Behavior of Square Footing on Cement Modified Fibre Reinforced Sand Layer Underlain by Soft Clayey Soil

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Abstract. Deep foundations are generally suggested when soil at the site is weak soft clayey soil. The cost of construction of deep foundations like piles and piers are generally very expensive. However, bearing capacity of weak foundation soil can be improved by various soil stabilization methods so that it becomes suitable for shallow foundation. In present investigation, a layer of sand modified with 5% cement and reinforced with 0.75% polypropylene fiber was placed on top of soft clayey soil. Optimum percentage of cement and fiber required was first determined from proctor compaction tests and direct shear tests. Three different percentages of cement as 2%, 3.5% and 5% and four different percentages of fiber as 0.25%, 0.5% 0.75% and 1% were used for the study. Laboratory modeling was carried out on steel tank with square concrete block of size 20cm x 20cm and thickness 4cm used as footing. Loads were applied by hydraulic jack and recorded in proving ring. Two dial gauges were used in diagonally opposite direction to measure settlement. Load-settlement behavior of footing was studied by varying the ratio of thickness of top sand layer (H) to the width of footing (B) (as H/B = 0, 0.5, 1, 1.5 and 2) for both unreinforced and cement modified fibre reinforced sand layer underlain by soft clay. Optimum H/B ratio for cement modified fibre reinforced sand layer was found to be 1. However, for unreinforced sand layer, the H/B ratio was found to be significantly higher.

Keywords: Soft clayey soil, Polypropylene fibre, Cement modified fibre reinforced sand layer

1 Introduction

Existing soil in the given site for construction may not always be acceptable for the intended purposes. Different types of problematic soils in the sites are inevitable and avoiding the site not suitable for construction is not a good option anymore. There have been an advancement in the Geotechnical Engineering area, which has provided today a solution for tackling numerous problems of soil by various new techniques like soil stabilisation and ground improvement techniques. In order to provide a solution in the most economical and safest way possible, many researches are being done in various areas. Soil stabilisation proved as an effective and promising method in significantly improving the geotechnical soil properties.

When the foundation soil at the site is a soft clayey soil and is very weak to support a shallow foundation, deep foundations are generally suggested. However, deep foundations are expensive and sometimes becomes cost effective only when the structures to be supported are quite huge and heavy. Many researches are going on, that goes beyond only piles and piers and are pushing the industry forward with their new alternative solutions so that a simpler and less costly shallow foundation can be used instead of deep foundations. Therefore, in some cases, the foundation soil bearing capacity improvement can be done by various new ground improvement methods and make it suitable for shallow foundation. Practically, placing a stronger sand layer of proper thickness on top of weak soft clay, can improve the bearing capacity [1]. Many researches are being done relating to inhomogeneous layer of soil bearing capacity, but , relating to this problem detailed design information is still lacking. Many studies are going on to modify the geotechnical properties of poorly graded sandy soil which is just locally available, using various soil stabilization methods like cement, lime, flyash, bitumen, natural and artificial fibres. Stabilisation of soil using cement is popular and attractive method having both soil and rock characteristics [2]. Cement modified soil is one type of soil cement which contains cement percentage of 5% or less [2]. Adding cement in proper percentages increases soil capacity to bear and reduces displacement which are two key parameters needed in the design considerations in geotechnical engineering problems. However, the artificially cemented soil exhibits a noticeably brittle behaviour at peak shear strength at higher percentages of cement which causes sudden failure of soil structures [3]. Hence, its usage is not allowed at shallow depths. However, this problem of sudden failure due to brittleness can be overcome by addition of reinforcing materials like fibres to artificially cemented sand which provides ductile characteristics to the soil at greater peak shear strength [3].

2 Materials Used

2.1 Study Materials

The materials necessary for the present study are as follows:
Clay. Clayey soil used for the study was collected from the paddy fields of Bariknagar. Wet sieving was done for 150g of the sample in which 91-93% of the soil pass through 75 μm sieve and for further analysis, hydrometer tests was done on 50g of soil and the results show 44.02% clay and 53.73% silt. In accordance to Indian Standard Classification System(ISCS), the soil is classified intermediate plasticity clay (CI).

Table 2 Properties of clay

PROPERTIES	VALUES
Liquid Limit	40%
Plastic Limit	22%
Plasticity Index	18%
Shrinkage Limit	13%
Specific Gravity	2.64

Moisture content during model tests	29%
Unit weight during model tests	17.8 kN/m^2
Gravel	0%
Sand	2%
Silt	53.73%
Clay	44.02%
IS Classification System	CI group

Sand. Sand used for the study was locally available, from NIT Silchar. In accordance to the Unified Soil Classification System (USCS), the soil was poorly graded sand (SP).

Table 1. Properties of sand

PROPERTIES	VALUES
Effective Grain Size	0.15 mm
D_{30}	0.20mm
D_{60}	0.23mm
Coefficient of uniformity (C_u)	1.53
Coefficient of curvature (C_c)	1.16
Optimum Moisture Content (OMC)	16.5%
Maximum Dry Density (MDD)	1.63 g/cc
Angle of internal friction (ϕ)	31°
Cohesion (c)	0.015 kg/cm^2
Specific Gravity of solids (G)	2.74

Cement. Cement used for the study is a Portland Cement. In accordance to ASTM C150 (2007), the Portland cement was classified as type II.

Fibre. The type of fiber used for the study was an artificial fibre called polypropylene fibre. The unit weight of this fiber is 8.93 kN/m^3 with average diameter and length of 0.034mm and 12 mm respectively.

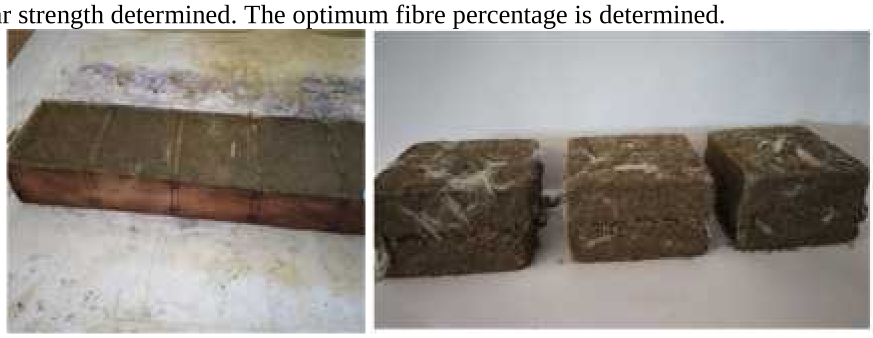
Figure 1. Polypropylene Fibre

3 Experimental Investigation

3.1 Methodology and Testing programme

Standard Proctor Compaction Tests. Standard Proctor Compaction Tests was done in accordance to Indian Standard Code IS: 2720 (Part VII) at three cement percentages (2%, 3.5% and 5%) and four fibre percentages (0.25%, 0.5% ,0.75% and 1%). For sand-cement mixture, the required first cement percentage was mixed thoroughly with the oven dried sand till uniformity in colour was achieved. For process of mixing and compaction, required water is added. The bulk density is calculated from compacted specimen and hence MDD and OMC is found out and the same is repeated for each cement percentage. Optimum cement is found out. Similarly, for sand-cement-fibre mixture, the optimum cement percentage was mixed thoroughly with the oven dried sand till uniformity in colour was achieved and then required first fibre percentage is added and mixed properly with required water. Then, the MDD and OMC is found out. The same is repeated for each fibre percentage.

Direct Shear Tests. Conventional Direct Shear tests apparatus was used to perform Direct Shear Tests. 0.5, 1 and 1.5 kg/cm2, were normal stress considered. Tests was performed by making cube specimens of size slightly smaller than 6cm x 6cm x 3cm at maximum dry unit weight and optimum water content obtained previously from standard proctor compaction tests. The required amount of cement and fibre mixed is calculated based on the sand dry weight. First, for sand-fibre mixture at four fibre percentages (0.25%, 0.5% , 0.75% and 1%) , the fibre is mixed directly with sand thoroughly with optimum water. Secondly, for sand-cement-fibre mixture at optimum cement determined from compaction tests and four fibre percentages, the sand and optimum cement mixture was made thoroughly first so that a uniform colour is acquired and then the fibre is added and mixed well with desired water. In three layers equally, the specimen was statically compacted. Specimen curing for 7 days was done and the tests was conducted. The soil characteristic shear strength determined. The optimum fibre percentage is determined.



(a) (b)

Figure 2. (a) Sample preparation for direct shear tests (b) Stabilized specimen failure at the end of direct shear tests

Experimental Modeling. Experimental test was carried out with the help of a steel tank having size 100cm (length) x 100cm (width) x100cm (height)with square reinforced concrete block of size 20cm x 20cm and thickness 4cm as footing and a steel plate of same size was placed over it to distribute the load equally. First for preparing a layer of clay bed, oven dried clay was pulverised properly and then batches of dried clay selected randomly was thoroughly mixed with calculated water content and density achieved by hit and trial method from unconfined compressive strength tests, to make a clay bed of desired soft consistency. The layer of clay bed of required density was made by dropping freely about 5 kg mass of lumps of clay from height of about 1m. With the help of wooden tamper, each clay bed layer was levelled properly before next clay lumps layer was placed till the required height. Then, to achieve saturation, for about 7 days the clay mass was covered properly using a polythene sheet. Then, for placing a layer of unreinforced sand on top of soft clay bed, the oven dried sand at maximum dry density and optimum moisture content is placed on top of clay bed. For sand layer which is cement modified fibre reinforced , the layer is prepared by manually mixing thoroughly determined optimum cement and optimum fibre with sand at respective optimum moisture content and maximum dry density and in layers is placed and compacted to the required thickness over the clay bed. The model square footing is centrally placed on the top levelled surface sand with the steel plate of same size over it. Loads were applied by hydraulic jack and recorded in proving ring. Two dial gauges were used in diagonally opposite direction to measure settlement.

(a) (b)

Figure 3. (a) Model tank with loading arrangement on soft clay layer (b) Placing the cement modified fibre reinforced sand layer on top of soft clay layer

4 Results and Discussions

4.1 Standard Proctor Compaction Tests Results

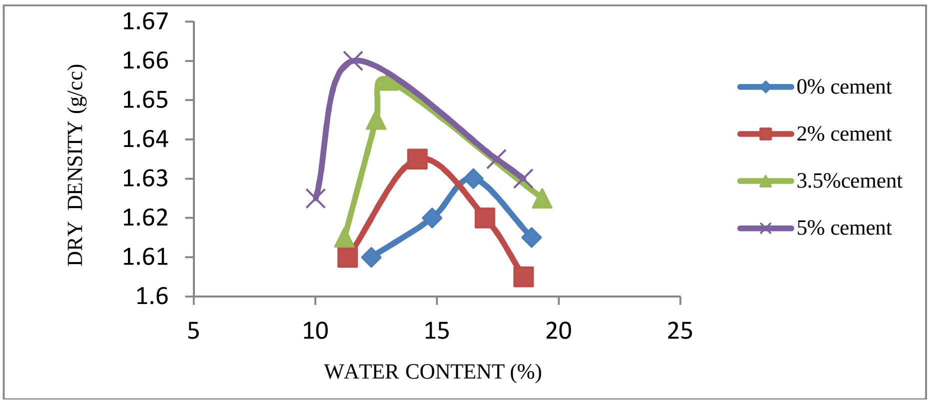


Figure 4. Compaction Curve For Different Cement Percentages

Figure 4 explains, with cement percentage increased as 2%, 3.5% and 5% , the optimum water content values reduced and maximum dry density increased till maximum cement percentage of 5%. Hence the maximum 5% cement is considered optimum cement for the study.

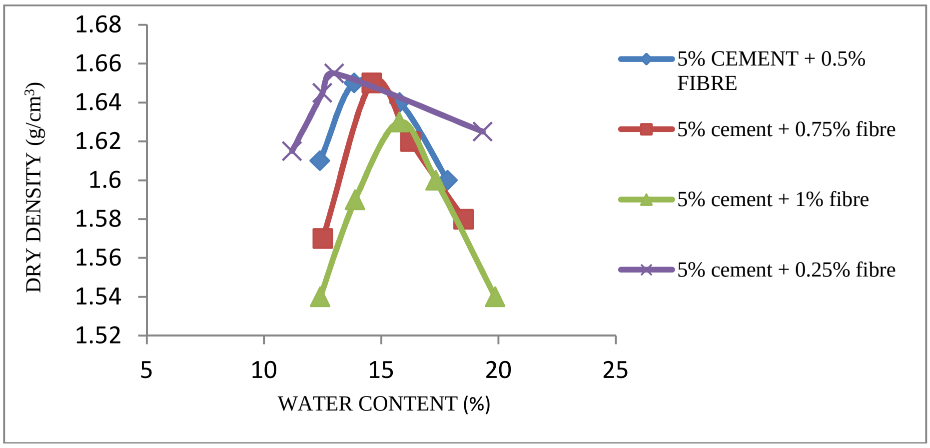


Figure 5. Compaction Curve for Different Fibre Percentages at Optimum Cement

Figure 5 explains, with including of fibre at percentages like 0.25%, 0.5%, 0.75% and 1% with optimum cement, the optimum water content values increased and maximum dry density reduced.

4.2 Direct Shear Tests Results

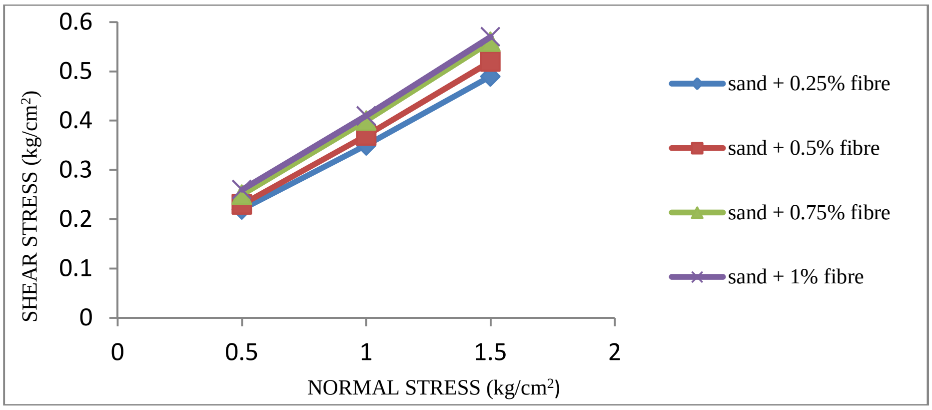


Figure 6. Shear Stress variation with Normal Stress for Different Fibre Percentages without cement

From figure 6, both the parameters of shear strength increases with the including of fibre at increasing percentage at 0% cement, however, upto 0.75%. At 1% fibre inclusion, the internal friction angle value remained constant.

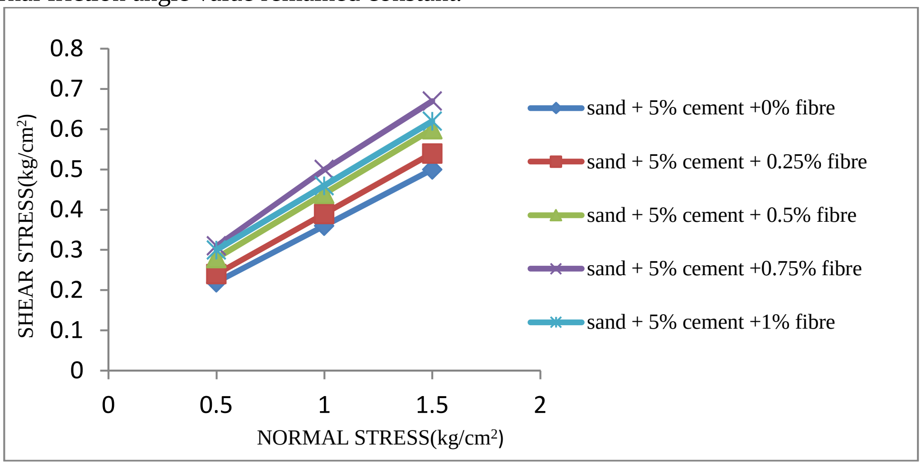


Figure 7. Shear Stress Variation with Normal Stress for Different Fibre Percentages at Optimum Cement

Figure 7 explains that the internal friction angle and cohesion values starts increasing with increasing fibre percentage with percentage of optimum cement, again upto 0.75% fibre. Beyond this fibre percent, the value remained reduced.

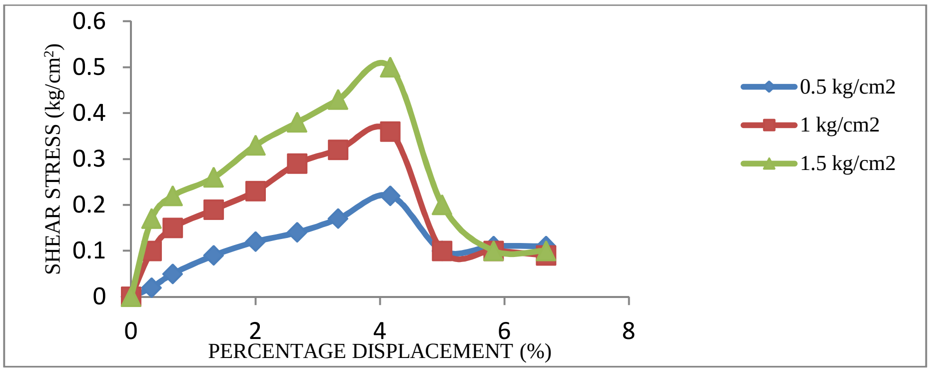


Figure 8. Shear stress variation with shear strain for 5% cement + 0% fibre

From figure 8, for certain normal stress value, the maximum shear stress increased for cement modified sand without fibre. But, the soil exhibited a brittle failure , as the maximum shear stress remarkably dropped.

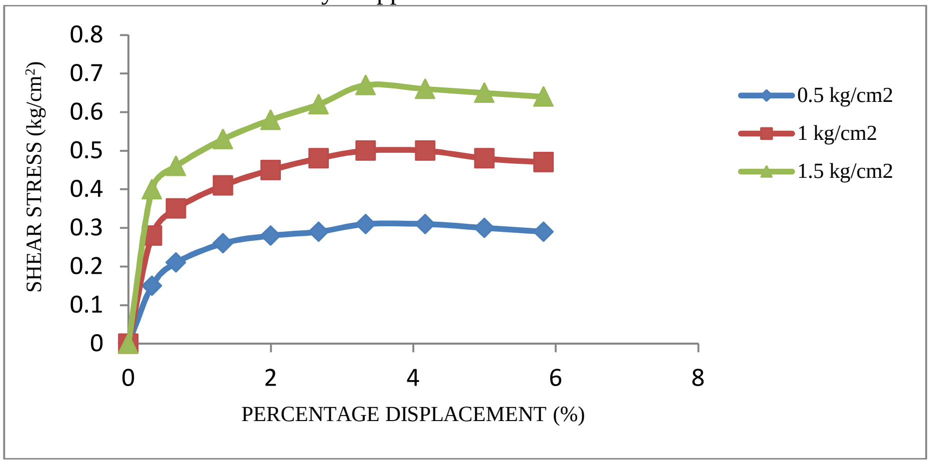


Figure 9. Shear Stress variation with Shear Strain for 5% cement + 0.75% fibre

However, from figure 9, reinforcing cement modified sand with fibre showed ductile characteristics and maximum shear stress also increased remarkably

4.3 Experimental Modeling Results

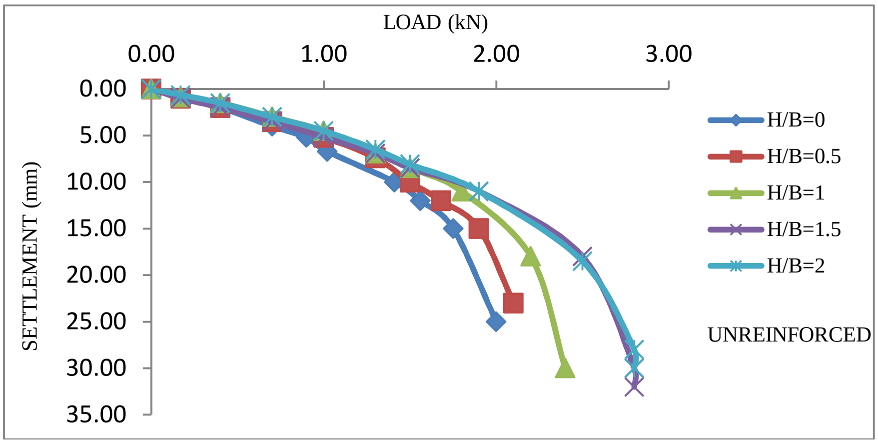


Figure 10. Load vs settlement graph for top sand layer unreinforced with soft clay below

Figure 10 presents the load vs settlement curve for top sand layer unreinforced with soft clay below for different H/B ratios (0,0.5,1,1.5 and 2). The increase of H/B ratios increases the soil bearing capacity, calculated by two tangent method and reduces settlement upto H/B=1, beyond which the increase was not significant.

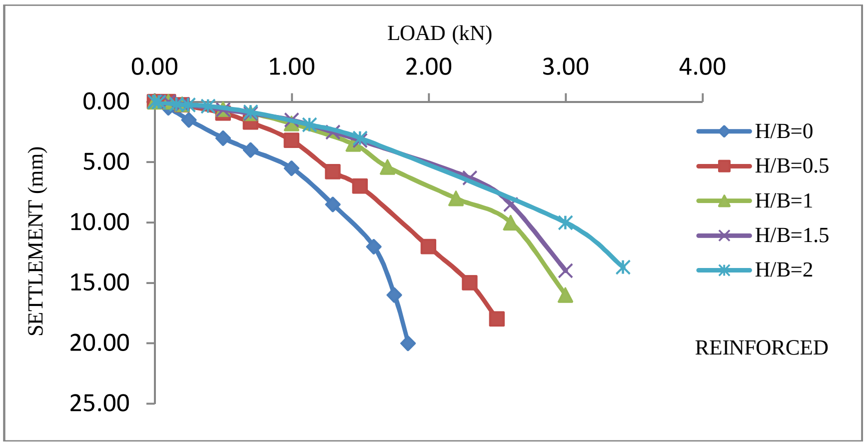


Figure 11. Load vs settlement graph for top sand layer cement modified fibre reinforced with soft clay below

Figure 11 shows a load vs settlement curve for the case when the weak soft clay is overlain by sand layer modified with optimum cement and fiber. The results showed that there was an increase in soil bearing capacity and settlement reduced upto H/B=1, beyond which the increase was not significant again. Hence, the optimum H/B ratio is taken to be 1.

Table 3 Comparison of Experimental Results

Variable Parameters	Experimental Results			
	Unreinforced sand layer		Cement modified fibre reinforced sand layer	
	Ultimate bearing capacity (kN/m^2)	Settlement (mm)	Ultimate bearing capacity (kN/m^2)	Settlement (mm)
H/B=0	37.5	9	37.5	9
H/B=0.5	40	8.5	45	6
H/B=1	47.5	8.5	55	4
H/B=1.5	50	8	57.5	3.5
H/B=2	50	7	60	3.5

5 Conclusion

The conclusions drawn from various tests results and analysis of the study are presented as follows:

1. The sand geotechnical characteristics which was cement modified and fiber reinforced was analysed with the help of Compaction tests and Direct Shear Tests. As the cement percentage increased, decrease in optimum moisture-content (OMC) and increase in maximum dry density (MDD) was seen. Hence, the maximum cement percentage was considered as optimum cement. Then, the fibre percentage was varied at the maximum cement percentage which led to OMC increase and MDD decrease.
2. The interaction of sand, cement and fiber was studied from Direct shear tests results which showed internal friction angle and cohesion significantly increasing as the fiber percentage is increased at maximum cement percentage upto 0.75% fiber and the internal friction angle value became constant at 1%. Hence, 0.75% was taken as the optimum fiber percentage. Reinforcing cement modified sand with polypropylene fibre showed ductile characteristics and maximum shear stress also increased remarkably, otherwise showing brittle nature.
3. From laboratory modeling for the case when the weak soft clay is overlain by sand layer which is unreinforced, the soil bearing capacity increased with H/B

ratio increased, which was calculated by two tangent method and reduces settlement upto H/B=1, beyond which the increase was not significant.

4. From laboratory modeling for the case when the weak soft clay is overlain by sand layer modified with optimum cement and fiber, the bearing capacity increased and settlement reduced upto H/B=1, beyond which the increase was not significant again. Hence, the optimum H/B ratio is taken to be 1.

6 References

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