A STUDY ON DEFORMATION OF THE INTERFACE BETWEEN SAND AND STEEL PLATE UNDER SHEARING

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ABSTRACT: In the present study, a large scale direct shear test of interface between sand and steel plate was performed. The box was filled with standard Ennore sand at a desired relative density. Lead beads of the same size as average size of sand were placed in thin strips at various position of the shear box. A steel plate was placed over the sand. Normal load was put over the steel plate. The box was then pushed at a constant rate for a maximum displacement of 5 mm. The box was then put in an X-ray machine and the X-ray plate was carefully observed for any deformation of the lead beads. The relative displacement of lead beads was found to be irregular but to a definite pattern. Similar observations were also made for different tests with strips of lead beads at different heights. In addition, the stress-strain properties of interface at different surface roughness were also examined.

INTRODUCTION

Large shear stress often exists between soil & structure material. This is due to the deformation discrepancy between the two materials. A foundation laid on relatively soft soil, is often subjected to a high stress, because the load is transferred from the soil into the foundation through their interface. The magnitude of stress in foundation depends upon such transfer. Thus to study the interface behavior & estimate correctly the transfer of load through the interface are of great importance.

Interface shear tests were often performed to study the mechanical behavior of a soil-structure interface. A cyclic multi-degree-of freedom (CYMDOF) shear device [1] was introduced for static and cyclic testing of interface and joints, which can measure the normal stress, shear stress, normal and shear displacements, rotation of the upper sample, and the pore fluid pressure. A cyclic three-dimensional simple shear interface apparatus C3DSSI [2] has been established to perform two-way cyclic tangential-displacement-controlled experiments with different normal stiffness. The behavior of sand structure adjacent to the geomembrane[3] was studied. A large scale direct shear test of interface [4] and developed a damage model to define stress-strain properties of interface[4].A systematic experimental investigation using direct shear test [5] was conducted to determine the interface behavior between several soils and construction materials such as steel, concrete and wood. A simple shear test device [6] was used to study the interface behavior between sand and steel plate of different roughness. Close-up photographs showed the formation of a shear zone within the sand along the rough interface. A large-size direct shear test [7] was conducted to observe the distribution of relative tangential displacement along the interface.

In the present study, to analyze the stress-strain properties and particle movement at the interface, a large scale direct shear test of interface between soil and steel plate is conducted. In addition, the effect of roughness on the interfacial properties is also examined.

DIRECT SHEAR TEST OF INTERFACE

Direct shear test is widely used to establish the interface behavior. Several factors such as grains movement, stress-strain relationship, & surface roughness have been investigated to better understand their effects on the interface characteristics behavior. In this part, a large scale direct shear test is performed. A CBR machine is converted to a Direct Shear Test machine. A shear box made of Perspex glass of square size 20cm×20cm & 10cm high was made. The box was filled with standard Ennore sand at 85% relative density by sand rainer. The density was achieved by sand rainer and subsequent compaction. The physical properties of the sand are given in table 1. The grain size distribution of the sample is given in figure 1. In order to see the slide deformation and relative displacement along the interface as well as at a certain depth from the interface, lead beads of the same size as sand were placed in thin strips at L/4, L/2 and 3L/4 of the box. Where L is the length of the shear box along the direction of motion. The plan of the shear box with distribution of lead beads is shown in the figure 1. A steel plate of square size 35cm×35cm & 1cm height was placed over the sand. The box was then pushed at a constant rate for a maximum displacement of 5mm. In each set of the experiment the Normal stress was kept 0.01 N/mm², 0.0125 N/mm² and 0.015 N/mm² respectively. A marking was made at the bottom of the shear box to measure the relative displacement of the lead beads before & after shearing. The box was then put into an X-ray machine. The scan copy of X-ray plate was then put in to Adobe Photoshop software to measure if any deformation of the lead beads. The scan copies of x-ray plates are shown in the figures 3 and 4.
Table 1 Physical properties of sand

<table>
<thead>
<tr>
<th>Sand properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle diameter, $D_{50}$ (mm)</td>
<td>0.5</td>
</tr>
<tr>
<td>Maximum void ratio, $e_{\text{max}}$</td>
<td>0.88</td>
</tr>
<tr>
<td>Minimum void ratio, $e_{\text{min}}$</td>
<td>0.62</td>
</tr>
<tr>
<td>Relative density, $D_r$</td>
<td>0.85</td>
</tr>
<tr>
<td>Specific gravity, $G_s$</td>
<td>2.65</td>
</tr>
</tbody>
</table>

Fig.1 Grain size distribution curve

Fig.2 Plan of shear box with lead beads distribution

Fig.3 Image of X-ray plate before shearing

Fig.4 Image of X-ray plate after shearing

TEST RESULTS AND DISCUSSION

Variation of grain movement at the interface

Figure 5 shows the grain movement at the interface at $L/4$, $L/2$ and $3L/4$ of the shear box at constant normal stress. Here, the ordinate is a reference scale and not the absolute scale to show the horizontal displacement of the lead particles at the interface, before and after shearing. It is not the level of the soil surface. Here $B$ is the width of the shear box and $b$ is a section of the box along the direction of $B$. It is clearly seen that, the grain movement at the interface is not uniform. At the edges of the shear box that is when $b/B = 0$ and $b/B = 1$, the particle displacement is minimum and its value lies between 0 and 0.5mm. But, at the centre of the shear box that is when $b/B = 0.4$ to 0.6, maximum particle displacement takes place which is up to a range of 4mm. again, from figure 4 it is clearly seen that, among $L/4$, $L/2$ and $3L/4$, the maximum particle displacement takes place at $L/2$ that is at the centre of the shear box.

(a) Grain movement at $L/4$ of the shear box.

(b) Grain movement at $L/2$ of the shear box.

(c) Grain movement at $3L/4$ of the shear box.

Fig. 5 Grain movement at the interface after shearing at $L/4$, $L/2$ and $3L/4$ of the shear box.
**Depth wise deformations of the particles**

Figure 6 shows the deformation of the particle at the interface and at 1, 2 and 3cm below the interface for a constant normal stress. Figure (a), (b) and (c) shows the deformations of the particles at L/4, L/2 and 3L/4 of the shear box. From the figure it is clearly seen that, at the centre of the shear box that is b/B = 0.4 to 0.6, the particle movement decreases with increase in depth of the shear box. But at the edges of the shear box that is b/B = 0 and 1, the particle movement increases with increase in depth. Thus, a reciprocal relationship of particle movement between the edges and the centre of the shear box has been observed.

![Image](image1.png)

(a) Depth wise deformation at L/4 of the shear box

![Image](image2.png)

(b) Depth wise deformation at L/2 of the shear box

![Image](image3.png)

(c) Depth wise deformation at 3L/4 of the shear box

**Stress-strain relationship at the interface**

Figure 7 shows the stress-strain relationship of the interface for different surface roughness at constant normal stress. The roughness factor is defined as the ratio of the surface roughness of the steel plate to the mean diameter of the sand particle D₅₀. The test is conducted in the laboratory in conventional direct shear test apparatus of sample size 60 mm x 60mm x 30 mm height. Here R₁, R₂ and R₃ are three roughness factors of the steel plates with different surface roughness. The roughness values of the structural materials are given in the table 2. From the figure 7 it is clearly seen that, the shear strength at the interface increases with increase in surface roughness. It has been observed that the shear strength at the interface increases approximately by 10% when the surface roughness gets doubled.

**Table 2** Properties of structural materials

<table>
<thead>
<tr>
<th>Roughness Factors</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₁</td>
<td>0.1</td>
</tr>
<tr>
<td>R₂</td>
<td>0.2</td>
</tr>
<tr>
<td>R₃</td>
<td>0.3</td>
</tr>
</tbody>
</table>

![Image](image4.png)

Fig.7 Stress-strain relationship at the interface for different surface roughness

**CONCLUSIONS**

From the detailed laboratory investigation on the displacement and stress-strain behaviour at the interface and the depth wise deformation of sand particle, the following conclusions are drawn:

1. In a direct shear test between soil and steel plate, the maximum particle displacement takes place at the centre of the shear box.
2. At the centre of the shear box, the particle displacement decreases with increase in depth and at the edges of the shear box, the particle displacement increases with increase in depth.
3. The shear strength at the interface between sand and steel plate increases with increase in surface roughness of the steel plates.
4. The shear strength at the interface increases approximately by 10% when the surface roughness of the steel plates gets doubled.

**REFERENCES**


