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# Model Studies on Partially Confined Sand Columns Using Goegrid Tubes

by

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## Introduction

Compacted sand columns are being increasingly used in the last two decades as a satisfactory ground improvement technique in soft and compressible soils. The conventional method of constructing a sand column consists of preparing a cased borehole of required diameter and depth which is filled with sand in layers, each layer being compacted with a rammer as the casing is withdrawn. Improvement in bearing capacity and settlement response of the soft soil mainly depend upon the strength and stiffness of the sand column which in turn depend on lateral confining pressure exerted by the surrounding soil to restrain the bulging of the sand column. Hence the use of conventional sand column in soft soils having undrained shear strength less than 15 kPa is not feasible.

As suggested by Madhav (1982), the strength and stiffness of a sand column can be increased either by the use of several reinforcing geofabric layers placed horizontally at different depths or by using a rigid hollow cylinder at the top portion. Maher and Gray (1990) have shown that the strength and stiffness of a sand column can be significantly increased by using randomly distributed reinforcing fibres. Further the experimental study of Junar and Oraccio (1991) has shown that the load settlement response of

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an artificially cemented sand column is independent of the small confining pressure exerted by the surrounding soft soil and hence such a sand column can be used even for soils of very low shear strength (less than 15 kPa).

The above methods are likely to pose constructional problems both in onshore and offshore environment. A more convenient and a better method of improving strength and stiffness of a conventional sand column is to provide a circumferential reinforcement in the form of an expandable or flexible tube or jacket for the entire length of the column.

The experimental study presented in this paper was conducted to evaluate the feasibility of using geogrid tubes for circumferentially reinforcing a compacted sand column. The basic concept consists of preventing the bulging of sand column by the lateral confining effect of the geogrid jacket in addition to the lateral confining pressure of surrounding soil.

The primary objective of the study was to investigate the effect of geogrid tube on the strength and stiffness of a compacted sand column and the load deformation behaviour of such a column surrounded by soft and compressible soil, and subjected to axial loading.

In order to achieve this objective, uniaxial compression tests were conducted on circumferentially reinforced compacted sand column, with different numbers of reinforcing layers. Further, vertical load tests were also conducted on reinforced sand column installed in a cylindrical tank filled with soft clay. Conventional triaxial tests on river sand, standard tension tests on geogrid strips and classification tests on sand and clay soil were performed to obtain the required properties of the materials used in the investigation.

## Details of Experimental Investigation

### Materials Used

The sand used in this study is a uniformly graded river sand passing through standard sieve of 2.8 mm opening and retained on sieve of 1.2 mm opening. The minimum size of sand particles was limited to 1.2 mm so that they do not pass through the openings of geogrid reinforcing tube. The maximum and minimum dry densities of the sand was found to be 15.02 $Kn/m^3$ and 13.81 $Kn/m^3$ respectively.

Geogrid mesh, commercially known as Netlon square mesh available in the local market was used to form circular reinforcing tubes. Thickness of the Netlon mesh was 1.0 mm and the openings of the mesh were about 1.1 mm by 1.1 mm. Tension tests conducted on geogrid strips of 200 mm by 200 mm indicated an average strength of 1.2 KN/meter width. The modulus of elasticity was found to be 3.7 KN/meter width.

The soft soil used in the investigation is a clay collected from a nearby tile factory. The grain size distribution of the soil includes

| Size | Percent |
|---|---|
| 90% | < 1 mm |
| 80% | < 0.02 mm |
| 70% | < 0.01 mm |
| 60% | < 0.006 mm |
| 50% | < 0.002 mm |

The liquid limit and plastic limit of clay were found to be 52% and 30% respectively.

## Conventional Triaxial Tests on Sand Samples

After a number of trials, it was found that a sand specimen having a dry density of 14.72 KN/m$^3$ (relative density of 76.7%) could be conveniently prepared. Using the procedure described by Bishop and Henkel (1962) saturated sand samples of 50 mm diameter and 100 mm height having density of 14.72 KN/m$^3$ were prepared. Conventional consolidated drained triaxial compression tests were conducted on the sand samples using different cell pressures between 10 KN/m$^2$ and 60 KN/m$^2$.

## Uniaxial Compression Tests on Reinforced Sand Column

Netlon square mesh of required size was cut and a tube of 50 mm diameter with a height of 125 mm was formed. An overlap of 20 mm was provided and it was stitched along the length using nylon wire so that the tube can resist hoop stress. A plexiglass plate of 10 mm thickness and 50 mm diameter was kept at the bottom of the tube. Required amount of dry sand to fill up the tube with a density of 14.72 KN/m$^3$ was weighed and divided in to three equal parts. Each part was poured in to the tube and compacted uniformly with a tamping rod. This procedure was meticulously followed each time so that the sample was of same height, diameter and weight to give same density.

Circumferentially reinforced sand column thus prepared was placed over the base of a standard loading frame. A steel plate of about 15 mm thick and 45 mm diameter was kept between the base and the plexiglass

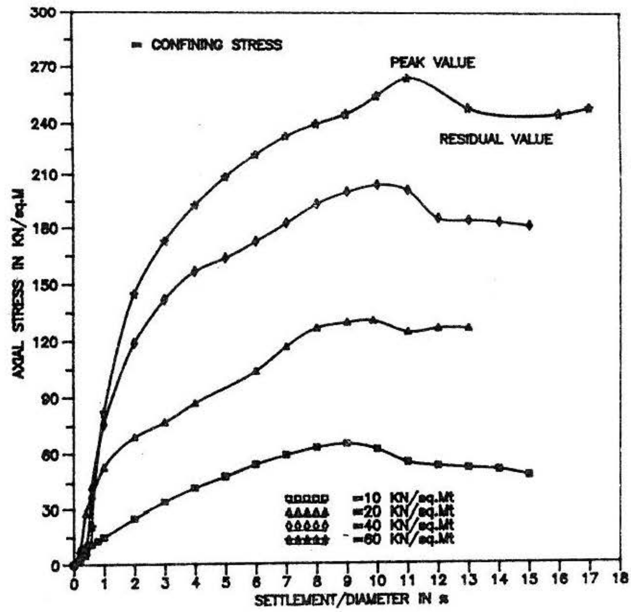


**FIGURE 1 : Stress–Strain Behaviour of Saturated Sand Sample — Triaxial Test**

plate in order to allow free movement of the mesh if any during loading. A circular steel plate of 15 mm thick and 50 mm diameter was placed on top of the sand column. Dial gauges having least count of 0.01 mm were arranged at proper positions to measure axial deformation at top and lateral deformations at top, middle and bottom of the sand column.

The loading was effected by compressing the sand column at constant rate and the load applied was measured by a proving ring of 0.75 KN capacity having a least count of 0.005 KN. The settlement of the column and lateral deformations were measured in the beginning for a load interval of 0.01 KN up to 0.1 KN. Afterwards it was increased to 0.02 KN until a final load corresponding to a settlement ratio (settlement/diameter of the column) of 15% was reached.

The influence of increase in reinforcement layers (increase in wall thickness) on the load deformation response of the sand column was investigated by using Netlon tubes of two and three layers. The effect of repeated loading was also studied by conducting cyclic loading test. The influence of size on the deformation behaviour of the sand column was studied by testing sand columns of 100 mm and 150 mm diameter with heights of 250 mm and 300 mm respectively, having one layer of reinforcement. However, sand columns of 150 mm diameter could not be tested beyond the load corresponding to 40 $KN/m^3$ due to limitation of the capacity of the loading frame. But the observed load settlement response was linear and similar to that of 100 mm diameter sand column.

**Axial Loading Test on Reinforced Sand Column Installed in Soft Clay**

In order to study the behaviour of circumferentially reinforced sand column installed in soft soil, a laboratory model was used. Model consisted of a circular steel tank of 300 mm diameter and 400 mm height which was filled with soft clay having about 60% moisture content (slightly higher than liquid limit). The tank was provided with 2 mm diameter holes along the periphery at the bottom to facilitate drainage. These holes were covered with filter paper from inside at the time of filling the soil. After filling the tank with soft clay it was consolidated for a period of 48 hours under a vertical pressure of 5 $KN/m^2$ . Undrained shear strength of clay after consolidation was measured using S.G.I. Fall Cone Test to ensure that soil of same strength was used in all the trials. Average undrained strength was found to be 12 kPa. After consolidation, a thin walled smooth pipe of 100 mm outside diameter and 300 mm length with handles fixed at one end was placed at the centre of the tank. It was pushed into soil for a depth of 250 mm. The clay inside the pipe was scooped out and the bottom surface was carefully levelled. The pipe was slowly withdrawn so that a bore hole of 100 mm dia. and 250 mm height was formed. Netlon mesh folded in to a circular tube was introduced slowly into the bore hole. A proper contact between the Netlon tube and the surrounding soil was possible as the sides were not stitched and an overlap of about 50 mm was allowed. The Netlon tube was filled with required quantity of sand in three layers and each time it was compacted so that the density was 14.72 $KN/m^3$. A rigid circular steel plate of 100 mm diameter and 15 mm thick was placed on top of the sand column.

Then the model was placed below a loading frame and the sand column was loaded through a proving ring by compressing it at a constant rate of strain. Proving ring of 2.0 KN capacity was used to measure the applied load and a dial gauge having the least count of 0.01 mm was used to measure the settlement of the column. Settlements were recorded for each load increment of 0.02 KN until the total settlement was about 15% of diameter of the sand column. The influence of increase in reinforcement layers (increase in wall thickness) on the load deformation response of the sand column was investigated by using Netlon tubes of one and two layers. The effect of repeated loading was also studied by conducting cyclic loading test.

Usually a soft compressible layer is underlain by a layer of higher rigidity like a sand layer or a sound rock formation. In order to simulate such a situation a rigid bed was placed in the tank used for testing before filling it with clay and installing the sand column. A circular steel plate of 10 mm thick was placed on a few concrete cubes of 120 mm size kept inside the tank and hence the effective depth of the tank was only 270 mm. The sand column was made to rest on the steel plate. The deformation behaviour of such a sand column also has been studied.

Three or four tests were carried out for each type of tests mentioned above and every time the procedure described was followed meticulously. Observed variation in the load deformation behaviour for the respective tests was negligible and hence the average of three trials were taken

## Results and Discussion

### Conventional Triaxial Compression Test on Sand

Stress strain behaviour of sand samples in drained triaxial test under different confining pressures are shown in Fig. 1. In all the cases considered, strength of the sand sample reaches a peak value and thereafter decreases to a constant residual value. As seen from the figure the increase in confining pressure not only increases strength and stiffness of the sand sample but also increases the strain at which the peak strength is attained. Using these results the angle of friction corresponding to peak and residual values are found to be 46° and 42° respectively.

### *Behaviour of Reinforced Sand Column under Uniaxial Compression*

Results of uniaxial compression tests on circumferentially reinforced sand column of 50 mm diameter with different number of Netlon mesh layers are presented in Fig. 2 in terms of intensity of axial load and observed settlement ratio. This figure clearly depicts a linear relationship between intensity of load and settlement ratio up to about 12% settlement ratio for all the cases considered. Figure 2 also indicates that the increase in number of reinforcing layers significantly increases the strength and stiffness of reinforced sand column. For the purpose of comparison, load settlement behaviour of sand samples tested under cell pressures of 10 KN/m$^2$ and 20 KN/m$^2$ are also shown in Fig. 2. It is evident from comparison that circumferential reinforcement produces an effect similar to confining pressure on a sand column. But the confining effect of the reinforcement increases with axial compression as indicated by constant stiffness even up to 15% axial strain whereas stiffness of unreinforced sand column under constant

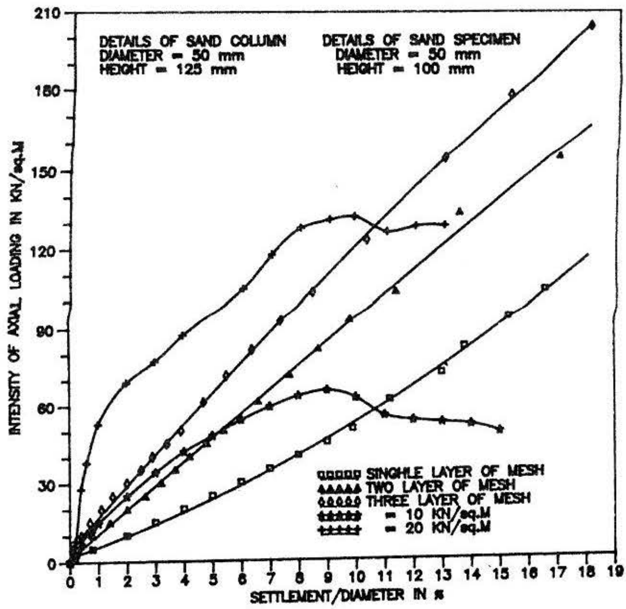


**FIGURE 2 : Comparison of Behaviour of Circumferentially Reinforced Sand Column and Sand Specimen in Triaxial Test**

confining pressure in triaxial test goes on decreasing.

Figure 3 shows intensity of loading versus settlement ratio for circumferentially reinforced sand column of 50 mm and 100 mm diameters as obtained in uniaxial compression tests. Single layer of reinforcement was used in both the cases and the length to diameter ratio was same. From the figure it is observed that stiffness of the reinforced sand column is almost constant up to about 12% settlement ratio irrespective of the size of the column. Beyond 12% settlement ratio the stiffness appears to decrease as the diameter increases.

The load deformation behaviour of circumferentially reinforced sand column with single layer subjected to cyclic loading is presented in Fig. 4 which clearly shows that stiffness of a reinforced sand column is increased by repeated loading. A similar response was observed for sand column with two layers of reinforcements. Further, it is clear from the figure that the load deformation behaviour beyond the load at which number of repetitions are given is not changed. Thus, repeated loading produces a well defined yielding close to the load at which the load is repeated and within this load only the stiffness of the sand column is increased.

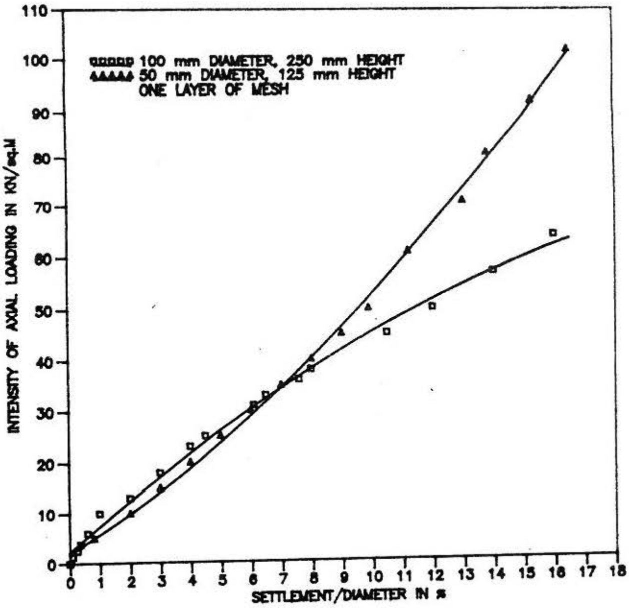


**FIGURE 3 : Load–Deformation Behaviour of Circumferentially Reinforced Sand Column under Uniaxial Compression**

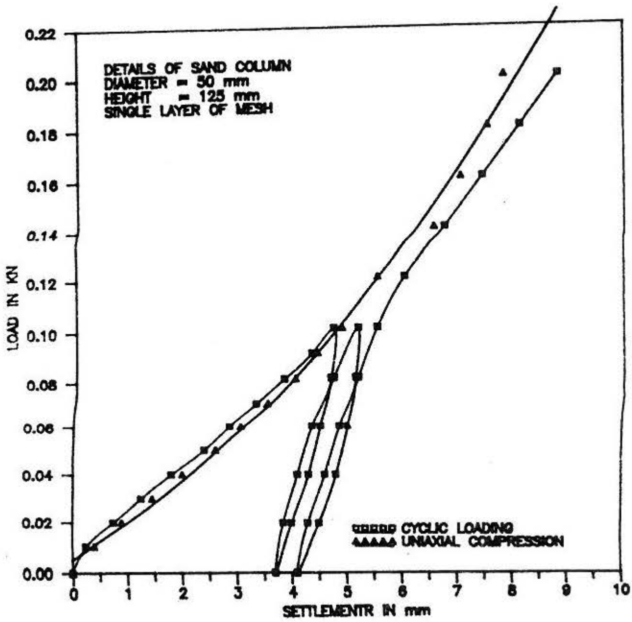


**FIGURE 4 : Load–Deformation Behaviour of Circumferentially Reinforced Sand Column**

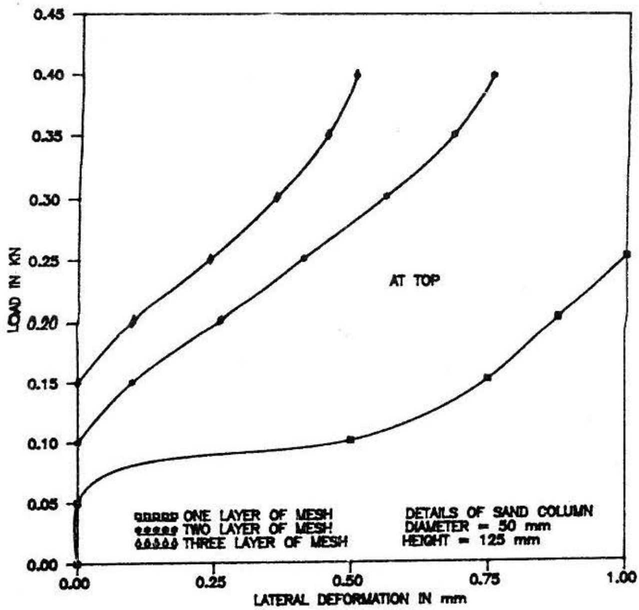


**FIGURE 5a : Lateral Deformations of Reinforced Sand Column during Uniaxial Compression**

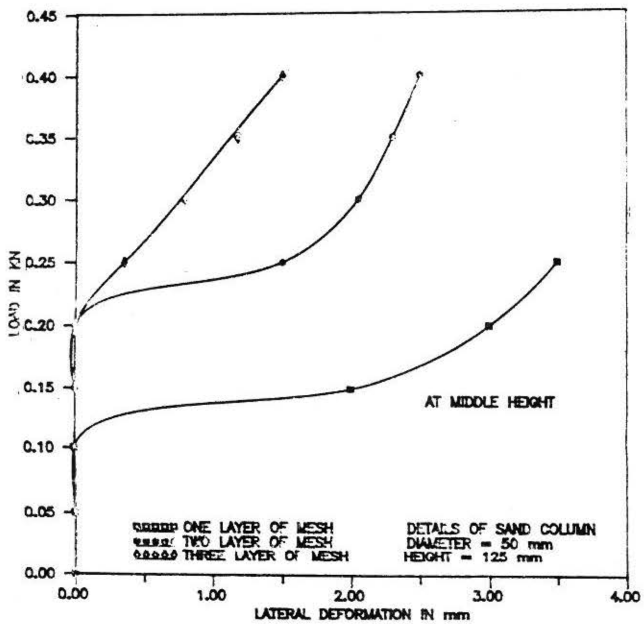


**FIGURE 5b : Lateral Deformations of Reinforced Sand Column during Uniaxial Compression**

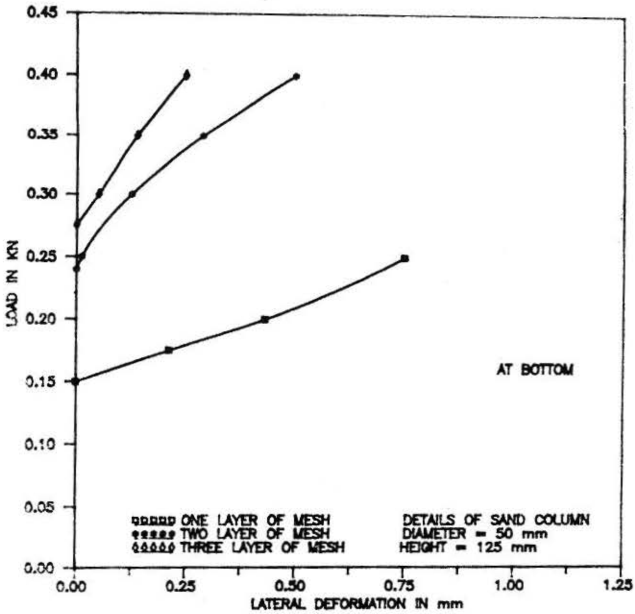


**FIGURE 5c : Lateral Deformations of Reinforced Sand Column during Uniaxial Compression**

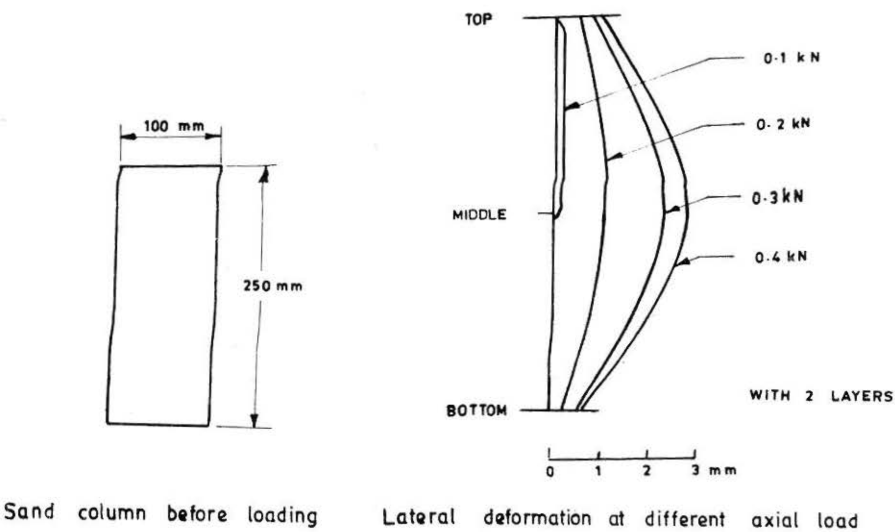


**FIGURE 5d : Sketch of Lateral Deformations of Reinforced Sand Column during Loading**

Observed lateral deformations of circumferentially reinforced sand column of 50 mm diameter under uniaxial compression are presented in Fig. 5. The lateral deformations at top, middle height and bottom are presented. From these figures it is observed that irrespective of the number of confining layers the lateral deformations are maximum at middle height which is more than three times that at top. The lateral deformations at bottom is found to be about two thirds of that at the top. This shows that circumferentially reinforced sand columns exhibit lateral deformations all along the length and this behaviour helps in maintaining a proper contact with surrounding soil which will be lacking in a rigid tubular foundation. Further, it is seen in the figures that the increase in number of confining layers decreases the lateral deformations throughout the length of the column. Therefore it is not advisable to increase the number of confining layers so large as to prevent lateral deformations.

## Behaviour of Reinforced Sand Column Installed in Clay

The load deformation behaviour of reinforced sand column installed in clay is shown in Fig. 6 where the size of the column and number of confining layers are also indicated. It depicts a gradual increase in load carrying capacity and after a settlement ratio of about 8% the load

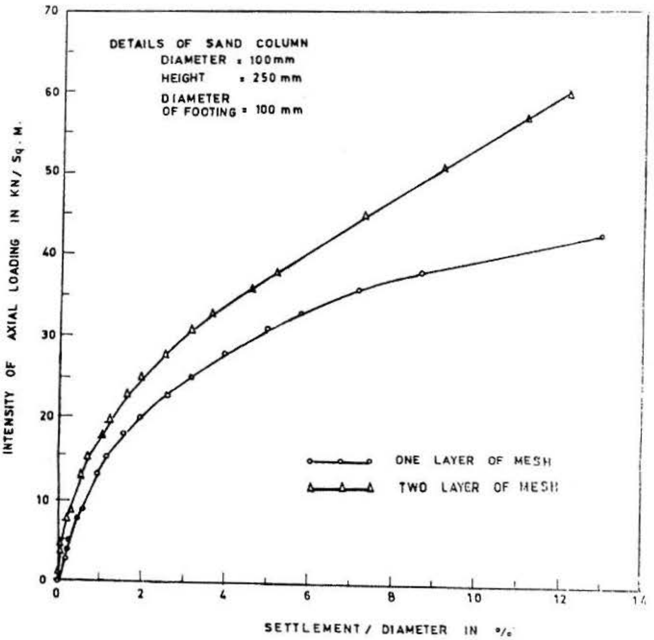


**FIGURE 6 : Load–Deformation Behaviour of Circumferentially Reinforced Sand Column Installed in Clay**

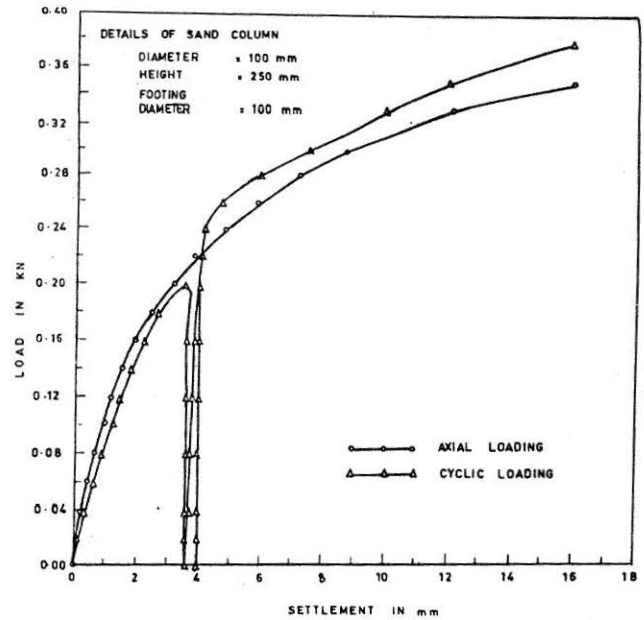


**FIGURE 7 : Load–Deformation Behaviour of Circumferentially Reinforced Sand Column Installed in Clay**

deformation behaviour becomes linear. This indicates that initially the major portion of the load is resisted by the shearing resistance between column and surrounding soil and when the mobilised resistance reaches maximum the additional load is to be borne by the soil at the bottom. The figure also indicates that the increase in number of confining layers increases the load carrying capacity for the same settlement ratio or decreases the settlement for the same load intensity. But the overall behaviour is similar to that with a single layer of reinforcement.

The Fig. 7 depicts the load deformation behaviour of reinforced sand column in clay subjected to repeated loading. It clearly shows that preloading or repeated loading causes development of friction between sand column and surrounding soil which prevents recovery of deformation due to unloading. Thus, the mobilized friction is stored or locked-up which reduces settlement in subsequent loading. If the intensity of loading is more than the preloaded value the load deformation relation beyond the preloading is similar to that of sand column without preloading. These results clearly show that preloading improves the performance of a reinforced sand column and the intensity of preloading should be decided depending upon the actual load coming on to the reinforced sand column.

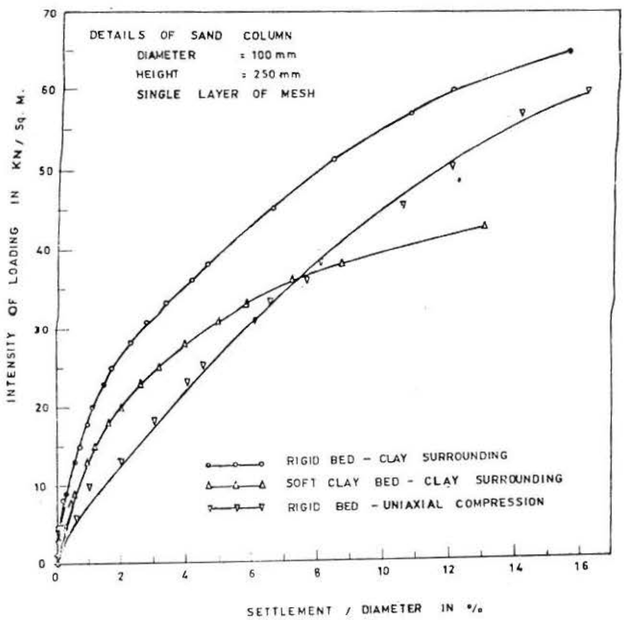


**FIGURE 8 : Load–Deformation Behaviour of Circumferentially Reinforced Sand Column**

Observed load deformation behaviour of reinforced sand column resting on a rigid bed and surrounded by clay is presented in Fig. 8 along with the behaviour of a similar column without rigid base. A comparison of behaviour of similar columns with two different base conditions indicates the influence of rigid layer. As seen from the figure the rigid layer has negligible influence when settlement ratio is less than 2%. But the presence of rigid layer increases load carrying capacity of a reinforced sand column considerably at settlement ratios greater than 2%. This is because the contribution of bearing resistance is larger in the case of a rigid layer than with clay layer at bottom. Hence a reinforced sand column resting on a rigid layer behaves similar to that of sand column under uniaxial compression. This is seen by comparing the behaviour of sand column resting on rigid layer with similar sand column subjected to uniaxial compression as shown in Fig. 8. As seen from the figure these relationships are almost parallel beyond settlement ratio of 5% .But a significant effect of surrounding clay layer in increasing the strength and stiffness of the reinforced sand column can be clearly seen in the figure. This is because the surrounding soil provides additional confining effect.

## Summary and Conclusions

The performance of saturated sand samples prepared with a relative density of 14.72 KN/m were studied in triaxial compression test under small confining pressures. Uniaxial compression tests were carried out on circumferentially reinforced sand column of same relative density to study the load deformation behaviour. Using a laboratory model the load settlement response of a circumferentially reinforced sand column installed in clay soil was also investigated. These experimental studies and their engineering analyses have lead to the following conclusions :

The increase in confining pressure increases the strength and initial stiffness of unreinforced sand samples. But the load deformation response is nonlinear for the pressures considered. The circumferential reinforcement produces an effect similar to confining pressure. But the confining effect increases with axial deformation of sand column whereas in a triaxial test on unreinforced sand column the confining pressure remains constant.

The stiffness of an unreinforced sand column with constant confining pressure goes on decreasing whereas circumferentially reinforced sand column exhibits constant stiffness up to settlement ratio of 15%.

The strength and stiffness of a circumferentially reinforced sand column can be significantly increased by increasing the number of reinforcing layers of Netlon mesh.

Available limited experimental data indicates that the size of the sand column has no influence on the stiffness of the reinforced sand column within a settlement ratio of 12%.

Irrespective of number of confining layers the stiffness of sand column is increased by repeated loading. However, the stiffness becomes constant after two to three cycles of loading.

Due to repeated loading a reinforced sand column either under uniaxial compression or installed in soft clay layer exhibits a well defined yield close to load level subjected to repeated loading.

The load carrying capacity of a circumferentially reinforced sand column installed in clay soil is influenced by the confining capacity of the surrounding soil and the bearing resistance of the layer below.

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