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# Soil-reinforcement interaction determined by extension test

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ABSTRACT: This paper describes the use of a new technique to determine the soil-reinforcement interaction. The testing apparatus is essentially a triaxial cell fitted with the capability to house a hollow cylindrical sample. A hollow cylindrical sand specimen with a concentric layer of reinforcing material sandwiched in the middle is used in this investigation. The reinforcement is fastened at the base. The hollow specimen can be viewed as a "unit sheet" of a soil-reinforcement composite system of infinite horizontal extent. Axial load as well as inner and outer chamber pressures can be applied to perform a test. The specimen is first subjected to an isotropic stress state corresponding to the overburden pressure. Next, an extension test by reducing the axial load is carried out. Since the reinforcement is fastened at its lower end to the base, any tendency of relative movement between the reinforcement and the sand during an extension test can induce tensile force in the reinforcement thus forming a "reversed pull-out" test condition. Preliminary test results have demonstrated positively the feasibility of the new approach to study the soil-reinforcement interaction.

## 1 INTRODUCTION

It was almost a decade ago that the late Professor Kenneth Lee (1978) in his state-of-the-art report to the first soil-reinforcement conference held in Pittsburg said that one of the most important and yet least known parameters in working with reinforced soil is the bonding capacity describing the soil-reinforcement interface behavior. In the ensuing years much has been done in the laboratory and field to identify factors, such as dilation, compaction, grain size, type and rigidity of reinforcement, overburden, etc., affecting the mobilization of interface resistance in reinforced soil. However, the overall picture of the interface behavior is still unclear as ever due to the lack of a testing device that is capable to quantify the various factors influencing the mobilization of interface resistance.

Quantitative evaluation of soil-reinforcement interactive behavior in the laboratory is normally done by determining the soil-reinforcement bonding capacity using either the direct shear test or the pull-out test. The direct shear test measures the resistance to sliding of a soil over a planar surface of the reinforcing material. The quantitative measure of resistance is a friction coefficient obtained as the ratio of the peak shear stress to the normal stress. The direct shear test is considered to accurately determine the friction coefficient because the normal force and shear force are both measured quantities.

However, the loading conditions are not felt to adequately describe the in situ soil-reinforcement interaction. In the pull-out test, the reinforcement is embedded in a soil-filled box and the force and displacement are measured as the reinforcement is "pulled-out" of the box. The force required to initiate slippage of the reinforcement is known but, depending on the geometry of the various elements and the loading and boundary conditions of a test, the normal pressure on the reinforcement may not be known with much certainty (Johnston, 1985). The test, however, rather closely simulate the slippage failure that may occur in the field in that the axial force in the reinforcement varies from zero at the free end to a maximum at the face of the box.

Nonetheless, the complex boundary conditions and bulkiness of the apparatus limit the effective usage of the pull-out testing device. In view of the current laboratory testing capability, it is obvious that significant improvement in laboratory determination of soil-reinforcing element interactive behavior is much desired.

## 2 THE TESTING APPARATUS

It can be summarized that a desirable testing apparatus to study the soil-reinforcement interaction behavior should have the following capabilities:

a. Ability to test reinforced soil specimens to determine the interactive bonding capacity of a soil-reinforcement system.

b. The apparatus should properly simulate in situ loading conditions with minimum boundary effects.

c. It should be able to perform accurate tests under short and long loading conditions.

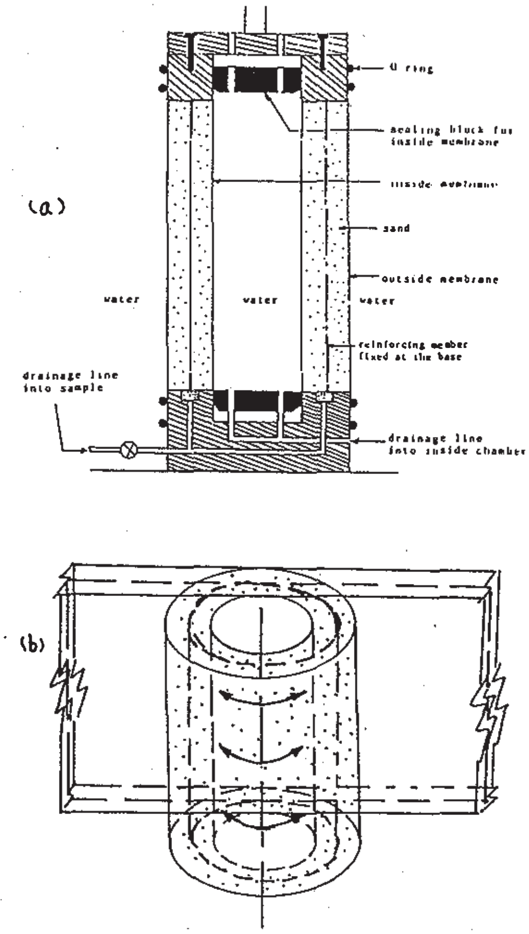


Fig. 1 A schematic diagram of a testing apparatus and a hollow cylindrical sample

A device that can satisfy the above is the triaxial testing apparatus with a hollow cylindrical sample (Kim, 1987). A schematic diagram of the apparatus and a sample is shown in Figure 1a. Briefly, a hollow cylindrical sand specimen with a concentric layer of reinforcing material sandwiched in the middle is formed. The reinforcement is fastened at the base. The hollow specimen can be viewed as a "unit sheet" of a soil-reinforcement composite system of infinite horizontal extent as shown in Figure 1b. To perform a test, the specimen is first subjected to an isotropic stress state corresponding to the overburden pressure. Next, an extension test (by reducing the axial load) is carried out and the load reduction vs. axial displacement readings recorded. The specimen is loaded in extension to failure by either the breakage of reinforcing material (tensile failure) or slippage which takes place at the soil-reinforcing element interface (i.e. the overcoming of the bonding capacity). In both cases necking, as a result of shear failure in the sand, occurs. The gradual reduction of axial load causes the specimen to elongate in the axial direction. Since the reinforcement is fastened at its lower end to the base, any tendency of relative movement between the reinforcing element and the sand can induce tensile force in the reinforcement thus forming a "reversed pull-out" test condition. This setup simulates closely the loading conditions existing at the soil-reinforcing element interface in reinforced soil structures.

The interactive behavior of a soil-reinforcement system is normally characterized by a Coulomb-type friction parameter, the apparent coefficient of friction, f. If the tensile capacity of the reinforcement is greater than the bonding capacity of the soil-reinforcement system, the reduction in axial load will lead to a "pull-out" failure; e.g. slippage between the soil and the reinforcement. This phenomenon can be detected by the presence of "necking" in the sand near the top of the specimen. The failure load is measured and the Coulomb-type friction parameter can be determined if the slipped length at the interface can be defined.

The apparatus described above satisfies most of the pertinent requirements needed for the study of interactive behavior of the various soil-reinforcement systems under a wide range of loading conditions anticipated in the field. The use of a hollow cylindrical specimen takes away most of the edge effects associated with conventional pull-out test. The wall friction is completely eliminated because no such boundary exists in a hollow circular specimen. As a result the overburden pressure is applied evenly over the entire specimen. Furthermore, the end restraints at the base and top of a hollow specimen is far less severe than the constraints experienced in pulling the soil against the front panel of the pull-out box.

As stated earlier, an accurate measure of the length over which slippage takes place and the corresponding axial load are essential in determining the apparent coefficient of friction for the "pull-out" mode of failure. In an extension test with the reinforcement fixed at the base, the length over which slippage takes place is difficult to determine. If slippage occurs along the full length of the reinforcement and if the end constraint effect is ignored, referring to Figure 2, the horizontal force $\Delta P$ acting on the reinforcement prior to slippage can be calculated as

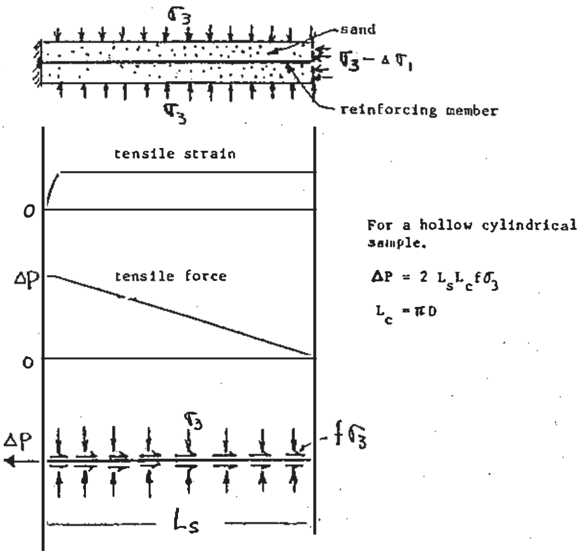


Fig. 2 Stress and strain developed along a reinforcing element

$$\Delta P = 2L_sL_cf\sigma_3 \qquad (1)$$

Where $L_s$ is the slipped length, $L_c$ is the circumferential dimension of the reinforcing element and $\sigma_3$ is the overburden pressure. Thus the apparent coefficient of friction,

$$f = \frac{\Delta P}{L_s}\left(\frac{1}{2L_c\sigma_3}\right) \qquad (2)$$

For a given test, $1/2L_c\sigma_3$ = constant = m, Eq. 2 can be written as

$$f/m = \Delta P/L_s \qquad (3)$$

If slippage does not take place along the full length of the reinforcement, then the tensile strain and the tensile force distributions along the reinforcement may not be approximated as in Figure 2. On the other hand, it is understood that shorter reinforcements (shorter specimens) are more prone to have slippage failure along the full length of the reinforcement. The exact length of slippage for a given sample, nevertheless, is unknown. To circumvent this it is proposed that a number of identical samples of different heights be tested under identical loading conditions. The apparent coefficient of friction is then calculated according to eq. 3 for each sample assuming that $L_s$ is the height of the sample (the total length of reinforcement). By plotting the corresponding $\Delta P$ vs. $L_s$ values as shown in Figure 3, one can establish a line OA to define the f/m ratio for the soil-reinforcement system tested. This approach is based upon the assumption that when friction is mobilized fully along the length of the reinforcement, the tensile force in the reinforcement is proportionate to its length. Furthermore, it is assumed that the fixation of the reinforcement at the base does not significantly affect the distribution of tensile force.

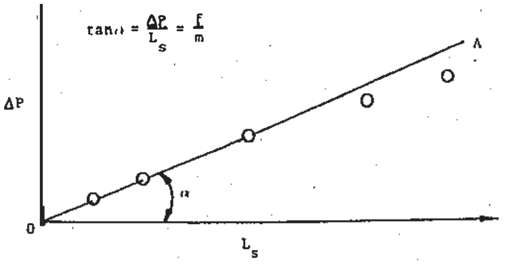


Fig. 3 Pull-out load vs. length of slippage

The testing device is operated with the automated control and data acquisition system originally developed for the automated triaxial testing system (Li, et al., 1988). The system has two feedback loops for axial and lateral actuators under software control; the two loops can work separately or synchronously. For the reinforced soil study, a uniform pressure in the inner and outer chambers representing the overburden pressure is applied to the hollow specimen. The specimen is initially subjected to a set of isotropic pressure (axial pressure equal to the chamber pressure) and followed by a gradual decrease in axial pressure leading to a failure of the specimen in extension.

## 3 PRELIMINARY TEST RESULTS

Described in this section is an exploratory laboratory investigation to demonstrate the feasibility of adopting the automated triaxial testing system and the hollow cylindrical sample to study the interactive behavior of reinforced soil systems. The dimensions of the hollow cylindrical sample were I.D. = 3.56 cm, O.D. = 6.35 cm, and L = 12.7 cm. The sand was the dry Monterey "0" sand placed at a density of approximately 1.5 ~ 1.6 gm/cm$^3$. A commercially available aluminum foil sheet was used as the reinforcement (ultimate strength = 1.0 to 1.5 N/mm at 2.5 to 2.7% elongation). The lower end of the aluminum foil cylinder was fastened at the base platen, whereas its upper end was free but in contact with the loading platen.

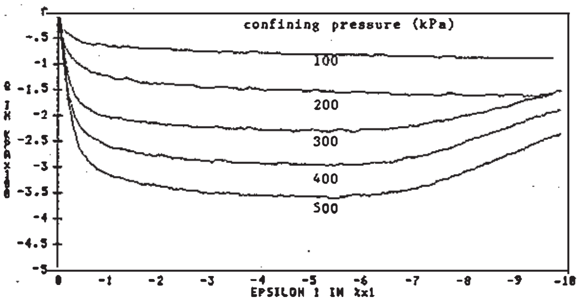


Fig. 4 Stress-strain curves - unreinforced

Figure 4 shows the extension test results of unreinforced samples under uniform chamber pressures ranging from 100 kpa to 500 kpa. The stress-strain curves (Q = deviatoric stress, epsilon 1 = axial strain) depict the behavior of a relatively loose sand; the angle of internal friction ($\phi$) in the Mohr-Coulomb stress space is approximately 31°. Figure 5

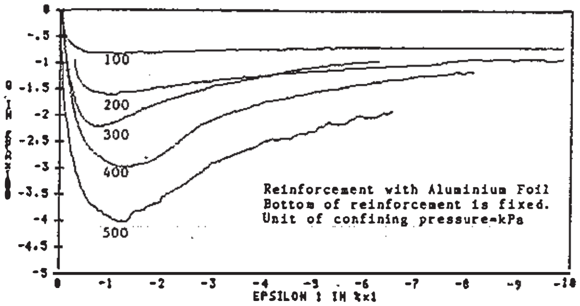
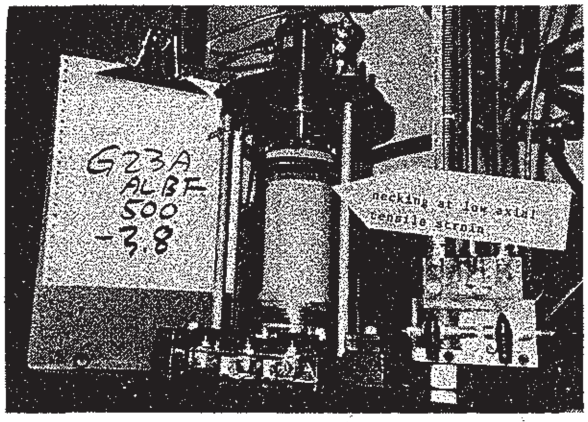


Fig. 5 Stress-strain curves - reinforced with aluminum foil

shows the corresponding stress-strain curves when a cylindrical aluminum foil reinforcement is placed in the middle of the sample. These curves exhibit the behavior of a dense sand, particularly under higher confirming pressures. The $\phi$ angle is measured at about 34°. It is also interesting to note that the rapid decrease in strength beyond the peak strain (1.0 ~ 1.5%) is associated with the detection of necking at the top of the sample (Fig. 6) indicating that slippage between the sand and the reinforcing element did occur. No breakage of the aluminum foil was observed in all the samples tested. Though the results presented are not sufficient to determine the apparent coefficient of friction for bonding capacity characterization, the increase in $\phi$ angle and the more brittle nature of the stress-strain behavior can be captured very well by this type of testing when a



Reinforced with Aluminium Foil, Hollow Cylinder Type

Confining Pressure= 500kPa

Axial Strain = -3.8%

Fig. 6 Necking due to slippage (pull-out)

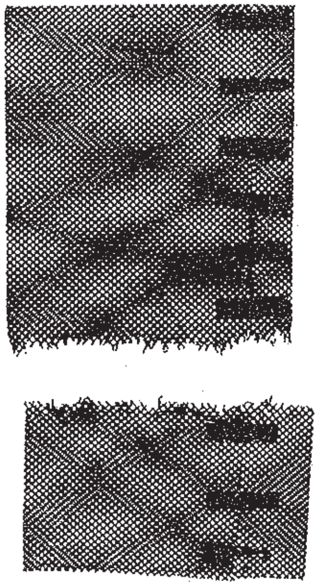
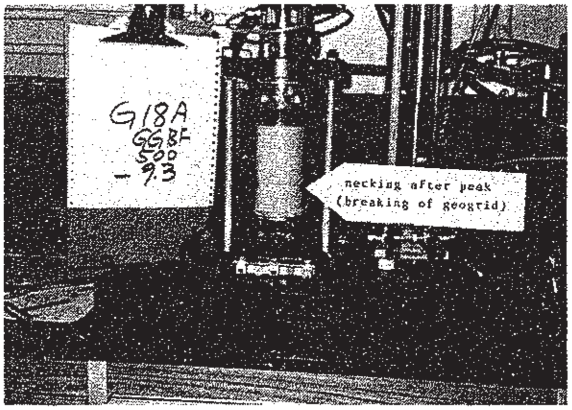


Fig. 7 Breakage of reinforcement (plastic netting)



Reinforced with Geogrid(Fixed-Bottom), Hollow Cylinder Type
Confining Pressure = 500 kPa
Tensile Axial Strain = -9.3%

Fig. 8 Necking due to reinforcement breakage

relatively inextensible aluminum foil reinforcement is used. Additional tests using a very weak plastic netting reinforcement were also conducted. Figs. 7 and 8 show respectively the breakage of the reinforcement and the necking in the sample where breakage occurred.

## 4 SUMMARY AND CONCLUSIONS

This paper describes the development of a testing apparatus for the purpose of studying the interactive behavior of reinforced soil systems. The system can be used effectively to provide much needed basic knowledge pertinent to soil reinforcement technology for the emerging geofabric industry. The testing condition simulates closely the field loading conditions at the soil-reinforcement interface; furthermore, the boundary constraints around the specimen are minimal enabling more accurate interpretation of test results.

An exploratory investigation to assess the feasibility of the approach was discussed. The authors believe that the new device presents a viable alternative to the current methodology in reinforced soil testing. The authors also realize that concerns pertaining to the design and development of the system still exist. For instance, the development of a shear band in the vicinity of the soil-reinforcement interface is closely related to the grain-size and the density of the soil, the type of reinforcement, and the overburden pressure; therefore, in deciding the thickness of the hollow cylindrical sample, considerations should be given to the formation of the shear band. The importance of membrane effect in extension test is another factor to be considered in data processing and interpretation.

This new approach to conducting laboratory reinforced soil testing is albeit unconventional, the authors believe it will help to remove some of the limitations in our ability to obtain meaningful and quantifiable information on reinforced soils and thus benefit the geotechnical profession; undoubtedly, much work is still needed to develop the "ideal device" for reinforced soil testing. It is hoped that this paper may stimulate interest and attention to this very important issue.

## 5 ACKNOWLEDGEMENT

The idea of testing reinforcing sheet in the triaxial cell under extension was first suggested to the senior author by Barry Christopher.

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