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TECHNICAL NOTE

Load - Settlement Characteristics of Granular Piles with Randomly Mixed Fibres

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Introduction

Marine clays located along and off the Indian coast are very soft and exhibit poor strength and high compressibility. Ground improvement techniques are usually adopted to enable the construction on such type of soils. Out of various types of ground improvement techniques, granular piles are ideally suited for foundations like raft foundations which can permit higher settlements (100 to 300mm). The beneficial effect of granular piles installed in weak deposits is manifested in the form of increased load carrying capacity, significant reduction in total and differential settlements, minimization of the post construction settlements effected by accelerated consolidation, reduction in liquefaction risks, etc.

Various researchers have carried out different experimental and analytical studies to predict the behavior of granular piles installed in soft soils. Bergado and Lam (1987) conducted experimental studies on granular piles on soft Bangkok clay. The ultimate bearing capacity with granular pile was found to be 3 to 4 times more than that of untreated ground. Al-Refeai (1992) examined the behavior of soft soil strengthened with fibre reinforced sand columns. Triaxial compression tests were performed on composite soil specimens made of annular soft clay samples, with both fibers reinforced and unreinforced sand columns. These tests showed that the column replacement ratio and depth of the fibre reinforced sand layer inside column have a significant effect on load carrying capacity and settlement response of the reinforced soft soil.

Triaxial compression tests were conducted by Ranjan et al. (1999) on soft clay sample with central sand fibre core and it was observed that sand fibre core was more effective in increasing the strength of soft clay as compared to granular material alone. Ranjan and Kumar (2000) described a design procedure for skirted granular pile foundation under sustained vertical compressive and uplift loads and for lateral loads with and without moments in

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loose to medium dense cohesionless soil deposits. Shahu et al. (2000) proposed a theoretical study based on unit cell concept and assigned equal strain condition to predict the deformation behavior of uniformly loaded soft ground reinforced by granular piles with granular mat on top of it. Sharma et al. (2004) performed a series of tests to investigate improvement in load-carrying capacity and reduction in bulging of a granular pile in soft clay by layered geogrid reinforcement. The study revealed an increase in the load-carrying capacity of geogrid-reinforced piles. The bulge diameter and bulge length decreased due to the incorporation of geogrid reinforcement.

In most of these studies, the granular pile was not reinforced and in few cases when it was reinforced with fibres, there is not much information available to predict its behavior. An attempt is therefore being made in this work, to study the effect of various parameters like length of pile, ratio of fibre length to granular pile diameter, fibre content and depth of sand pad placed on top of granular pile-reinforced soft soil system on load carrying capacity of piles. Experiments in this study basically are model load tests conducted on clay bed with and without granular piles with and without nylon fibres.

Specifications of Materials Used

Clay bed was prepared in the laboratory in which granular pile made of sand or sand with fibres was installed for conducting the experiments. The clay used for the test bed was borrowed from Mewar, 20 km from IIT Roorkee campus, India. Near surface clay was excavated after removal of top vegetative cover. It was air-dried, pulverized and sieved to remove coarser fraction before using for preparation of test bed. Properties of the clay are given in Table 1.

Table 1 Properties of Clay Used for Preparation of Test Bed

Parameter	*Value*
Specific gravity	2.68
Liquid limit, LL	47%
Plastic limit, PL	22%
Plasticity Index	25%
Clay fraction	52%
Silt fraction	48%
Classification	CI
Max. dry unit weight	16.20 kN/m^3
Optimum moisture content	18.20%

The sand used in the preparation of granular piles for tests was collected from Badsai Bagh, 100 km from IIT Roorkee campus. Properties of sand are mentioned in Table 2.

Nylon fibres of diameter 0.2 mm were used to reinforce the granular pile. The specific gravity of fibre was 0.833. To obtain the tensile strength of fibre, test was conducted on Material Testing Machine in Metallurgy lab of IIT Roorkee, India and result of the same in the form of load-elongation curve was directly obtained and printed from the computerized machine and reproduced in Figure 1. The tensile load at failure has been obtained as 10 N.

Table 2 Properties of Sand Used for Preparation of Granular Piles

Parameter	*Value*
Specific gravity	2.65
D_{60}	0.68 mm
D_{30}	0.295 mm
D_{10}	0.16 mm
C_u	4.25
C_c	0.8
Classification	SP
Max. dry unit weight, γ_{dmax}	19.9 kN/m^3
Min. dry unit weight, γ_{dmin}	16.4 kN/m^3
Angle of friction at 65% relative density from Direct Shear Test	45.81^o

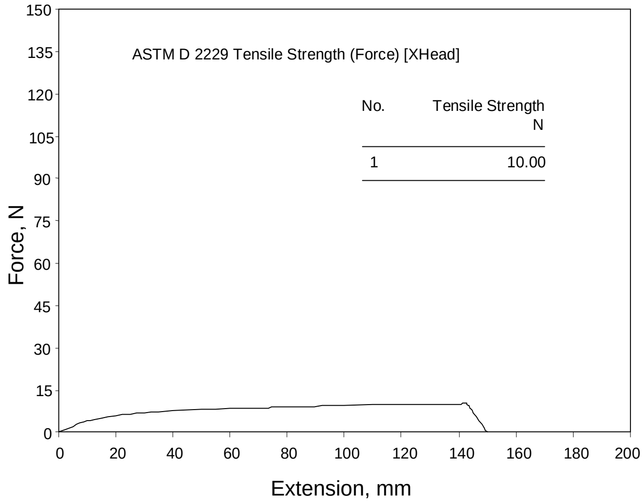

Fig.1 Load – Elongation Response for the Fibres

Experimental Setup and Preparation of Granular Pile

Model tests were conducted in a steel tank of size 52.5 cm × 52.5 cm and 45 cm depth. The set up is shown in Figure 2. The tank was filled with clay of desired consistency in five layers. The water content and dry unit weight of clay have been so maintained that unconfined compressive strength (UCS) of the clay corresponds to that of soft clay. The dry unit weight and water content of clay in the model test were maintained as 15 kN/m^3 and 30 % respectively corresponding to which UCS lies between 30 kPa and 40 kPa. After preparation of the clay bed, a bore hole was drilled by spiral auger as shown in Figure 3.

Diameter of the bore hole has been kept as 50 mm uniformly over the length for all the experiments. Depth of bore hole varied so as to have different L/D ratios. Oven dried coarse sand with fibre (0.2 mm diameter fibre) was mixed with 5% water. The addition of water facilitated easy mixing of fibres and sand. The mixture was then transferred to the borehole in five layers. Each layer was compacted with the help of a steel rod.

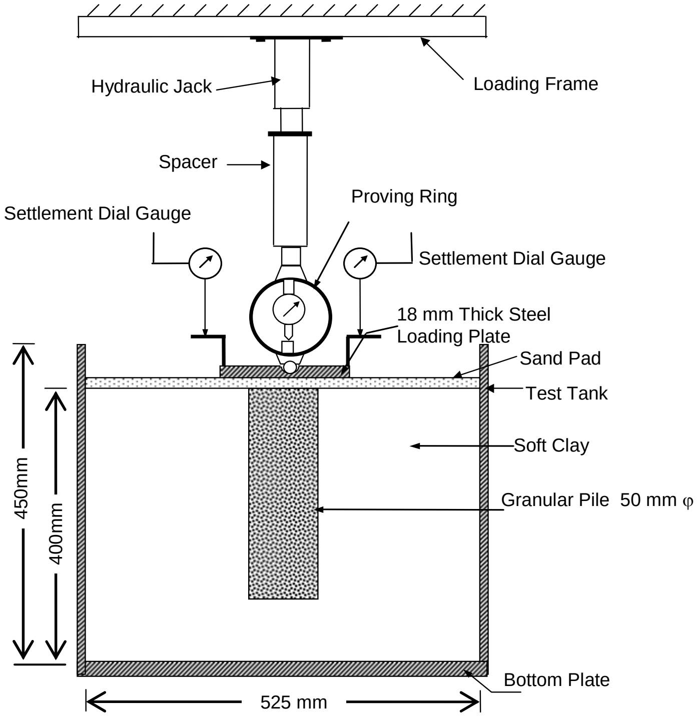

Fig.2 Schematic Diagram of Experimental Set up

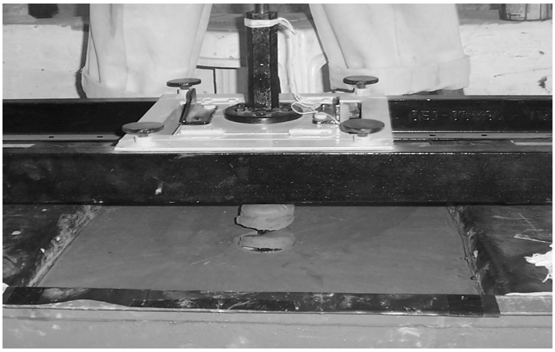

Fig. 3 Drilling of Bore Hole in Prepared Clay Bed by Spiral Auger.

Figure 4 shows the plan view of the granular pile installed in the clay bed. Similar procedure was adopted for the preparation of granular piles without fibres. After the preparation of granular pile, a preload of 5 kPa was applied for 24 hrs over the entire top surface of the clay bed.

Fig.4 Plan View of Reinforced Granular Pile Installed in Clay Bed

A circular steel plate of 100 mm diameter was then placed on the granular pile, through which the load applied in increments. The loading arrangement is shown in Figure 5. Short term load tests were conducted as per the procedure/guideline provided by FHWA (1983). Each load increment was maintained for 15 minutes before the next increment was added. Settlement at the end of 15 minutes after each increment was recorded and the load was incremented until the settlement exceeded 20mm. Unloading was done in five equal decrements with each intermediate load maintained for a period of 15 minutes as per the guidelines of FHWA (1983).

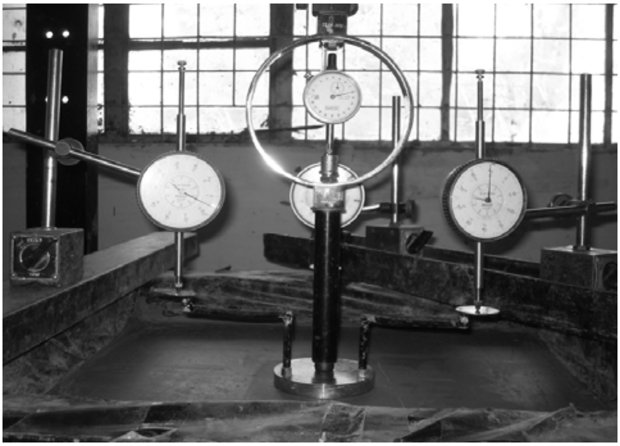

Fig.5 View of Loading Arrangement

Experiments were conducted on 50 mm diameter granular piles of different lengths such as 50mm, 100mm, 150mm, 200mm and 250mm achieving length to diameter ratios (L/D) 1, 2, 3, 4 and 5. A sand pad was placed over the fibre reinforced granular pile-clay bed as shown in Figure 2. To quantify the enhancement in load carrying capacity, load tests were carried out on clay bed without granular pile and with granular pile without fibres. Vertical load was applied by using a mechanical jack against the load frame used in the setup and load applied was measured with the help of proving ring a of 2 kN capacity (Figure 5). Settlement of the sand pile was measured using three dial gauges of 0.01 mm least count placed on the top of the plate. To study the effect of fibre content and fibre length, experiments were conducted with granular column having fibre contents 0.5, 1 and 2% by weight of sand and for fibre lengths 10mm, 20mm and 30mm. Fibres longer than 30mm could not be mixed uniformly with sand and therefore, the fibre length was restricted to 30mm (0.6 times the diameter of the pile in this case). To study the effect of sand pad placed on the top of the clay bed, experiments were conducted with sand pad thickness 25mm (0.50 times the pile diameter) and 50mm (equal to the pile diameter).

Results and Discussion

Effect of Granular Pile Length on Ultimate Load Carrying Capacity

Experiments were conducted on unreinforced granular pile installed in clay bed by varying the length of granular pile. However, the diameter of the pile was kept as 50 mm constant for all these experiments.

Figure 6 shows the applied load intensity vs. settlement response of unreinforced granular pile installed in soft soil for different L/D ratio of granular pile. The response for clay bed without granular pile is also plotted in the same figure (L/D = 0).

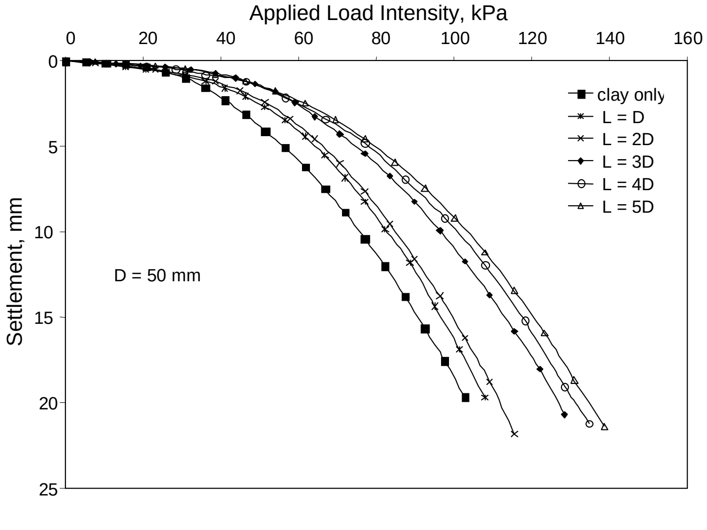

Fig. 6 Applied Load Intensity vs. Settlement Response for Various Length of Granular Pile

Significant increase in the ultimate load intensity is observed as L/D ratio increases from 0 to 5 (142.31 %). As the load is applied on granular pile reinforced soft soil system, the sand in granular pile gets pushed into the surrounding soft soil resulting in passive earth pressure conditions (Rao and Reddy, 1996) and hence an increase in the capacity is observed. Critical pile length has been found to be 4 - 5 D, i.e., beyond this length of granular pile, no significant increase in its capacity has been observed.

Effect of Fibre Content on Ultimate Load Carrying Capacity

Applied load intensity - settlement response of granular pile reinforced with fibre is depicted in Figure 7. Different fibre content by weight of sand were used in the experiments keeping the other parameters like, diameter of granular pile D = 50 mm, length to diameter ratio L/D = 5 and fibre length = 0.6D and the consistency of clay bed constant. It has been observed that ultimate load intensity that can be carried by pile increases as fibre content increases from 0 to 1%, while the trend reversed for more fibre content (2% fibre content). Friction between sand and fibres in granular pile reinforced with fibres comes into play resulting in the development of the tensile stress in the fibres. This tensile stress is responsible for maintaining a rising trend of ultimate load (Ranjan et. al. 1999). The reduction in ultimate load intensity for 2% fibre content may be explained as with high fibre concentration, the dry unit weight of the mixture rapidly decreases, indicating a decrease in relative amount of sand in mixture and so in the ultimate load carrying capacity of granular pile (Al-Refeai 1992).

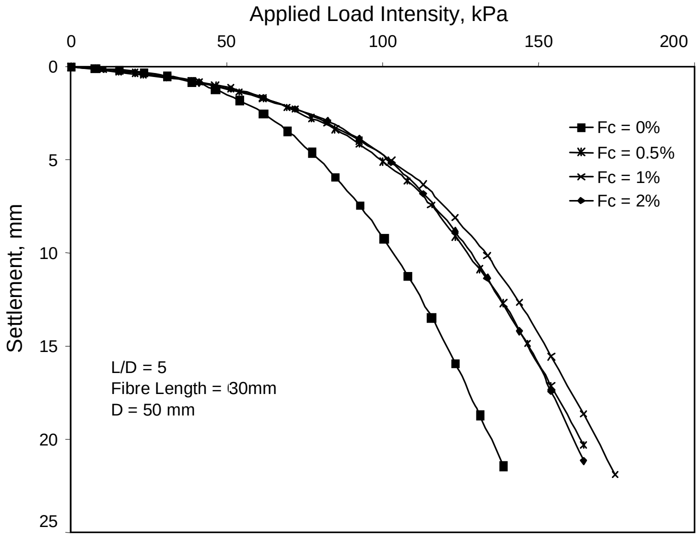

Fig. 7 Applied Load Intensity vs. Settlement Response for Different Fibre Content in Granular Pile

Effect of Fibre Length on Ultimate Load Carrying Capacity

Figure 8 depicts the applied load intensity - settlement response of granular piles reinforced with fibre for various fibre lengths along with the curve corresponding to granular pile without fibre reinforcement for comparison purpose. Other parameters were kept constant and shown in the figure. Increase in ultimate load capacity has been observed with increase in the fibre length. This increase is found to be around 8%, 13% and 21% as fibre length increased from 0 to 10mm, 20mm and 30mm respectively. It may be noted that with the increase in fibre length, the length of fibre available to mobilize frictional resistance between sand and fibre is increased resulting an increase in tensile stress in the fibre and consequently results in an increase in the strength of clay reinforced with fibre reinforced granular pile (Ranjan et al. 1999).

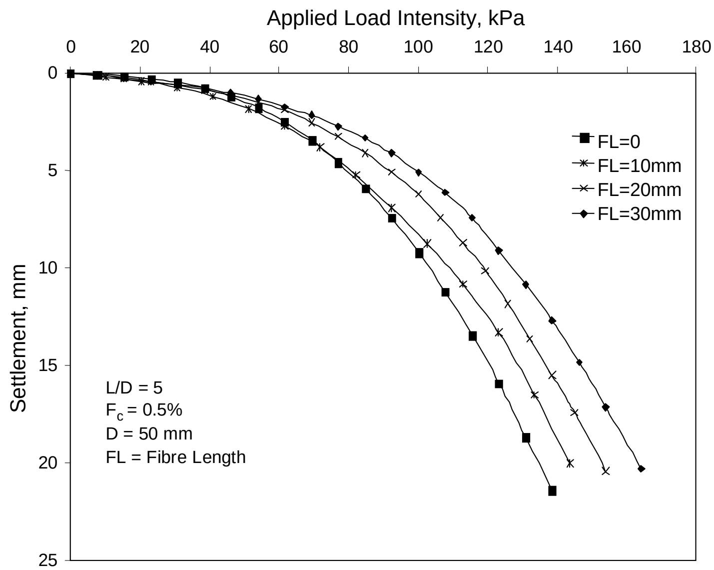

Fig. 8 Applied Load Intensity vs. Settlement Response for Different Fibre Length in Granular Pile

Effect of Sand Pad thickness on Clay Reinforced with Granular Pile on Ultimate Load Carrying Capacity

The effect of sand pad, placed on clay-pile system, on applied load intensity – settlement characteristics of granular pile is presented in Figure 9. The ultimate load intensity is found to increase by 31.58% and 59.21% for corresponding increase in sand pad thickness from 0 to 0.5D (25mm) and D (50mm). This reveals the fact that there is an increase in the ultimate load intensity due to increase in sand pad thickness placed on clay-pile system. Larger thickness of the sand pad leads to more uniform and lesser stress distribution in reinforced ground (both in soil and pile) and the stress transfer from granular pile to soft soil reduces (Shahu et al. 2000).

However, the possible increase in load carrying capacity by the mere presence of sand pad (of thickness as large as 0.50 times the loading area diameter, which is very significant to improve the bearing capacity) is not studied here.

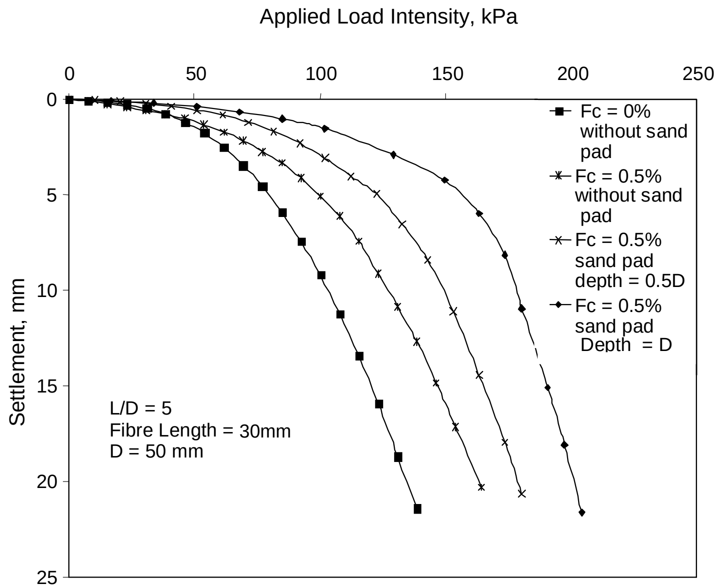

Fig. 9 Applied Load Intensity vs. Settlement Response of Granular Pile for Various Sand Pad Thickness Placed on Clay-Pile System

Conclusions

Based on the experiments carried out in the laboratory, the major conclusions drawn have been listed below:

Load carrying capacity of the granular pile increases with the increase in granular pile length, but the increase in capacity remained stagnant beyond L/D ratio 4 to 5.

The load carrying capacity of the granular pile reinforced with fibres has been found to increase with increase in fibre content in granular pile. As the fibre content increases from 0 to 0.5%, the increase in ultimate load intensity carried by the treated clay bed is about 20%. Fibre content more than 1% did not result further improvement, but showed a declining trend at 2% fibre content.

Soft clay with fibre reinforced granular pile has been found to carry more load as the fibre length in the granular pile increases. The increase in ultimate load intensity has been found to be around 12% as fibre length increases from 10mm to 30mm.

Notations

D	Diameter of granular pile
F_c	Fibre content
FL	Fibre length
L	Length of granular pile

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