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Response of Sand at Low Normal Stresses using Gravity Shear Test

Kiranmai Konda[1], Kadali Srinivas[2] and Madhav Madhira[3]

[1]Post Graduate Student, kiranmaigupta.k@gmail.com
[2]Associate Professor,srinivas_kadali@vnrvjiet.in (Corresponding Author)
[3]AICTE-INAE Distinguished Visiting Professor, madhavmr@gmail.com
VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, 500090, India

Abstract. Shallow slope failures have been observed due to loss of strength, infiltration of water, climatic factors, etc. Strength properties of near surface soils especially at low normal stresses have rarely been studied. Similar problems occur at the interfaces between geosynthetic and soil/backfill in case MSW (Municipal Solid Waste) disposal site as, for such materials (soils and geosynthetics) shear response of interfaces becomes significant considering the fact very low normal stresses act along the potential failure plane. The bond strength for such materials is usually measured either by direct shear test or a tilt test. Gravity induced shear test is proposed herein to be performed for conditions of low normal stress. In the present study, a new test set-up was developed and tests have been carried on sand at different normal stress conditions for relative density of 50% and 75%. Response of granular material at very low normal stresses is thus studied and results presented.

Keywords: Gravity induced shear test, Shear stress-displacement, Angle of shear resistance, Low normal stress.

1 Introduction

Liner systems on slopes are a combination of various materials like soil and geosynthetics. Designing of such systems on slopes necessitates prior knowledge of angle of shear resistance between various layers, as the critical failure plane is usually located at the interface between these components. Shear strength of materials can be characterized either by direct shear test (IS 2720-13) or an inclined plane or tilt test (EN ISO 12957-2). Tilting frame or a gravity induced shear test is used to measure shear/frictional characteristics of soil, soil-geosynthetic or geosynthetic-geosynthetic interfaces where shearing occurs for a material placed on an inclined surface under gravity. Shear strength behaviour of a soil and geosynthetic interfaces on an inclined plane has been studied at different test conditions by Palmeria et al., 2002; Lopes et al., 2014. Several studies have been reported comparing the two methods (direct shear and inclined plane/tilt) and they conclude that "Gravity Induced Shear test" is more suitable for conditions under low normal stress of less than 10 kPa (Reyes and Gourc, 2003) and direct shear performs well under conditions of relatively high normal stresses (Izgin and Wasti, 1998; Palmeria et al., 2002; Reyes and Gourc, 2003;

Pitanga et al., 2009). The above studies measure only the strength and not the shear stress – displacement responses of the material or the interface.

In this study, gravity induced shear test set-up was developed to measure the shear stress – displacement response considering the factors effecting the test results. Tests has been performed for a normal load of 0.7 kPa, 0.9 kPa and 1.6 kPa at 50% and 75% density index and the angle of shearing resistance was evaluated. A graph has been plotted between shear stress and horizontal displacement. It is observed that the plot (shear stress vs Displacement) depicts a stick-slip phenomenon i.e., as the shear stress increased the displacement remained constant and then gradually increased, later the displacement continued persistent and thereafter with no rise in the shear stress the horizontal displacement increased. A similar analysis has been carried for direct shear tests performed at normal loads of 9.8 kPa, 24.5 kPa, 49.0 kPa, 98.1 kPa and 147.1 kPa and the test results depicted a gradual increase in the shear stress with increase in the horizontal displacement.

2 Methodology

To measure the shear stress – horizontal displacement response a test set-up was fabricated as shown in Fig.1. Shear box of size 6 cm x 6 cm is mounted on a fabricated table which can be inclined. A lifting jack is provided to allow inclination of the box. To record the displacement of shear box a horizontal dial gauge is fixed. A graduation scale is erected to measure the angle of inclination of the test box.

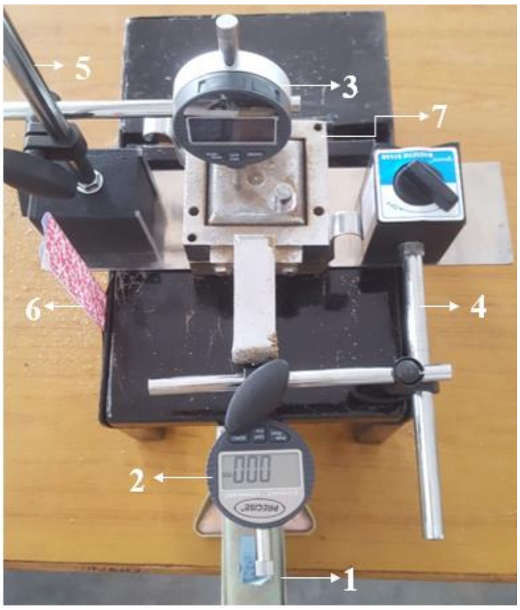


Fig.1. Gravity Induced shear test set-up (1)Lifting jack, (2)Dial gauge (to measure horizontal displacement), (3)Dial gauge (to measure dilation), (4 &5)Magnetic stands(6)Graduation scale,(7) Shear box (6 cm x 6 cm)

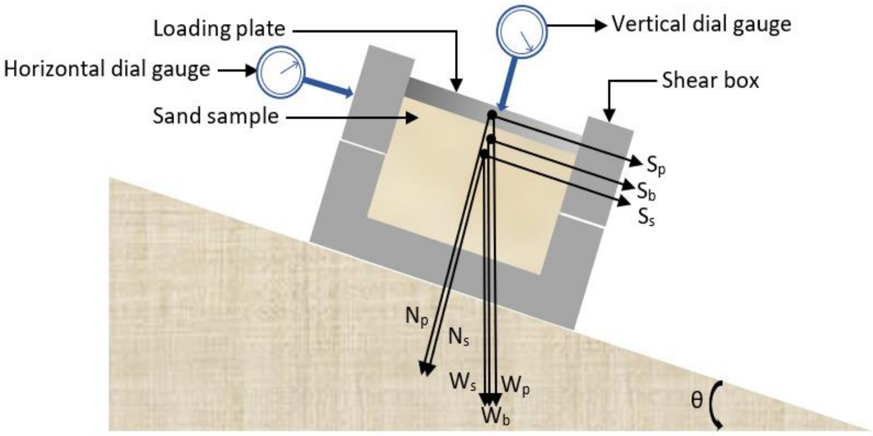


Fig.2. Forces acting on the shear box

The forces acting on the test specimen is represented in Fig.2. The net normal stress and the shear stress are calculated as per equations 1 and 2 respectively.

$$Normal\ stress = \frac{W_s\cos\theta + W_p\cos\theta}{A} \quad (1)$$

$$Shear\ stress = \frac{W_s\sin\theta + W_p\sin\theta + W_b\sin\theta}{A} \quad (2)$$

where W_s = Weight of soil in the upper half; W_p = Weight of loading plates; W_b = Weight of upper half of box; N_s = normal component of soil weight = $W_s\cos\theta$; N_p= normal component of weight of plates = $W_p\cos\theta$; S_s = shear component of soil weight = $W_s\sin\theta$; S_P = shear component of weight of plates = $W_p\sin\theta$; S_b= shear component of weight of upper half of box = $W_b\sin\theta$; A = Area of the specimen

3 Results and Discussion

Naturally available sand is considered for the study. Sieve analysis (IS 2720-4) has been performed to evaluate the particle size distribution (refer Fig.3) of the representative sample. The Cu and Cc values were recorded to be 2.63 and 0.92 respectively, it is clearly observed that the soil is classified as poorly graded sand.

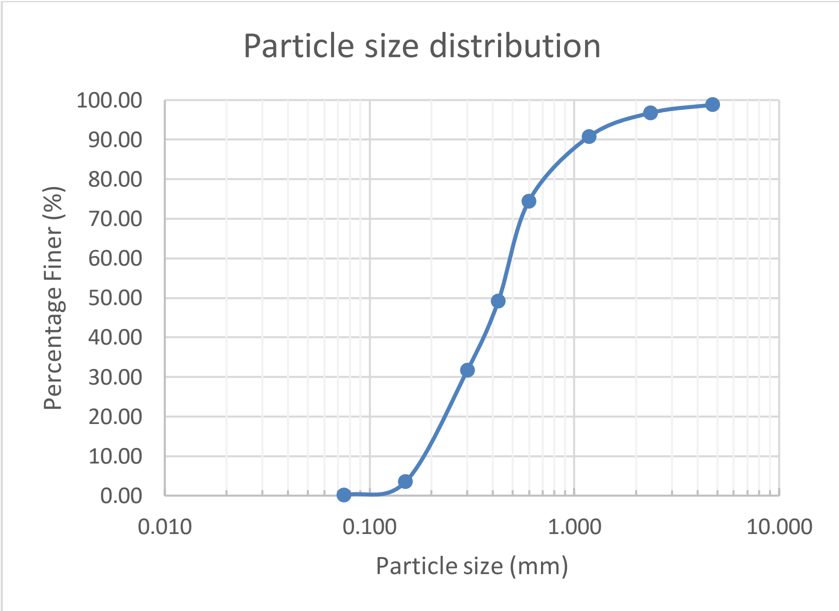


Fig.3. Particle size distribution of sand sample

A relative density test (IS 2720-14) has been carried to estimate the in-situ dry density of the sample with density index equal to 50% and 75% and is measured to be 1.61 g/cm^3 and 1.64 g/cm^3 respectively (refer Table 1).

Table 1. Relative density test results of sand sample

	Density value (g/cm^3)
Minimum density	1.56
Maximum density	1.67
Dry density	
RD = 50%	1.61
RD = 75%	1.64

With known density and volume, the weight of the sand is assessed and is filled in a standard size shear box (6 cm x 6 cm) which then placed on the table top. Stainless steel loading plates of size 6 cm x 6 cm are placed on top of the shear box to act as a normal load. The horizontal dial gauge is positioned to measure the shear displacement. Agraduation scale is provided to estimate the test box inclination. The inclinationof the shear box is advanced with the help of lifting jack to measurestress-displacement response and also the angle of shearing resistance of the representative sand.Fig. 4 shows the failure of the test specimen under gravity.

Fig.4. Failure of sand sample under gravity

To know the frictional resistance between the boxes a test has been carried for the test box without sand. From Fig.5 it is envisioned that the horizontal displacement remained constant up to an inclination of 12.4° and the displacement increased extremely causing sudden sliding of the test box indicating no friction between the boxes.

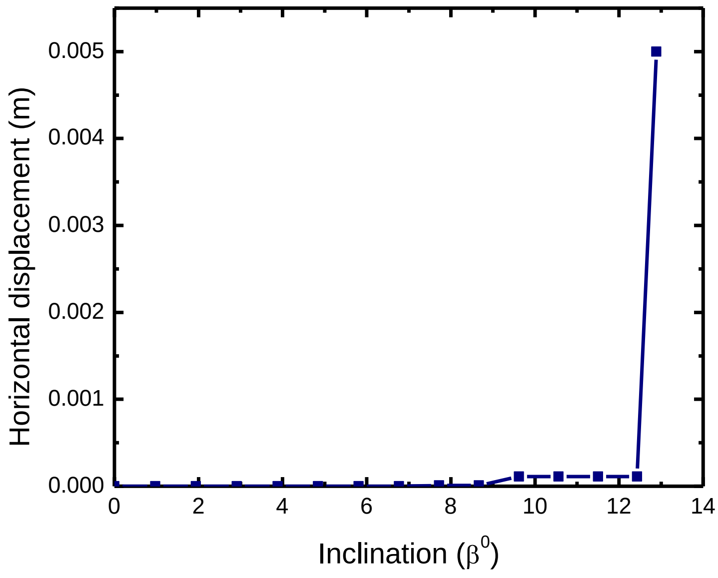


Fig.5. Inclined shear test box without sand

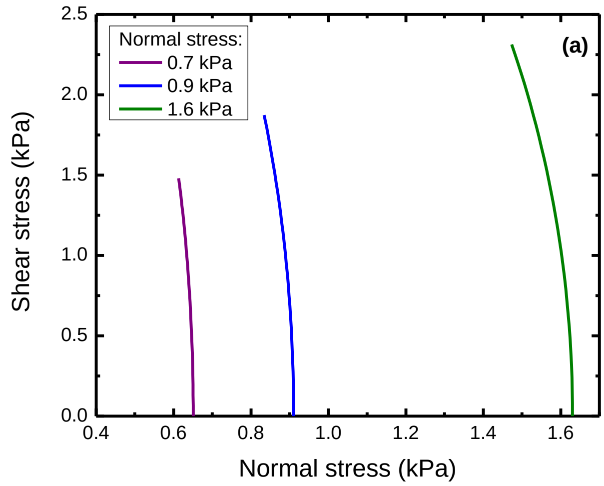
3.1 Gravity induced shear test results

The test result with three normal loading conditions (0.7 kPa, 0.9 kPa and 1.6 kPa) has been plotted (Fig.6). Fig.6(a) reflects the plots for shear stress vs normal stress at a density index of 50%. It is observed that as the test is advanced the normal stress decreased from 0.7 kPa to 0.6 kPa. The shear stress increased from 0 kPa to 1.4 kPa andthe friction angle is evaluated to be 66.6° at failure. Likewise, for a loading condition of 0.9 kPa the normal stress decreased from 0.9 kPa to 0.8 kPa and theshear stress increased from 0kPa to 1.9 kPa with the friction angle equal to 65.7° at failure. And hence for 1.6 kPa normal loading conditionthe normal stress reduced to 1.5 kPa and shear stress increased to 2.3 kPa for a friction angle being 56.7° at failure. The details of the failure condition for all the three test cases were tabulated in Table2.

Table 2. Gravity induced shear test results at failure condition for 50% density index

Density (g/cc)	Initial Normal stress (kPa)	Normal stress at failure (kPa)	Shear stress at failure (kPa)	Angle of shearing resistance (ϕ^0)
1.61	0.7	0.6	1.4	66.6
1.61	0.9	0.8	1.9	65.7
1.61	1.6	1.5	2.3	56.7

Fig.6(b) represents shear stress vs displacement curve for normal loads of 0.7 kPa, 0.9 kPa and 1.6 kPa with density index being 50 %. A stick-slip phenomenon is depicted from the test results. For a loading condition of 0.7 kPa the shear stress increased form 0 kPa to 0.6 kPa with no increase in the displacement. Later, with minor increase in the displacement the shear stress increased to 1.1 kPa. Thereafter with small increase in the shear stress the displacement increased from 0.06 mm to 0.38 mm. Now, the displacement remained constant and the shear stress increase to 1.4 kPa. Later, with no increase in the shear stress the displacement augmented. Likewise, for normal loads of 0.9 kPa and 1.6 kPa an equivalent response is noticed. Fig.6(c) depicts the plots of displacement vs angle of shearing resistance. A similar phenomenon (stick-slip) has been observed, the displacement progressively augmented and then nearly maintained continual. Later, the displacement increased drastically.



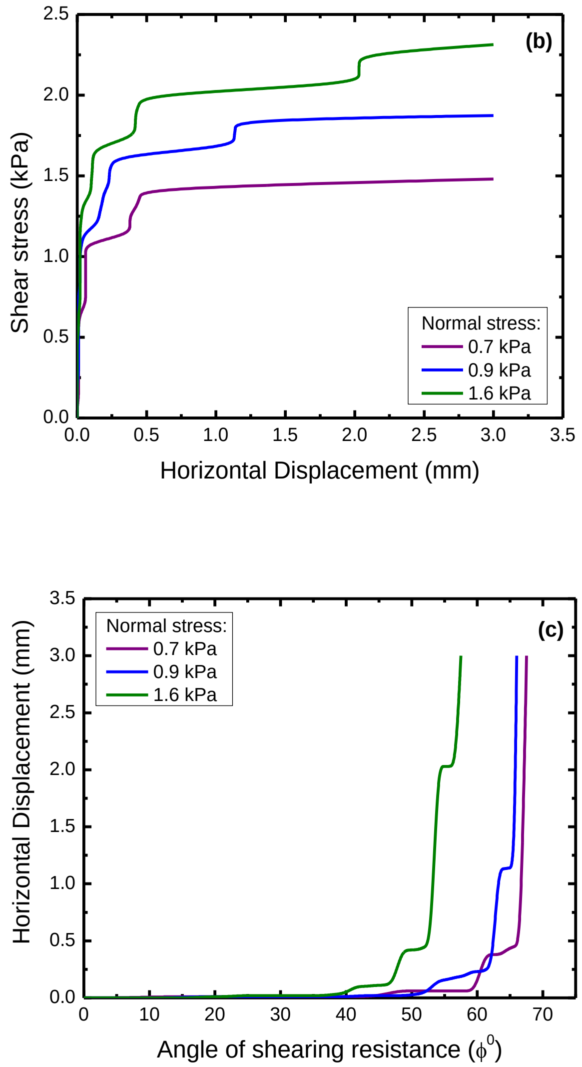


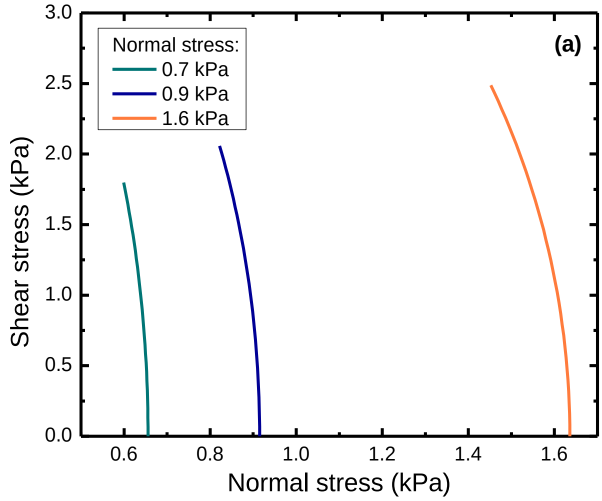
Fig.6. Gravity induced shear test results at 50% density index

A similar analysis has been carried with increase in density index from 50% to 75% (refer Fig.7). The details of the failure condition for the three loading conditions were tabulated (refer Table3). Comparing the test results from Table2 and Table3 it is envisioned that with increase in density a minor increase in the normal load is observed. However, with the slight increase in the normal load there is a rise of 2° to

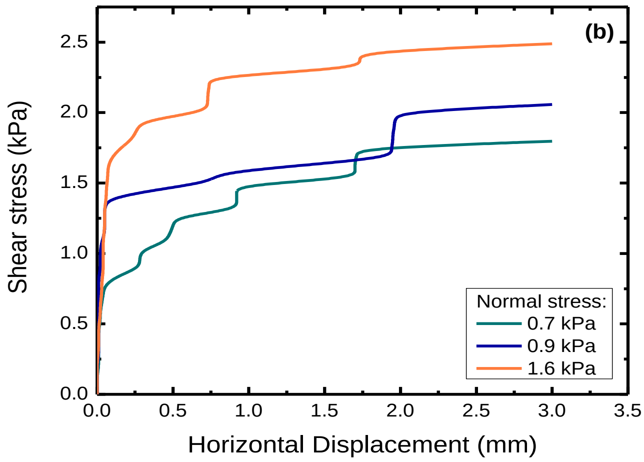
4°in the friction angle. This is due to the influence of the sand particles with varying densities.

Table 3. Gravity induced shear test results at failure condition for 75% density index

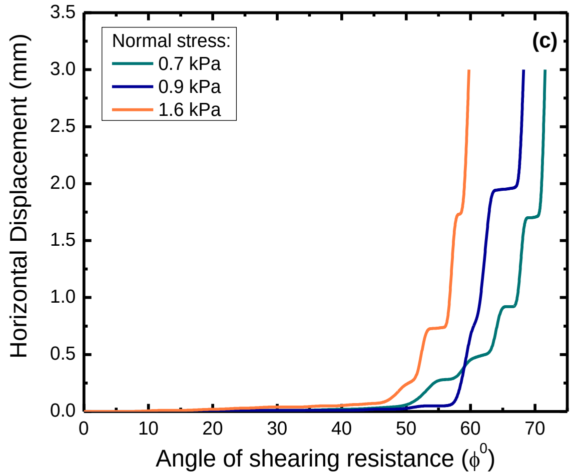
Density (g/cc)	Initial Normal stress (kPa)	Normal stress at failure (kPa)	Shear stress at failure (kPa)	Angle of shearing resistance (ϕ^0)
1.64	0.7	0.6	1.8	71.0
1.64	0.9	0.8	2.0	67.6
1.64	1.6	1.4	2.4	59.0



(a)



(b)



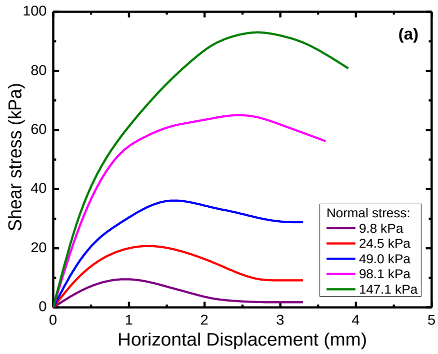
(c)

Fig.7. (a,b,c) Gravity induced shear test results at 75% density index

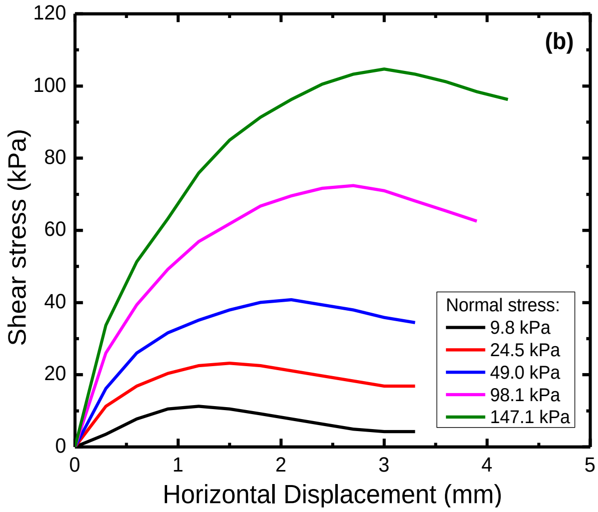
3.2 Direct shear test results

Direct shear tests have been carried for normal loads of 9.8 kPa, 24.5 kPa, 49.0 kPa, 98.1 kPa and 147.1 kPa at 50 % and 75 % density index. A shear stress vs horizontal displacement curve has been plotted for the test results. Fig.8(a)

shows the plots for a relative density of 50 % and Fig.8(b) for 75 % density index. It is observed that the shear stresses at failure was recorded to be 9.84 kPa, 21.1 kPa, 36.6 kPa, 65.4 kPa and 93.5 kPa for the normal loads of 9.8 kPa, 24.5 kPa, 49.0 kPa, 98.1 kPa and 147.1 kPa respectively with a density index of 50 %. Similarly, for a density index of 75 % the shear stresses at failure is 11.2 kPa, 23.2 kPa, 40.8 kPa, 72.4 kPa and 104.7 kPa for normal loads of 9.8 kPa, 24.5 kPa, 49.0 kPa, 98.1 kPa and 147.1 kPa respectively. It is hence concluded that the shear stress increased gradually with increase in the horizontal displacement.



(a)



(b)

Fig.8. Direct shear test results at (a) 50 % density index (b) 75 % density index

3.3 Strength envelope

A unified Mohr-Coulomb envelope has been plotted combining the test results from gravity induced and the direct shear tests at 50% and 75% density indices (Fig.9). The normal stresses range from a low 0.7 kPa though 0.9 kPa, 1.6 kPa, 9.8 kPa, 24.5 kPa, 49.0 kPa to a maximum of 98.1 kPa. An inset graph has also been plotted to visualize the normal stresses of 0.7 kPa, 0.9 kPa and 1.6 kPa. A non-linear Mohr-Coulomb envelope is obtained indicating the angle of shearing resistance to be a function of normal stress. The angle of shearing resistance reduces from 66.6° at a normal stress of 0.7 kPa to 33.7° at 98.1 kPa for 50 % density index. Likewise, for 75 % density index the angle of shearing resistance decreases from 71° at normal stress of 0.7 kPa to 36.4° at maximum stress of 98.1 kPa. Fannin et al. (2005) report a similar result.

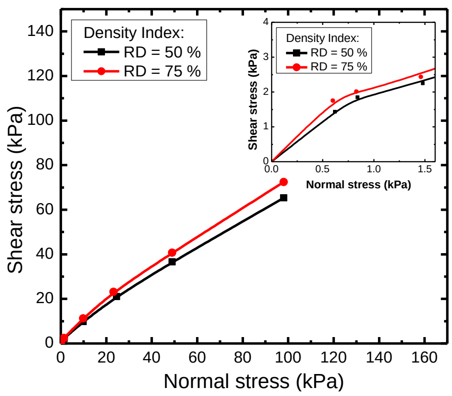


Fig.9. Unified Mohr-Coulomb envelope

4 Conclusions

Present study reports development of the gravity induced shear test set-up to measure the shear stress – displacement responses at low normal stresses. Three low normal loading conditions of 0.7 kPa, 0.9 kPa and 1.6 kPa at 50% and 75 % density indices were considered. A similar study has been carried using direct shear tests at normal stresses of 9.8 kPa, 24.5 kPa, 49.0 kPa, 98.1 kPa and 147.1 kPa. A unified Mohr-Coulomb envelope represented by a non-liner curve indicates the angle of shearing resistance is a function of normal stress, decreasing with increasing normal stresses.

References

1. EN ISO 12957-Part 2: Determination of Friction Characteristics - Inclined plane test, European Committee for Standardization, Brussels (2005).
2. IS 2720-Part 13: Methods of test for soils - Direct shear test, Soils and Foundation Engineering (1986).
3. IS 2720-Part 14: Methods of test for soils - Determination of density index of cohesionless soils, Soil and Foundation Engineering (1983).
4. IS 2720-Part 4: Methods of test for soils - Grain size analysis, Soil and Foundation Engineering (1985).
5. Fannin, R.J., Eliadorani, A. and Wilkinson, J.M.T.: Shear strength of cohesionless soils at low stress. Geotechnique55(6), 467-478 (2005).
6. Izgin, M. andWasti, Y.: Geomembrane-sand interface frictional properties as determined by inclined board and shear box tests. Geotextiles and Geomembranes 16, 207-219 (1998).
7. Lopes, M.L., Ferreira, F., Carneiro, J.R. and Vieira, C.S.: A new procedure for measuring geosynthetic friction with an inclined plane. International Journal of Geotechnical Engineering 8(3), 335-342 (2014).
8. Palmeira, E.M., Lima, Jr.N.R. and Mello, L.G.R.: Interaction between soils and geosynthetic layers in large-scale ramp tests. Geosynthetics International 9(2), 149–187 (2002).
9. Pitanga, H.N., Gourc, J.P. andVilar, O.M.: Interface shear strength of geosynthetics: Evaluation and analysis of inclined plane tests. Geotextiles and Geomembranes 27, 435-446 (2009).
10. Reyes, R.R. andGourc, J.P.: Use of the inclined plane test in measuring geosynthetic interface friction relationship. Geosynthetics International 10(5), 165-175 (2003).