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Study of stress strain behavior of granular soil at inclined plane of shear using a newly developed modified direct shear test set up

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ABSTRACT

In this paper an experimental investigation has been conducted to study the stress strain behavior of granular soil and fiber reinforced granular soil. A newly developed modified direct shear apparatus has been used to maintain failure plane at an inclination of 10^0 with respect to standard horizontal plane, while normal stress applied on soil specimen remains vertical. Compacted granular soil having relative density 65% and 80% is used as test sample along with root fibers of limited length. The modified direct shear test set up uses different specially designed boxes for different angle of inclination (i.e. 0^0 and 10^0) and variable gear system to vary the rate of strain. Results are presented and discussed in terms of shear stress, normal stress, angle of inclination of failure plane, relative density of soil. Due to limitation number of pages, the results shown are only for the normal stress case of 0.5kg/cm^2. The influence of soil particle size and presence of root fibers are discussed by analyzing test results. It has been observed that the shear stress value is lesser in case 10^0 inclined planes compared to 0^0 inclined planes (Standard direct shear test set up) for different relative densities (65% and 80%). The presence of root fibers in the soil sample has increased the stress value for both 0^0 and 10^0 inclinations.

Keywords: Modified direct shear test; Angle of inclination; Relative density; Root-fiber reinforced soil

1 INTRODUCTION

Granular soils consist of individual particles that can slide and roll relative to one another. Strength of a soil is equal to the maximum value of shear resistance that can be mobilized within a soil mass before the failure started taking place. The shear strength of a soil is a function of the external stresses applied to it as well as the plane in which the failure occurs. Knowledge of shear resistance developed in soils is necessary to analyze different practical geotechnical problems like the lateral pressure exerted on retaining walls, and the stability of slopes.

Considering the practical scenario, in case of hilly regions with steep slopes the shear force acting on soil at any point around the failure zone is not perfectly horizontal, rather it acts at some inclination with respect to the horizontal (Fig. 1). During the experimental analysis of shear strength of the soil through direct shear test we consider shear plane to be horizontal and the normal stress applied in perpendicular to it. This does not truly represent some of the practical failure cases. To address this issue it was necessary to simulate the on field conditions in the laboratory more accurately. So for this, a modified apparatus of the direct shear test is built with a provision to apply the vertical normal load and keeping the shear at some angle with respect to horizontal (e.g. 0^0,5^0,10^0 etc.). This will help us to understand the shear resistance developed in a inclined failure plane, keeping the normal load perfectly vertical soil on a sloppy ground more precisely.

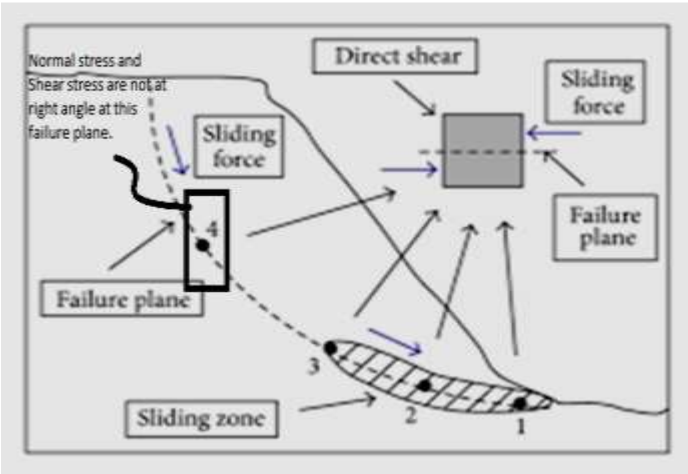

Fig. 1: Modified Direct Shear Test Apparatus

Not much study is done in this line of thought. The available literature related to inclined plane of failure is mostly related to geosynthetic reinforced soil like Briancon et al.(2002)[1], where the upper box slide with respect to lower box and at the interface geomembrane is used. The experimental results provide the resistance developed between the soil and geomembrane, for the case of inclined plane of failure. The reason for reinforcing the soil with plant root is to observe if the reinforcement effect changes when the failure plane is inclined. The relevant literature of fiber reinforced soil like Hu, T.H.,(1998); Wu, T.H., Beal,(1998)[2-3] and Freitag, D.R.(1986)[4], shows a improvement in strength compared to unreinforced soil.

2 EXPERIMENTAL STUDY

The experimental program includes the direct shear test on granular soil on a newly modified direct shear test apparatus as shown in (Fig.2) to obtain the stress v/s strain relationship. In this investigation two inclinations are chosen e.g. 0^0 and 10^0, for which two different shear boxes are designed whose dimensions are stated in table 1. Details of the experimental program and analysis of the test results from the stress v/s strain relationship for the granular soil and the root-fibre reinforced granular soil are presented below.

2.1 Material

For preparing the sample, sun-dried river sand is used which is kept in airtight containers and is found to have the following properties:

Table 1: Properties of the soil sample

Properties	Sand
D_{10}	0.17
D_{30}	0.22
D_{60}	0.3
C_u	1.76
C_c	0.95
γ_{min}	14.5 kN/m^2
γ_{max}	16.5 kN/m^2
Relative density & "φ" value	60% (φ= 42) & 80% (φ = 44)
Specific Gravity	2.62

From sieve analysis of the soil, D_{10}, D_{30}, D_{60}, C_u and C_c values of soil are found out. C_u is the coefficient of uniformity and C_c is the coefficient of curvature. Since C_u is less than 5 and C_c is less than 1, the sand chosen is poorly graded. "φ" is the value of the angle of friction determined through the direct shear test performed for 60% and 80% relative density of the sand sample. The roots used in the experiment are of the plant named stipa capillata. All the root fibers are having the length between 15 to 20mm. The diameter of the root ranges from 0.05 to 1mm.

2.2 Modified Direct Shear Test Apparatus

The apparatus comes with a shear box holding frame with normal load application system and shear force application system as shown in (Fig.2). This frame allowed to be set at different angle of inclination as per required angle of shear failure. As per the angle of inclination, specific shear box has been created e.g. separate box for 5^0 and 10^0 inclination. The sample is prepared in the shear box. A hydraulic jack is used to apply the normal load through a plunger via ball-bearing arrangement. An electric motor system is used to apply the shear deformation to the sample by keeping the upper box fix and moving the lower box. Although there is a option of multiple strain rate, for this paper constant strain rate of 2mm/min.

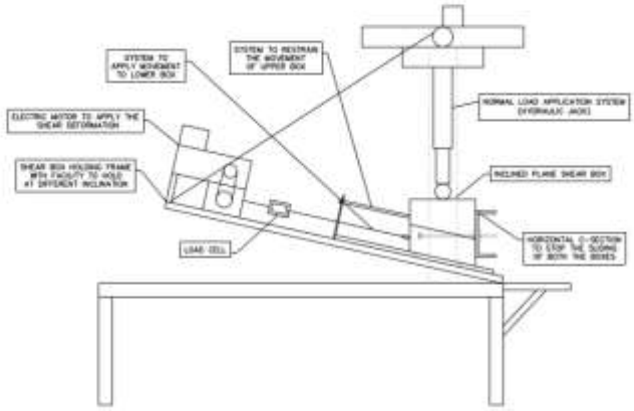

Fig. 2: Line Diagram-Modified Direct Shear Test Apparatus

2.3 Preparation of Soil Test Sample

Fig. 3: Actual set up-Modified Direct Shear Test Apparatus

The volume of sand required to achieve the required relative density (65% and 80%) is first calculated and then placed and compacted in the shear box using tamping rod in three layers of equal thickness. The shear box is well connected to both the normal load and shear force application system. Horizontal displacement of lower box is noted dial gauge placed over the extended part of shear box and holding frame. After the application of desired normal load shear force is applied gradually through the electric motor. The test is carried out until the soil sample failed in shear. Similar test is conducted for the granular soil reinforced with the root-fibers homogeneously (Fig.3).

2.4 Results and Discussion

2.4.1 Stress v/s Strain Relationship (Normal Soil)

A curve between stress v/s strain is plotted and shown in (Fig. 4 & 5). It can be observed that the shear stress value is lesser in case 10^0 inclined planes compared to 0^0 inclined planes for different relative densities (65% and 80%). This is the case of normal granular soil without root-fibers.

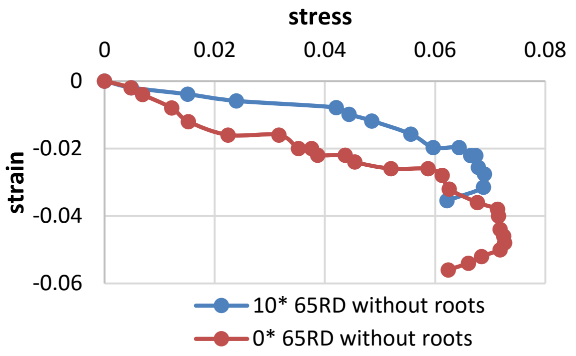

Fig. 4: Comparison between 0^0 and 10^0 (65 % RD

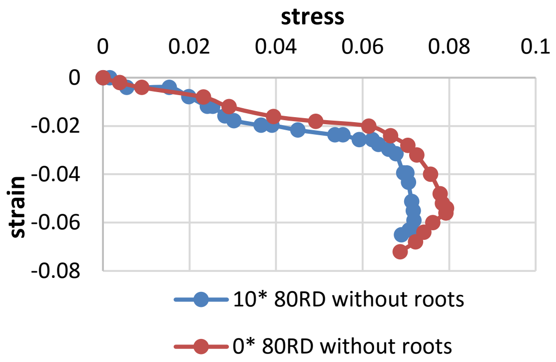

Fig. 5: Comparison between 0^0 and 10^0 (80 % RD)

It can be seen that in both the relative density of 65% and 80%, the shear stress is more in case of 0^0, compared to 10^0. The reason can be that as the as angle of inclination increases the shear area increases, thereby decreasing the shear stress.

2.4.2 Stress v/s Strain Relationship (Root-fiber reinforced soil)

Similar stress v/s strain curve is obtained for the case of root-fiber reinforced soil and shown in (Fig. 6-7), stating that the shear stress value is lesser in case 10^0 inclined planes compared to 0^0 inclined planes for different relative densities (65% and 80%).

Also the value of shear stress is higher for the 80 % relative density than that of 65 % relative density (Fig. 7-8).This behavior can similarly be attributed to reason given for unreinforced soil. The reinforcement is not influencing the common pattern observed earlier.

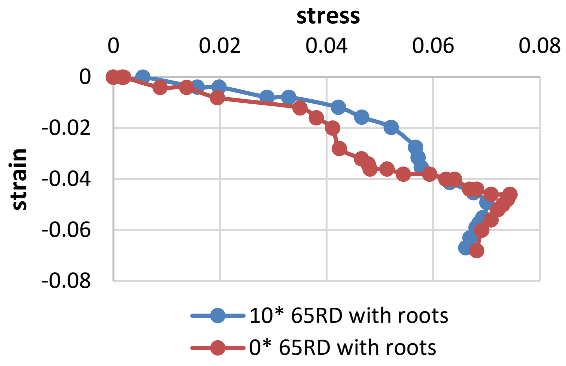

Fig. 6: Comparison between 0^0 and 10^0 (65 % RD)

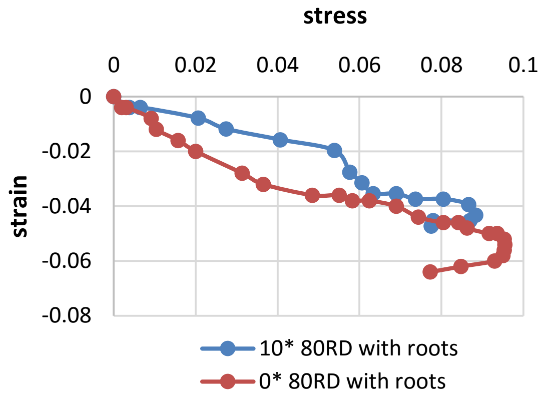

Fig. 7: Comparison between 0^0 and 10^0 (80 % RD)

2.4.3 Comparison between Normal soil and Root-fiber reinforced soil

2.4.3.1 0^0 Inclination

While comparing the stress v/s strain between normal soil and root-fiber reinforced soil it is observed that the shear stress value for the soil reinforced with the root-fibers is higher than that of normal soil for 65 % relative density as seen from (Fig.8). The effect of reinforcement is seen more dominant in case of 80% relative density compared to 65% relative density and the reason can be that more the denser soil, more the interaction and friction between the roots and the soil, there by developing more resistance. Similar trend is observed for the 80% relative density case (Fig. 9).

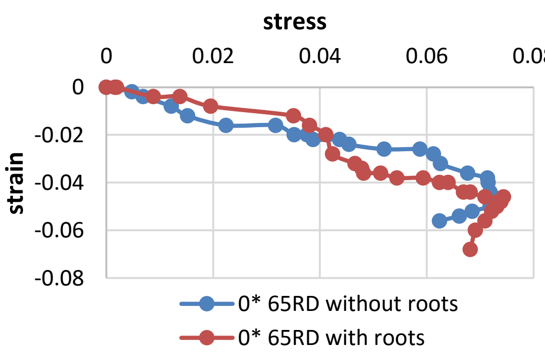

Fig. 8 : Normal soil v/s Root-fiber reinforced soil at 0^0 (65% RD)

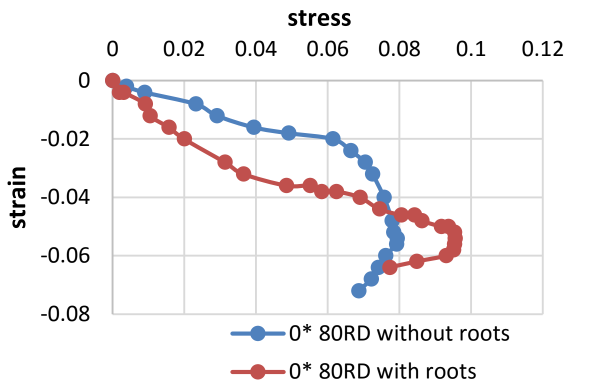

Fig.9: Normal soil v/s Root-fiber reinforced soil at 0^0 (80% RD)

2.4.3.2 10^0 Inclination

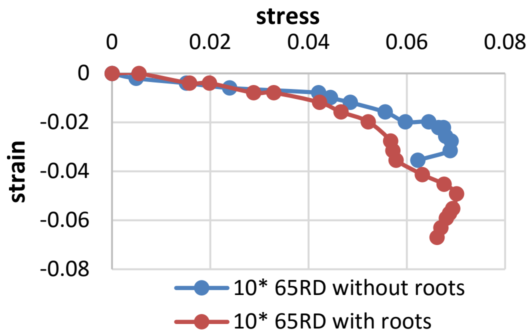

Fig.10:Normal soil v/s Root-fiber reinforced soil at 10^0(65% RD)

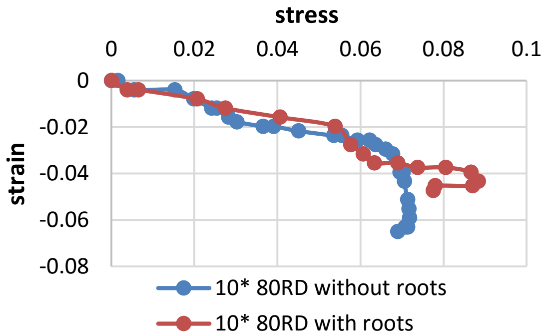

Fig.11:Normal soil v/s Root-fiber reinforced soil at 10^0(80% RD)

The behavior in this case is similar as compared to the 0^0 inclination, so we can conclude that in relative terms, that incase of inclined plane the relative behavior remains same.

2.4.4 Relative Density v/s Ultimate Shear Stress

A curve between Relative density and ultimate shear stress is plotted and shown in (Fig. 12-13) for the normal soil as well as the root-fiber reinforced soil.

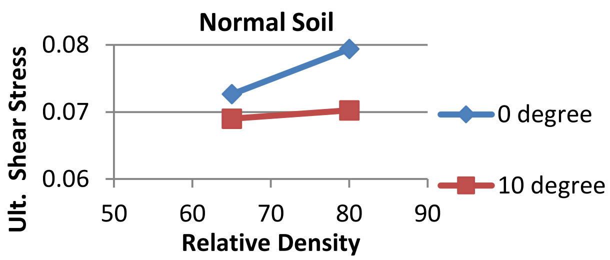

Fig.12 : Ultimate Shear Stress v/s Relative Density

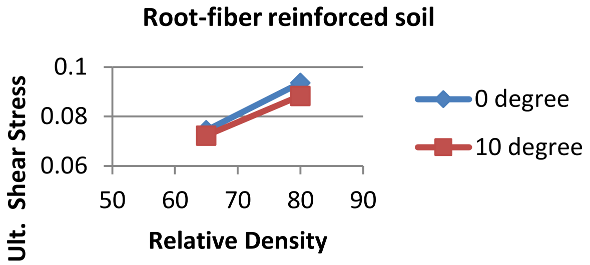

Fig.13 : Ultimate Shear Stress v/s Relative Density

It can be seen that the value of ultimate shear stress increases as the relative density increases for both the normal soil and the root-fiber reinforced soil. When comparing the behavior in terms of the angle of inclination, as the angle of inclination increases the value of ultimate shear stress decreases in both the normal soil and the root-fiber reinforced soil.

3 CONCLUSION

From the results obtained it is observed that as the inclination of shear plane increases, the value of shear stress decreases. The reason for this effect can be that as the as angle of inclination increases the shear area increases, thereby decreasing the shear stress. Comparing the shear stress values of the soil with different relative density it is seen that the denser soil behaves better in the shear as compared to the loose soil. With the reinforcement of soil with root-fibers there is an increase in the shear strength of the soil. This effect is more prominent for the soil having higher relative density this is due to the more interaction and friction between the root-fibers and the soil particles.

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