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Strengthening of soft soil by fiber-reinforced sand column

T.O.Al-Refeai
King Saud University, Riyadh, Saudi Arabia

ABSTRACT : This paper presents the results of a laboratory investigation that was conducted to study the behavior of soft soil strengthend with fiber reinforced sand columns. In fiber reinforced sand column, lateral restraint comes not only from the surrounding soil but also from the restraint offered by the fiber reinforcement. Triaxial compression tests were performed on composite soil specimens made of annular soft clay samples, with both fiber reinforced and unreinforced sand columns. These tests show that the column replacement ratio and depth of fiber reinforced sand layer inside column have a significant effect on load carrying capacity and settlement response of the reinforced soft soil. The study showed that a fiber content of 0.2% by weight can be used effectively to increase stress resistance properties of sand without any reduction in the soil density, permeability or ductility.

1 INTRODUCTION

The improvement of soft and compressible soil deposits by granular columns is now a well-established construction procedure (Greenwood and Kirsch 1983, Bachus and Barksdale 1989). The Primary aim of granular columns is to increase the load carrying capacity of compressible fine grained soils, reduce and control total and differential settlement, accelerate consolidation and improve shearing resistance (Mitchell et al 1985, Bergado et al1988, Goughnour and Bayuk 1979, Rathgeb and Kutzner 1976). Seed and Booker (1977) recommend their use for improving resistance to liquefaction of alluvial deposits.

The interrelated performance of granular columns and in- situ soil depends to a large extent on the lateral pressure in the surrounding soil. The rigidity and the bearing capacity of the granular columns are governed mainly by the amount of lateral restraint or passive resistance that can be mobilized in the surrounding soil. Granular columns are viable and cost-effective in stabilizing soft and compressible soils ranging from soft clays to loose silty sand (Bachus and Barksdale, 1989). However, this method is unfeasible when lateral confining stress in the surrounding soil is too small, as is the case in very soft clay and silty deposits. For preventing bulging of granular columns near surface, Van Impe et al (1985) proposed wrapping the upper portion of the column with geotextile, while Jones (1972) suggested stabilizing the top of the column with cement.

Permeability of sand column is conspicuously reduced with the use of cement, which in turn means prolongation of consolidation and reduction of stresses within the surrounding soft soil. The rigidity of granular columns encapsulated in stiff geotextile is increased, whereas cement reduces the ductility, putting severe limitation on the allowable deformation.

The objective of this study is to evaluate the feasibility of using randomly oriented fiber reinforced sand columns to strengthen soft soil. The tensile stresses developed in the fibers through friction induce an equivalent confining stress on sand (Yang, 1972), which may equal or exceed the restraint provided from the surrounding soft soil. The present paper describes the results of triaxial tests on fiber reinforced granular column surrounded by annulus of soft soil confined by constant radial pressure and loaded between rigid end plattens (Fig.1). This type of boundary conditions simulate a single column in a semi-infinite soft soil (Aboshi et al 1979). The principal purpose of this work is to study the effects of replacement ratio and depth of fiber reinforced sand layer in the sand columns, on the load carrying capacity and settlement of composite foundation.

2 MATERIALS AND SPECIMEN PREPARATION

2.1 Materials

Fiber: Fibrillated polypropylene fibers in 25 and 50 mm bundles were used in this study. The fibers have: equivalent diameter of 0.4 mm, specific gravity of 0.9, tensile strength of about 0.36 GN/m^2 at a failure strain of 17% and Young's modulus of 3.5 GN/m^2 .

Clay: The soft soil used was silty clay from Al-Ammariyah near the city of Riyadh. The particle analysis indicated that 60% of the sample was smaller than 0.005 mm. The main characteristics of this soil are given in Table 1.

Sand: The granular soil used was a poorly graded fine sand with 100% smaller than 2 mm. The physical properties of the sand are also shown in Table 1.

Table 1. Physical and index properties of soils

		Clay	Sand
Specific gravity		2.75	2.67
Liquid limit	%	40	-
Plastic limit	%	25	-
Plasticity index	%	15	-
D_{10}	mm	-	.08
Coeff. of curvature		-	1.34
Uniformity coeff.		-	2.63
e_{max}		-	.806
e_{min}		-	.455
MDD *	kN/m^3	16.8	18.0
OMC	%	18.3	10
ϕ deg. (D_r=60%)		24	31
Unified soil class.		CL	SP

* Standard proctor - ASTM 698.

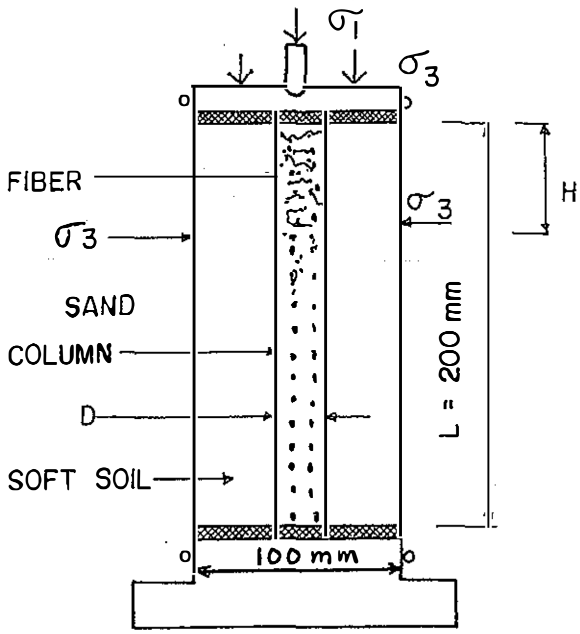

Fig.1 Schematics of test setup.

2.2 Specimen preparation

The required amount of air dry clay was mixed with sufficient distilled water to increase the water content to 40%. The soil and water were throughly mixed using an electric mixer. After mixing, the slurry was transferred to a special one dimensional consolidation cell-100 mm in diameter and 300 mm in height- with a central wood cylinder covered with nonwoven geotextile sleeve, (outside diameter = 25 or 50 mm) and consolidated under vertical pressure of about 100 kPa. Water content throughout the preconsolidated sample after two weeks consolidation was 31% with less than 1% variation.

At the completion of consolidation, cylindrical annular specimens for triaxial tests, 100 mm in diameter and 200 mm in height were trimmed and mounted on the triaxial cell base. A mixture of sand, water (10%) and fibers (0.2% by weight and fiber length = column diameter) was placed in cavity of the preconsolidated cylindrical samples in four successive layer, which were compacted to a relative density of 60% by light tamping with a circular glass disk (48 or 98 mm in diameter) attached to the end of the tamping steel rod. To obtain uniform test specimens, two identical compositereinforced soil samples were compacted consecutively. The unit weight of the two specimen obtained were compared with each other. When the margin of error exceeded 1%, a third specimen was prepared. The composite- reinforced specimen and the porous stones were enclosed in a 0.2 mm thick rubber membrane which was sealed between the pedestal on the base of the cell and the loading cap by O-rings. The specimen was placed in the triaxial cell, was saturated and further consoli- dated under 40 kPa triaxial pressure. Undrained triaxial tests were performed on test composite reinforced samples at a deformation rate of 0.05 mm/min. under confining pressure of 40 kPa. For this study the average value of two specimens is taken to be the representative value.

3 TEST RESULTS AND DISCUSSION

3.1 Fiber effect on compaction

The results of standard compaction tests (ASTM D698-78) performed on mixture of wet sand (w=10%) and predetermined amount of fiber content (% by weight of dry sand) are presented in Fig.2 which indicate that up to a fiber content of 0.2%, the dry unit weight of the mixture is slightly greater than that for the sand alone. Therefore the presence of the fiber does not cause an increase in porosity. With high fiber concentration more than 0.2% the dry unit weight of the mixture rapidly decreased, indicating a decrease in the relative amount of sand in the mixture. A fiber content of 0.2% by weight was, therefore, selected to reinforce the sand columns in this study.

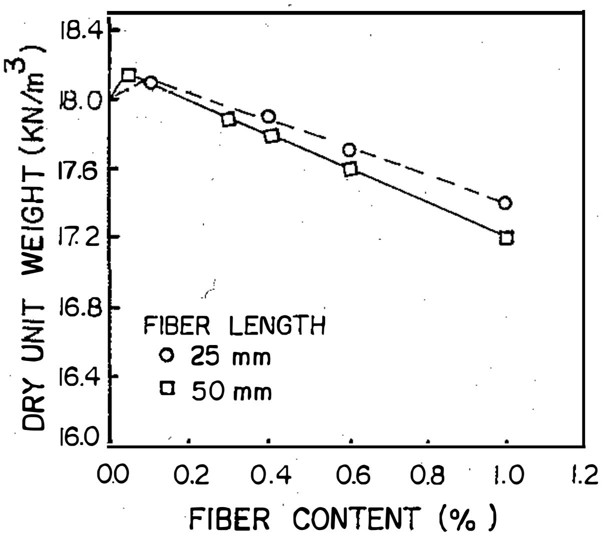

Fig.2 Effect of fiber content on dry unit weight of compacted sand.

3.2 Fiber effect on permeability

The primary function of the granular columns is reinforcing of soft soil and a secondary function of augmenting drainage to dissipate the excess pore water pressure. In order to evaluate the hydraulic characteristics of fiber-sand mixture, falling head permeability tests were performed on the composite material samples which were compacted to a relative density, D_r, of 60%. Fig.3 shows the relation between coefficients of permeability and fiber content. The figure shows that the coefficient of permeability increases greatly with increasing fiber content with longer fiber creating more pronounced effects.

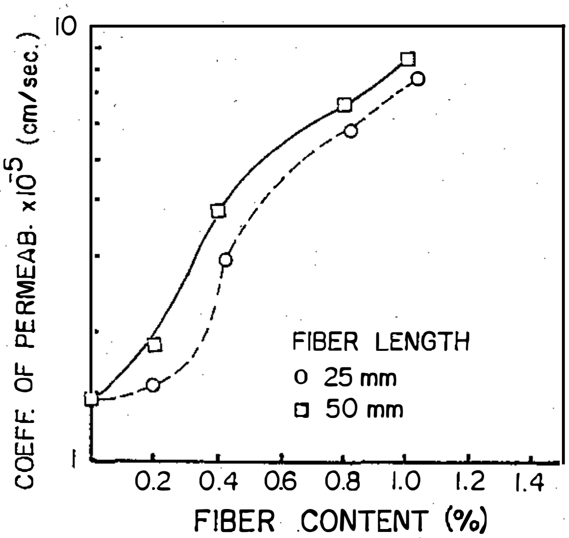

Fig.3 Effect of fiber content on permeability of sand.

3.3 Strength properties of fiber reinforced sand

Typical stress-strain curves, obtained from drained triaxial tests on 100 mm diameter and 200 mm high specimens of sand with and without 0.2% fibers are shown in Fig.4. All samples were compacted to the same relative density (D_r=60%). Fig.4 shows that fibers increased the stiffness and strength of all the samples. Tests were stopped at 15% strain as failure was not reached. Under low confining stress the deviator stresses at 3% strain in the samples with 25 and 50 mm fibers increased by about 50% and 70% respectively. These results confirm the efficiency of fibers to reinforce the sand even at low strain level, and low confining pressure.

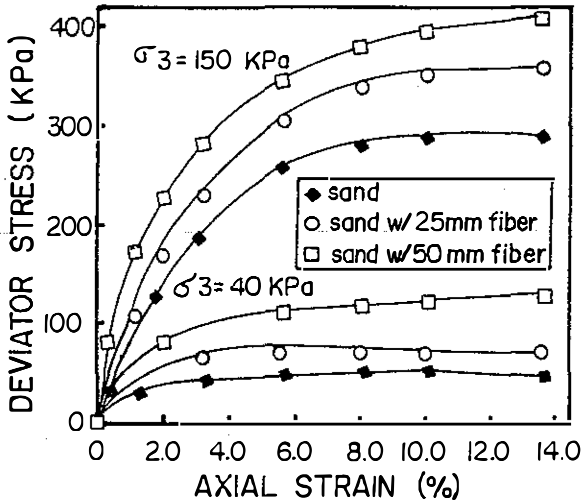

Fig.4 Stress-strain curves of test samples with columns of sand and reinforced with 0.2% fiber.

3.4 Bearing capacity of stabilized clay

Fig.5 shows the triaxial compression curves at 40 kPa confining pressure for clay samples stabilized by both unreinforced sand and fiber reinforced sand columns with area replacement ratio, a, of 6.25% and 25% (a = area of sand column / total area within the unit cell). The results of consolidated undrained triaxial tests on untreated clay is also shown in the same figure. It can be clearly seen that fiber inclusion considerably increased the load carrying capacity of the reinforced soft soil. In contrast to cemented sand column (Juran and Riccobono, 1989), fiber inclusion did not limit boundary deformation nor contributed to increase in strength to the same extent. They have the advantage, however, of being able to stretch and continue mobilizing tensile resistance at relatively high strains. It may be seen by comparing Fig.5 (A) with (B) that although longer fibers and larger sand column greatly increased the load carrying capacity of the reinforced clay, the difference of fiber effect over sand alone is strongly dependent on the replacement factor. Fiber inclusion, at a small replacement ratio, results in a significant improvement in the load carrying capacity of clay samples reinforced with sand columns.

Since the lateral support given by the surrounding soil near the surface,in general, is not adequate to resist bulging of sand columns and both, the laboratory studies (Hughes and withers, 1974)

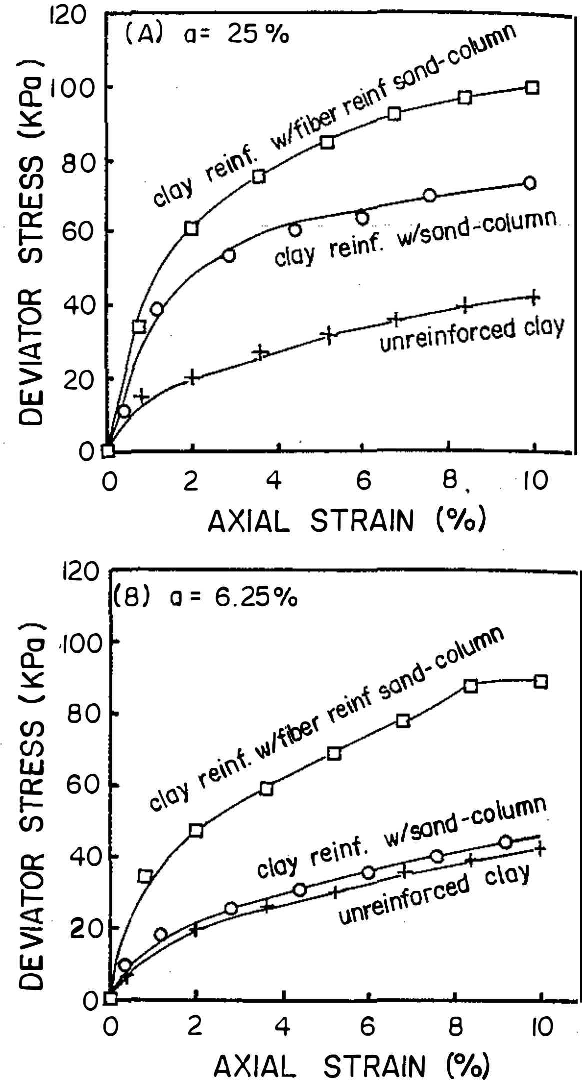

Fig.5 Effect of fiber reinforcement on performance of composite soil.

and the full scale tests (Jones 1972), have shown that the columns transfer the bulk of their load to the clay within a depth equivalent to one to two column diameters. A series of triaxial tests was performed on clay specimens stabilized with sand columns where only the upper part of the columns (1 or 2 column diameters) were reinforced with fibers. The results are shown in Fig.6. It can be seen that the strength of specimens increases as the depth of fiber reinforced sand layers increase. However considering the fact that settlement of structures on soft soil controls the design, there is almost no difference in reinforcing effect achieved increasing the depth of fiber reinforced sand layer beyond one column diameter.

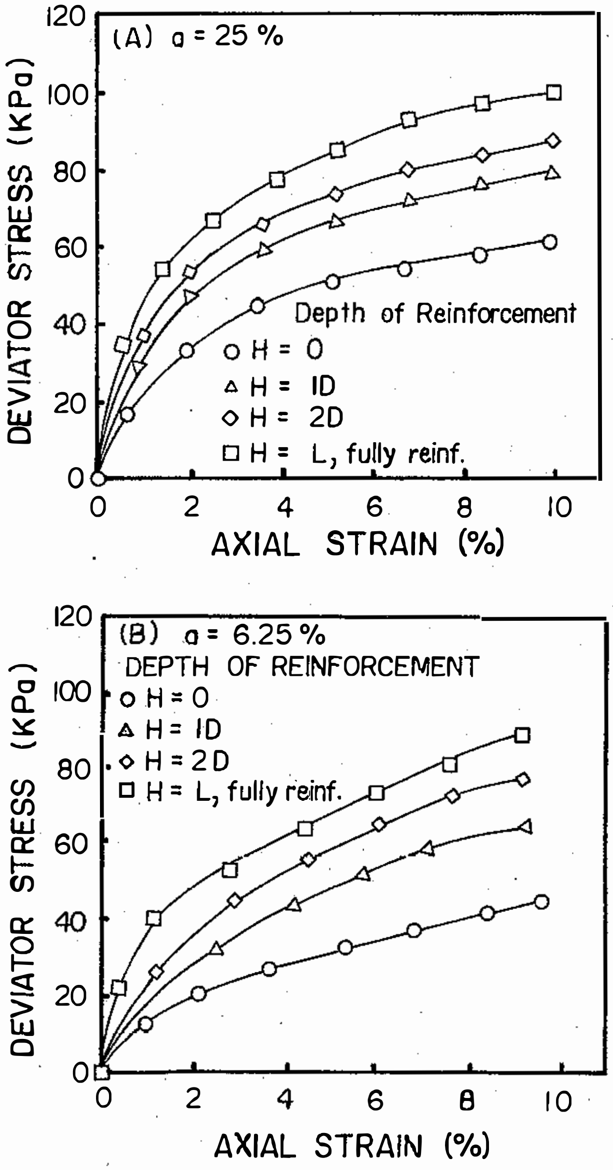

Fig.6 Effect of depth of fiber reinforcement on response of composite soil.

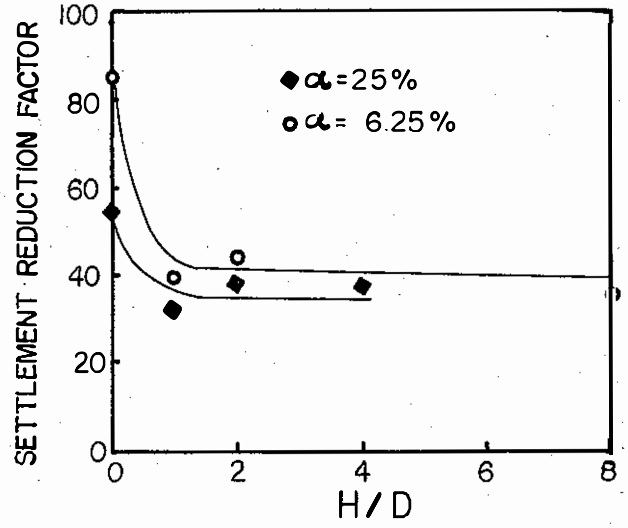

Fig.7 Effect of depth of fiber reinforcement on settlement reduction factor.

3.5 Settlement reduction

The stress-strain relationships from the triaxial compression tests shown in Figs.5 and 6 illustrate the major effect of sand and fiber reinforced sand columns on the settlement response of the reinforced clay specimens.

In order to express the improvement in settlement behavior of the clay stabilized with unreinforced sand and fiber reinforced sand columns, the settlement reduction factor, β ,is defined as the ratio of settlement of reinforced clay specimen to settlement of untreated clay specimen.

The values of the settlement reduction factor were estimated from the initial tangent moduli of the stress-strain curves obtained for untreated clay, clay with sand and fiber reinforced sand columns, under a confining pressure of 40 kPa.

The settlement reduction factor variation with depth of fiber reinforcement layer in terms of columns diameter for two different values of replacement ratio is shown in Fig.7, which indicates that the magnitude of the reduction in vertical compression of clay when reinforced with untreated sand colum is clearly a function of column diameter as increasing the column diameter resulted in a reduction in vertical stress in the clay. It is further observed from Fig.7 that with inclusion of fibers in the sand columns, a significant reduction in the settlement is achieved. The settlement reduction factor increases with the depth of fiber reinforced sand layer upto a maximum value of H/D=1 and remains practically constant thereafter regardless of the column replacement ratio.

4 CONCLUSIONS

Based on the results of this investigation, these conclusions can be made:

1. A fiber content of 0.2% by weight can be used effectively to increase stress resistance properties of sand without any reduction in the soil density, permeability or ductility.

2. The results show a drastic increase in the bearing capacity and a great reduction in compressibility of clay when stabilized with sand column containing 0.2% fiber.

3. The most economical and practical depth of fiber reinforced sand layer in the sand colums as determined from this study is about one column diameter.

Full scale experimental test under traffic, since 1988, (Lindah and Eriksson 1988) utilizing sand reinforced with 48 mm fibers in road pavement indicated a significant improvement in strength and deformation properties with no difficulties during mixing, transporting and compaction. However, more full scale tests are needed to examine the reliability of the foregoing conclusions.

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