A STUDY ON SLIDING RESISTANCE OF EARTH REINFORCEMENTS

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SUMMARY

The sliding resistance of earth reinforcements plays a very important role in the design of these structures. Limited study has been reported on the problem of sliding resistance in reinforced earth structures. Triaxial and direct shear tests on reinforced soil samples were carried out for the purpose of this present investigation. It is observed that the sliding resistance factors that approximately fit with the experimental results of triaxial tests using finite element method (FEM) are compatible with the factors experimentally determined from direct shear tests for the concerned reinforcement and soil placement conditions.

INTRODUCTION

Several small scale laboratory model tests to simulate retaining structures and a few laboratory triaxial tests on reinforced earth were performed by Vidal to study the mechanism of reinforced earth. If the reinforcement is properly placed and designed , it is possible to avoid shear and any sliding , so that the entire mass behaves like a cohesive solid capable of withstanding both internal and external forces (1). Investigations have been generally confined to the analysis and behavior of retaining structures built with reinforced earth using granular back-fill. But the new technique has the potential for application in other fields of construction as well (2) and calls for a wider study for the behavior of reinforced earth material under a variety of other conditions. The following areas of reinforced earth have been identified by Lee (3) for further study:

(1) Sliding shear resistance between soil and reinforcing material.
(2) Fundamental behavior mechanisms and practical design parameters.
(3) Long term durability or corrosion of reinforcing materials.
(4) Backfill of cohesive soil or soil with fines.

Mckittrick (4) suggested the following areas for investigation.

(1) Basic mechanism of reinforced earth.

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a. State of stress in a reinforced earth structure.
b. Frictional relationship between soil and reinforcements.
(2) Durability of burried metal reinforcements.
(3) Selection of soil for use in reinforced earth structures.

Hausmann and Lee (5) carried out strip pullout tests from a rigid rotating model wall. They showed that the soil reinforcement friction mobilization is a function of overall deformation of the reinforced earth mass. Schlosser and Elias (6) , and Mckittrick (4) hypothesized that the apparent friction coefficient from the pull-out tests are generally significantly greater than the values obtained from the direct shear tests.

The soil reinforcement friction coefficient is the complex parameter to be determined for the reinforced earth structure. The main purpose of this present investigation is to analyse the interaction between soil and reinforcements under triaxial loading conditions. Stress - strain relationships obtained from triaxial tests using finite element technique have been analysed with varying friction factors. The resistance factors evaluated from the direct shear test are compared with the results of finite element solutions.

MODEL TESTS

A number of triaxial tests were performed on a local silty clay and Ennore standard sand samples. Mild steel and aluminium plates in the form of solid plates and perforated plates in varying percentages by volume of soil was used as the reinforcing materials. The plates or discs (25 mm dia.) were kept horizontally in the samples. The detailed test procedure is given elsewhere (7).

ANALYTICAL APPROACH

Almost all finite element solutions reported in the literature (8 , 9 , 10 , 11) relate to the prediction of the behavior of reinforced earth walls utilising a composite representation for the purpose of analysis. The reinforced system was modelled as a locally homogeneous material termed the ' composite material ' . The present investigation being of a different nature and the objective being to analyse the interaction between the soil and reinforcements under triaxial loading conditions and obtain the stress - strain relation in the soil due to the geometric discontinuities resulting from the presence of reinforcing members , edge effects at boundaries etc. Two types of boundary conditions were imposed i.e. (1) Displacement boundary condition , (2) Force boundary condition. The sample is loaded at top and bottom through rigid metallic plates and in addition it carries hydrostatic pressure from all sides. The matrix boundary in half - band form is solved using Gaussian elimination. This routine returns the load matrix converted into the displacement matrix.

The applied vertical loading is lumped at the three top nodes , the lumping being proportional to the sectional area around the node. Subsequently the lumping ratios were modified so as to keep the top loading surface level. The hydrostatic pressure was lumped at the nodes in proportion to the areas around the nodes. The cohesive or adhesive forces act horizontally at the inter faces between the soil and loading plates / reinforcements the direction being opposite to the movement of the load and are proportional to the surface area on which they act. These forces are absent in the case of sand samples. Friction is difficult to evaluate as to extent to which it is mobilised between the soil and the loading plates / reinforcements. Hence arbitrary trial values were assumed consistent with the direct shear test results and the displacements obtained. In case of incompatible displacements , suitable correction was made in the values of coefficients assumed. Since it is not known priori how much sliding resistance is actually mobilised along the reinforcements , friction coefficients were assumed and the stress - strain relation obtained for each assumed friction coefficient.

Increments of load were applied in nine load steps i.e. initially the sample was analysed for 1/9 th maximum load. Next it was analysed for 2/9 th the maximum load and so on. For cohesionless soils 7 load steps were used. A loop was set over the load stages. During the first load stage all elements were assumed to be elastic. During higher loading stages the strain in the element due to previous loading stage is compared with the predefined strain stages. As the nonlinearity increases , it was felt necessary to repeat the calculations of stresses and deflections for the same load stage by iteration.

RESULTS AND DISCUSSION

For the finite element analysis of the reinforced triaxial specimens, the maximum friction that can be mobilised between the particular form of reinforcement and the soil grains corresponding to their placement condition in the case of sand and the maximum friction and adhesion that can be mobilised between the reinforcement and soil corresponding to its placement condition in the case of cohesive soil , are necessary. Direct shear tests were carried out for this purpose and the results are given in Figs. 1 and 2 which were used in the finite element analysis. The adhesion and friction developed between the reinforcement and the soil were obtained from the envelopes of Figs. 1 and 2 and are given in Table 1 and 2.

TABLE 1.-Direct Shear and FEM Results for Cohesionless Soil Placement Density = 1.5 g/cc

	Direct Shear Tests		From FEM Solution	
Parameters	C (Kg/cm^2)	ϕ^0	C (Kg/cm^2)	ϕ^0
Between aluminium solid plate and sand	0.0	21.0	-	21.5
Between mild steel solid plate and sand	0.0	24.0	-	22.0
Between perforated aluminium plate and sand	0.0	36.0	-	27.5

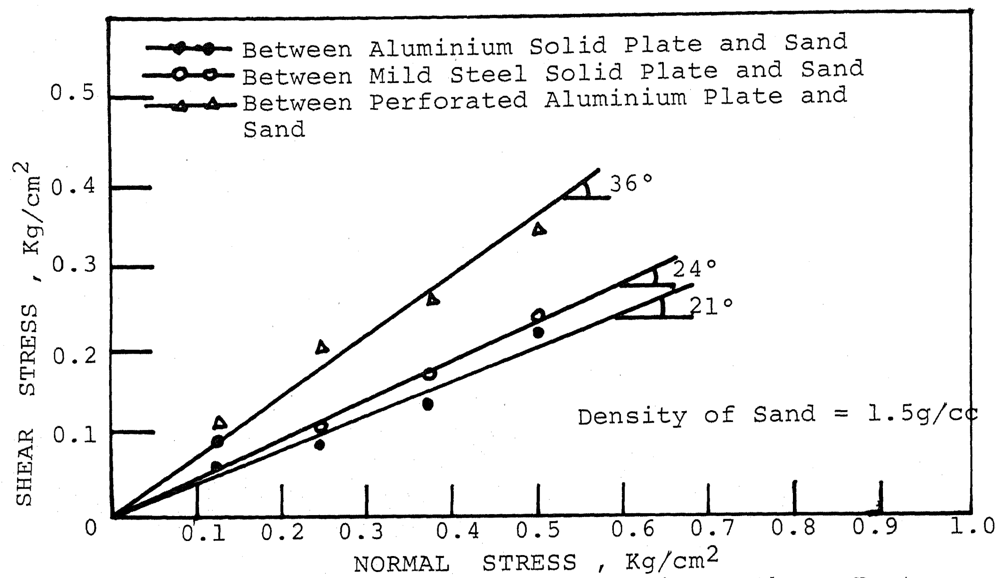

FIG.1.-Shear Strength Envelopes from Direct Shear Tests.

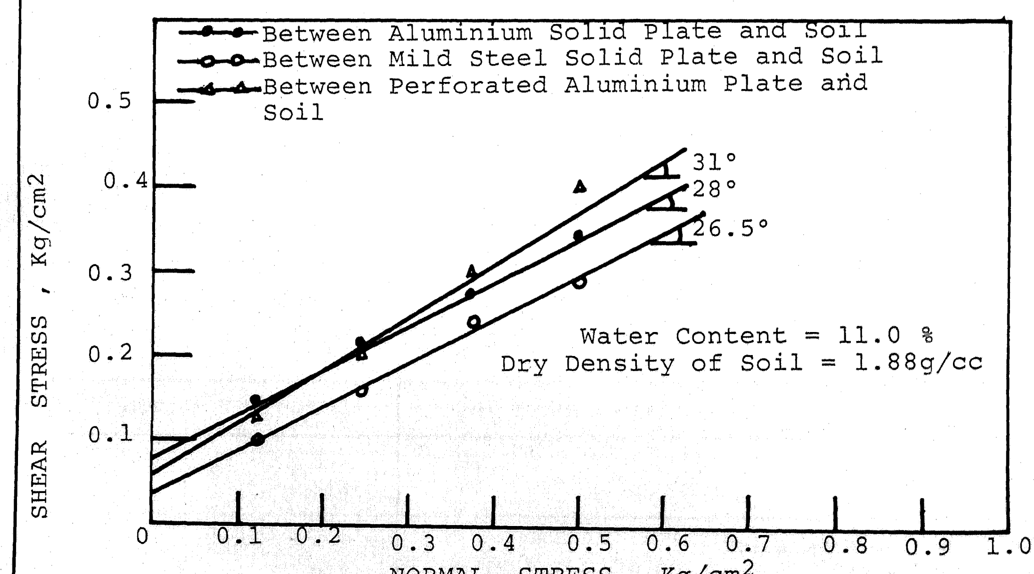

FIG.2.- Shear Strength Envelope from Direct Shear Tests.

TABLE 2.-Direct Shear and FEM Results for Cohesive Soil
Placement Moisture = 11.0 % , Placement Dry Density = 1.88 g/cc

	Direct Shear Test		From FEM Solution	
Parameters	C_a (Kg/cm^2)	ϕ^0	C_a (Kg/cm^2)	ϕ^0
Between mild steel solid plate and soil	0.03	26.5	0.03	26.0
Between aluminium solid plate and soil	0.08	28.0	0.08	27.0
Between perforated aluminium plate and soil	0.06	31.0	0.06	27.0

The typical stress - strain relations for the different samples analytically obtained using finite element technique with different friction factors (F) are given in Figs. 3 and 4. Resistance factors that fit the experimental curves are shown in Tables 1 and 2 along side for comparison.

CONCLUSIONS

The resistance factors that approximately fit with the experimental results are compatible with the factors experimentally determined from the direct shear test for the concerned reinforcement and soil placement conditions for triaxial loading conditions. The results indicate that the finite element method modelling can be advantageously used to analytically determine the stress - strain relation for reinforced soils with different configurations of reinforcements.

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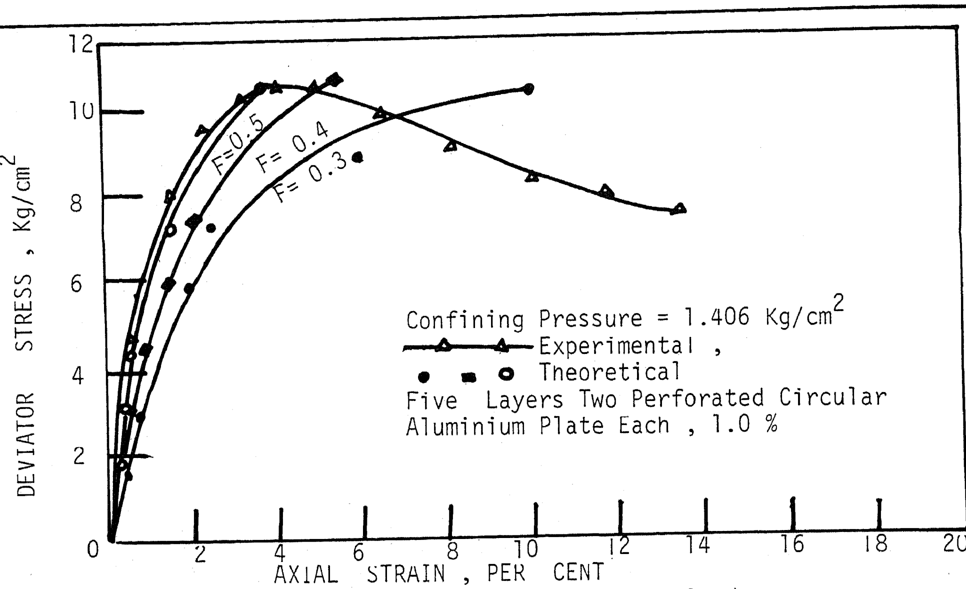

FIG.3.- Stress Strain Curves of Reinforced Ennore Sand

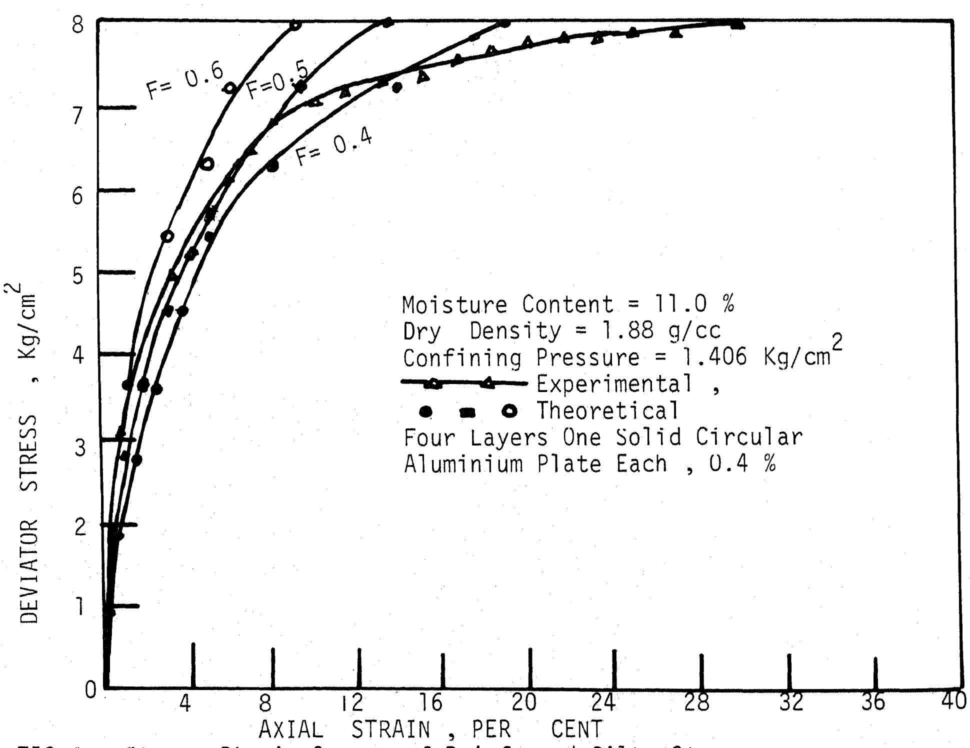

FIG.4.- Stress Strain Curves of Reinforced Silty Clay

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