Index Properties and Strength of Artificial Soil Using the Harvard Miniature Method

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1. ABSTRACT

Compaction of soil comprises an important aspect of geotechnical investigation involving fill applications. Preparation of compacted specimen in the laboratory is essential to study the moisture-density and moisture strength relationships of soils and their mixtures. In the present study compaction and unconfined compression tests were conducted on artificial mixed soils by using Harvard miniature compaction tool. The variables investigated are index properties of soil, maximum dry density, optimum moisture content and the unconfined compressive strength of soil. Moisture-density relationship of the soil and compressive strength of the soil was correlated with index properties of the soil.

2. INTRODUCTION

Compaction characteristics of soil are usually determined by conducting Standard Procter tests in the laboratory over the soil and the test results are utilized in the field for different construction and also for ensuring the quality of construction. However, the test is quite costly and time consuming. Further when extent of construction is very large for example making sub-grade of roads of large length, generally existing materials along the length widely varies due to depositional reasons, and in such cases, number of compaction tests to be performed, becomes very large, extremely time consuming and costly. In such cases if the estimation of the moisture-density relationship could be developed on the basis of some test which are quick to perform, less time consuming and cheap, then the process will help the constructors enormously. In the present study moisture-density relationship from Harvard Miniature compaction method with the help of index properties and compressive strength of the soil was studied. Throughout this research project, the relationship between index properties (liquid limit, plasticity index), maximum dry unit weight and strength of artificial soil was observed. The tests performed included the unconfined compression test using the Harvard Miniature apparatus, liquid limit, and plastic limit tests.

3. OBJECTIVES

The overall objective of this research project was to investigate the relationships between the maximum dry unit weight ($\gamma_{dry}$), the index properties (LL, PI) and strength of artificial soil prepared using the Harvard Miniature Method.

4. MATERIALS AND METHODS

A compilation of artificial soil mixtures were used in varying proportions in order to better observe the characteristics. These mixtures consisted of poorly graded sand with a specific gravity of 2.65, kaolinite containing a specific gravity of 2.623 and bentonite containing a specific gravity of 2.89. Grain size distribution of soil samples was
determined using sieve analysis for sand and Hydrometer tests (ASTM D 422-63) for kaolinite and bentonite. The grain size distribution is as shown in Fig. 2. For the sand, coefficient of uniformity \((C_u)\) and coefficient of curvature \((C_c)\) are 3.15 and 1.15 respectively for the sand. The \(C_u\) and \(C_c\) values indicate that the ASTM C-33 sand is poorly graded and classified as SP. The tests performed included compaction test, unconfined compression, liquid limit, and plastic limit by using different mixtures of kaolinite and sand, bentonite and sand and bentonite, kaolinite and sand.

![Grain Size distribution of sand, kaolinite and bentonite](image)

**Fig. 1.** Grain Size distribution of sand, kaolinite and bentonite

### 4.1 Compaction test

Compaction is a process by which the soil particles are artificially rearranged and packed together into a closer state of contact by mechanical means in order to decrease the porosity of the soil and increase its dry density. The compaction process may be accomplished by rolling, tamping or vibration. The compaction characteristics are determined in the laboratory by various compaction tests. These tests are based on any one of the following methods are types of compaction: dynamic or impact, kneading, static and vibration. Some of the usual compaction tests in the laboratory are: Standard and Modified Proctor tests, Harvard Miniature compaction test, Abbot compaction test etc.

#### 4.1.1 Harvard Miniature Compaction

Harvard Miniature compaction (Fig. 2) was developed by Wilson (1950). The intent was to duplicate more closely field compaction using a sheep-foot roller. In this test soil is compacted by kneading action of a cylindrical tamping foot 0.5 in. in diameter. The apparatus consists of a mold 1 5/16 in. in diameter x 2.816 in. long having a volume of \(1/454 \text{ ft}^3\). The tamping foot operates through a pre-set compression spring so that the tamping force does not exceed appreciably a predetermined value. Commonly three layers at 25 tamps per layer may be used. The principal test advantages are
1) Only small amounts of soil are required (but must pass through No. 4 sieve)
2) One can obtain samples of dimensions suitable for testing unconfined or triaxial compression. These samples also may be suitable for falling-head permeability tests using triaxial apparatus.

![Harvard Miniature compaction apparatus](image)

**Fig. 2** Harvard Miniature compaction apparatus. (A=tamper, B-mold with collar attached to the base, C-device to remove mold collar without tearing last layer, D-sample extruder, E-compacted samples.)

### 4.2 Unconfined compressive test

The unconfined compressive test is a special case of triaxial compression test in which $\sigma_2=\sigma_3=0$. Due to the absence of confining pressure the uniaxial test is called the unconfined compression test. The cylindrical specimen of soil is subjected to major principal stress $\sigma_1$ till the specimen fails due to shearing along critical plane of failure. Samples prepared from Harvard miniature mold was used to perform the unconfined compressive strength tests.

### 5. ANALYSIS AND DISCUSSION

#### 5.1 Liquid limit and Plastic limit ASTM D 4318-00

The mechanical properties of a fine grained soil are altered by changing the water content. Liquid limit and plastic limit tests were performed on different mixtures of artificial soil in order to find the relationship between mechanical properties and index properties. The results of liquid limit, plastic limit and plasticity index on different soil mixes are summarized in Table 1. The classification of soil based on USCS soil classification has been found from the plasticity chart Fig. 3.
Table 1: Summary of liquid limit and plastic limit for different mixes

<table>
<thead>
<tr>
<th>Artificial Mixture</th>
<th>Liquid Limit (%)</th>
<th>Plastic Limit</th>
<th>Plasticity Index (%)</th>
<th>USCS Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>30K70S</td>
<td>7</td>
<td>NP</td>
<td>7</td>
<td>CL-ML</td>
</tr>
<tr>
<td>50K50S</td>
<td>22</td>
<td>15</td>
<td>78.21</td>
<td>CL-ML</td>
</tr>
<tr>
<td>70K30S</td>
<td>31.709</td>
<td>16</td>
<td>15.92</td>
<td>CL</td>
</tr>
<tr>
<td>B10K40S50</td>
<td>68.25</td>
<td>12</td>
<td>56.25</td>
<td>CH</td>
</tr>
<tr>
<td>B15K35S50</td>
<td>80.816</td>
<td>10</td>
<td>70.85</td>
<td>CH</td>
</tr>
<tr>
<td>B20K30S50</td>
<td>106.7</td>
<td>14</td>
<td>93.1</td>
<td>CH</td>
</tr>
<tr>
<td>30B70S</td>
<td>142.19</td>
<td>17</td>
<td>124.08</td>
<td>CH</td>
</tr>
<tr>
<td>50B50S</td>
<td>213.006</td>
<td>27</td>
<td>185.81</td>
<td>CH</td>
</tr>
<tr>
<td>70B30S</td>
<td>342.45</td>
<td>36</td>
<td>306.4</td>
<td>CH</td>
</tr>
</tbody>
</table>

The liquid limit of bentonite and kaolinite was 450 and 42 respectively. Plastic limit for bentonite and kaolinite was 43 and 25 respectively. The liquid limit and plasticity index of soil increases with increase in clay content. The increase in more pronounced in the case of bentonite mixtures.

5.2 Compaction characteristics

Figures 4 and 5 shows the moisture density relationship for the bentonite, sand, and kaolinite, sand mixtures. The maximum dry density varies from 311 – 261 pcf and optimum moisture content (OMC) varies from 16.6-21.5 % for increase in bentonite content whereas maximum dry density for kaolinite varies from 338-273 pcf and OMC varies from 11-23 for the similar sand ratios. It has been found that maximum dry density decreases and OMC increases with the increase in bentonite and kaolinite content. The moisture density relationship for the bentonite, kaolinite and sand mixtures was shown in
Fig. 4. Moisture density relationship for bentonite and sand mixture

Fig. 5. Moisture density relationship for kaolinite and sand mixture

Fig. 6. Moisture density relationship for bentonite, kaolinite and sand mixture
Fig. 6. The ratio of bentonite and kaolinite was varied keeping the sand as constant. OMC increases with increase in bentonite and decreases with the increase in kaolinite.

Figure 7 shows the variation of optimum moisture content with maximum dry density for different mixtures. The variation is linear in the case of kaolinite, sand and bentonite, sand mixtures. The bentonite, kaolinite and sand mixtures shows a parabolic variation which shows that ratio of bentonite and kaolinite plays an important role in the moisture density relation irrespective of the increase in the bentonite content.

![Graph](image)

**Fig. 7. Maximum dry unit weight Vs. OMC**

### 5.3 Strength characteristics

Unconfined compressive strength was performed on the samples prepared from the Harvard miniature mould for different moisture contents. Figures 8, 9 and 10 show the unconfined compressive strength values for bentonite, kaolinite and sand mixtures with variation in moisture content. Unconfined compressive strength increases with increase in moisture content and after reaching a optimum moisture value the strength decreases. The strength values shows similar trend for all the mixtures of soil. The peak strength value increases with increase in clay content except for the kaolinite and sand mixture which shows more strength. In the bentonite, kaolinite and sand mixture B10K40S50 shows more strength.
Fig. 8 Variation in $Q_u$ for bentonite and sand

Fig. 9 Variation in $Q_u$ for kaolinite and sand

Fig. 10 Variation in $Q_u$ for bentonite, kaolinite and sand
5.4 Relationship between index properties and strength properties

Based on the various tests performed on artificial soil of different mixes relationship has been brought out for the index properties (LL and PI) and the strength properties (unconfined compressive strength $Q_u$, maximum dry density $\gamma_{\text{dry}}$ and optimum moisture content OMC)

Relationship between maximum dry density and Index properties (Figs 11(a) and 11(b))

\[ \gamma_{\text{dry}} = -0.116 \text{ LL} + 314.25 \]

\[ \gamma_{\text{dry}} = -0.1139 \text{ PI} + 312.63 \]

Figs. 11(a) and (b) Relationship between maximum dry density and Index properties
Relationship between optimum moisture content and index properties (Figs. 12(a) and 12(b))

\[ \text{OMC} = 0.0155 \times \text{LL} + 15.327 \]

\[ \text{OMC} = 0.0162 \times \text{PI} + 15.511 \]

Figs. 12(a) and (b) Relationship between optimum moisture content and Index properties
Relationship between shear strength and index properties (Figs. 13(a) and 13(b))

\[ Q_u = -0.005 \text{ LL} + 44.388 \]

\[ Q_u = -0.0098 \text{ LL} + 44.779. \]

Figs. 13(a) and (b) Relationship between shear strength and Index properties
CONCLUSIONS

Relationships between the index properties and strength of artificial soil were investigated in this research project and the following conclusion has been brought out.

1. The liquid limit and plasticity index of the artificial soil increases with increase in clay content and the increase is more pronounced in bentonite and sand mixtures and bentonite, kaolinite and sand mixtures.
2. Maximum dry density decreases and OMC increases with increase in bentonite, sand and kaolinite, sand mixtures.
3. OMC increases with increase in bentonite and decreases with the increase in kaolinite in bentonite, kaolinite and sand mixtures for the same sand content
4. Peak shear strength increases with increase in the clay content except for 50K50S mix which shows high strength.
5. In the bentonite, kaolinite and sand mix B10K40S50 shows high strength.
6. Relationship between strength and index properties has been brought out based on the test

REFERENCES

