Influence of geotextile reinforcement on shear modulus of saturated sand

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Abstract—The increasing use of geotextile-reinforced soil systems for important earth structures requires proper understanding of their behaviour and validation of the assumptions in their design. This paper investigates the shear modulus of saturated reinforced sand throughout the undrained cyclic triaxial tests. The cyclic triaxial tests are conducted on remolded specimens which reinforced by different arrangement of non-woven geotextile. The tests results indicate that the geotextile reinforcement increase \( G_{\text{max}} \) of saturated silty sand and \( G_{\text{max}} \) increased as the geotextile layer increased. It is also concluded that as the geotextile close to the top of the specimen (load applying part) the maximum shear modulus increased and by increasing space between geotextile and cap of the sample, the reinforcement effect on \( G_{\text{max}} \) decreases.

Keywords— Dynamic Behavior; Reinforced Sand; Triaxial Test; Geotextile; Shear Modulus

I. INTRODUCTION

Soil reinforcement is one of the improvement methods in which tensile elements are set into the soil body to compensate the soil weakness in tension. Although examples of reinforced soils can be seen in ancient structures, it was only in the 1960’s that the modern concepts of composite soil-inclusion material were developed. Steel strips or meshes were primarily being used as inclusions before geosynthetics appeared within the last two decades. Since 1970s, the use of geotextile as reinforcement has become more popular due to a more satisfactory performance compared with metal reinforcement, which has been reported in several instances [1]. The reason is that geotextiles or synthetic fabrics have relatively low stiffness compared to that of metals. Thus, they are more compatible with soil in view of deformability. Currently, three main geosynthetic families of products are used as soil reinforcement: geogrids, geotextiles, and synthetic fibers. Geotextile reinforced structures are increasingly being used in a wide range of applications, such as transportation infrastructures, coastal protection, slope stabilization, embankment dams, retaining walls and also in preventing liquefaction of sand deposits [2]-[7]. These structures are subjected to various loading conditions including dynamic or cyclic loads. The most important parameters in evaluation of dynamic behavior of aforementioned soil structures are and axial modulus. The locus of points corresponding to the tips of hysteresis is loops of various cyclic strain amplitudes is called a backbone (or skeleton) curve (Fig. 1); its slope at the origin (zero cyclic strain amplitude) and certain cyclic strain amplitude represent the largest value of the shear modulus, \( G_{\text{max}} \) and secant shear modulus \( G_{\text{sec}} \) respectively [8]. Similarly, according to Fig. 2, maximum elastic modulus \( (E_{\text{max}}) \) and \( E_{\text{sec}} \) estimated by slope of deviatoric stress \( \sigma_d \) versus axial strain \( \varepsilon \), [9].

The present study is aimed at obtaining a better understanding of shear modulus during cyclic undrain loading of geotextile reinforced saturated sand. This study included a number of undrained cyclic triaxial tests on Firouzkhu #161 sand samples reinforced with different arrangement of geotextile, to characterize the role played by this inclusion on the shear and axial modulus.

![Fig. 1. Backbone curve showing the typical value of \( G_{\text{max}} \) and \( G_{\text{sec}} \) [8].](image1)

![Fig. 2. The \( E_{\text{max}} \) and \( E_{\text{sec}} \) definition in hysteresis loop of deviatoric stress \( \sigma_d \) versus axial strain \( \varepsilon \).](image2)
II. **EXPERIMENTAL APPARTUS AND MATERIAL USED**

A. **Cyclic Triaxial Setup**

Specimens were tested in a cyclic triaxial device. The device is instrumented with LVDT, a load cell, pore pressure and a cell pressure transducer and a computer controlled data acquisition system (Fig. 3).

B. **Material Used**

**Sand**

The sand used in this study is Firouzkuh #161 crushed silica sand. This type of sand has a golden yellow color and has a uniform aggregation, which henceforth briefly named Firouzkuh Sand (Fig. 4). Toyoura and Sengenyama standard sands that their characteristics are described in this paper were compared to Firouzkuh sand (Table 1). Grain size distribution curves of the last two mentioned sands are presented in Fig. 5.

![Cyclic triaxial device](image1)

*Fig. 3. Cyclic triaxial device set*

![Magnified picture of Firouzkuh sand grains](image2)

*Fig. 4. Magnified picture of Firouzkuh sand grains.*

![Grain size distribution curve](image3)

*Fig. 5. Grain size distribution curve of Firouzkuh sand compared with the curves.*

**Table 1. Firouzkuh Sand Physical Characteristics and Comparing With Toyoura and Sengenyama**

<table>
<thead>
<tr>
<th>Sand type</th>
<th>Firouzkuh #161</th>
<th>Toyoura</th>
<th>Sengenyama</th>
</tr>
</thead>
<tbody>
<tr>
<td>D_v (mm)</td>
<td>0.27</td>
<td>0.17</td>
<td>0.27</td>
</tr>
<tr>
<td>C_u</td>
<td>1.87</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C_t</td>
<td>0.88</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>G_s</td>
<td>2.685</td>
<td>2.65</td>
<td>2.72</td>
</tr>
<tr>
<td>e_max</td>
<td>0.94</td>
<td>0.97</td>
<td>0.91</td>
</tr>
<tr>
<td>e_min</td>
<td>0.60</td>
<td>0.597</td>
<td>0.55</td>
</tr>
<tr>
<td>D_10 (mm)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Puncture strength</td>
<td>D-4833</td>
<td>1100 N</td>
<td></td>
</tr>
<tr>
<td>Wide width tensile strength</td>
<td>D-4595</td>
<td>23.1 kN/m</td>
<td></td>
</tr>
</tbody>
</table>

**Geotextile**

Table 2 presents the properties of this non-woven PET geotextile. The picture of geotextile is shown in Fig. 6.
III. EXPERIMENTAL PROCEDURE

A. Sample Preparation

The tests were performed on samples with a slenderness coefficient of 2, and a height of 14 cm. With a density of 13 kN/m$^3$, corresponding to a relative density of 27%, the dry sand specimens were prepared by pouring the sand through a funnel in a mould by maintaining a constant funnel height above the sand surface. Geosynthetic inclusions of 7 cm diameter are placed horizontally in the sample as each of the sand layers is formed. The specimens with different geotextile arrangement are shown in Fig. 7. After the specimen has been formed, the specimen cap is placed and sealed with O-rings, and a partial vacuum of 35 kPa is applied to the specimen to reduce the disturbances. Tubing connections to the top and bottom specimen platens permit flow of water during saturation, consolidation and measurement of pore water pressure during cyclic loading.

B. Saturation and consolidation

When the triaxial cell is assembled and filled with water, an isotropic pressure of 10 kPa is applied. After circulating a flow of carbon dioxide (CO$_2$) under a low pressure gradient (5 kPa) through the sample for 7 min, water is circulated about 30 min until the total quantity of water passing through the sample is at least equal to twice the initial volume of the sample. After this water percolation period, the effective stress acting on the sample is kept constant by a parallel increase in the back pressure and cell pressure. The back pressure used varies from 10 to 90 kPa, which is sufficiently high to dissolve the carbon dioxide and to obtain Skempton B coefficients greater than 0.95. Following saturation, the specimens are consolidated isotropically at mean effective pressures 100 kPa.

After saturation and consolidation, the specimen is subjected to a sinusoidal varying axial load by means of the load rod connected to the specimen top platen. The cyclic load, specimen axial deformation, and pore water pressure development with time are monitored. The test is conducted under undrained conditions to approximate essentially undrained field conditions during earthquake or other dynamic. The cyclic loading generally causes an increase in the pore water pressure in the specimen, resulting in a decrease in the effective stress and an increase in the cyclic axial deformation of the specimen.

C. Cyclic Triaxial Tests

The Cyclic triaxial tests are performed by applying a sinusoidal stress deviator at a frequency $f=2$ Hz and by keeping the confining pressure $\sigma_{cell}$, constant at 100 kPa. Cyclic Stress Ratio (CSR) is equal to 0.30 for all tests.

IV. RESULTS

The sand Firouzkuh #161 sand is used to construct the specimens and to study shear modulus of reinforced sand. Undrained triaxial tests under dynamic loading condition on unreinforced and reinforced samples are performed with different geotextile arrangement. It can be observed that reinforcement lead to increase the shear and axial modulus of samples (Fig. 8). The reinforcement arrangement effect on the results $G_{max}$ and $E_{max}$ of these cyclic tests are analogous.

Observed from aforementioned figure F specimen (2 layer geotextile at H/3 and 2H/3 distances from top of sample) presented more $G_{max}$– and axial modulus compared to others.

By comparison of B, C, D, and E arrangement described that as geotextile close to top of specimen (load applying part) the $G_{max}$ increased and E type (1 layer geotextile at H/5 distance from top of specimen) of reinforcement arrangement tested lead to a significant increase in $G_{max}$ and $E_{max}$ of the sand.

The variation of the $G/G_{max}$ for sand reinforced with different arrangement of geotextile layer with respect to increasing the shear strain is plotted in Fig. 9. As shown in this figure, the F specimen (2 layer geotextile reinforced) and A (unreinforced sample) presented brittle and ductile behavior, respectively. In other word by increasing $G_{max}$ of the specimen, behavior varies from ductile to brittle, smoothly.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Axial modulus (MPa)</th>
<th>Shear modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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CONCLUSIONS

A series of undrained cyclic triaxial tests were conducted to investigate the arrangement of geotextile inclusion on the shear modulus of saturated sand. It has been brought out that the geotextile reinforcement plays a dominant role in controlling the dynamic response. Based on this experimental study, the main conclusions are summarized as follows:

Geotextile reinforcement increases the maximum shear modulus of saturated sand, and $G_{\text{max}}$ increased as the geotextile layer increased.

As geotextile is close to the top of the specimen (load applying part), the maximum shear modulus increased. By increasing the space between geotextile and cap of the sample, the reinforcement effect on $G_{\text{max}}$ decreases.

The addition of geotextile inclusion changed its ductile behavior to a more brittle one, and specimen ductility decreased as the $G_{\text{max}}$ increased.

As explained, the geotextile presence affects the $G_{\text{max}}$ and axial stiffness significantly. Consequently, it is necessary to reinvestigate the geotextile arrangement carefully to calculate the reinforced earth structure seismic responses more realistically.

REFERENCES


