Experimental and Numerical Studies of Circular Footing Resting on Fibre Reinforced Cohesive Soil

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Abstract: The reduction in land resources of good quality fill for construction purposes leads to build structures over weak soil after developing its strength through various ground improvement techniques. To increase the strength of the soil, the interaction of reinforcement with soil is very important as this helps to achieve the required strength. This work presents the strength behaviour of cohesive soil reinforced with Poly Vinyl Alcoholic (PVA) fibre of 12mm length varied at 0.1%, 0.2%, 0.3%, 0.4% and 0.5% by dry weight of the soil and Aramid fibre of the same length and same percentage variation. Unconfined Compressive Strength (UCS) of each of the fibre reinforced soil was carried out in the laboratory. Experimental results showed that, the UCS increased with increase in the percentage addition of both the fibres and the strength was also found to be more or less equal. But, when the cost is compared, PVA fibre was found to be cost effective. Hence, to study the behaviour of circular footing on fibre reinforced soil, the PVA fibre was selected for the experimental load test. The results obtained from the experimental study was compared by conducting numerical study using PLAXIS 2D.

Keywords : Fibre reinforced soil, PVA fibre, Aramid fibre.

1 Introduction

Problems like swelling and shrinkage of the soil adversely affects the strength of the soil. Weak soils generally poses problems to structures, placed on such soils due to low bearing capacity and high settlement. Hence, weak soils can be improved by providing reinforcement to the soil. The addition of fibre to the soil increase the strength, reduces the development of crack towards the depth of the soil, and increases the bearing capacity of soil. Inclusion of fibre also showed large reduction in settlement. Usually, cohesive soils experience shrinkage in dry season when exposed to sunlight and results in formation of desiccation cracks which reduces the effective depth of the impermeable layer which enhances the penetration of leachate into the ground. Addition of fibre helps in the prevention of desiccation cracks in soil thereby preventing leachate penetration in waste containment facilities.Subsequent paragraphs, however, are indented.

This paper reports the results of laboratory study of unconfined compressive strength on fibre reinforced soil compacted at optimum moisture content and maximum dry density with various proportions of PolyVinyl Alcoholic fibre and Aramid fibre by weight of the soil. Percentage increase in strength are studied to determine the proportion of fibre at which maximum increase in strength is attained. Laboratory tests show that the unconfined compressive strength of the soil increased with increase in fibre content and the failure nature of the specimen also changed drastically from brittle failure to plastic failure with the addition of fibres to the soil. The loading test using a circular footing over the fibre reinforced soil shows the reduction in settlement and increase in ultimate load carrying capacity.

The present work aims to evaluate the strength characteristics of unreinforced and reinforced soil and to study the failure behaviour of the soil at optimum proportion of fibres. Further, load tests on the fibre reinforced soil with different proportion of fibres are carried out and numerical modelling of the same is performed using PLAXIS 2D.

Lei Gao et al., [1] have conducted a series of unconfined compressive strength tests on clay soil reinforced with basalt fibre under the condition of optimum water content and maximum dry density in order to study the mechanism and effect of basalt fibre reinforced clay soil. The effect of proportion and length of basalt fibre are considered. The results show that the best content and length are 0.25% and 12mm, respectively. Based on this model and SEM images, the effect of fibre content and length is related to the change of fibre-soil column and formation of effective fibre-soil net.

Zeynep H.Ozkul et al., [2] evaluated the drained and undrained shear strength of mixtures of clay and tire buffing. Mixtures of silty low plasticity kaoline clay and 10% by dry weight of tire buffing were compacted at both Standard and Modified compaction energy. By conducting pre shear and post shear permeability tests, it is seen that the peak strength of the composite is comparable to or greater than that of clay alone when tested at confining stresses below 200–300kPa. Above this threshold, the presence of inclusions tends to degrade the strength of the clay. No significant changes in permeability were observed.

Costas A. Anagnostopoulos et al., [3], Chao-Sheng Tang et al., [5], B.Ye, Z.R. Cheng, et al., [8] have investigated the influence of various parameters, such as the strength properties of fibres, the relative size of fibres and grains and the rate of shear on the shear strength of polypropylene or carbon fibre reinforced cohesive soils with different percentage loading of fibres. The experimental results reveal that the inclusion of polypropylene fibres in soil increases considerably the shear strength but the inclusion of the carbon fibres did not produce a clear beneficial effect. Moreover, the addition of the fibres results in substantial increase of friction angle. On the other hand, cohesion does not change considerably with fibre content.

Nilo C.Consoli et al., [4] have discussed the load–settlement response from two steel plate load tests of 0.3 m diameter, 25 mm thick carried out on a thick homogeneous stratum of compacted sandy soil, reinforced with polypropylene fibres, as well as on the same soil without the reinforcement. The strength was found to increase continuously at a constant rate, regardless of the confining pressure applied, not reaching an asymptotic upper limit, even at axial strains as large as 25%. The reinforcement changed dramatically the stress–strain behaviour only at very large strains.

In the present study, two fibres namely, PolyVinyl Alcoholic fibre and Aramid fibres (Fig.1 and Fig.2) are used as reinforcement in soil. PVA fibres have been widely used for industrial, agricultural, fishing applications and are grown world-wide. PVA fibre has suitable characteristics as reinforcing materials for cementious composites. Aramids are generally prepared by the reaction between an Amine group and a carboxylic Acid halide group. They are used in fibre-reinforced concrete, reinforced thermoplastic pipes. PVA fibre and Aramid fibre have high strength and Modulus of Elasticity when compared to other general organic fibre used for reinforcement widely. The size of the Poly Vinyl Alcoholic fibre and Aramid fibre used in this project is 12mm in length and 40µ in diameter.

Fig. 1. Polyvinyl Alcoholic fibre

Fig. 2. Aramid fibre

2 Experimental Investigations

Representative soil samples were collected near Alumni Block, Government College of Technology, Coimbatore at a depth of 1m below existing ground level. The soil collected was classified as Silt of Medium Compressibility (MI) and its properties are tabulated in Table 1.

Table 1. Properties of the soil sample

S.No	Soil Property	Values
1.	Specific gravity, G	2.75
2.	Percentage of Sand Percentage of Silt Percentage of Clay	31% 55% 14%
3.	Liquid limit, w_L	37%
4.	Plastic limit, w_P	29%
5.	Plasticity index, I_P	8%
6.	Optimum moisture content	16%
7.	Maximum dry density, $\gamma_{d(max)}$	1.4 g/cc
8.	Unconfined Compressive Strength	52 kN/m^2

Various experimental studies have been carried out on the fibre reinforced soil by various researchers Chao-Sheng Tang et al.,[6][7] , H.Nahlawi and J.K.Kodikara[9] Abdelaziz Meddah et al.,[11] ,P.J.Venda Oliveira, et al.,[12] to study the strength improvement, such as unconfined compressive strength using carbon fibre. In the present work, unconfined compressive strength, experimental loading test and numerical modelling using software tool on circular footing over reinforced soil are done and reported.

Unconfined compressive strength (UCS) value for unreinforced soil was found to be 52kN/m^2 . The UCS test conducted on soil reinforced with both fibres were carried out at varying proportions such as 0.1% to 0.5% by dry weight of the soil. The proportions are arrived from various studies by M. Jalili Ghazizade and E. Safari 10 .The fibre is mixed with the dry soil thoroughly without any cluster of fibres accumulated so as to form a homogeneous soil matrix. The results of the Unconfined Compressive Strength (UCS) using both fibres are tabulated in Table 2 and Table 3.

Table 2. UCS of Aramid fibre reinforced soil

S.No.	Fibre proportion	Unconfined Compressive Strength (N/mm^2)	Percentage increase in strength
1.	Soil + 0%	0.053	-
2.	Soil + 0.1%	0.065	23%
3.	Soil + 0.2%	0.070	32%
4.	Soil + 0.3%	0.080	51%
5.	Soil + 0.4%	0.097	83%
6.	Soil + 0.5%	0.142	167%

Table 3. UCS of PVA fibre reinforced soil

S.No.	Fibre proportion	Unconfined Compressive Strength (N/mm^2)	Percentage increase in strength
1.	Soil + 0%	0.053	-
2.	Soil + 0.1%	0.065	23%
3.	Soil + 0.2%	0.085	60%
4.	Soil + 0.3%	0.108	103%
5.	Soil + 0.4%	0.124	133%
6.	Soil + 0.5%	0.141	166%

Comparing these two fibres, Poly Vinyl Alcoholic fibre is more suitable than Aramid fibre in a way that the unconfined compression strength of both the fibres are more or less equal but when the costs of the fibres are compared, PVA was found to be cheaper than Aramid fibre. Additional benefits using PVA fibre compared to Aramid fibre includes better mixing of fibre with the soil and high tensile strength. Hence, for experimental loading test on fibre reinforced soil, PVA fibre was chosen.

Experimental loading test was carried out using vertical loading frame arrangement. The loading frame is hydraulically operated, loading is given with the help of proving ring of capacity 50kN. A model circular footing of 80mm diameter is used for the loading test. The foundation medium is prepared by mixing a moisture content of 26% by dry weight of the soil. The soil is placed in a circular tank of size 30cm diameter and is placed in the loading frame. Load is applied to the model footing by using the hydraulic jack and the settlement corresponding to the load is recorded using LVDT. The load vs settlement graph is plotted from the observation made. The ultimate load is calculated from the load vs settlement relationship. The experimental arrangement is shown in Fig.3.

Fig. 3. Experimental setup of circular footing over reinforced soil

3 Numerical Analysis

Numerical analysis of the circular footing was carried out by PLAXIS 2D and involves the following steps. The geometry of the required model is created using Geometry Line command. The circular footing is created using Plate element. The input of soil layers, structures, construction stages, displacement and boundary conditions are created by geometry line. In order to simulate the behaviour of soil, a suitable soil model and appropriate material parameters as shown in Tables 4 and 5 are assigned to the model.

Table 4. Properties of soil in numerical modelling

Properties	Soil
Model type	Mohr-Coulomb (drained)
Saturated unit weight, γ_{sat}	14 kN/m^3
Unsaturated unit weight, γ_{unsat}	16 kN/m^3
Modulus of Elasticity	1.46 x10^4 kN/m^2
Poisson's Ratio	0.35
Friction Angle	5^o
Cohesive strength	26 kN/m^2

Table 5. Properties of circular footing

Parameters	Footing
Normal stiffness (EA)	1.680x10^5 kN/m
Flexural rigidity (EI)	1.407 kN-m^2/m
Equivalent thickness (d)	10mm
Radius	40mm

For simulation of circular footing in axisymmetric configuration, the fixities are established and the displacement is prescribed. The geometric model of circular footing is shown in Fig.4. The numerical analysis is done as per the procedure given PLAXIS 2D manual[10] in series of phases like modelling, mesh generation, calculation and output.

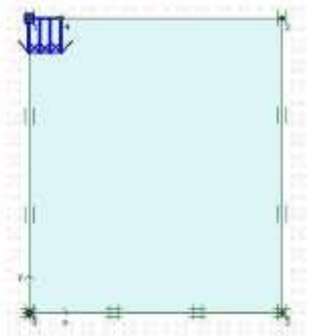

Fig. 4. Model of circular footing in PLAXIS 2D

4 Results and Discussion

The stress - strain graph of unreinforced soil and reinforced soil with various proportions of PVA fibre and Aramid fibre are shown in Figure 5 and 6 respectively. From the relation, the UCS strength is obtained and tabulated in Table 6.

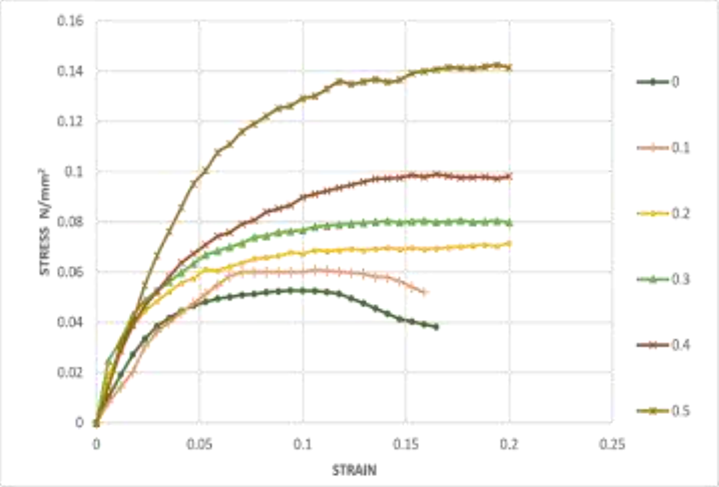

Fig. 5. Stress vs strain of reinforced soil with varying proportions of Aramid fibre

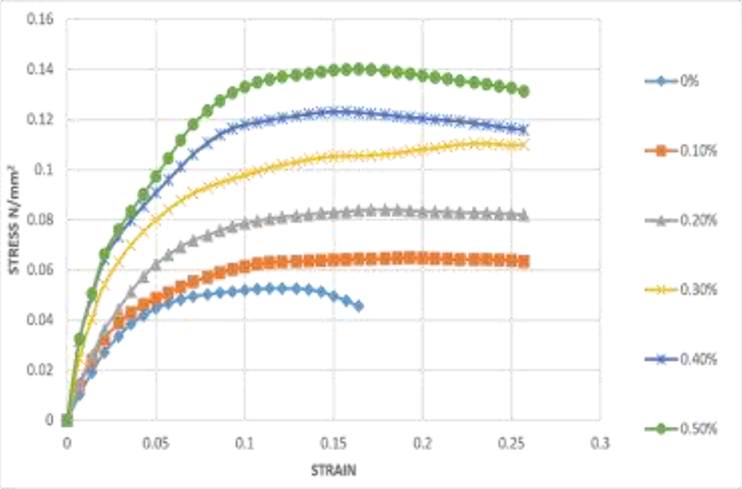

Fig. 6. Stress vs strain graph for reinforced soil with varying proportions of PVA fibre

From the table 6, it is clear that, increase in fibre content in the soil increases the unconfined compressive strength of the soil using both the fibres, but the improvement for a particular percentage of both the fibres was found to be very marginal. It was also observed that, the percentage increase in UCS strength was higher for soil mixed with PVA fibre compared to aramid fibre. The increase in percentage was found to be 23%, 60%, 104%, 134% and 166% respectively for 0.1%, 0.2%, 0.3%, 0.4% and 0.5% of PVA fibre compared to that of unreinforced soil.

Table 6. UCS of unreinforced and reinforced soil

S.No.	**Fibre proportion**	**Unconfined compressive Strength(N/mm^2)**		**Percentage increase in UCS**	
		Aramid	**PVA**	**Aramid**	**PVA**
1.	Soil + 0%	0.053	0.053	-	-
2.	Soil + 0.1%	0.065	0.065	23	23
3.	Soil + 0.2%	0.070	0.085	32	60
4.	Soil + 0.3%	0.080	0.108	51	104
5.	Soil + 0.4%	0.097	0.124	83	134
6.	Soil + 0.5%	0.142	0.141	167	166

After the completion of UCS test, the shear failure pattern (Fig.7) of the tested specimen was studied. UCS sample which was reinforced with fibres showed plastic failure in comparison with to that of unreinforced sample in which the failure is brittle in nature.

Fig. 7. Failure pattern of unreinforced and reinforced soil

4.1 Experimental Loading Test on Fibre Reinforced Soil

The data obtained from the model test conducted on circular footing is plotted in Fig. 8 that shows the relationship between load vs settlement. All the curves show non-linear relationship and the ultimate load obtained from the graph is shown in Table 7.

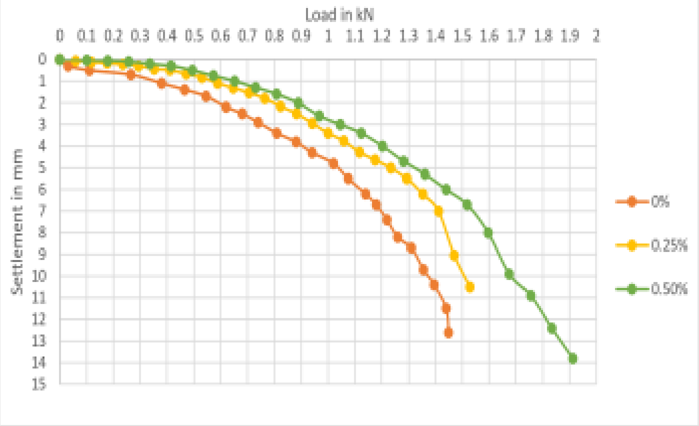

Fig. 8. Load vs settlement relationship of PVA fibre reinforced soil from experimental study

Table 7. Ultimate load obtained from experimental loading test

S.no	Percentage of fibre mixed with the soil	Ultimate load (kN)	Percentage increase in strength
1.	0%	1.1	-
2.	0.25%	1.2	9%
3.	0.5%	1.4	16%

4.2 Numerical analysis on Fibre Reinforced Soil

The load vs displacement relationships obtained through numerical analysis is shown in Fig. 9 for the prescribed settlement that are reached in the laboratory loading test. The figure shows that, with increase in fibre percentage in soil, the ultimate load remains the same but the settlement corresponding to the ultimate load decreases with increase in percentage of fibre. The reason could be the numerical modelling in

PLAXIS 2D involves the calculation of load in terms of settlement, so for the same ultimate load the settlement of the footing gets reduced.

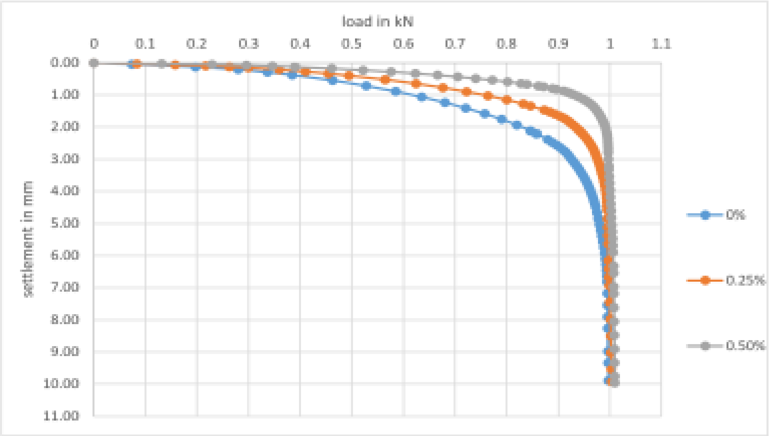

Fig. 9. Load vs settlement relationship of PVA fibre reinforced soil from numerical analysis

The ultimate load and settlement obtained from numerical analysis for the different percentages of fibres are tabulated in Table 8.

Table 8. Ultimate load and settlement obtained from numerical analysis

S.No.	**Percentage of fibre**	**Ultimate Load in kN**	**Settlement in mm (from Numerical Analysis)**	**Percentage reduction in settlement**
1.	0%	0.975	2.2	-
2.	0.25%	0.98	1.3	41
3.	0.5%	0.995	0.8	64

Observing the Tables 7 and 8, the ultimate load from the numerical analysis for the selected percentage of PVA fibre such as 0%, 0.25%, and 0.5% is comparatively less than that of the experimental results by 11%, 18% and 28% respectively. Similarly, the percentage reduction in settlement was found to be 41% and 64% respectively for 0.25% and 0.5% addition of PVA fibre compared to that of unreinforced soil.

5 Conclusion

Based on the results obtained from unconfined compressive strength tests, experimental loading test and numerical analysis of fibre reinforced soil, the following conclusions are made.

1. The unconfined compressive strength of the soil increases with increase in fibre content and attained a maximum strength of 0.142 N/mm^2 at 0.5% of fibre by dry weight of the soil. The increase in strength is due to the confinement of the fibre in all directions probably in the direction perpendicular to the application of load.
2. With the addition of fibre content, the failed samples obtained from unconfined compressive strength test showed that the failure mode changed from brittle to plastic failure.
3. From the experimental loading test, the increase in percentage of fibres in the soil increased the load carrying capacity of the soil to about 16% at 0.5% of fibre in the soil.
4. In numerical analysis, it was observed that increase in percentage of fibre reduced the settlement of the footing in the reinforced soil mass.

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