behaviour of it (Rao & Revanasiddappa, 2006; Huat et al., 2008). Sarma et al. (2008) observed that the consolidation properties of soils indicate an insight on the compressibility behaviour of soils with associated expulsion of water. Abbasi et al. (2012) brought out that the compressibility characteristics of fine-grained soils are often the most important parameters for settlement evaluation. These characteristics are usually described using two well-known coefficients: the compression index, \( C_c \) and the coefficient of consolidation, \( C_v \).

Hong et al. (2012) observed that the natural clays generally have a compression curve lying above that of reconstituted clays owing to the effect of soil structure. It has been recognised that the soil structure restrains the deformation of natural clays under effective vertical stress up to the consolidation yield stress, consequently resulting in the low compressibility of clays until the stress level exceeds the consolidation yield stress (Butterfield, 1979; Burland, 1990). The difference of void ratio between natural clays and reconstituted clays at the same stress level often increases with increasing consolidation stress up to the consolidation yield stress, but decreases when the applied stress level is larger than the consolidation yield stress. Nagendra Prasad et al (2007) brought out sample disturbance index, using merely the slopes of compression paths, (representing mechanical response), in the pre- and post-yield stress regimes under oedometric loading conditions. However, there appears to be a need to examine the possibility of analysing the test results of residual soils to understand the compression response and the possibility of evolving sample disturbance for comprehensive understanding of the behaviour under compression and its application to solve a practical problem.
3. EXPERIMENTAL INVESTIGATION

3.1 Introduction

The study area lies to the extreme south of Andhra Pradesh state (India) approximately between 12° 37' - 14° 80' north latitudes and 78° 30' - 79° 55' east longitudes. Experimental investigations are carried out on tropical residual soils of Tirupati region.

3.2 Details of the Experimental Investigation

The present experimental investigation is carefully planned such that a framework for analysis and assessment can be developed to understand the behavior of tropical residual soils. The experimental program involves determination of the following aspects.

- Basic properties of soils
- Engineering properties of soil such as compressibility.

All the tests are conducted as per the relevant provisions stipulated in Bureau of Indian Standards.

3.3 Soils Tested

The soils considered in the present investigation have been obtained from the surroundings of Tirupati region. The details of locations of sampling are as follows:

1) Mullapudi (Village), Tiruchanur, Tirupati, Chittoor (District)
2) Yogimallavaram Residential Area, Tiruchanur, Tirupati, Chittoor (District)
3) Industrial Development Park, Gajula Mandyam, Renigunta, Chittoor (District)
4) Fire Station Building at Nagari, Chittoor (District)
5) Besides Thiruchanur by-pass road, Tiruchanur, Tirupati, Chittoor (District)
6) Renigunta Road, Near Hyundai Show Room, Tirupati, Chittoor (District)
7 & 8) Nadavalur, Ramachandra Puram (Mandal), Tirupati, Chittoor (District).

3.4 Collection of Samples

Soil samples have been collected by exercising necessary care to see that the natural constituents are represented and the same were transported to Geotechnical Engineering laboratory. The samples were air dried and stored in air tight containers for use in rest of the investigation.

3.5 Properties of Soils

3.5.1 Basic Properties of Soils

The properties of soils considered in the present investigation are presented in table 1. It may be seen from the table that all the soils represent Clayey Sand (SC) excepting one which is of Clay with Intermediate compressibility (CI). The grain size distribution curves for soil samples are shown in figure 1. It may be noticed from the figure that the grain size distribution curves are wide spread with fine fraction ranging from 30% to 70% and hence the soils considered represent wide spectrum of soil samples normally found in this region. The liquid limit values range from 47% to 85%. Further, the plastic index values range from 33% to 59% covering wide spectrum of soils.
### TABLE 1: SOIL PROPERTIES

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Description</th>
<th>Values</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
<th>Sample 5</th>
<th>Sample 6</th>
<th>Sample 7</th>
<th>Sample 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth at, m</td>
<td></td>
<td>2.0</td>
<td>2.8</td>
<td>2.1</td>
<td>3.0</td>
<td>2.4</td>
<td>2.3</td>
<td>1.7</td>
<td>2.5</td>
</tr>
<tr>
<td>1</td>
<td>Gravel (%)</td>
<td></td>
<td>1.4</td>
<td>1.4</td>
<td>7.90</td>
<td>10.15</td>
<td>9.1</td>
<td>7.6</td>
<td>0.3</td>
<td>1.3</td>
</tr>
<tr>
<td>2</td>
<td>Sand (%)</td>
<td></td>
<td>58.1</td>
<td>56.7</td>
<td>52.20</td>
<td>54.35</td>
<td>62.3</td>
<td>57.9</td>
<td>31.7</td>
<td>53</td>
</tr>
<tr>
<td>3</td>
<td>Silt+Clay (%)</td>
<td></td>
<td>40.5</td>
<td>41.9</td>
<td>39.85</td>
<td>35.50</td>
<td>28.6</td>
<td>34.5</td>
<td>68.0</td>
<td>45.7</td>
</tr>
<tr>
<td>4</td>
<td>0.425 mm Size (%)</td>
<td></td>
<td>67.0</td>
<td>58.8</td>
<td>61.65</td>
<td>42.50</td>
<td>38.71</td>
<td>42.9</td>
<td>90.7</td>
<td>67.6</td>
</tr>
<tr>
<td>5</td>
<td>Liquid Limit (%)</td>
<td></td>
<td>58.0</td>
<td>59.5</td>
<td>68.0</td>
<td>69.5</td>
<td>85</td>
<td>68.7</td>
<td>47.5</td>
<td>56.0</td>
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<tr>
<td>6</td>
<td>Plastic Limit (%)</td>
<td></td>
<td>15</td>
<td>20</td>
<td>14</td>
<td>24</td>
<td>26</td>
<td>23</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>Plasticity Index (%)</td>
<td></td>
<td>43.0</td>
<td>39.5</td>
<td>54.0</td>
<td>45.5</td>
<td>59</td>
<td>45.7</td>
<td>33.5</td>
<td>40.0</td>
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<tr>
<td>8</td>
<td>IS Classification</td>
<td></td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
<td>CI</td>
<td>SC</td>
</tr>
<tr>
<td>9</td>
<td>Free Swell Index (%)</td>
<td></td>
<td>40</td>
<td>90</td>
<td>35</td>
<td>110</td>
<td>320</td>
<td>25</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>Degree of Expansion</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Very</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>11</td>
<td>Modified Liquid Limit, $W_{lm}$ (%)</td>
<td></td>
<td>39.0</td>
<td>35.0</td>
<td>42.0</td>
<td>29.5</td>
<td>33</td>
<td>29.5</td>
<td>43</td>
<td>38</td>
</tr>
<tr>
<td>12</td>
<td>In-situ Density, $\gamma$ (kN/m)$^3$</td>
<td></td>
<td>18.67</td>
<td>20.15</td>
<td>17.48</td>
<td>20.07</td>
<td>20.87</td>
<td>20.48</td>
<td>19.17</td>
<td>17.63</td>
</tr>
<tr>
<td>13</td>
<td>Natural moisture content, (%)</td>
<td></td>
<td>15.15</td>
<td>17.28</td>
<td>13.15</td>
<td>17.49</td>
<td>12.16</td>
<td>15.29</td>
<td>23.64</td>
<td>13.23</td>
</tr>
<tr>
<td>14</td>
<td>Dry density, $\gamma_d$ (kN/m)$^3$</td>
<td></td>
<td>16.21</td>
<td>17.18</td>
<td>15.45</td>
<td>17.08</td>
<td>18.60</td>
<td>17.76</td>
<td>15.50</td>
<td>15.56</td>
</tr>
<tr>
<td>15</td>
<td>Initial void ratio, $e_0$</td>
<td></td>
<td>0.646</td>
<td>0.553</td>
<td>0.727</td>
<td>0.562</td>
<td>0.435</td>
<td>0.503</td>
<td>0.722</td>
<td>0.715</td>
</tr>
<tr>
<td>16</td>
<td>Over burden pressure,$\sigma_o$ (kN/m)$^3$</td>
<td></td>
<td>32.43</td>
<td>48.12</td>
<td>32.45</td>
<td>51.24</td>
<td>44.64</td>
<td>40.85</td>
<td>26.35</td>
<td>38.92</td>
</tr>
</tbody>
</table>

### Shear Strength Parameters

| Angle of internal friction, $\phi$, in degrees | 7.48 | 9.55 | 25.08 | 12.99 | 27.92 | 7.02 | 4.19 | 7.38 |
| Cohesion, $C$ in kPa | 42.24 | 73.16 | 31 | 44.95 | 26.5 | 46.56 | 58.66 | 49 |

| Compression Index, $Cc$ (post yield) | 0.117 | 0.170 | 0.162 | 0.149 | 0.219 | 0.083 | 0.113 | 0.231 |

**Figure 1:** Grain-size distribution curves for combination of all samples
3.5.2. Compressibility

Compressibility represents volume change behavior of soils under loading; it is one of the important engineering properties of soil representing the magnitude of settlement under unit increase in pressure. As the field compression most often takes places under one-dimensional compression, oedometer tests have been conducted on soil samples under consideration. Necessary care has been exercised to retain basic constituents of the material and the in-situ density. Samples have been saturated under a normal stress of 5 kPa to attain nearly the state of saturations.

![Figure 2: One-dimensional consolidation test curves for combination of all samples](image)

The compression behavior of all eight soil samples is presented in figure 2. It may be noticed that the compression behavior depicts initially stiff response up to a certain normal stress value and shows greater degree of compression beyond this stress value. The same compression behavior is noticed with respect to all the soil samples tested.

4. ANALYSIS OF TEST RESULTS

4.1 Introduction

The usual object of detailed experimental investigation will be to propose a basic framework for analysis of the observed behavior so that assessment of behavior would be based on mechanistic approach. A detailed analysis of test results is presented in the following section.

4.2 Normal Compression Line (NCL) as State Boundary Surface

An attempt has been made to examine the compression behavior with respect to Normal Compression Line (NCL) for which the equation given by Nagaraj et al. (1994) as reproduced below has been adopted.

\[
e = \frac{e}{e_L} = 1.23 - 0.276 \log \sigma_v
\]

Eq. (1)

Where,

- \( e \) = Void ratio at a given pressure of \( \sigma_v \)
- \( e_L \) = Void ratio corresponding to liquid limit
Most of the natural soils have particle sizes ranging from 4.75mm to 2\( \phi \). The liquid limit is normally determined from the fraction passing through 425\( \phi \). Since, the soils considered in the present investigation have fractions passing through 425\( \phi \) ranging from 38\% to 90\%, modified liquid limit is considered as given by the following equation:

\[
W_{lm} = \frac{w_f \times F}{100}
\]

Eq. (2)

Where,

\( w_f \) = Liquid limit of the soil passing 425\( \phi \)
\( W_{lm} \) = Modified liquid limit for the total soil
\( F \) = Fraction of passing through 425\( \phi \)

Accordingly Equation (1) is modified as:

\[
\frac{e}{e_{lm}} = 1.23 - 0.276 \log \sigma_v
\]

Eq. (3)

Where,

\( e_{lm} \) = Void ratio corresponding to modified liquid limit (\( W_{lm} \))

Using equation (3) the Normal Compression Line (NCL) for all the soil samples is shown in figures 3-10. It may be noticed that the compression behavior of natural soils is located on left hand side of Normal Compression line (NCL) and hence the behavior of natural soils is akin to the compression behavior of over consolidated soils. It is also seen that the compression behavior of natural soils merge with Normal Compression Line, after a particular stress value confirming that Normal Compression Line (NCL) forms the state boundary surface.

\textbf{Figure: 3} Comparision between normal compression line and natural compression line for sample 1

\textbf{Figure: 4} Comparision between normal compression line and natural compression line for sample 2
**Figure: 5** Comparison between normal compression line and natural compression line for sample 3

**Figure: 6** Comparison between normal compression line and natural compression line for sample 4

**Figure: 7** Comparison between normal compression line and natural compression line for sample 5

**Figure: 8** Comparison between normal compression line and natural compression line for sample 6
Comparision between normal compression line and natural compression line for sample 7

Comparision between normal compression line and natural compression line for sample 8

4.3 Compression Moduli and Yield Stress

Compression curve of natural soils is characterized by relatively rigid response at initial stress levels and by greater compression at higher stress levels. The change of slope in the compaction curve is characterized by the yield. The stress corresponding to yield point is termed as yield stress. Accordingly, an attempt has been made to determine the compression modulus before the yield ($C_{c1}$) and compression modulus after the yield stress ($C_{c2}$) as shown in figures 11-18.

Relation between specific volume and effective stress for sample 1

Relation between specific volume and effective stress for sample 2
Figure: 13 Relation between specific volume and effective stress for sample 3

Figure: 14 Relation between specific volume and effective stress for sample 4

Figure: 15 Relation between specific volume and effective stress for sample 5

Figure: 16 Relation between specific volume and effective stress for sample 6

Figure: 17 Relation between specific volume and effective stress for sample 7

Figure: 18 Relation between specific volume and effective stress for sample 8
The compression index before yield stress ($C_c^1$) and the compression index after yield stress ($C_c^2$) are determined for all the soil samples. Here, the sample disturbance is defined for the purpose of the analysis, as given by following expression

$$Sample\; disturbance = \frac{C_c^1}{C_c^2} \times 100$$

$C_c^2$ represent compression index of NCL which corresponds to 100% disturbance and $C_c^1$ represent pre-yield for rigid response of the soil.

If $C_c^1 = C_c^2$ the soil sample is completely remolded; the sample disturbance is 100%. The sample disturbance values from the table 2 indicate that the samples are disturbed from 7% to 34% in the present investigation. The test results indicate that the value of $C_c^1$ is of the order of 1/3 to 1/14 of $C_c^2$ value depending on state of soil. It turns out that the ratio of compression moduli for natural residual soils is significantly different from normally consolidated soils whose ratio varies from 1/3 to 1/5 (as indicated in Atkinson et al., 1978).

**Table 2:** Compression index at pre and post yield, yield stress and over burden pressure values

<table>
<thead>
<tr>
<th>Soil</th>
<th>Description</th>
<th>Compression Index, $C_c^1$ (pre-yield)</th>
<th>Compression Index, $C_c^2$ (post-yield)</th>
<th>$C_c^1/C_c^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample1</td>
<td></td>
<td>0.033</td>
<td>0.117</td>
<td>0.283</td>
</tr>
<tr>
<td>Sample2</td>
<td></td>
<td>0.015</td>
<td>0.17</td>
<td>0.09</td>
</tr>
<tr>
<td>Sample3</td>
<td></td>
<td>0.042</td>
<td>0.162</td>
<td>0.259</td>
</tr>
<tr>
<td>Sample4</td>
<td></td>
<td>0.01</td>
<td>0.149</td>
<td>0.069</td>
</tr>
<tr>
<td>Sample5</td>
<td></td>
<td>0.027</td>
<td>0.219</td>
<td>0.127</td>
</tr>
<tr>
<td>Sample6</td>
<td></td>
<td>0.011</td>
<td>0.083</td>
<td>0.139</td>
</tr>
<tr>
<td>Sample7</td>
<td></td>
<td>0.038</td>
<td>0.113</td>
<td>0.34</td>
</tr>
<tr>
<td>Sample8</td>
<td></td>
<td>0.056</td>
<td>0.231</td>
<td>0.245</td>
</tr>
</tbody>
</table>
5. CONCLUDING REMARKS

Based on detailed experimental investigation and analysis of test results the following concluding remarks may be made.

- The compression behavior depicts initially stiff response up to a normal stress value and shows greater degree of compression beyond this stress value. The same compression behavior is noticed with respect to all the soil samples tested.
- The compression behavior of natural soils is located on left hand side of Normal Compression line (NCL) and hence the behavior of natural soils is akin to the compression behavior of over-consolidated soils.
- The compression behavior of natural soils merge with Normal Compression Line after a particular stress values confirming that Normal Compression Line (NCL) forms the state boundary surface.
- The compression curves of natural soils are characterized by relatively rigid response at initial stress levels and by greater compression at higher stress levels.
- Sample disturbance is defined as the ratio of compression indices at pre and post yields, given by following expression

\[
Sample \, disturbance = \frac{C_{c1}}{C_{c2}} \times 100
\]

- Sample disturbance in the present investigation ranges from 7% to 34%.
- The test results indicate that the value of \( C_{c1} \) is of the order of \( 1/3 \) to \( 1/14 \) of \( C_{c2} \) value depending on state of soil. It turns out that the ratio of compression moduli for natural residual soils is significantly different from normally consolidated soils whose ratio varies from \( 1/3 \) to \( 1/5 \).

REFERENCES


