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Experimental Study of Soft Clay Reinforced with Sand-Fiber Core

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Introduction

Soft clay deposits invariably pose problems of low bearing capacity and excessive settlements over long periods of time. Such deposits can be effectively utilized either by providing special type of foundations or by improving the soil. Use of special type of foundations may not always be possible and many a times be uneconomical. A variety of ground improvement techniques have been developed and successfully applied in several cases (Ranjan, 1989). Granular piles/stone columns (Ranjan, 1989), lime columns (Broms, 1985) or cement columns (Pan et al., 1994) are the well accepted techniques of deep ground improvement for soft clay deposits. All these techniques basically involve introduction of different material in the clay deposit and in general may be considered to be identical in nature. In these techniques primarily, a stiffer material is introduced in the weak subsoil as a pile upto certain depth and at regular spacing.

In a recent study, Gray and Al-Refeai (1986) suggested sand-fiber core/column as an alternative to granular piles/columns to stabilize the soft/weak clay deposits. Sand-fiber mixture is a composite material formed by adding discrete fibers to sand. The engineering behaviour of sand-fiber composite is similar to traditional reinforced soil. However, in preparation it is similar to soil stabilization by admixtures i.e. discrete fibers are simply added and mixed with the soil in the same manner as cement, lime or other additives.

Several studies on fiber reinforced sand have been reported in the

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literature. Experimental results reported by Hoare (1979), Gray and Ohasi (1983), Gray and Al-Refeai (1986), Setty and Rao (1987), Gray and Maher (1989), Maher and Gray (1990), Al-Refeai (1991) and Ranjan et al. (1994) revealed that: fiber reinforced sand is a potential composite material which can be advantageously utilized to improve the engineering behaviour of sand. Fiber reinforcement in sand results in significant improvement in its shear strength. More importantly it exhibits greater extensibility and small loss of post peak strength (i.e. greater ductility of the composite material) as compared to unreinforced sand.

Studies on the use of sand-fiber composite as a reinforcing core/column to treat deep deposits of soft clay have not been reported in the literature. In the present study, the suitability of sand-fiber cores in stabilizing soft clay has been investigated through a well planned series of triaxial compression tests on soft clay samples with central sand-fiber core. The influence of different parameters namely; relative core area (i.e. the ratio of the cross section of the sand-fiber core and that of the sample), amount of fiber in the core and confining stress on the strength of soft clay have been investigated. A comparative study of soft clay treated with sand-fiber core, and granular column and sand columns has also been made.

Material and Experimentation

Materials

Fibres

Synthetic polypropylene fibers have been used in the present investigation. These fibers are resistant to sea water, acids, alkalies and chemicals. These have high breaking strength and abrasion resistance (Setty and Rao, 1987 and Rehsi-1988). The fiber characteristics are given in Table 1.

Soil

Three types of soils namely clay, sand and granular material have been used in the present investigation. Clay has been used for preparing parent sample and sand and granular material have been used for making cores which are introduced in the clay samples.

The properties of the soils used are presented in Table 2.

Sample Preparation and Testing

Clay samples were prepared in cylindrical split mould of 50 mm diameter and 100 mm height. The quantity of clay required to fill the mould

Table 1 : Fiber Characteristics

Characteristic	Value
Diameter	0.3 mm
Specific gravity	0.92
Tensile strength	1.5×10^6 kPa
Angle of skin friction	21°

Table 2 : Properties of Soils Used

Property	Value
A. Clay	
Liquid limit	58%
Plastic limit	37%
Unconfined compressive strength at moisture content 35%	42 kPa
Unit weight	18 kN/m^3
Classification	CH*
B. Sand	
Classification	Uniformly graded fine sand (SP*)
Unit weight	18 kN/m^3
Cohesion, c	10.5 kPa
Friction Angle, Φ	34°
C. Granular material	
Type	Crushed stone
Size	2mm - 3mm

* as per Unified Soil Classification System

** $c - \Phi$ parameters have been determined by triaxial tests on samples prepared at OMC and γ_{dmax}

at desired unit weight of 18 kN/m^3 along with water of known quantity (35%) was worked out. Required quantity of water was sprinkled over the powdered clay of required weight and was slowly kneaded to form a uniform mix. The mixed clay was divided into approximately three equal parts. Each part is placed in the split mould and compacted lightly and uniformly with a wooden tamper. After putting the last layer and compacting it lightly, the sample was finally compressed statically through end plugs to obtain the desired height.

Before taking out the sample from the mould, the core for installing column was made. The central core of desired diameter was taken out by inserting a thin walled steel tube. For a centrally and vertically aligned core, the tube was inserted with the help of wooden block having a central hole. The steel tube is slowly pushed to the full depth and rotated slowly 3 - 4 times in alternating reverse directions to minimize side friction. The tube is then gradually pulled out slowly and carefully leaving a central hole in the clay sample.

The unit weight of parent clay sample and column material is kept the same. Fibers and sand with required quantity of water were mixed thoroughly to achieve a uniform mix. The moist sand-fiber mix was then transferred to central hole in the clay sample in three layers each layer being duly compacted by a light tamper. The sample was taken out from the mould.

Unconsolidation undrained triaxial tests were conducted on samples of soft clay with sand-fiber core of relative core area of 0.0, 0.09, 0.25, 0.36, 0.56 and 1.0. Fiber contents in the core were 0.0%, 0.5%, 1.0% and 2.0% (by weight of dry sand). Samples were tested at confining stress of 75, 150 and 300 kPa, at an axial strain rate of 1.25 mm/min. using GDSTTS.

Test Results

Data obtained from triaxial compression tests has been analyzed to study the stress-strain behaviour and strength characteristics of soft clay treated with sand-fiber core.

Stress-Strain Behaviour

Figure 1 shows the typical plot of deviator stress-axial strain of soft clay reinforced with sand-fiber core (having fiber content 1% by weight) of relative core area of 0.36 and confining stress ranging from 75 to 300 kPa.

A glance at the figure indicates that while the untreated clay sample attains a peak stress at about 10% axial strain which then remains almost constant upto 20% axial strain, the clay samples reinforced with sand fiber core do not exhibit any peak stress. The stress-strain curves of clay samples with sand-fiber core indicate a rising trend even at axial strain of 20%, exhibiting a ductile behaviour of composite soil. Similar deviator stress-axial strain behaviour is observed for soft clay samples with sand-fiber core with relative core areas of 0.09, 0.25, 0.36, 0.56 and 1.00.

The behaviour of the clay treated with sand-fiber core is distinctly different from that of the untreated clay. The difference in behaviour may be due to the fact that as the composite sample is subjected to deformation, load is shared between sand-fiber core and surrounding clay. With increase in

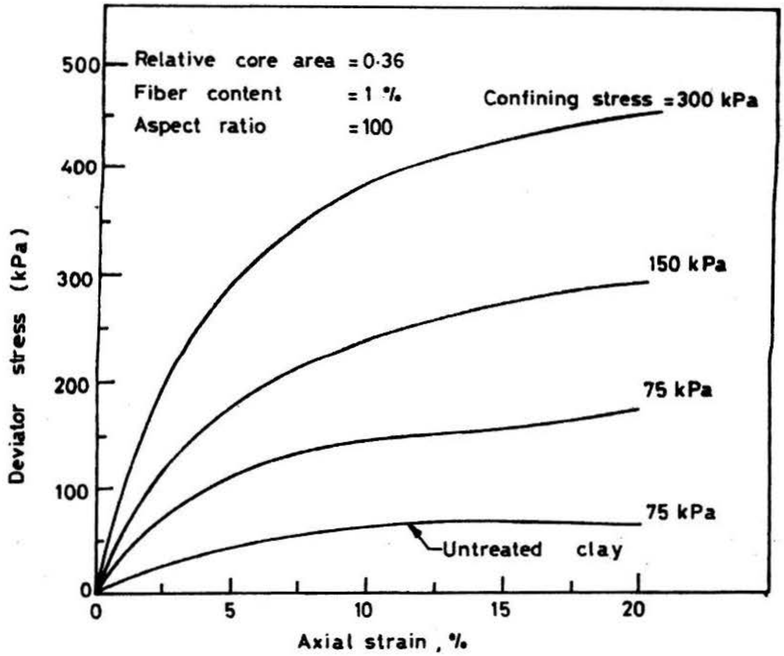

FIGURE 1 : Stress-Strain Behaviour of Soft Clay Reinforced with Sand-Fiber Core

deformation, the sharing of load between core and clay goes on rescheduling resulting into a transfer of more load to the core. With deformation of the composite soil, friction between sand and fibers in sand-fiber core comes into play resulting in the development of tensile stress in the fiber. The tensile stress developed in the fibers is responsible for maintaining a rising trend of deviator stress even upto 20% axial strain. Thus, the introduction of sand-fiber column in the clay sample makes it more ductile.

Since the stress-strain curve for composite samples do not indicate peak stress, the failure condition in such situation is generally governed by the permissible amount of deformation. Usually failure stress is taken at a corresponding strain of 15 to 20%. In the present study, however, for subsequent analysis, the failure has been defined as the stress corresponding to the peak stress condition or at 20% axial strain whichever is earlier.

Strength of Composite Samples

The strength of soft clay reinforced with sand-fiber columns has been defined in terms of major principal stress at failure (σ_{1f}). The strength is affected by relative core area, fiber content, fiber aspect ratio (length over diameter) and confining stress.

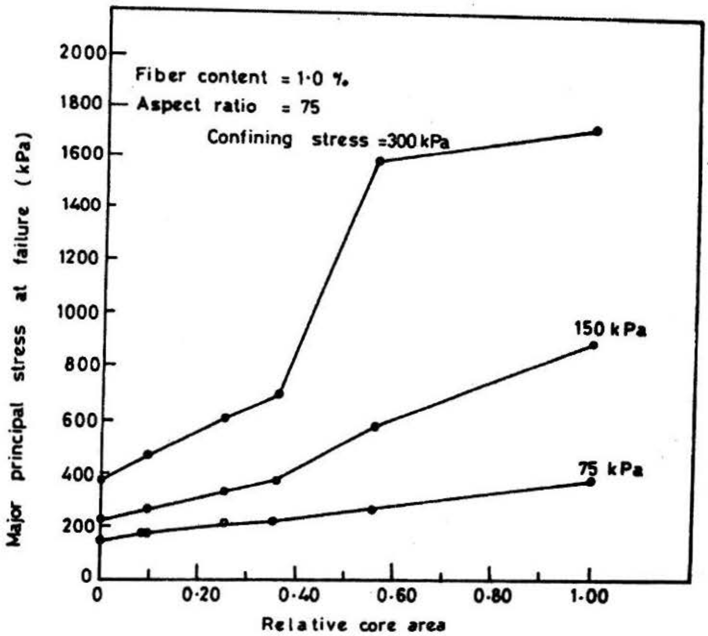

FIGURE 2 : Effect of Relative Core Area on Strength of Soft Clay Treated with Sand-Fiber Core

Relative core area

Figure 2 shows the variation of shear strength of composite soil with relative core area of sand-fiber core under confining pressure of 75 to 300 kPa. The strength of composite sample was observed to increase with increase in relative core area of sand fiber core. The rate of increase in strength is small for a relative core area upto about 0.36 and thereafter the rate of increase in strength is much higher. It was also observed that with increase in confining stress the rate of increase in strength is more at higher confining stress.

Fiber content

Figure 3 shows the variation of shear strength of composite sample with fiber content in the sand-fiber core for confining pressure ranging from 75 to 300 kPa. It is seen from the figure that the strength increases with an increase in fiber content in the core. Such a behaviour is due to the fact that, with increase in fiber content, the fiber surface area available for mobilization of friction increases thereby increasing the tensile stress in the fibers which ultimately increases the strength of composite sample.

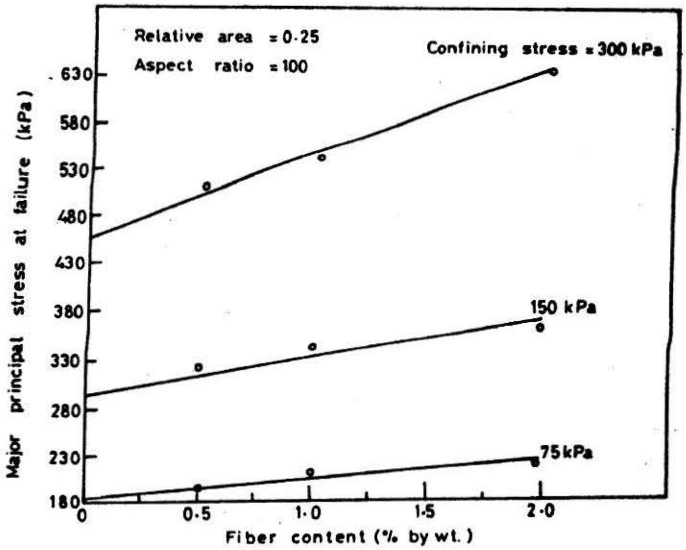

FIGURE 3 : Effect of Fiber Content in the Sand-Fiber Core on the Strength of Treated Clay

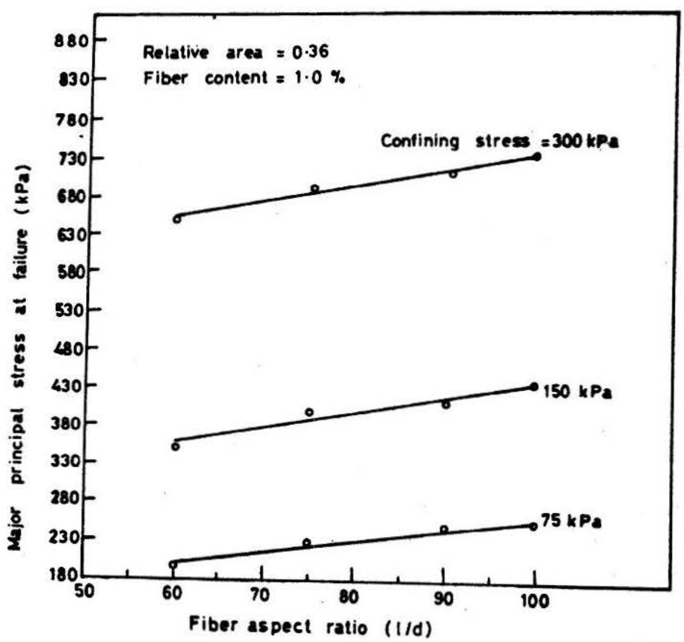

FIGURE 4 : Effect of Aspect Ratio of Fiber in Sand-Fiber Core on the Strength of Treated Clay

Aspect ratio

Figure 4 shows the plot of strength of composite sample with fibers aspect ratio (length over diameter ratio), for a fiber content of 1.0% and confining pressure 75 to 300 kPa. The figure indicates that the strength of composite samples increases with an increase in aspect ratio. It may be noted that with increase in aspect ratio of fibers, the length of fiber available to mobilize frictional resistance between sand and fiber is increased resulting in an increase in tensile stress in the fiber and consequently results in an increase in the strength of the composite sample.

Comparison of Behaviour of Samples with Sand-fiber Core with Granular Material Core

Triaxial tests were also conducted on samples with sand-fiber core and granular core, for comparison. The comparative behaviour with respect to stress-strain failure envelopes and shear strength have been discussed in the following section.

Stress-Strain Behaviour

Figure 5 shows the plots of deviator stress-axial strain of soft clay treated with granular core and sand-fiber core (with fiber content of 0.5%, 1% and 2%) for a constant relative core area of 0.25 and confining stress 150 kPa. Stress-strain curve of untreated clay is also plotted for comparison.

It can be seen from the figure that soft clay sample and clay sample with granular core, attain a peak value at about 10% axial strain which then remains practically constant even upto 20% axial strain. Whereas, in case of clay sample with sand-fiber core, it goes on increasing with increase in axial strain even up to 20% which shows that the residual strength of clay treated with sand–fiber columns is greater than the strength of clay sample with granular material core.

Table 3 presents data on the gain in strength (in terms of ratio of strength of treated clay to untreated clay) of soft clay with sand-fiber core and granular core over unreinforced clay for different relative core areas at confining stress of 150 kPa and fiber content of 1%. It can be seen from the table that the strength of samples with sand fiber cores is more than that of granular material core for each relative core area. For example, for relative core area of 0.25, the strength of soft clay is observed to increase by 33% and 51% respectively, due to the installation of granular core and sand-fiber core respectively.

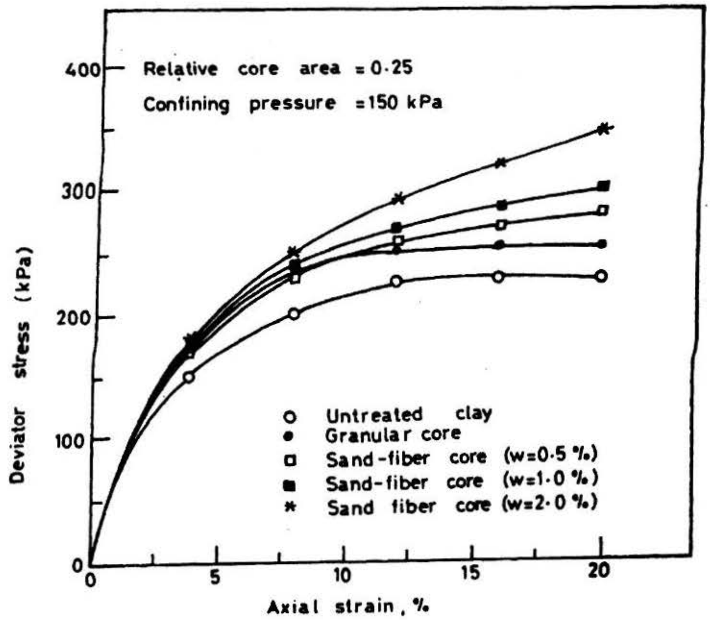

FIGURE 5 : A Typical Plot of Deviator Stress-Axial Strain of Soft Clay Reinforced with Granular Core and Sand-Fiber Core

Table 3 : Gain in Strength of Soft Clay with Granular Core and Sand-Fiber Core

Relative core area	Ratio of strength of treated clay to untreated clay at confining stress of 150 kPa		
	Untreated clay	Granular core	Sand-Fiber* core
0.00	1.00	1.00	1.00
0.09	—	1.13	1.19
0.25	—	1.33	1.51
0.36	—	1.45	1.73
0.56	—	2.10	4.08
1.00	—	2.89	5.54

* Fiber content in sand-fiber core = 1%

Conclusions

A series of triaxial compression tests were conducted to study the stress-strain behaviour of soft clay samples with sand–fiber cores and the corresponding increase in shear strength. Analysis of experimental test data indicates that the introduction of sand fiber core in clay sample increases the shear strength and modifies stress-strain behaviour of reinforced soft clay. The main conclusions emerging from the study are:

1. The stress-strain behaviour of the soft clay treated with sand-fiber core in significantly different from that of only clay sample. Clay sample with sand-fiber core exhibits no peak strength and higher residual strength as compared to only clay sample.

2. The strength of clay sample with core in terms of major principal stress at failure increases with increase in relative core area, fiber content in the core, aspect ratio of fiber and confining stress.

3. The comparison of increase in strength of clay sample with sand fiber cores and granular material core reveal that the former is more effective in increasing the strength of soft clay.

The findings of the study are of great practical relevance as a ground improvement technique for soft clay under heavy loads. Further, experimental work is in progress to study settlement/consolidation characteristics of soft clay treated with sand fiber core.

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