Characterization of Strength and Stiffness Parameters of Clayey Soil Partially Replaced with Plastic Granules

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Abstract

Objectives: In the present study, recycled plastic granules that are available as a raw material to plastic industries are utilized to investigate their role in influencing the shear strength and stiffness parameters of the clayey soil.

Methods/Statistical Analysis: Undrained Tri-axial tests are performed on various samples of clayey soil that are partially replaced with recycled plastic granules at different percentages (2.5%, 5%, 7.5%, 10%, and 12.5%) by the weight of dry soil. Findings: Plastics contribute major portion of waste generated by human civilization. As these materials are non-biodegradable, they have considerable life and huge potential in providing solutions to complex engineering problems. In geotechnical engineering applications, researchers are motivated to use plastic wastes either as an alternative to or as a partial replacement of the conventional materials. The experimental results have clearly shown a significant improvement in the shear strength parameter cohesion (c) parameter although there was some compromise on the other parameter angle of internal friction (φ) of the soil – plastic granules mixtures.

Application/Improvements: Bearing capacity and slope stability can be improved by adding plastic granules in clayey soil.

Keywords: Plastic Granules, Stiffness, Strength, Tri-Axial Test

1. Introduction

Geotechnical engineering problems, such as, bearing capacity of shallow footing, stability of slopes or embankments, etc., are dependent up on the shear strength parameters of the soil, i.e., cohesion (c) and angle of internal friction (φ) and thus the improvement in shear strength of soil requires improvement in these parameters. Researchers suggest different approaches and techniques for improving the engineering properties of soil through various ground improvement methods available in literature¹⁻⁴. In recent years, use of plastic waste in geotechnical engineering applications has gained considerable popularity and provided many useful practical solutions to the unending engineering
problems. On these lines of thought, various researchers in the past have used (natural or synthetic) coir fibers and discussed on the altered values of the shear strength parameters with % addition of the fiber content. Researchers\textsuperscript{5–7} reported linear increase in angle of internal friction value with percentage of fiber content added to the soil. Others\textsuperscript{8–10} worked with silt clay showed that only cohesion depends on the fiber content. Reinforcing with fibers is not a new technique and in recent years it has found space in the other fields of engineering and medical lines\textsuperscript{11–13}.

In the present work, clay soil was mixed with recycled plastic granules (at varying percentages by the weight of dry soil) and was compacted on the wet-side of Optimum Moisture Content (OMC) with a target bulk density value of 1.8 gm/cc and Tri-axial soil specimen were extracted from the compacted soil sample to conduct shear strength test on the same. These tests were performed to evaluate the response of plastic granules reinforced soil in terms of shear strength and ultimate behavior. These characteristics were quantified by measuring the elastic modulus and shear strength parameters of the different soil – plastic granules mixes and proposing a regression equation relating the percentage of plastic granules mixed in clayey soil to the $c$, and $\phi$ values of the mix. Further, it is shown that altered shear strength parameters of soil – plastic granules improves the bearing capacity of a shallow footing as well as stability of the given soil slope.

2. Experimental Program

2.1 Planning and Analysis of Experiments

Experimental planning was done with the target of evaluating the relevant soil mix properties, starting with minimal percentage of plastic granules in the soil and increasing it till the percentage of plastic granules in the mix would range so high that the samples formed would turn out to be of unacceptable quality. The tests were conducted at different plastic granule mix percentages by the weight of dry soil as 2.5%, 5.0%, 7.5%, 10%, 12.5%. For each soil mix, 3 undrained tri-axial tests were performed at different cell pressures of 50kpa, 100kpa and 150kpa each and average response is reported for each case. It was observed that the samples cast at 15% plastic granule mix by the weight of dry soil turned out to be of extremely poor quality and thus the scope of the work was restricted to 12.5 % mix.

The analysis of the findings was done by stress-strain plotting of the results and observing the corresponding ultimate strength and Elastic modulus of the specimens for different cases. To obtain the shear strength parameters $(c, \phi)$, stress path method was used to plot through the stress points obtained from respective Mohr circles derived for a certain soil mix.

2.2 Materials

The Clayey soil used in the present study was sampled from the region of Madhya Pradesh, in central India. The property of clayey soil used in the present study is provided in Table 1. As per Bureau of Indian Standards (BIS) soil classification system\textsuperscript{14}, the clay soil is classified as CL – CI (clay with low to intermediate plasticity). The clayey soil is mixed with plastic granules shown in Figure 1.

Table 1. Index properties of clay soil utilized in the experimental program.

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Numerical values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Limit ($w_L$)</td>
<td>35%</td>
</tr>
<tr>
<td>Plastic Limit ($w_p$)</td>
<td>21%</td>
</tr>
<tr>
<td>Shrinkage Limit ($w_s$)</td>
<td>16%</td>
</tr>
<tr>
<td>Maximum Dry Density ($g_{\text{dmax}}$)</td>
<td>1.85 g/cc</td>
</tr>
<tr>
<td>OMC (Standard Proctor Test)</td>
<td>12%</td>
</tr>
</tbody>
</table>

Figure 1. Clayey soil mixed with plastic granules to perform undrained tri-axial test.
The Plastic granules used in the present study were obtained from a mini plastic recycling plant in Mumbai, Maharashtra and are classified as Low Density PolyEthylene (LDPE). The size of these granules is Indian standard sieve 2.36 mm passing and 1.18 mm IS sieve retaining. The average size of a cylindrical granule is 1.8 mm in diameter and 3 mm in length. LDPE granules have a density of 0.917 – 0.94 g/cc. They possess low hardness and stiffness but high resistance to water, moisture, organic solvents and chemicals.

The plastic granules are manufactured after recycling of plastic waste in a five step process, i.e.: 1. Waste Plastic collection; 2. Manual sorting; 3. Chipping; 4. Washing; and 5. Pelleting. The pelleting is done by melting the chips and extruding them out first through a fine grill to remove any solid dirt or metal particles that have made it through the treatment thus far and then through a die of small holes. If the plastic was simply allowed to extrude from these holes it would come out as spaghetti-like strings and quickly tangle together. However, it is sprayed with water as it comes out (to prevent the plastic from sticking together) and cut off by rotating knives to give small, cylindrical pellets.

2.3 Specimen Preparation and Testing Procedures

Clayey soil passing the 425 micron IS sieve was mixed with plastic granules (2.36mm-1.18mm) weighed at a certain percentage by the weight of dry soil is shown in Figure 2. A water content of 15% by the weight of dry soil was then added to the dry mix to prepare it on the wet side of OMC. The soil mix was then compacted in a mould of 1000 cm³ capacity to achieve a targeted bulk density of 1.8g/cc. The mould containing the compacted moist soil was then placed in a sample extractor and the Tri-axial moulds were placed in position to extract the samples. The cylindrical samples were finally prepared with a diameter of 38mm and length of 76mm. In Figure 3 shows typical soil specimen prepared with 5% plastic granules mix. Undrained triaxial tests were then conducted on the prepared samples, compliant with Bureau of Indian Standard.

3. Results of the Analysis and Discussion

In Figure 4 provides comparison of the Stress - strain plots of clayey soil with no mixing and different % mixing of plastic granules at cell pressures of 50, 100 and 150kpa, respectively. These stress–strain plots provided values of Elastic modulus (initial modulus, E) as well as ultimate strength (deviatoric strength) of the clayey soil with no mix as well as clay–plastic granules mixes at different confining pressure values as summarized in Table 2.
Characterization of Strength and Stiffness Parameters of Clayey Soil Partially Replaced with Plastic Granules

Figure 4. Comparison of the stress - strain plots of clayey soil with no mixing and different % mixing of plastic granules @ Cell pressures of 50, 100 and 150 kpa.

Table 2. Initial tangent modulus ($E_u$) and ultimate strength ($\sigma_{u_f}$) for clay soil – plastic granules mixed at different confining pressures.

<table>
<thead>
<tr>
<th>% Plastic Granules mix</th>
<th>Initial Tangent Modulus ($E_u$, MPa)</th>
<th>Ultimate strength ($\sigma_{u_f}$), kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50 kPa</td>
<td>100 kPa</td>
</tr>
<tr>
<td></td>
<td>50 kPa</td>
<td>100 kPa</td>
</tr>
<tr>
<td>0</td>
<td>3.10</td>
<td>5.10</td>
</tr>
<tr>
<td>2.5</td>
<td>3.26</td>
<td>3.29</td>
</tr>
<tr>
<td>5.0</td>
<td>2.36</td>
<td>4.53</td>
</tr>
<tr>
<td>7.5</td>
<td>3.52</td>
<td>4.53</td>
</tr>
<tr>
<td>10.0</td>
<td>4.53</td>
<td>3.84</td>
</tr>
<tr>
<td>12.5</td>
<td>4.16</td>
<td>4.53</td>
</tr>
<tr>
<td>15.0</td>
<td>4.16</td>
<td>4.53</td>
</tr>
<tr>
<td></td>
<td>118</td>
<td>134</td>
</tr>
</tbody>
</table>

The undrained tri-axial tests results are further utilized in estimating the shear strength parameters, i.e., cohesion ($c_u$) and angle of internal friction ($\phi_u$), for the no mix soil and soil – plastic granules mixes after plotting stress path for different cases of confining stresses. The results are summarized in Table 3. From these results, it can be noted that $c_u$ and $\phi_u$ value of clayey soil (no plastic granules mix) is obtained as 33.7 kPa and 17.4°, respectively. After adding 2.5% plastic granules $c_u$ value is reduced to 30.5 kPa and angle of internal friction ($\phi_u$) value is slightly improved to 18.2°. Further addition of plastic granules (up to 7.5%) reduced the cohesion ($c_u$) parameter but at the same time improved the $\phi_u$ parameter. After that (10% and 12.5% of plastic granules mix) the cohesion ($c_u$) parameter improves while the $\phi_u$ value reduces. It may be due to the fact that the soil specimen prepared at 15% plastic granules mix was of poor quality. Hence, the there is a sudden drop in the $c_u$ parameter ($\phi_u$ remains unchanged) at 15% plastic granules mix. These results clearly indicate that adding plastic granules in the clay soil greatly influence the undrained cohesion parameter ($c_u$) as well as angle of internal friction ($\phi_u$) parameter.

Table 3. Shear strength parameters ($c_u$, $\phi_u$) obtained for different soil – plastic granules mixes.

<table>
<thead>
<tr>
<th>% Plastic granules mix</th>
<th>Undrained Cohesion ($c_u$) kPa</th>
<th>Angle of internal friction ($\phi_u$) (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>33.7</td>
<td>17.4</td>
</tr>
<tr>
<td>2.5</td>
<td>30.5</td>
<td>18.2</td>
</tr>
<tr>
<td>5.0</td>
<td>21.0</td>
<td>21.7</td>
</tr>
<tr>
<td>7.5</td>
<td>20.0</td>
<td>25.5</td>
</tr>
<tr>
<td>10</td>
<td>28.0</td>
<td>21.2</td>
</tr>
<tr>
<td>12.5</td>
<td>53.0</td>
<td>9.8</td>
</tr>
<tr>
<td>15</td>
<td>40.6</td>
<td>9.8</td>
</tr>
</tbody>
</table>

In Figure 5a and 5b shows variation of undrained cohesion ($c_u$) and angle of internal friction ($\phi_u$) of the clay soil as well as clay soil mixed with different % of plastic granules. From Figure 5a, it can be noted that with addition of plastic granules the undrained cohesion parameter ($c_u$) initially decreases and then increases. A minimum value is achieved around 6-7% plastic granules mix. On the other hand, Figure 5b shows initial improvement in angle of internal friction value and then there is a decrease. A maximum value is achieved around 6-7 % of plastic granules mix. A 2nd degree polynomial shows best fit for the experimental data in both the cases with $R^2$ value close to 1.0. It can be noted that there is a nega-
tive correlation between cohesion \(c_u\) and angle of internal friction \(\phi_u\) parameters. In order to investigate the influence of variation of the shear strength parameters \((c_u, \phi_u)\) with addition of plastic granules and to assess its suitability in geotechnical engineering applications, examples of bearing capacity of a shallow footing and stability of a given slope are presented. Finite element tool PLAXIS 2D\(^{16}\) has been utilized for the purpose.

### 4. Example Applications

#### 4.1 Stability of Soil Slope

For the stability analysis, a slope of 15 m height at an angle of 37° is taken into consideration. The input soil properties are taken as follows: Bulk unit weight \((\gamma_t) = 18.0 \text{ kN/m}^3\), Dry unit weight \((\gamma'_d) = 15.6 \text{ kN/m}^3\) (for moisture content = 15%), Poisson’s ratio \((\nu) = 0.32\). The elastic modulus \((E)\) and the shear strength parameters \((c_u, \phi_u)\) are adopted from Table 3 for different % of plastic granules mixed with soil. The factor of safety for the given soil slope is obtained using strength reduction technique\(^{17}\) available as an inbuilt option in the numerical code. Duncan\(^{18}\) indicated that a factor of safety can also be taken as a factor by which the soil shear strength is reduced to bring the slope on the verge of failure. The concept is used in the slope stability analysis in which a number of simulations are run for trial factor of safety \((F_{\text{trial}})\) with shear strength parameters, i.e., cohesion \((c_u)\) and angle of internal friction \((\phi_u)\) are reduced as below:

\[
c_{\text{trial}} = \frac{1}{F_{\text{trial}}} c_u
\]

\[
\phi_{\text{trial}} = \tan^{-1}\left(\frac{1}{F_{\text{trial}}} - \tan \phi_u\right)
\]

The factor of safety values for the given soil slope for different cases of soil – plastic granules mix are provided in Table 4. It can be noted that the factor of safety value initially decreases (up to 5%) and then increases. It can be noted that at 12.5% plastic granules mix, the factor of safety value is more than the corresponding value achieved at no mix. At 15% plastic granules mix, the factor of safety drastically reduces due to reduction in cohesion parameter. Hence, it can be noted that maximum improvement in the stability of slope is achieved by adding 12 – 13% (average 12.5%) plastic granules.

### Table 4.

<table>
<thead>
<tr>
<th>% Plastic granules</th>
<th>Factor of safety (FS)</th>
<th>Applied pressure, kPa (for 50 mm settlement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1.63</td>
<td>187</td>
</tr>
<tr>
<td>2.5</td>
<td>1.57</td>
<td>159</td>
</tr>
<tr>
<td>5.0</td>
<td>1.41</td>
<td>147</td>
</tr>
<tr>
<td>7.5</td>
<td>1.53</td>
<td>184</td>
</tr>
<tr>
<td>10</td>
<td>1.61</td>
<td>186</td>
</tr>
<tr>
<td><strong>12.5</strong></td>
<td><strong>1.81</strong></td>
<td><strong>197</strong></td>
</tr>
<tr>
<td>15</td>
<td>1.49</td>
<td>178</td>
</tr>
</tbody>
</table>
4.2 Bearing Capacity of Circular Footing

A circular footing with a radius of 1.0 m is placed on clayey soil having thickness of 4.0 m that exists over a rock layer on infinite extent. The properties for clay soil – plastic granules mix, i.e., average value of elastic modulus is taken from Table 2 and shear strength parameters (\(c_u, f_u\)) are taken from Table 3. From the load – settlement response of footing for different cases of soil – plastic granules mixes the values of applied pressure for the prescribed 50 mm settlement of footing are provided in Table 4. It can be noted that with increase in % addition of plastic granules mixed in clayey soil the value of applied pressure initially decreases and then increases. At 12.5% of plastic granules mix, the applied pressure corresponding to 50 mm settlement is achieved maximum.

5. Conclusion

It is noted that the addition of plastic granules in the clayey soil initially reduces the cohesion parameter but increases the angle of internal friction. Around 6 – 7% of plastic granules mix the values are optimum, i.e., minimum \(c_u\) and maximum \(f_u\), respectively. Through example applications of slope stability and bearing capacity problem, it is shown that at 12.5% plastic granules mix the factor of safety of the given soil slope and applied pressure for a prescribed settlement of 50 mm is highest. This indicates maximum shear strength of the soil is achieved when the plastic granules are added in the range of 12 – 13% (average = 12.5%). The results of the present study clearly indicate the potential use of plastic granules in geotechnical engineering problems, such as, improving the bearing capacity and enhancing the stability of soil slope.

6. References