Soil strengthening using randomly distributed mesh elements

Renforcement de sol par éléments de grillage distribués au hazard

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SYNOPSIS

The paper considers the influence of randomly distributed polymeric mesh elements on the strength of a granular soil. Their action is to interlock particles and groups of particles together to form a coherent matrix. 150mm diameter drained triaxial tests and small scale footing tests both show that the mesh elements improve the strength of the soil at all strain levels, even very small strains.

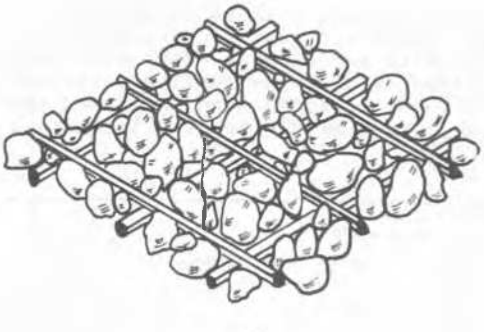
INTRODUCTION

Recently undertaken research into the use of randomly distributed polymeric mesh elements in soils, MERCER et al (1984), has shown that the meshes interlock with the soil particles and produce a strengthening at the meso-scale. As with soil strengthening by roots, WALDRON (1977), and by man-made fibres, ANDERSLAND AND KHATTAR (1979), HOARE (1979), LEFLAIVE (1982) and GRAY and OHASHI (1983), the ductility and permeability of the soil are not reduced and a relatively homogeneous composite is produced. The principal advantage of using mesh elements is their interlock action. This occurs at two levels with the ribs of individual mesh elements interlocking with groups of soil particles to form an aggregation of particles, Fig. 1(a), then adjacent aggregations interlocking to form a coherent matrix, Fig. 1(b). Numerous types of mesh elements are now being tested in a range of soil types and the practical problems of supplying and mixing them with different soils in various situations are being investigated. However, in order to demonstrate the operational mechanisms and levels of soil improvement to be gained from the use of these materials, this paper will only describe triaxial and model footing test data obtained using one mesh type mixed with one soil type.

MATERIALS TESTED

Soil: The soil used is a processed fluvio-glacial sand known as Mid-Ross sand. It has sub-angular particles ranging in size from 0.05 to 7.0mm diameter with a uniformity coefficient of 5.

Mesh Elements: The mesh is manufactured from polypropylene using the NETLON extrusion process. It has a mass per unit area of 52g/m^2, filament thicknesses of 0.5mm (M.D.) and 0.48mm (X.M.D.) and openings 6.7 x 7.1mm. The maximum tensile strength of the mesh when tested as 200 x 100mm specimens, at a constant rate of strain of 2 per cent per min. and temperature of 20°C was 3.5 kN/m (M.D.) and 3.8 kN/m (X.M.D.). For the tests reported in this paper, the mesh was cut into elements 50 x 50mm.


(a)

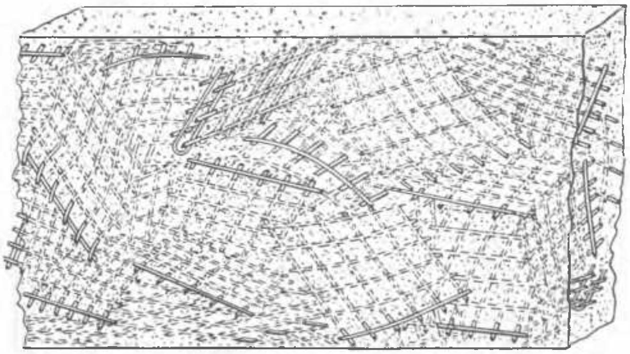

(b)

Fig. 1. THE INTERLOCK MECHANISM FOR MESH ELEMENTS
(a) Interlock with groups of particles
(b) Interlock of adjacent aggregations

TRIAXIAL TESTS

To determine the fundamental stress-strain behaviour of soil-mesh mixtures, drained triaxial tests 150mm diameter x 200mm high with lubricated ends, were carried out on Mid-Ross Sand alone and when it was mixed with various proportions of mesh elements. The sand with or without the mesh elements, was compacted and tested in a dry state. The type and level of compactive effort was equivalent to the standard Proctor compaction but was carried out in a specially prepared split mould. The achieved dry densities of sand and sand-mesh mixtures varied from 1800 to 1849 kg/m^3 the sand alone having an average of 1827 kg/m^3 and the sand-mesh mixtures having the same or a slightly greater average density. Cell pressures used ranged from 10 to 300 kN/m^2 and the tests were conducted at a constant rate of strain of 0.05 per cent per minute.

<u>Test Series A:</u> A large number of triaxial tests were conducted on the soil alone. The deviator stress-axial strain behaviour of the sand recorded in these tests was then used as the basis of comparison for the behaviour of the sand when mixed with various proportions of mesh elements.

<u>Test Series B:</u> These were conducted on sand with 0.18 per cent of mesh by dry weight of soil, which is 66 m^2 of mesh per m^3 of soil (66m^2/m^3). Figure 2 shows the relationship between deviator stress and axial strain for the sand with and without these mesh elements, when tested at different cell pressures. It clearly shows that the mesh increased the deviator stress developed at all strains, even at very small strains, and that peak stresses in the sand-mesh mixture occurred at slightly higher axial strains than for the sand alone. To illustrate these improvements Mohr failure envelopes for the sand with and without the mesh elements were constructed for peak stress conditions as shown in Fig. 3(a). Equivalent envelopes, based on mobilised stresses at 1.0 and 15.0 per cent axial strains were also produced, Fig. 3(b), to show the improved behaviour of the composite at low and high strain conditions. From these and similar envelopes at different constant axial strains, the increase in shear resistance ($\Delta\tau$) can be plotted against normal stress (σ) for both peak stress and constant axial strain conditions, as shown in Figs. 4(a) and (b) respectively. The peak stress condition does not fit exactly the pattern shown for constant axial strain conditions as it compares stresses developed at unequal axial strains.

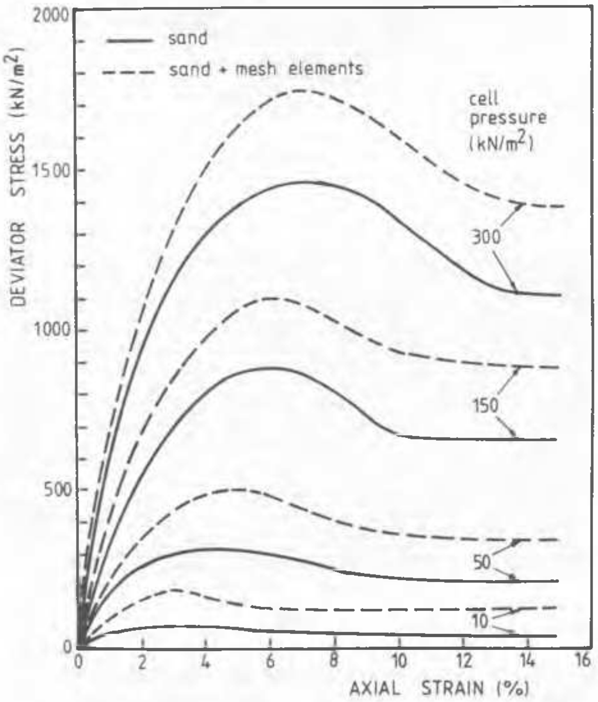


Fig. 2. RELATIONSHIPS BETWEEN DEVIATOR STRESS AND AXIAL STRAIN FROM DRAINED TRIAXIAL TESTS

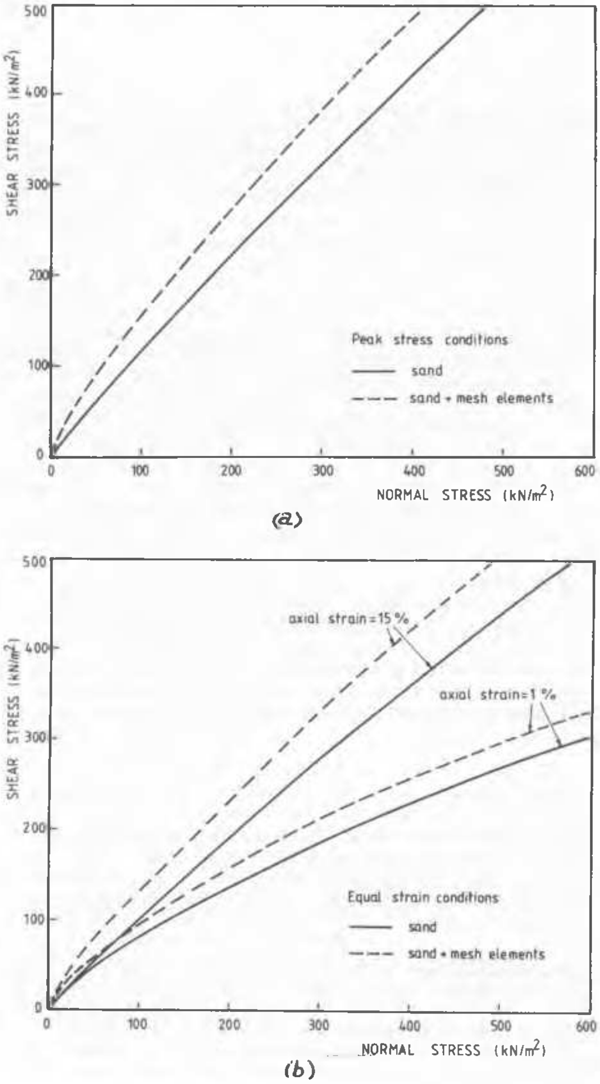


Fig. 3. MOHR ENVELOPES
(a) At peak stress conditions
(b) At 1 and 15% equal strain conditions

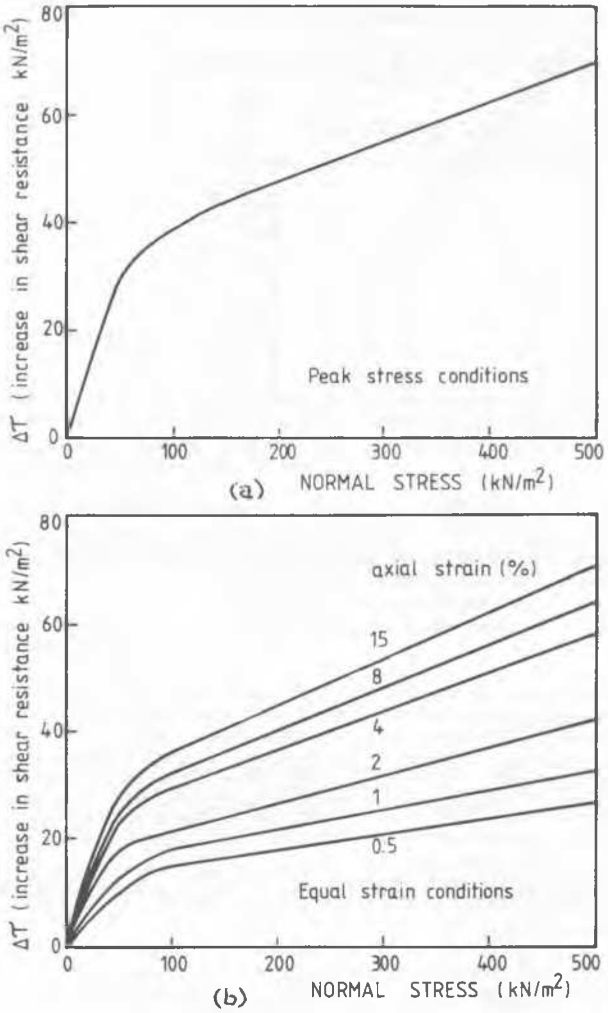


Fig. 4. INCREASE IN SHEAR RESISTANCE WITH NORMAL STRESS
(a) At peak stress conditions
(b) At equal strain conditions

The behaviours indicated by the data from Test Series A and B clearly demonstrate the ability of the mesh elements to generate tensile strain resistance from the beginning of the test. The tendency for the improvements to level-off at high axial strains is believed to be associated with the soil alone and soil-mesh composite both approaching their state of constant volume. Further drained triaxial tests on saturated samples in which volume changes can be measured to investigate this phenomenon are planned, but photographic records of the forms of soil alone and soil-mesh test specimens when both are at large strains, Figs. 5(a) and (b), illustrate the changes in overall deformation characteristics that the mesh content imposes on the sand as it is strained. Thus the sand with mesh elements has both different strength and deformation characteristics from the sand alone.

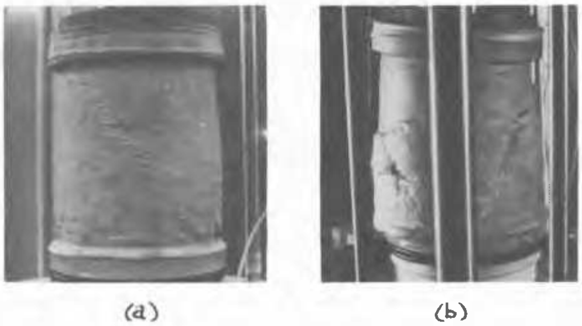


Fig. 5. THE DEFORMED TRIAXIAL SAMPLES AT LARGE STRAINS
(a) Sand alone
(b) Sand with mesh elements

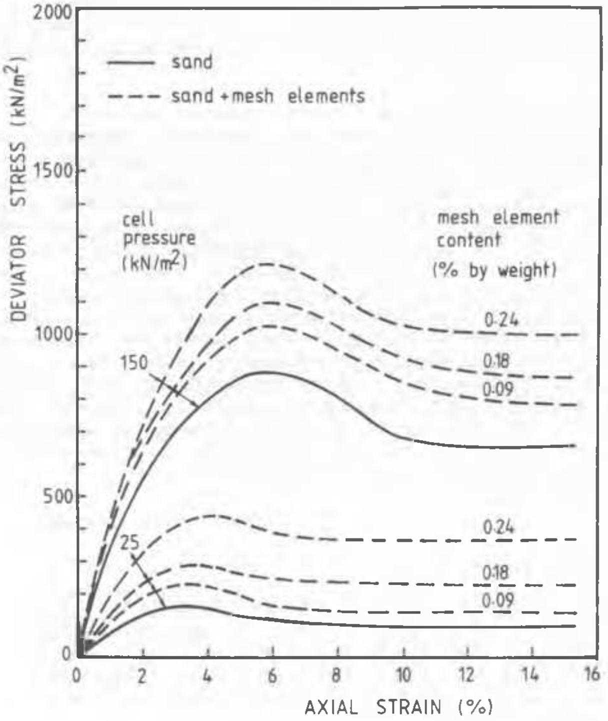


Fig. 6. RELATIONSHIPS BETWEEN DEVIATOR STRESS AND AXIAL STRAIN FOR DIFFERENT PROPORTIONS OF MESH ELEMENTS

<u>Test Series C:</u> As an indication of the influence of the proportion of mesh elements mixed with the sand, further tests were conducted using the same mesh elements as before, but in the proportions of 0.09, 0.18 and 0.24% by weight of soil which are 33,66 and 90 m^2/m^3 respectively. The data obtained for these three mesh proportions are shown in Fig. 6 for 25 and 150 kN/m^2 cell pressures. As indicated in this diagram the improvement in deviator stress is related to the proportion of mesh elements present. Obviously it will be important to determine the actual quantitative relationship between the proportion of mesh and improvement achieved, for the design of soil-mesh mixtures.

MODEL FOOTING TESTS

In order to ensure that the improvements measured in the triaxial tests could be measured in a simple soil-mesh system, model footing tests were undertaken. The test tank was glass-sided and 640mm long x 300mm deep x 75mm wide. It was filled with dry Mid-Ross Sand placed in a dense state. A smooth metal footing 75 x 75mm was pushed into the soil at a constant rate of penetration of 1mm/min. Tests were conducted on sand alone and on sand overlain by a layer of sand-mesh mixture with 0.18% ($66m^2/m^3$) of mesh elements, the depth of this layer varying in each test from 0.5 to 4.0 times the breadth of the footing. Each test was repeated at least twice and the data obtained are shown in Fig. 7(a). Once again very large improvements were obtained at all strain levels from the use of the mesh elements. These improvements are indeed very similar to those measured in the triaxial tests in terms of both strength and deformation characteristics and confirm that the improvements measured in the triaxial testing are not specific to that test.

When unloading the footing tests, a further significant difference was observed between the behaviour of the sand and the sand-mesh mixture, as indicated in Fig. 7(b). This shows that where a layer of the sand-mesh mixture was present, almost 20 per cent of the imposed vertical settlement was recovered, which was 4 times that for the soil alone. This was probably due to the partial recovery of the strains in the mesh elements and this improved system elasticity could well prove to be a very important property of soil-mesh mixtures, particularly where repeated loading is involved. For this reason, cyclic triaxial and plate bearing tests are now planned on soil-mesh layers to investigate their deformation characteristics under repeated loading conditions.

CONCLUSIONS

The use of randomly distributed polymeric mesh elements in Mid-Ross Sand has been shown to greatly improve its strength and beneficially alter its deformation properties. Triaxial tests using other soil types mixed with the mesh show that similar levels of improvement are obtained. The proportions of the mesh elements present in any mixture have also been shown to be important and tests using different types,sizes and shapes of mesh show that the tensile load-strain behaviour, flexural stiffness, rib shapes and sizes and opening sizes of the mesh are all important factors influencing the behaviour of the soil-mesh mixture.

ACKNOWLEDGEMENTS

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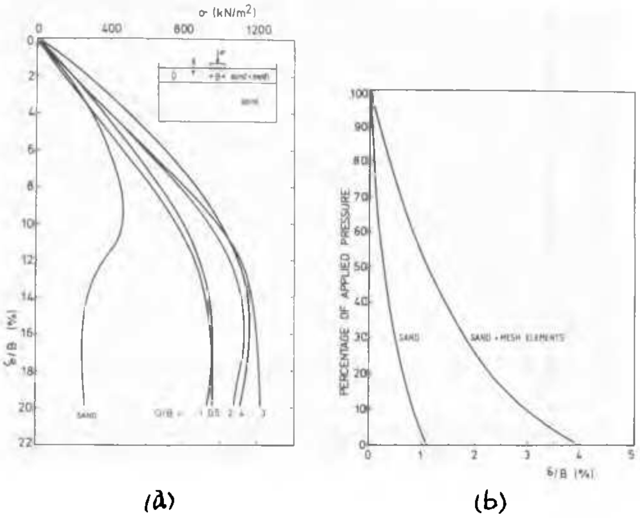

(a) (b)

Fig. 7. EFFECT OF DEPTH OF SAND/MESH LAYER ON THE LOAD SETTLEMENT BEHAVIOUR
(a) Load-settlement behaviour
(b) Recoverable settlements.

REFERENCES

Andersland, O.B. and Khattak, A.S., (1979). Shear Strength of Kaolinite/fibre soil mixtures. Int. Conf. on Soil Reinforcement: Reinforced Earth and Other Techniques. (1). 11 - 16. Paris.

Gray, D.H. and Ohashi, H. (1983). Mechanics of fibre reinforcement in sand. Jour. of Geot. Eng. ASCE. 109. 3. 335 - 353.

Hoare, D.J. (1979). Laboratory study of granular soils reinforced with randomly oriented discrete fibres - a laboratory study. Int. Conf. on Soil Reinforcement: Reinforced Earth and Other Techniques. 1. 47 - 52. Paris.

Leflaive, E. (1982). The reinforcement of granular materials with continuous fibres. Proc. 2nd Int. Conf. on Geotextiles. 3 721-726. Las Vegas.

Mercer, F.B. Andrawes, K.Z., McGown, A., and Hytiris, N. (1984) A new method of soil stabilisation. Proc. Sym. Polymer Grid Reinf. in Civil Eng. London. March. Paper 8.1. 7pp.

Waldron, L.J. (1977). The shear resistance of root-permeated homogenious and stratified soil. Jour. Soil Sci. Soc. Amer. 41.843 - 849.