Indan Geotechnical Journal, 18 (2), 1988

Evaluation of Soil-Reinforcement Friction

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Introduction

Rapid development in 'reinforced earth' technique is taking place since introduction of its concept by Henri Vidal in 1960's. Reinforced earth is a composite material formed by introducing suitable reinforcement into soil and is relatively strong and stable. Geotechnical engineers all over the world have well realised the merits of this recent technique. Significant research is being pursued in this area to understand the behaviour of such material for further rationalisation and improvisation of the technique.

The basic mechanism of reinforced soil involves the generation of frictional forces at the soil-reinforcement interface. These forces are analogous to an increased confining pressure and thus restrict the lateral strains of soil by providing an apparent anisotropic cohesion. The bond between soil and reinforcement is of frictional nature and depends upon coefficient of friction between these materials and imposed stresses. Thus, in an approach to successful design of any structure involving the application of reinforced earth, it is essential to understand the friction generated at the interface of these materials. In this context, in the present study an attempt has been made to evaluate the frictional and stress-deformation behaviour of reinforcing material with sand. The effect of the width of reinforcing strips on the frictional behaviour have been studied.

Reinforcement Materials and Testing Methods

Reinforcement materials can be classified as metallic and nonmetallic. Amongst metallic reinforcement the most common material is Galvanised steel. (Jones, 1985) Hoshiya and Mandal (1985) have shown that with

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(*This modified paper was received in January* 1988 *and is open for discussion till the end of July* 1988)

increase in vertical pressure the friction coefficient between Galvanized steel strip and sand decreases.

Amongst nonmetallic reinforcement, the use of various types of synthetic materials in the form of tough fabrics has been spreading in the recent past. A whole range of Synthetic materials such as terylene, nylon, polyethylene, poly-propylene, P.V.C., polymide etc. are utilized. These materials have the advantages of good strength, good anchoring effects and good drainage. They have some disadvantages too, such as deterioration under exposure to sunlight and high creep etc. The choice of reinforcement materials depends upon the design considerations related to theoretical needs, material properties, availability and relative costs etc.

In order to assess the engineering behaviour of reinforcing materials, a number of tests have been proposed which adopt either conventional soil mechanics test methods or methods in vogue for textiles. In addition, to simulate the actual field conditions more realistically some new tests are being developed.

Methods of assessment of soil-reinforcement friction are brieflys discussed below.

Soil-Reinforcement Friction

The soil-reinforcement friction angle is usually determined by 'Direct shear (modified) technique'. In this method the reinforcement is held securely between the soil. The friction angle (δ) is calculated on the basis of stress required to slide the soil against reinforcement under known values of applied normal stresses. On the basis of laboratory study on woven polyporpylene fabric, Subba Rao and Ghosh (1984) suggested that the friction angle of fabric in sand may be assumed to be equal to 90% of the angle of shearing resistance of sand in direct shear tests.

'Pull-out test' is another test which is used to obtain soil-reinforcement friction (μ). In this, the reinforcement strip is placed between soil and pressed together under known normal stress. The strip is then pulled out and the magnitude of pulling force required under different normal stresses provides the soil-reinforcement friction.

Sridharan and Singh (1984) conducted pull out tests on different reinforcing materials and sands to assess the friction coefficient. It has been observed that the surface conditions affect the value significantly and appears to be independent of ϕ. Also the grain size has marginal effect on the friction coefficient.

Venkatappa Rao et al (1986) have reported preliminary studies on friction behaviour of metallic and non-metallic reinforcement with sand as back fill.

Experimental Programme

A correct assessment of the coefficient of friction μ between the soil and reinforcement is essential to determine the effective length of the reinforcement so that the full capacity of the reinforcement can be utilized without any danger to the structure. This has been carried out in this study by both the modified direct shear technique and pull out test method. The details of all tests conducted, reinforced fill material and reinforcing material used and the test programme adopted are presented here. Aluminium foil has been chosen as the reinforcing material, as it is used later in preliminary model studies (Saxena, 1987).

Materials

Fill

Badarpur sand was used as a fill material in the present study. The particle size distribution curve for this sand is shown in Fig.1. The sand is coarse grained and uniformly graded having coefficient of curvature and uniformity coefficient of 1.09 and 2.36 respectively.

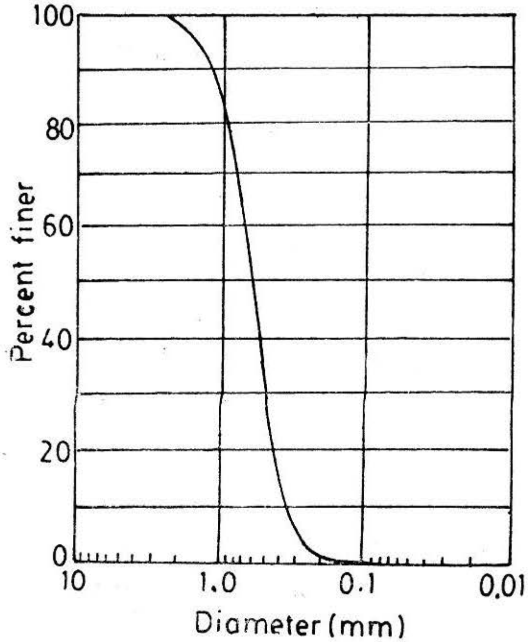

FIGURE 1 Grain Size Distribution Curve for Badarpur Sand

Reinforcing material

Aluminium foil of 0.03 mm thickness was used as reinforcing material in the tests. The test length (1) of aluminium foil was maintained at 6 cm whereas to assess the effect of width (*b*) on frictional behaviour, the widths studied were 1, 3 and 5 cm.

Tests

Direct Shear Tests

Conventional direct shear tests were conducted on Badarpur sand at normal stresses (σ_n) of 0.5, 1 and 2 kg/cm^2. The tests were conducted under controlled conditions of density of sand (1.39 g/cc).

Modified Direct Shear Test

The test method consists of placing the reinforcement in a conventional direct shear device (6 × 6 × 2 cm) between two boxes filled with soils and held under a known normal-stress. Set up for the test is shown in Fig.2 which has the two boxes and necessary arrangement for application of loads and their measurement. The soil was first filled in the bottom box upto nearly 1 mm above its top. Reinforcement was then placed over it as indicated in figure and both the ends of the reinforcement were clamped to the container. The remaining procedure is the same as for conventional shear box test i.e. to fill the soil in top container and apply normal stress of known magnitude and obtain corresponding shear stress (τ) at failure.

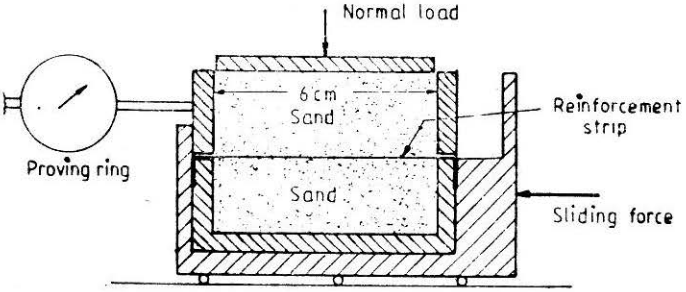

FIGURE 2 Modified Direct Shear Test

Pull-out Test

In this method a strip of reinforcement was placed within a soil under known normal stress. The strip was pulled out and the pulling force was measured. The schematic arrangement of test set-up developed is shown in Fig.3. For this, the conventional shear box assembly was modified and a clamping arrangement for the strip was fabricated. As pull out resistance has to be measured, a tension proving ring was used. The effect of width of reinforcement on the friction coefficients have been studied in pull-out tests.

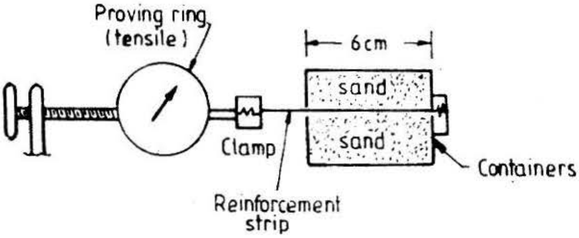

FIGURE 3 Pull Out Test

Results and Discussion

The stress-deformation curves obtained for different type of tests and loading conditions have been presented in Fig.4. To facilitate comparison, the curves present the results of conventional direct shear tests (conducted only on Badarpur sand) as well as modified shear test and pull-out tests conducted with aluminium foil of 5 cm width as reinforcement. The figure clearly indicates that the overall nature of stress-deformation curves remain the same irrespective of the type of test. A marked increase in shear strength with normal stress has been observed for all the cases. In general, with increase in normal stress, the curves indicate a transition from ductile to brittle nature. It is very interesting to note that at a given normal pressure, the uppermost stress-deformation curve is for conventional direct shear, followed by the curve for modified shear test and the bottom most is always for pull out test. This pattern is observed for all the cases studied.

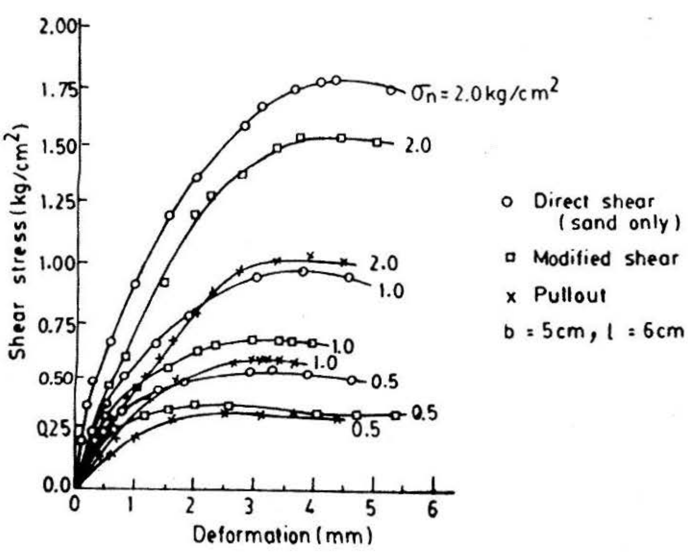

FIGURE 4 Stress Deformation Curves for Different Tests

The value of friction angle (ϕ) obtained from conventional direct shear test for Badarpur sand is 44°. Table 1 shows the values of friction coefficient (μ) obtained by different tests; for conventional tests $\mu = \tan\phi$ and for modified direct shear and pull-out tests $\mu = \tan\delta = \zeta/\sigma_n$. The highest value of μ is obtained in direct shear tests on sand alone, followed by the values for modified shear tests with reinforcement, the least being from the pull-out tests. It is also observed that the friction coefficient decreases with increase in normal pressure (σ_n) for pull-out tests. Such a behaviour was also observed earlier by Hoshiya and Mandal (1985). However, values of friction coefficient, μ are found to increase marginally with normal pressure in the modified shear tests. In any case, it is expected that beyond a critical value of σ_n no further increase will be there in μ.

TABLE 1

Friction coeficients under Different Test Conditions

Type of test	Direct shear		Modified shear		Pull-out	
Material	Sand/sand		Sand/aluminium strip			
Shear parameter σ_n kg/cm^2	ζ (kg/cm^2)	tan ϕ	τ (kg/cm2)	$\mu=\tan\delta$	ζ (kg/cm2)	$\mu=\tan\delta$
0.5	0.48	0.96	0.35	0.70	0.33	0.66
1.0	0.96	0.96	0.72	0.72	0.58	0.58
2.0	1.91	0.955	1.48	0.74	0.94	0.47

Effect of Reinforcement Width on Friction Coefficent

The stress-deformation curves obtained in pull-out test for reinforcement of different widths have been shown in Fig.5. The curves indicate brittle nature of failure for lesser width of reinforcement. However, with increase in their width, the failure pattern turns out to be ductile. The shear stress at any particular normal pressure is observed to increase with decrease in the reinforcement width. The friction coefficients have been calculated from stress-deformation curves and their variation with normal stress has been depicted in Fig.6. The figure indicates a decrease in friction coefficients with increase in normal stress. Further, under a given normal stress, the friction coefficients decreases with increase in reinforcement widths. Hoshiya and Mandal (1985) observed a similar behaviour in pull-out tests.

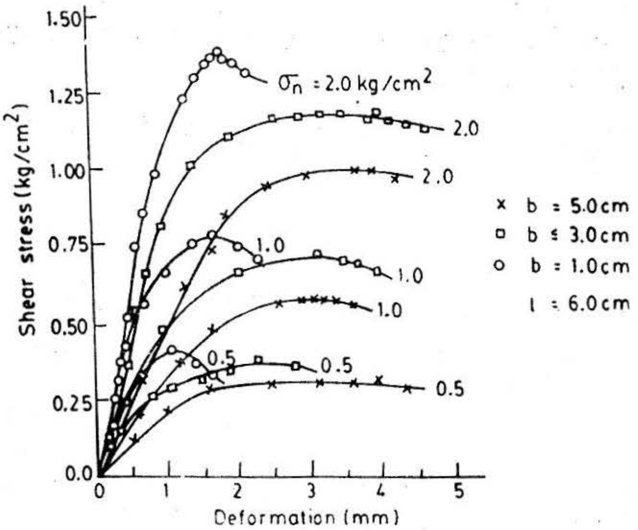

FIGURE 5 Stress Deformation Behaviour Under Different Reinforcement Widths

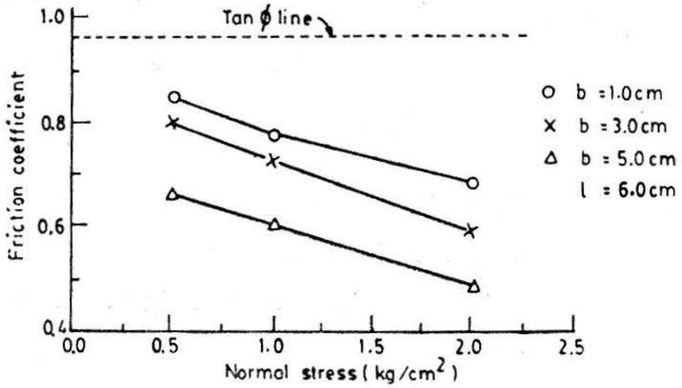

FIGURE 6 Variation of Friction Coefficients with Normal Stress

Conclusions

The findings of the laboratory studies conducted with aluminium foil as reinforcement and sand as a fill, to understand the effect of reinforcement width and nature of test on friction coefficients, are summarized below.

(*i*) The stress-deformation curves in pull-out tests show a transition from brittle to ductile nature as the reinforcement width increases.

(*ii*) The friction coefficients from pull-out tests decreases both with increase in normal stress as well as reinforcement widths.

(*iii*) Under any given normal stress the failure shear stress and friction coefficient obtained therefrom decreases in order of direct shear, modified shear and pull-out tests.

The results of these studies are promising and indicate scope for further detailed investigation.

References

HOSHIYA, M. and MANDAL, J.N. (1985), "Experimental Investigation on Model Reinforced Retaining walls", *Indian Geotechnical Journal*, 15 : 4 : 165-186.

JONES J.F.P. COLIN (1985), "Earth Reinforcement and Soil Structures", *Butterworth and Co. Ltd.*, London.

SAXENA, A., (1987) "Model Studies of Reinforced Soil Retaining Structures—A critical appraisal" M. Tech Thesis, Dept of Civil Engineering, IIT Delhi.

SRIDHARAN, A. and SINGH, H.R. (1984) Friction coefficient in Reinforced Earth" *Proc. Indian Geotechnical Conference*-84, Calcutta, I : V 43-V 47.

SUBBA RAO, C. and GHOSH, A. (1984) "A Study for design of Fabric Reinforced Earth", *Proc. Indian Geotechnical Conference*-84, Calcutta, I : V 5—V 8.

VENKATAPPA RAO, G., KATE, J.M. and TYAGI, S.K. (1986), "Evaluation of Reinforcing Materials for Reinforced Soil Structures", *Proc. 53rd Annual Research and Development Session*, Bhubaneswar, Central Board of Irrigation & Power, Vol., 3 pp. 103-114.

Notations

b = width of reinforcement strip

l = test length of reinforcement strip

μ = coefficient of friction between sand and reinforcement.

σ_n = normal stress

ζ = shear stress

ϕ = angle of shearing resistance of sand

δ = angle of friction between reinforcement and sand.