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A re-assessment of the contribution of mesh elements to the load carrying capacity of soil-mesh element mixtures

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ABSTRACT: The results of a reassessment of the performance of soil-mesh mixtures are presented. It is suggested that when the mesh elements are subject to low level straining, as is the case in most of the current applications, they are strained biaxially. Thus it is their biaxial tensile stiffness that is of significance. From the test data on the mesh element materials it is shown, using the Isochronous Strain Energy Approach, that at low biaxial strain levels, the mesh elements have a predominantly elastic (recoverable) load-strain behaviour. This greatly influences the initial stiffness of the soil-mesh element mixture and particularly the proportion of the recoverable strains of the mixtures under low loading levels. These behavioural patterns are of particular importance to the performance of soil - mesh element - grass root zone systems, where it is vital to maintain a high degree of porosity in the system in order to allow good drainage. A more general conclusion is that the ability of the Isochronous Strain Energy Approach to separate out the contributions of the soil and the reinforcement in soil-geosynthetic reinforced systems is of considerable importance to the back analysis of the performance of all soil reinforcing systems.

1 INTRODUCTION

Mesh elements are used to reinforce soils in civil engineering roads, car parks, sports surfaces and in landscaping applications, Mercer et al (1984). The strain levels involved are relatively low under normal operational conditions, (usually less than 5 per cent strain). The soil-mesh element mixtures, (sometimes involving grass root zones), have proven to provide additional bearing capacity for the same strain level or reduced deformations under a specified loading. They also exhibit increased resilience over that of the soil alone, (i.e. the recovery of deformation on unloading is greater). In previous studies of soil-mesh element mixtures, the approach developed for their assessment, has been to test the soil alone, the soil-mesh element mixtures and for specific applications the soil-mesh element-grass root zone systems, McGown et al (1985) and Andrawes et al (1986). The benefits from the use of these systems have been assessed and quantified in terms of the improvement of specific performance parameters. The role of the mesh elements in achieving these improvements has been described only in qualitative terms.

Recently, a reassessment of the performance of soil-mesh element mixtures has been undertaken, Msukwa (2001). Tests have been conducted on the soils alone and on the mesh element materials in uniaxial and biaxial tensile loading modes and on soil–mesh element mixtures in triaxial tests. The data so obtained have been analysed and interpreted using the Isochronous Strain Energy [ISE] Approach. This has allowed the contribution of the mesh elements to the load-strain behaviour of the mixture, to be separated out from that of the soil in the soil-mesh element mixture and for the low strain levels in the mesh elements to be confirmed.

In this paper, details of the soil and mesh elements used in this reassessment are given. The test methods employed to assess the properties of the soil, mesh elements and the soil - mesh element mixtures are described. A brief description of the ISE Approach is presented, as it relates to soil - mesh element mixtures. The results of the testing programme are then assessed using the ISE Approach and the critical performance parameters for the mesh elements identified.

2 TEST MATERIALS

The mesh elements used were made from polypropylene and produced by the Netlon extrusion process. They have a mass per unit area of 42 g/m^2, mesh pitches of 10 by 10 mm and filament sizes of 0.6 by 0.4 mm. Each mesh element was 50 by 100 mm. They are designated as Netlon Advanced Turf (NAF) mesh elements.

The soil used was Leighton Buzzard sand. This consists mainly of rounded quartz particles with a uniform grading, (D_{10} = 0.62 mm, D_{30} = 0.715 mm and D_{60} = 0.85 mm). It has a specific gravity of 2.67 and a maximum dry density under BS 1377 (1990) standard compaction of 1632 kg/m$^{3.}$

3 TEST METHODS AND TESTING PROGRAMME

Uniaxial constant rate of strain (CRS) tests were carried out on 200 mm x 200 mm sheets of the material from which the mesh elements were produced. The test methodology was generally in accordance with BS 6906 (1987) with a test specimen size of 200 mm wide by 100 mm long held in specially designed friction clamps which prevented slippage during testing. The tests were carried out at 20 ± 2˚C at four strain rates, (7.62, 1.14, 0.102 and 0.012 percent per minute). Tests were conducted in both the machine and cross machine directions up to 20 percent strain.

In addition to the uniaxial tests, biaxial CRS tests were conducted in a specially developed biaxial testing machine. The test specimen sizes and shape are shown in Figure 1 and the test set up in Plate 1. It should be noted that the cross filaments outside the central zone were cut to avoid local distortions of the mesh near the clamps. The same rates of strain were applied in the machine and cross machine directions and the deformations of the material in each direction assessed using digital photogrammetry of the central section. The strain rates used were the same as in the uniaxial CRS testing but the maximum strain was limited to 5 percent.

For calibration purposes, uniaxial CRS tests were conducted in the biaxial apparatus. The results obtained showed no difference to the standard uniaxial CRS test data.

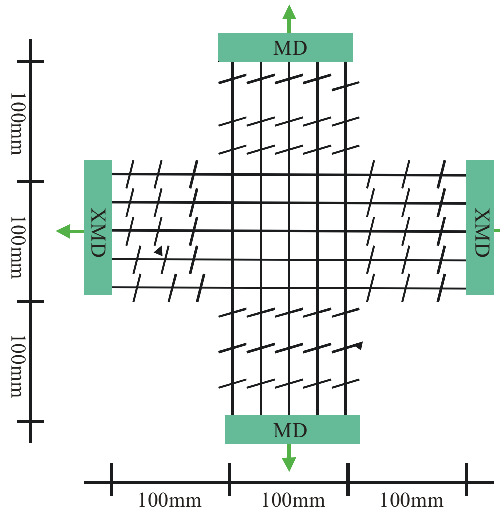

Figure 1 Specimen for biaxial testing

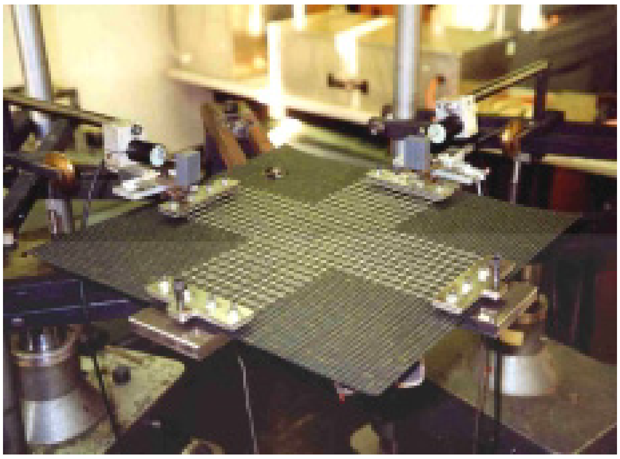

Plate 1 Biaxial test apparatus with clamped specimen

Uniaxial loading and unloading sustained load (creep) tests were conducted in both the uniaxial and biaxial test apparatus for a period of 10 hours in order to estimate the elastic, (Immediately Recoverable), and visco-plastic, (Locked-in), strain behaviour of the material.

Triaxial tests on the soil alone and on the various soil-mesh element mixtures were carried out with 155 mm diameter and 200 mm high samples. Lubricated end platens were used to minimise end friction. The samples were prepared in split mould formers with a thin rubber membrane stretched inside the mould. The soil and soil-mesh mixtures were all prepared dry and compacted into the moulds using BS 1377 (1990) light compaction. Instead of an externally applied cell pressure, an internal vacuum of 50 kN/m^2 was applied as the all-round stress. The deviator stress was applied vertically. Four vertical strain rates were used, (2, 0.5, 0.05 and 0.005 percent per min.) Three soil-mesh mixtures were tested, (0.09, 0.18 and 0.27 percent mesh elements by weight of dry soil).

4 TEST RESULTS

4.1 *Mesh Element Material*

The test data obtained from the CRS tests (at 7.62, 1.14, 0.102 and 0.012%/min) conducted uniaxially, (in the machine direction and in the cross-machine direction), and biaxially, are shown in Figure 2, for strains up to 5 percent. Clearly over the strain rang presented, the biaxial data indicates much higher stiffnesses tha the uniaxial data.

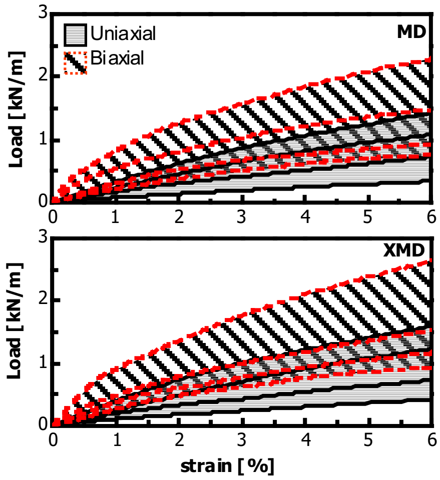

Figure 2 Load-strain curves from uniaxial and biaxial CRS loading

Biaxial creep test data, using the same loading and unloadin levels in the machine and cross-machine directions, are shown i Figure 3. These clearly indicate the high degree of recoverabl strains for maximum strain levels up to 5 percent.

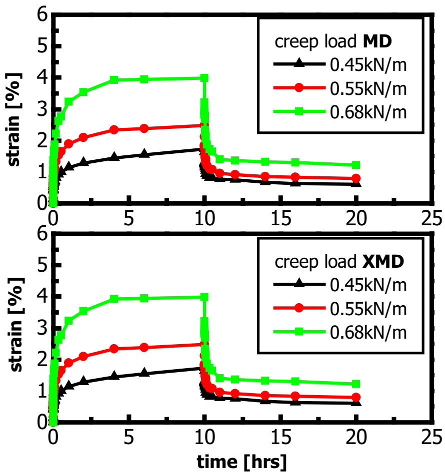

Figure 3 Biaxial creep test data

4.2 *Soil Alone*

The test data obtained from the triaxial tests at the four strai rates used on the Leighton Buzzard sand and the three soil mes mixtures (0.09, 0.18 and 0.27 percent by weight of dry soil), ar shown in Fig. 4.

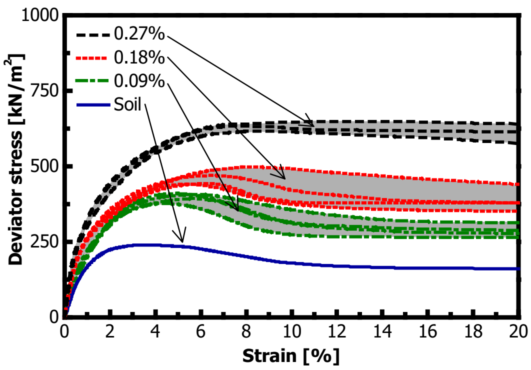

Figure 4 Triaxial tests for Leighton Buzzard with mesh elements

5 ISOCHRONOUS STRAIN ENERGY APPROACH

For single-stage loading under isothermal conditions, the external work done per unit width of a geosynthetic at any time (t) may be taken to be equal to the "Absorbed Strain Energy". All single-stage loading test data can be represented by Isochronous Load-Strain curves. The areas under the curves represent for any specific time, (t), the "Absorbed Isochronous Strain Energy", McGown (2000).

The unit of Isochronous Strain Energy [ISE] for geosynthetics is:

Force per unit width times unit strain

$$= (\text{kN/m}) \times \text{m/m}) = \text{kNm/m}^2 = \text{kJ/m}^2 \quad (1)$$

Thus at any temperature (T) and time (t) after the application of a particular loading regime, there will be a finite amount of work done per unit width, which can be represented as the "Absorbed ISE", $[A]_t$. The amount of ISE to develop a limiting strain or rupture at that temperature for a particular Single-stage Loading regime is termed the "ISE Capacity" $[C]_t$ of the geosynthetic at the specified time (t).

From loading and unloading tests it can be shown that at any time (t), there are two components of ISE. One component is "Immediately Recoverable" ISE on unloading, whilst the other is "Locked-in" ISE at that time (t). Some of the Locked-in ISE is later recoverable, however, some is "Irrecoverable Locked-in" ISE. But at any time (t), the Absorbed ISE may be represented as comprising two components, which are the Immediately Recoverable ISE $[R]_t$ and the Locked-in ISE $[L]_t$, These two components vary with time for any limiting strain condition or rupture.

6 ANALYSIS OF THE TEST RESULTS USING THE ISE APPROACH

The ISE Approach was used to interpret the test obtained from the mesh element material in-isolation, the soil alone and the soil-mesh element mixtures. In each case, the CRS test data obtained at different rates of strain were replotted as Isochronous Load-Strain curves. From these, the Isochronous Strain Energy at different strain levels and times were determined from the areas under the appropriate curves. The Recoverable and Locked-in ISE components were then identified using the loading/unloading creep test data in the manner previously described by McGown (2000).

To derive the ISE contribution of the mesh elements within the soil-mesh element mixture, the ISE contribution of the soil alone was subtracted from the Absorbed ISE of the soil-mesh element mixture assuming that there is strain compatibility between the soil and the mesh elements. An important aspect of this calculation is that the Absorbed ISE of the soil alone and soil-mesh element mixtures in the triaxial test, at any limiting strain, relates to a unit volume and not a unit width, as for geosynthetics. However, knowing the area of geosynthetic per unit volume of the soil-mesh element mixture, a simple conversion may be made. Further since strain energy is a scalar quantity not a vector quantity, the change from compression to tensile strain energy may be made.

6.1 *Mesh Element Material*

The calculated ISE Capacities for different strain levels and times for the mesh material are shown for uniaxial and biaxial test conditions in Figures 5 and 6 respectively. It is to be noted that for uniaxial conditions, the ISE Capacities are very similar in the machine and cross-machine directions. The two ISE Capacities from the biaxial test data are again similar, however, they are greater in magnitude than the uniaxial data. Given that the mesh elements are subject to biaxial stressing in the soil it is these data that are relevant. Also it is the numerical sum of the biaxial ISE that is relevant, (note again that ISE is a scalar not a vector quantity).

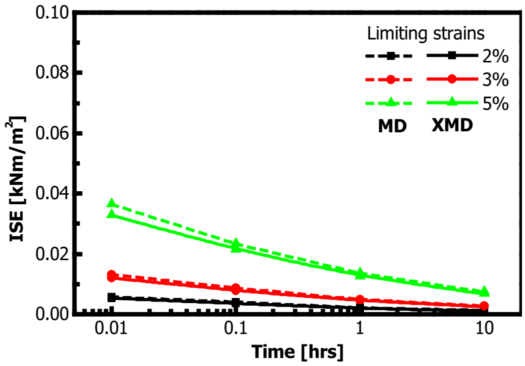

Figure 5 ISE-Time relationships under CRS (uniaxial)

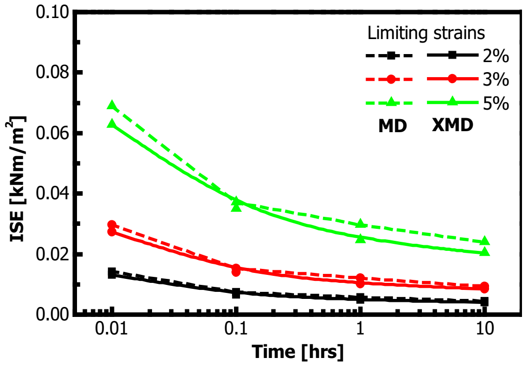

Figure 6 ISE-Time relationships under CRS (biaxial)

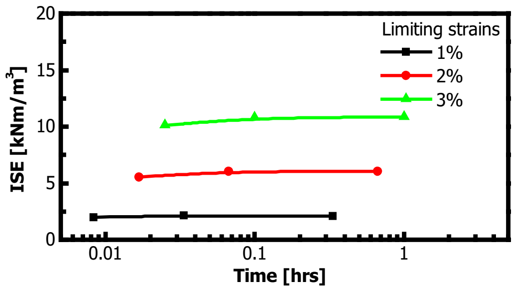

Figure 7(a) ISE-Time for soil + mesh elements per unit volume

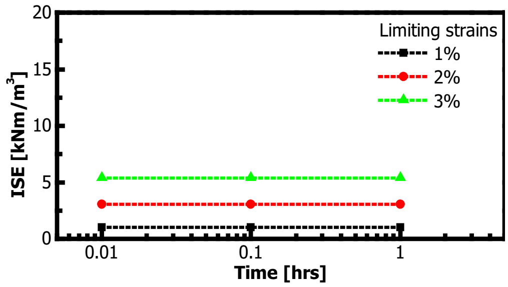

Figure 7(b) ISE-Time for soil alone per unit volume

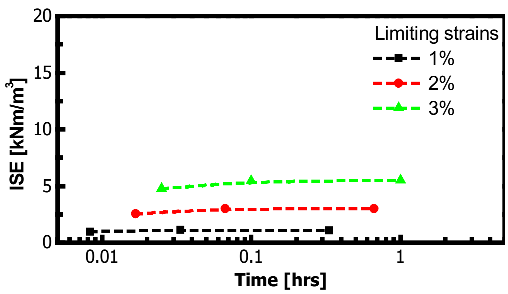

Figure 7(c) ISE-Time mesh elements alone per unit volume

6.2 *Soil Alone and Soil-Mesh Element Mixtures*

The calculated values of the Absorbed ISE for different strain levels and times of the soil alone and soil-mesh element mixture (0.27% mesh elements by dry weight of soil) are given in Figure 7. Similar plots were constructed for each mesh element content tested and in each case, the contribution of the mesh elements assessed, Figure 7(c) as the difference between the data in Figures 7(a) and 7(b). Knowing the areas of mesh elements in the unit volume for each mesh element content, the units of the ISE could be converted from kNm/m^3 to kNm/m^2, Figure 8.

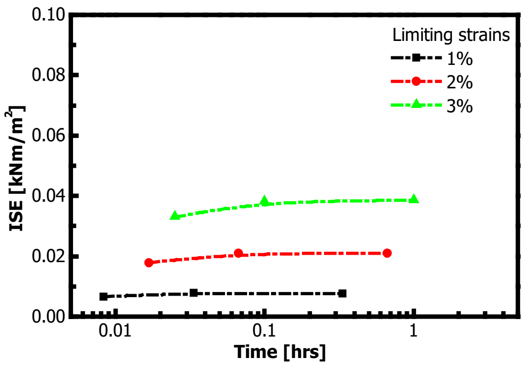

Figure 8 ISE-time mesh elements alone per unit area

6.3 *Absorbed ISE by the Mesh Elements*

The ISE data for the mesh elements obtained from the in-isolation biaxial test data and the mesh elements ISE from the triaxial test data, may be combined as shown in Figure 9. Where these data intersect, identifies the strain levels in the mesh elements with time. The data for all the mesh element contents confirm that, (using the in-isolation biaxial test data), the mesh element strain levels are consistent with the assumption of strain compatibility. At such low strain levels, the high proportion of the ISE that is Immediately Recoverable on unloading, indicates that the soil-mesh element mix is likely to have a high proportion of recoverable strains. This confirms field observations.

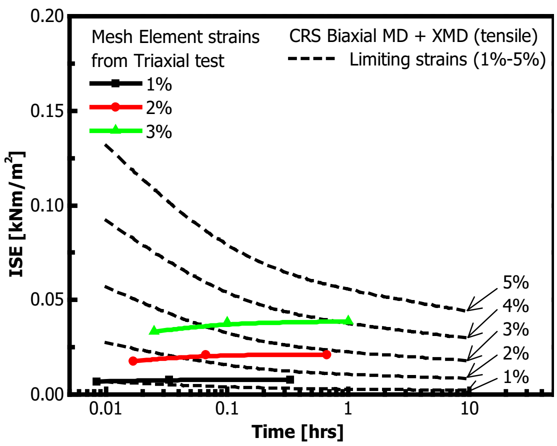

Figure 9 ISE comparison (triaxial compression and biaxial tensile testing)

7 DISCUSSION AND CONCLUSIONS

It is suggested that when mesh elements are subject to low level straining, as is the case in most of the current applications, they are strained biaxially. In-isolation CRS testing shows that under biaxial loading conditions the mesh elements absorb more energy at low strain levels than in uniaxial loading conditions, i.e., they are much stiffer. Also a high proportion of this Absorbed Energy is Immediately Recoverable, i.e., elastic. These factors will influence the initial stiffness and the proportions of recoverable strains in soil-mesh element mixtures.

Analysis of triaxial test data using the ISE Approach combined with the ISE data from in-isolation testing of mesh element, materials confirms that under biaxial loading conditions the strain levels in the mesh elements are indeed low and in line with these to be expected assuming strain compatibility between the soil and the mesh elements.

In general terms, the ability of the ISE Approach to separate out the contributions with time of the soil and the reinforcement in soil-geosynthetic reinforced systems, has considerable potential for the back-analysis of the performance of such systems.

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