Load-Settlement Behaviour of Soft Soil Reinforced with Sand Piles

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Abstract – *Recently increasing infrastructure growth in urban and metropolitan areas has resulted in a dramatic rise in land price and lack of suitable sites for development. These factors forced the building industry to look for cheaper land for construction. As a result, construction is now carried out on sites which have poor ground condition that would not previously have been considered economic for construction. Black cotton soil is a problematic soil, often softens under wet condition and has a tendency to swell and shrink in dry state. In the present investigation, square test tank of size 255 mm × 255 mm is used. Tests were conducted on a single pile surrounded by other similar piles. The soft soil water content was kept constant. The test beds were prepared in a model test tank. The soil is used in this study is black cotton soil and the pile material is sand. The sand column diameter 25.4 mm is adopted. Sand piles were constructed and tests were conducted on single pile, and the effective size of footing was varied with their S/D ratio (i.e. 2, 2.5, 3) respectively and also the sand pile L/D ratio (i.e. 3, 5, 7) was also varied. Based on the detailed investigation it is noted that sand pile in soft black cotton soil enhanced load caring capacity and also concluded that the optimum spacing for stone piles is 2.5 times of diameter of sand piles. The optimum length of sand pile is observed as 5 times of its diameter for testing of footing on pile. It gives more reliable results because its boundary condition is similar to field condition.*

Key Words: Sand column, black cotton soil, Sand, S/D ratio, L/D ratio, Bearing capacity ratio.

1. INTRODUCTION

The soil which have undrained low shear strength (<50 kPa) or loose sandy soils including silty or clayey sands are considered as soft soils. The soft clays or soft deposits are found in the subsoil profile at number of places particularly along the coastal region (India has large coastline exceeding 6,000 kms) and swamp area. Soft soils are geologically young sediments, which are unconsolidated deposits having poor strength and high compressibility. Collapsible soils and volumetric unstable soil are also problematic soils. Black cotton soil is a problematic soil, often softens under wet condition and has a tendency to swell and shrink in dry state. Construction solutions on black cotton soils includes methods such as replacement with quality fill materials, chemical stabilization, displacement of soft material, piling, pre-consolidation (sand drains, PVDs, vacuum consolidation), reinforcing with geosythetics. But various problems are not effectively solved with above suggested solutions due to time and money constraints particularly when the geological strata of soft soils extended to large depth. The concept has been successfully applied to improve the soft soils such as marshy lands, marine clays, loose sand, silty or clayey sand and compressible soils. This technique has also been successfully applied for the foundation of structures like oil storage tanks, earthen embankments, raft foundations etc. where large settlement is to be restricted. The technique of stone column or granular pile may then prove effective method of improving black cotton soils and is still in investigation stage.

A brief review of the common methods and their shortcomings has been discussed by various researchers, Sharma et al (2004) performed a series of laboratory analysis to investigate the effect of geogrid on the load bearing capacity and bulging reduction on granular column, Dipty Sarin Isaac and Girish M. S. (2009) study the effect of column material in the performance of stone column in laboratory model test. In their study they used five different materials like quarry dust, sea sand, river sand, gravel and stones, Dash and Bora (2010) performed a series of test on group of floating stone columns reinforced clay bed, Tandel et al. (2012) studied reinforced granular pile as remedial measure of ordinary granular pile, Kumar and Jain (2013) and Kumar (2014) and it is concluded from model study that granular piles/stone columns could be used successfully in improving the behavior of soft expansive black cotton soil, Arora et al (2014) studied behavior of floating granular pile with and without encasement constructed in soft black cotton soil, Samadhiya and Hasan (2015) study a series of laboratory model tests were performed in a circular unit cell tank with the floating granular piles at the centre and the soft soil surrounding it to study the influence of the length and bulging characteristics of granular pile, Thakare and Ahmed (2016) conducted series of model test on soft clay reinforced with stone column, encased stone column and geocell mattress, the encasement of stone column, length of stone column and height of gecell mattress are varying parameter, many researches done so far in black cotton soil with granular pile/stone column is limited to study of single pile with variation of unconfined compressive strength, S/D ratio of pile, floating and end bearing of pile. In most of these studies the granular pile/stone column is loaded directly therefore showing very high strength compared to untreated ground. So, in this study the behavior of soft clayey soil i.e. black cotton soil with sand piles/columns is studied by varying S/D ratio for single as well as group of sand piles with varying L/D ratio and loading plate dimension is decided as per effective diameter concept as suggested by IS:15284 (Part-I):2003[1].

2. LABORATORY MODEL TEST

The objectives of the experimental investigation in the present work are to study the pressure-settlement behavior of a footing resting on a sand pile amongst the group of piles for different S/D ratio and L/D ratio in soft black cotton soil (where L is length of pile, D is diameter of pile and S is centre to centre spacing of piles). The circular footing of different diameter with respect S/D ratio and 10 mm thickness resting on soft black cotton soil is used in the present study. To achieve these, a detailed experimental program has been carried out:

2.1 Test Setup

Fig.-1 shows the model test setup schematically. The model test tank square section with inside dimensions 255 mm × 255 mm and 300 mm (height) was used for preparing test beds. The four sides of tank are made of mild steel sheet and are braced laterally on outer surface with thick steel sheets to avoid yielding during the tests. A proving ring of capacity 4 kN has been used for loading and loading frame of CBR test machine is used to apply load to the pile through the proving ring. The loading platform moves by a strain controlled machine which has rate of strain 1.25 mm per minute. So by recording the load values of the proving ring at regular time interval, load settlement relation is obtained.

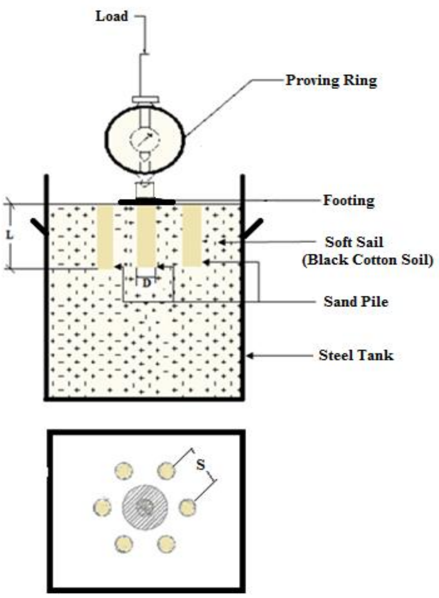

Fig.-1: Setup for Load Test on Sand Pile

2.2 Material Used

The materials used in the investigation consist of Black Cotton soil as soft soil and sand as pile material. The source and relevant properties of these materials are as follows:

Black Cotton Soil - The black cotton soil used in the present study is taken from MANIT, Campus, Bhopal (India). It is black in color and is found mainly in top portion of the ground for about 1-4 m depth. The soil is collected from the ground in bags and cleaned from plastic, wood, tree roots, stones, brick pieces etc. It is then dried in sun to such an extent that it can be broken by wooden hammer. The dry pulverized soil is sieved through 425-micron sieve to find out all basic tests for determining physical properties of the soil. The finer part has been stored in bags for carrying the tests. The physical properties of the clay are determined by following relevant IS code and are presented in Table-1:

Table-1: Properties of Black Cotton Soil

Properties	Value
Liquid limit	50.20%
Plastic limit	25 %
Plasticity index	25.20%
Specific gravity	2.68 %
MDD (Standard compaction)	15.02 kN/m^3
OMC (Standard compaction)	19.20 %
IS Classification of Soil (IS:1498-1970)	CH

Sand Used-The sand used as pile material is taken from the river Narmada passing through a nearby town Hoshangabad (India). It is dried in sun and sieved through 4.75 mm IS sieve. The particles larger than 4.75 mm size have been removed and that passing has been stored. The following laboratory tests were conducted on this sand, specific gravity test, sieve analysis and relative density test, maximum dry unit weight and minimum unit weight etc. And from particle size curve, sand was classified as SP. Properties of sand used is provided in Table. -2:

Table-2: Properties of the Sand

Properties of Sand	Value
Silt and clay content	0.42%
Sand content	99.58%
Gravel content	Nil
10 percent finer than particular size, D_{10}	0.108 mm
30 percent finer than particular size, D_{30}	0.205 mm
60 percent finer than particular size, D_{60}	0.305 mm
Coefficient of Uniformity, C_U	2.824
Coefficient of Curvature, C_C	1.276
Soil classification	SP, Poorly graded sand
Maximum Density, γ_{max}	16.47 kN/m^3
Minimum Density, γ_{min}	14.18 kN/m^3
Maximum Void Ratio, e_{max}	0.8854
Minimum Void Ratio, e_{min}	0.623

2.3 Preparation of Soil Bed

Series of unconfined compressive strength (U.C.S) tests were carried out on clayey soil by varying water content. Curve of variation of U.C.S with water content is shown in Fig.-2. For our investigation water content of 30% is chosen which corresponds to U.C.S of 44.4 kPa.

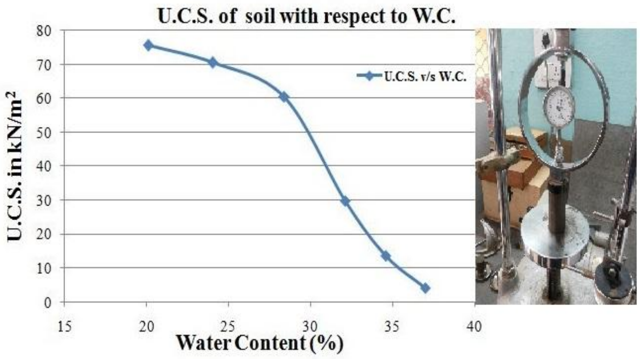

Fig.-2: U.C.S. v/s Water Content of the clay soil

To keep these water content air dried soil was mixed with required quantity of water by weight to achieve required water content. Initially soil was mixed with thoroughly with water and kneading properly and kept covered with impermeable plastic sheet for 24 hrs to ensure uniform water content, after 24 hrs soil was mixed and kneaded well and checked for water content. Before filling the tank with soft soil, thin layer of oil was laid on internal walls of the tank to avoid any friction between soil and walls of tank to prevent loss of water to maintain same unit weight of soil in each test, the tank was filled in five equal layers with measured quantity by weight, each layer was compacted with steel rammer to achieve required thickness and unit weight of the soil is about 18.95 kN/m^3. Care was taken to ensure that no significant air voids were left out in the test bed.

2.4 INSTALLATION OF SAND PILE

After preparing clay bed in tank, granular pile was constructed by a replacement method. A steel pile having outer diameter equal to the diameter of the granular pile was used to the diameter of the granular pile. A thin open ended steel pipe of 25.4 mm diameter and wall thickness 2 mm were used in the present study. The pipe was lubricated with oil at outer surface and it pushed (form sharp edge side) into the soil up to 1.5 to 2 (inches) in every turn for insuring there is no suction pressure generates by surrounding soft clay during withdrawal and hole make desired length of pile. Static force applied manually to push the steel pile gently into the soil (specified pattern) so as to minimize the disturbance in the clay soil that may change the properties of the clay after reinforcement.

Sand was charged into the hole in layers of 25.4 mm thickness with measured quantities and a layer was compacted with steel temper, light compaction effort was adopted to ensure that there is no significant lateral bulging of pile with uniform compacted density of 15.85 kN/m^3 (equivalent to 76 % relative density). This process repeated for all the sand piles and it is shown below step by step with the help of Fig.-3:

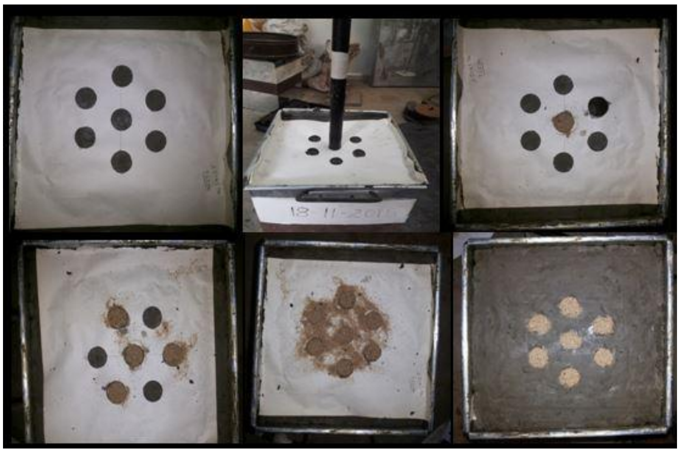

Fig.-3: Installation of Sand Pile in Prepared Clay Bed for Single Sand Pile Load Test

2.5 TEST PROCEDURE

After installation of sand pile was completed, mould was kept under the loading machine, the loading plate (i.e. footing) used in these tests were circular, having diameter equal to the effective diameter of the sand piles with respect to S/D ratio of sand pile. The load was applied through proving ring by a motorized mechanism operating at a constant strain rate of 1.25 mm/min. The settlement readings up to 10% of the diameter of the footing were recorded. The experimental program consisted of a series of model plate load tests with sand piles in a black cotton soil bed. Tests will also be carried on unreinforced clay beds, without sand piles. Test procedure was shown in Fig.-4 and Summary of tests planned and conducted is shown in Table. - 3:

Fig.-4: Experimental Setup for Single Pile Load Test

Table -3: Model Load Tests Conducted on Sand Piles

Test Description	L/D Ratio of pile	S/D Ratio of pile	Dia. of footing plate with respect to S/D Ratio	Total no. of Test
Only clay bed	-	-	D_{f1}	1
Loading on single pile (Total no. of piles constructed 7)	3	2, 2.5, 3	D_{f1}, D_{f2}, D_{f3}	3
	5	2, 2.5, 3	D_{f1}, D_{f2}, D_{f3}	3
	7	2, 2.5, 3	D_{f1}, D_{f2}, D_{f3}	3
Total				10

Where, L = Length of pile,

D = Diameter of pile

S = centre to centre spacing of piles

D_{f1} = 53.3 mm, D_{f2} = 66.6 mm, D_{f3} = 79.9 mm

D_{f4} = 92.3 mm, D_{f5} = 115.4 mm, D_{f6} = 138.4 mm

3. RESULT AND DISCUSSION

As described in previous sections, present work consists of two series of load tests on prepared clay soil beds reinforced with sand piles. The sand piles (floating) of different lengths were prepared. In test series, a central pile, of the group of 7 piles, was tested with varying size of footing (53.3 mm, 66.6 mm and 79.9 mm as per S/D ratio 2, 2.5 and 3 respectively).

Besides these, tests on footings of size 53.3 mm resting on unreinforced clay bed, were also conducted for the purpose of comparison between pressure-settlement behavior of unreinforced and sand pile reinforced clay bed. Pressure-Settlement Behavior of Soft Soil for Single Sand Pile Load Tests as follow:

3.1 Pressure-settlement Behavior of Footing for S/D=2:
The Pressure-settlement behavior of footing of 53.3 mm diameter resting on soft soil and sand pile of S/D ratio 2 and L/D ratio 3, 5 and 7 shown in Fig.-5:

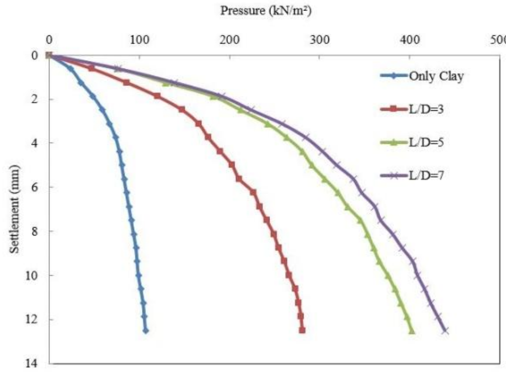

Fig.-5: Pressure-settlement for Single Sand Pile Load Test at S/D=2

1. **3.2 Pressure-settlement Behavior of Footing for S/D=2.5:**
2. The Pressure-settlement behavior of footing of 66.6 mm diameter resting on soft soil and sand pile of S/D ratio 2.5 and L/D ratio 3, 5 and 7 shown in Fig.-6:

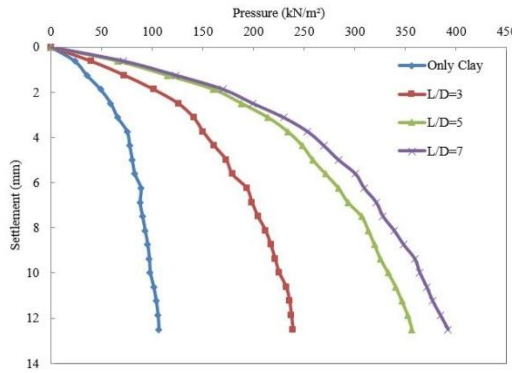

Fig.-6: Pressure-settlement for Single Sand Pile Load Test at S/D=2.5

3. **3.3 Pressure-settlement Behavior of Footing for S/D=3:**
The Pressure-settlement behavior of footing of 79.9 mm diameter resting on soft soil and sand pile of S/D ratio 3 and L/D ratio 3, 5 and 7 shown in Fig.-7:

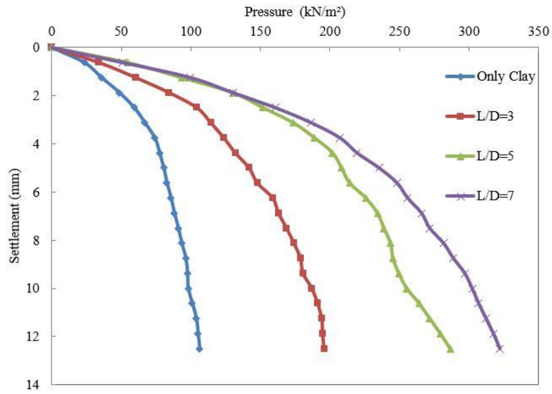

Fig.-7: Pressure-settlement for Single Sand Pile Load Test at S/D=3

From the figures shown above it is noticed that the pressure bearing capacity of floating sand piles are more for the S/D ratio 2 and it is decreasing with increasing the spacing between the sand piles at the constant moisture content.

The results of Fig.-5 to Fig.-7 are used to calculate bearing capacity ratio (B.C.R) i.e. $Q_{(ultimate)}/Q$ and presented by Table-4 and Fig.-8.

Table-4: B.C.R for various L/D & S/D Ratios for Sand Pile Tests

L/D ratio	Bearing Capacity Ratio $Q_{(ultimate)}/Q$		
	S/D = 2	S/D = 2.5	S/D = 3
3	2.53	2.2	1.86
5	3.65	3.25	2.61
7	4.02	3.55	3.01

For given S/D ratio the value of B.C.R with L/D ratio is shown in Fig.-8:

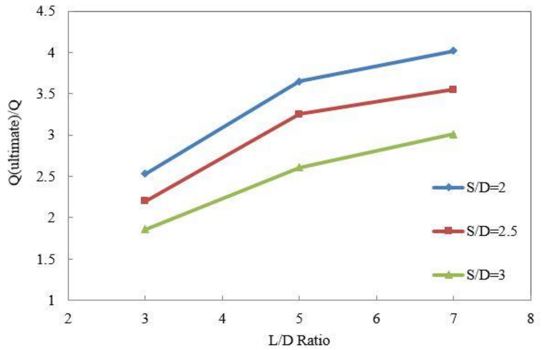

Fig.-8: B.C.R for various L/D & S/D Ratios for Sand Pile Tests

From the results of Table 4 and Fig.-8 above in sand pile load tests the bearing capacity increases with decrease of spacing between sand piles for all L/D ratio but increase of bearing capacity from S/D ratio 2.5 to 2 is less than increase of bearing capacity from S/D ratio 3 to 2.5. And also from above Fig.-8 it is observed that the initial increment in bearing capacity of soil with sand piles of length equal to 3 times to 5 times of pile diameter is more but when we go to increase its length the increment is marginal from length equal to 5 times to 7 times of pile diameter.

4. CONCLUSIONS

Use of sand piles as a method of reinforcing of black cotton soil has been studied in the present work. Loading tests were conducted in the laboratory on soil beds prepared at 30(±1) % of water content and sand piles of varying lengths and spacing's were installed. The diameter of the sand piles was kept as 25.4 mm and the test beds were prepared in a model tank. The pressure-settlement behavior of a sand piles for different S/D and L/D values has been studied. The outcome of the investigation is as follows:

1) The sand pile in soft black cotton soil gives enhanced load carrying capacity in comparison to the footing directly placed on the soft soil alone for any size of footings.
2) L/D equal to 5 may be regarded as optimal pile length to achieve benefit of installing sand piles in the soft black cotton soil.
3) From the results shown above in single pile load tests the bearing capacity increases with decrease of spacing between sand piles for all L/D ratio but increase of bearing capacity from S/D ratio 2.5 to 2 is less than increase of bearing capacity from S/D ratio 3 to 2.5.
4) From these results, it is concluded that the optimum spacing for sand piles is 2.5 times of diameter of sand piles. At this spacing the sand pile gave improvement of bearing capacity of soil up to 3.25 times over soft soil without any sand piles for length equal to 5 times of sand pile diameter.

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