Deformation Characteristics of Geosynthetic-Reinforced Soil

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ABSTRACT: The results of laboratory tests performed on specimens of reinforced sands using a unit cell device are presented. The reinforced specimens, representative of unit elements within a geosynthetic-reinforced structure, were subjected to deformation under plane strain loading conditions. Four woven and two nonwoven geotextiles and a steel sheet were used to reinforce two different sands. Reinforcing was placed horizontally at midheight in the soil specimen 100 mm (length) by 200 mm (width) by 200 mm (height). Flexible membranes were used to apply uniform lateral confining pressure and load to the top and bottom of the specimen, and the load induced in the reinforcing, principal stresses, and specimen displacements were measured. The response of the various soil-reinforcing combinations are described. It was found that the increased load supporting capacity of the composite resulted from an increase in effective confining pressure in the soil due to stresses which developed in the reinforcing.

1 INTRODUCTION

Because the behavior of cohesionless soils can be significantly modified by the introduction of tensile reinforcement, hundreds of geosynthetic reinforced soil (GRS) retaining walls and slopes have been successfully constructed. Virtually all of these structures were designed using limit state methods. Although these methods are sufficient to avoid failure, they are not able to predict deformations under working stress conditions. This paper presents results from a research program undertaken to improve our understanding of the properties of the reinforcement, the soil and the GRS composite at working stress levels.

2 UNIT CELL TEST APPARATUS

A plane strain unit cell device (UCD) has been developed at the University of Washington in order to investigate GRS at small (working) strains, Fig. 1. This device differs from previous unit cell devices, e.g., McGown et al. (1978) and Ling (1992), in two fundamental ways. First, in our UCD device, tension developed in the reinforcing can be measured directly because it is clamped at each end of the specimen. Secondly, stiff end plates, to which the clamps are mechanically linked, ensure that the reinforcing and soil displace equally in the lateral direction during loading and that the faces of the specimen remain orthogonal.

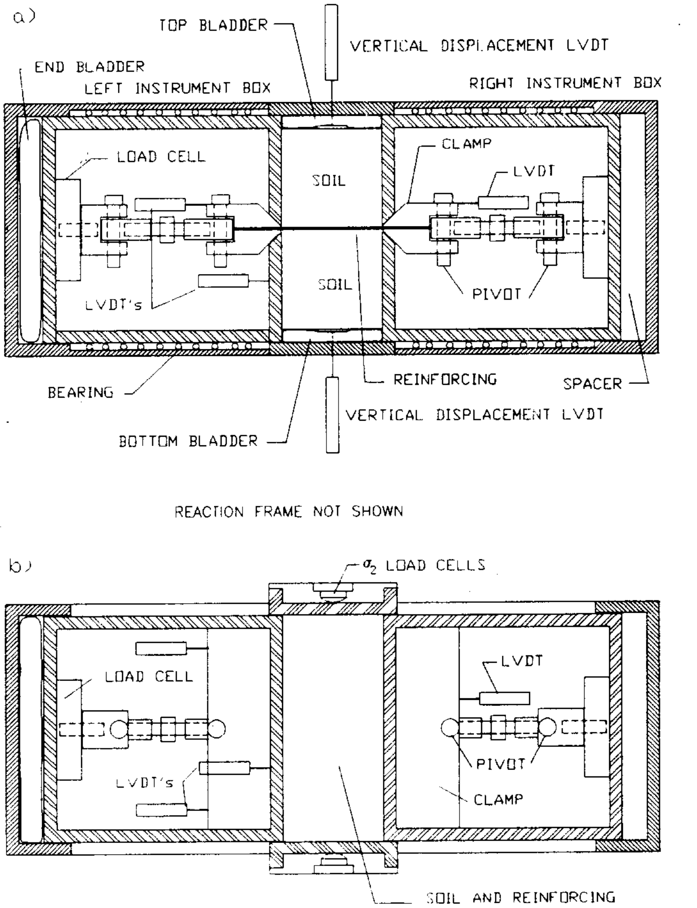

Fig. 1 Schematic of unit cell device: a) profile and b) plan view sections.

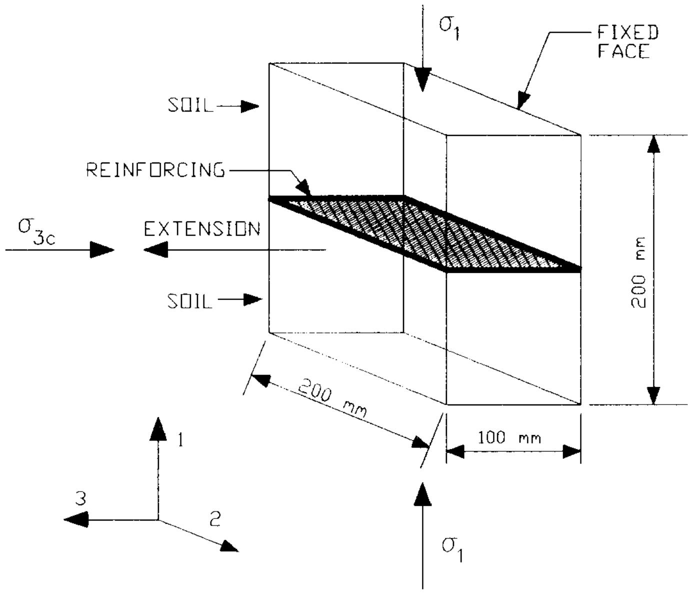

Fig. 2 Unit cell specimen dimensions and operation principle.

A schematic diagram of the UCD and its principle of operation are illustrated in Figs. 1 and 2. Pressure is applied to the top and bottom of the reinforced soil via flexible latex bladders. The left instrument box is free to displace horizontally when applied vertical pressure causes lateral expansion of the specimen. Horizontal displacement of the soil is resisted by an applied lateral confining pressure and by loads induced in the reinforcing. Constant lateral confining pressure is maintained by increasing the pressure in the end bladder to compensate for vertical strains of the soil specimen and for changes in pressure in the top and bottom bladders. Load cells, positioned behind the plates which maintain plane strain conditions, record intermediate principal stresses. The rigid vertical faces of the device force the specimen faces to remain mutually perpendicular. To minimize boundary friction, the interior of the UCD is lubricated with silicone grease and lined with a 0.3 mm latex membrane prior to placement of the specimen.

3 TESTING PROGRAM

Two sands, four woven and two nonwoven geotextiles, and a steel sheet were used in this study. The properties of the reinforcing materials and soils are presented in Tables 1 and 2. Tests were conducted on reinforced and unreinforced samples of each of the soils at confining pressures between 12.5 and 100 kPa. All tests were performed with soils 1 and 2 at relative densities of 96% and 101%, respectively.

Typical test results are presented in Figs. 3 through 5.

Table 1 Reinforcing material, type and ASTM D 4595 wide width test results.

Reinforcing No.	Material and Type[1]	Wide Width Data Strength (kN/m)	Elongation (%)
1	PP-W	31	21
2	PP-W	62	16
3	PP-W	92	17
4	PET-W	186	18
5	PP-NP	16	95
6	PP-NP	26	95
7[2]	ST-SH	11	0.6

[1] PP = polypropylene, PET = polyester, W = woven, NP = needle-punched nonwoven, ST-SH = steel sheet.

[2] Yield strength and yield strain.

Table 2 Soil properties.

Soil	D_{60}	C_u	C_c	ϕ_{ps}*
1	0.28 mm	1.6	1.0	42
2	0.61 mm	4.1	1.0	55

*Plane strain angle of internal friction.

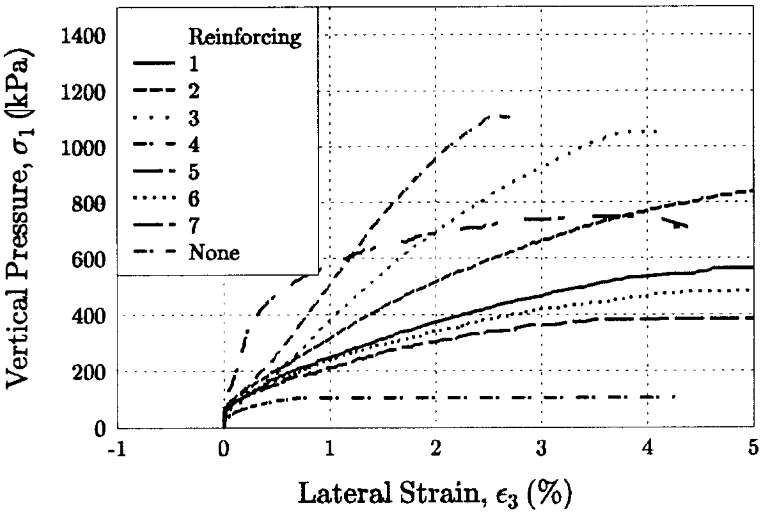

Fig. 3 Applied pressure, σ_1, versus lateral strain, ε_3, for soil 2 with various reinforcements, σ_{3c} = 12.5 kPa.

4 DISCUSSION

Fig. 3 illustrates that the reinforced soil behaves as postulated by McGown et al. (1978), Fig. 6. The reasons for this are clearly illustrated in Fig 4. Reinforcing of higher modulus develops greater tension for each lateral strain increment, permitting the composite to support a greater load. Because our UCD is load controlled, as opposed to the strain controlled devices used by McGown et al. (1978) and Ling (1992), post peak behavior of the composite when reinforced with weaker geosynthetics could not be obtained.

As had been observed by, e.g., McGown et al., (1982), the strength of nonwoven geotextiles was significantly

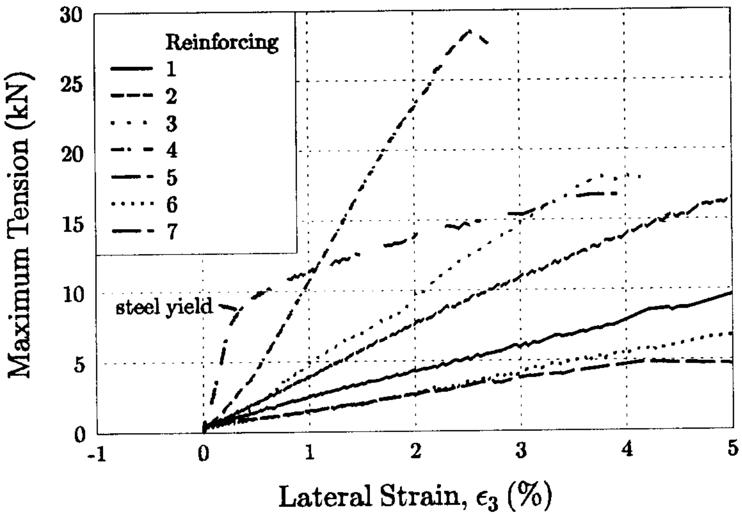

Fig 4 Maximum tension recorded versus lateral strain, ε_3, for soil 2 with various reinforcements, $\sigma_{3c} = 12.5$ kPa.

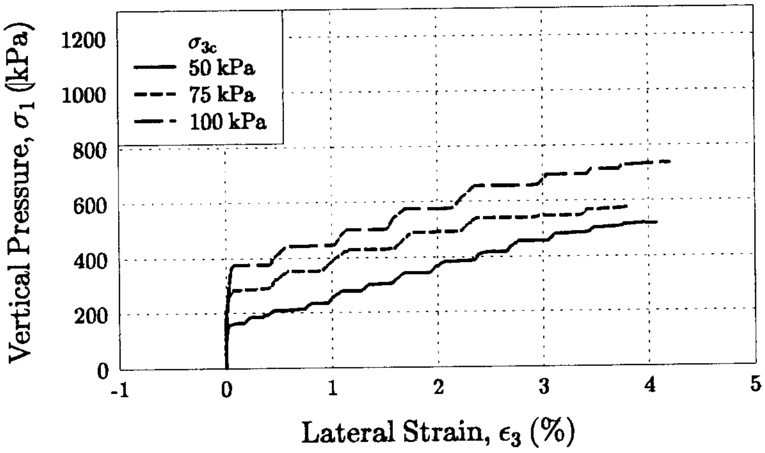

Fig. 5 Applied pressure, σ_1, versus lateral strain, ε_3, for soil 1 with reinforcement 2 at various σ_{3c}.

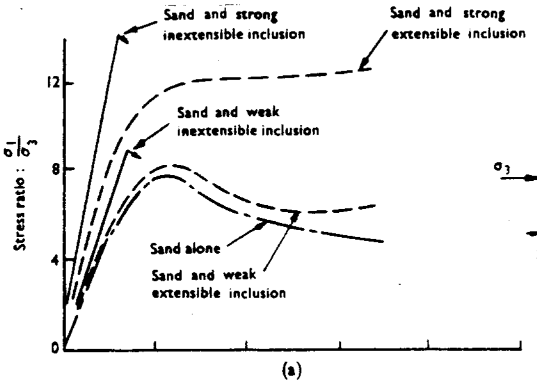

Fig. 6 Postulated behavior of reinforced and unreinforced dense sand (after McGown et al., 1978).

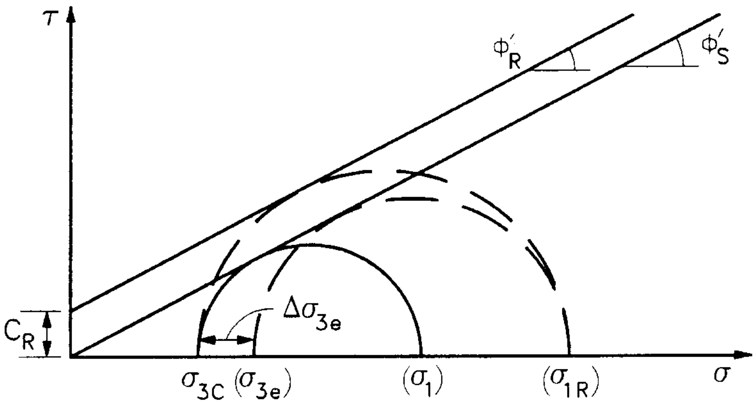

Fig. 7 Increased confining pressure concept (after Yang and Singh, 1974).

increased when confined in soil. For example, the pressure versus lateral strain curve for soil 2 reinforced with geotextiles 1 and 6 are very similar despite significant differences in their wide width stress-strain properties, Table 1.

The lateral deformation of the reinforced soil was also found to be closely related to the initial lateral pressure applied to the soil, Fig. 5. The slope of the stress-strain curve for the composite was essentially the same for all lateral pressures but the total load supported by the composite, at any given lateral strain, was dependent upon the initial lateral pressure. This observation could be very useful in predicting construction induced deformations of GRS structures.

Two hypotheses have been proposed to explain the mechanism by which reinforcing improves the load supporting capability of soil: (1) the reinforcing provides an apparent cohesion to the soil (Schlosser and Long, 1972), or (2) the reinforcing provides resistance to lateral expansion which increases the effective confining pressure experienced by the soil (Yang and Singh, 1974), Fig. 7. The resulting strength of the composite is the same for both interpretations, although neither hypothesis could be verified because tests were performed in a cylindrical triaxial apparatus.

Our UCD tests have verified the Yang and Singh hypothesis. Since, for any test in the UCD, the end area of the specimen was known and the load in the reinforcing was measured, the effective confining stress, σ_{3e}, could be computed using Eq. 1.

$$\sigma_{3e} = \sigma_3 + \frac{tension}{B * H} \tag{1}$$

For comparison between tests an effective stress ratio experienced by the soil could be obtained by dividing the vertical pressure, σ_1, by σ_{3e}. The results for various soils, reinforcing and initial lateral stresses are presented in Fig. 8. Note the stress ratio is nearly constant for each soil, regardless of the initial applied lateral confining pressure or reinforcing utilized. This validates the effective confining stress principle.

Soil mobilization was also found to affect the response of the composite. After 2 to 3% lateral strain, the slope of the composite stress-strain curve tended to decrease. This decrease can be attributed to the drop in the

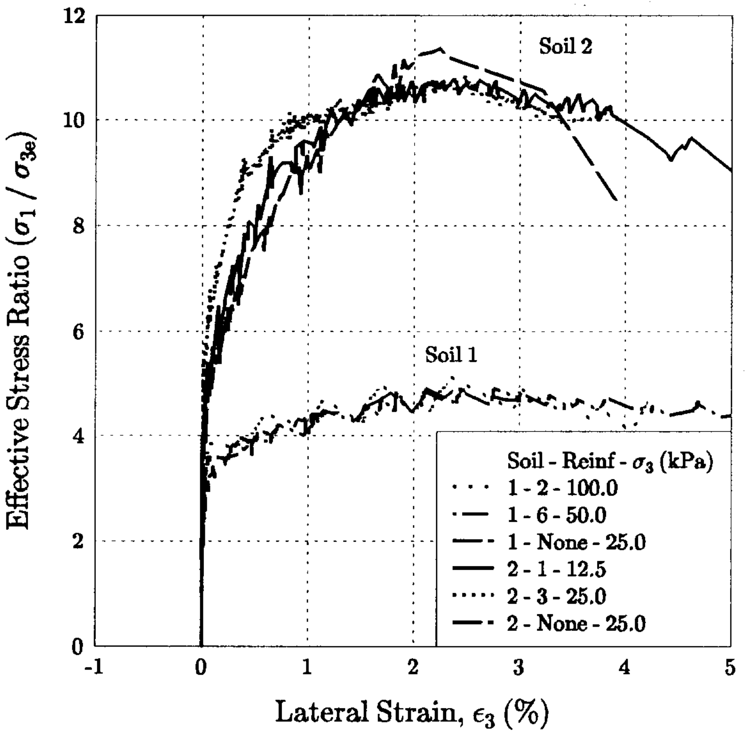

Fig. 8 Effective stress ratio, σ_1/σ_{3e}, versus lateral strain, ε_3, for various soils, reinforcing and σ_{3c} combinations.

effective stress ratio of the soil, after reaching a maximum between 2 and 3% strain, Fig. 8.

5 SUMMARY AND CONCLUSIONS

The Unit Cell Device is capable of measuring the composite strength properties of reinforced soil as well as the properties of the reinforcing and soil separately. Clamping each end of the reinforcing permitted direct measurement of the reinforcement loads. The clamps also ensured equal lateral displacements of the soil and reinforcing; thus the integrity of the unit cell was maintained.

The deformation characteristics of GRS samples were observed to be dependent upon the particular soil and reinforcing as well as the initial lateral confining pressure. The influence of soil mobility on the deformation of the composite was found to be related to a decrease in the effective stress ratio of the soil after reaching a maximum between 2 and 3% lateral strain. The load-deformation properties of nonwoven geotextiles were observed to improve when confined during testing.

This research has confirmed the Yang and Singh (1974) hypothesis that in GRS systems, the reinforcing increases the effective lateral confining pressure experienced by the soil, thereby increasing the load carrying capacity of the soil.

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