Load Settlement Behavior of Soft Soil with 3D Reinforced Sand Piles

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Abstract. Nowadays due to scarcity of land, structures are built in sites with the available soil conditions including soft soil layers. In site conditions where deep foundations are not a viable solution due to economic considerations, the existing foundation soil has to be modified for better bearing capacity and reduced settlement. In the present scenario a wide variety of ground improvement techniques are available including modification by inclusions and confinement. The use of sand piles is a proven technique to improve the desirable properties of soft soil. In this study the effectiveness of sand piles are further improved by introducing 3D elements into the sand piles. A series of laboratory plate load tests were conducted on a model footing resting on soft clay reinforced with sand pile with and without 3D elements in it. The tests were conducted using two different shapes of 3D elements namely tetrapod and pentapod. Also tests were conducted for different volume ratio of 3D elements as 1.82%, 2.27%, and 2.73% at a constant relative density. Between the two shapes, pentapod elements were more effective due to better confinement of soil between the legs owing to the geometry. Also the bearing capacity improved by increasing the volume content of 3D elements from 1.82% to 2.73%. From the results it can be found that for clay only, the bearing capacity at a settlement ratio of 4% is 94.86 kN/m^2. The bearing capacity of the clay improved to122.76 kN/m^2 when reinforced with sand pile only at 50% relative density. For same relative density of sand pile the bearing capacity of clay improved to 167.40kN/m^2 and 212.04kN/m^2 for sand piles reinforced tetrapod and pentapod elements respectively at volume content of 2.73%. This shows that 3D elements can be effectively used in sand piles for improving the properties of soft clay.

Keywords: Sand pile, 3D elements, Bearing capacity

1 Introduction

Ground improvement is a prerequisite for shallowfoundation structures constructed in soft soil which has low bearing capacity and susceptibility to excessive settlement on loading. There are different methods to improve soft soil as per the site requirement such as mechanical modification, hydraulic modification, physical and chemical modification and modification by inclusions and confinement. Modification by inclusions and confinement denotes stabilizing the soil using fibers, strips, bars, geotextile, etc.

The use of sand piles can also be included in this category to improve the soil properties. In this study the effectiveness of 3D reinforcement namely tetrapod and pentapod along with sand pile to improve the bearing capacity of soft soil was studied by conducting a series of plate loads.

Lawton et al. (1993) introduced the concept of three dimensional reinforcement, by conducting field experiments performed to evaluate the practical aspects of reinforcing cohesionless soils with multioriented geosynthetic inclusions. Tests on California bearing ratio, resistance to compaction, rutting etc. were conducted. Substantial increases in stiffness and strength were obtained by reinforcing cohesionless soils with multioriented inclusions. Multioriented elements also proved useful in reducing rutting in soft and loose soils. Merry S.M.et al. (1999) carried out a study based on the performance of cohesionless soil reinforced multi-oriented geosynthetic inclusions, or geojacks placed over a biaxial geogrid. The results indicate that the combined reinforcement of biaxial geogrids and geojacks improves the ultimate bearing capacity in comparison with geogrid alone.

Harikumar et al. (2016) carried out a study to investigate the effect of hexapods on the shear strength characteristics of sand using triaxial testing. The variables are volume content, hexapod concentration, and number of hexapods per layer and the spacing of layers. From this study it was concluded that the hexapods are effective for improving the shear strength characteristics of sand, and the layered arrangement is more effective. Harikumar et al. (2016) carried out another study on the behaviour of model footing resting on sand bed reinforced with multi directional reinforcing elements. The main objective of this study is to investigate the feasibility of using multi directional reinforcement to improve the bearing capacity of soil. The reinforcement used was hexapods. The variables are depth to first layer of reinforcement, spacing between reinforcing elements, number of layers, and spacing between layers. From this study it was found out that the optimum depth to first layer of reinforcement is 0.5B, optimum spacing between reinforcement 1b, optimum number of layers 2 to 3 and optimum spacing between layers 0.5B.

Load settlement behaviour of soft soil reinforced with sand piles was studied byDevendra et al. (2016). The main objective of the study was to investigate the pressure settlement behaviour of a footing resting on a sand pile for different S/D ratio and L/D ratio in soft black cotton soil. The materials used are black cotton soil and poorly graded sand. The variables are length of pile, centre to centre distance of pile, and diameter of footing. From this it was found out that the optimum spacing of sand pile is 2.5 D and the optimum length of pile is 5 D where D is the diameter of the pile.

2 Test Materials

2.1 Clay

Locally available clayey soil, collected from Alappad region, Thrissur was used in the investigation. The properties of clay are given in Table 1.

Table 1. Properties of test soil

Property	**Value**
Specific gravity	2.36
Liquid limit	53%
Plastic limit	27%
Shrinkage limit	16%
OMC	18%
Maximum dry density	1.54 g/cc
Unconfined compressive strength	27.2 kN/m^2
IS Classification	CH
Organic content	8.3%
Clay content	61.82%
Sand content	20.17%
Silt content	18%

2.2 Sand

Locally available clean river sand obtained from Pattambi region, Palakkad was used for the study. The engineering and index properties of sand are given in Table 2.

Table 2. Properties of sand

Property	**Value**
Specific gravity	2.65
Uniformity co efficient	3.36
Co efficient of curvature	0.94
IS Soil classification	SP
Maximum dry density	1.83 g/cc
Minimum dry density	1.48 g/cc
Effective size D_{10}	0.22
D_{30}	0.39
D_{60}	0.74
Angle of internal friction at relative density 50%	39^0

2.3 3D reinforcement

Two types of 3D jacks are used in this study, namely Tetrapods and Pentapods. Reinforcing elements were manufactured by 3D printing using polypropylene. The physical properties of the material are: density - 0.995 g/cm^3 and melting point - 175 ^{0}C (as provided by manufacturer). The width of Tetrapod is 2 cm and that of Pentapod 2.84 cm. Both Tetrapod and Pentapod are having a surface area of 15.53 cm^2 and weight of 3 g. The reinforcing elements are shown in Fig. 1 and Fig. 2

Fig 1. Tetrapod

Fig 2. Pentapod

3 Methodology

3.1 Test Setup

The test setup for laboratory plate load test consists of the following.

a) Test tank of size 500 x 500 x 700 mm, made of mild steel sheets.

b) MS plate of size 100 x 100 x 20 mm

c) Hydraulic jack, 100 kN capacity

The test setup and loading arrangement are shown in Fig. 3 and Fig 4.

3.2 Test Procedure

Series of plate load test were conducted as IS 1883-1962.A pre-calculated weight of clay was mixed with water at a moisture content of 24%, which is greater than OMC (wet of optimum) and filled in five layers to reach the required height. At the bottom of the tank there is layer of sand in 5cm thickness, which is provided for drainage. After filling the clay up to the mark made on the side wall of the tank each layer was compacted and leveled using a rammer. Tank was filled with clay up to the level were footing has to be placed in unreinforced case, and then it is subjected to loading.

The inner faces of the test tank were made smooth to reduce the boundary effects. Holes are made in the bottom of the tank for drainage. A pre-calculated weight of clay was mixed with water at a moisture content of 24%, which is greater than OMC (wet of optimum) .A PVC pipe of 25cm depth and 5cm diameter is used for providing sand pile. Initially sand is placed in the bottom of the tank at thickness of 5cm for drainage.

Then clay is placed in layers of equal thickness, upto the required height. Then the PVC pipe is placed in the center of the tank, and again clay is filled upto the required level. Sand is placed inside the pipe at the required relative density.

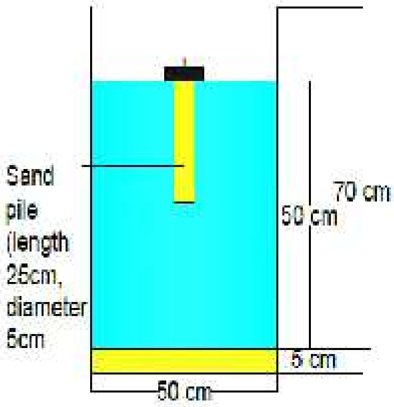

Fig 3. Schematic Test setup

The sand is compacted using a small rammer. Then the pipe is slowly lifted. Then test is also conducted using 3D jack reinforced sand pile. Tetrapods and pentapods are used to reinforce sand. The volume content of jacks is varied as 1.82%, 2.27%, and 2.73%.

Fig 4. Loading arrangement

Then the load is applied by means of hydraulic jack, and the load and settlement are measured. The maximum bearing capacity was compared at a settlement ratio of 4%.

4. Results and discussions

4.1 Effect of unreinforced sand pile

Figure 5 shows the load settlement behavior of unreinforced soil and soil reinforced with sand piles at different relative densities .The sand piles improve the bearing capacity of footing resting on soft clay from 94.86 kN/$m^2$to 122.76 kN/m^2 with a percentage improvement of 29% at relative density of 50% at settlement ratio of 4%.

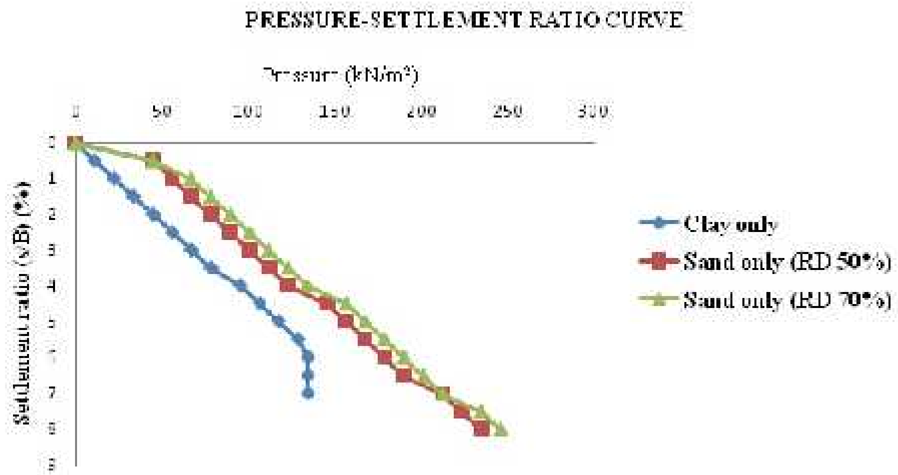

Figure 5.Pressure settlement ratio curves for soil with and without sand pile reinforcement

Table 3. Effect of sand pile on bearing capacity of soil

Test condition	Bearing capacity at s/B of 4% (kN/m^2)
Clay only	94.86
Clay+sand pile (RD 50%)	122.76
Clay+sand pile (RD 70%)	133.92

From the pressure – settlement ratio curves it was found that when sand pile is provided there is a large increase in bearing capacity.This is because of the increased stiffness of the reinforced soil medium due to the installation of the sand pile.

4.2 Effect of Volume content of Tetrapod (RD 50%)

Figure 6 and table 4 show the effect of volume content of tetrapod on the bearing capacity of footing resting on tetrapod reinforced sand pile at a relative density of 50%. Volume content (Vr) is varied as 1.82%, 2.27%, and 2.73%. From the pressure – settlement ratio graphs it was found that as the volume content increases the bearing capacity also increases. The optimum volume content is 2.73%.The increase in bearing capacity is due to the fact that as the volume content increases the number of tetrapods increases. So the surface area of reinforcement that comes in contact with the soil will be more, which in turn increases the friction, confinement, and stiffness of reinforced soil mass.Comparing the increment in volume content from 1.82% to 2.27%, the percentage improvement in bearing capacity is about 16% at a settlement ratio of 4%. Similarly for the increment of volume content from 2.27 % to 2.73%, the percentage improvement is 7 %. There is a marginal increase only in the second case.This may due to transfer of load from sand particles to 3D jacks and less coherent soil structure to increased number of 3D elements.

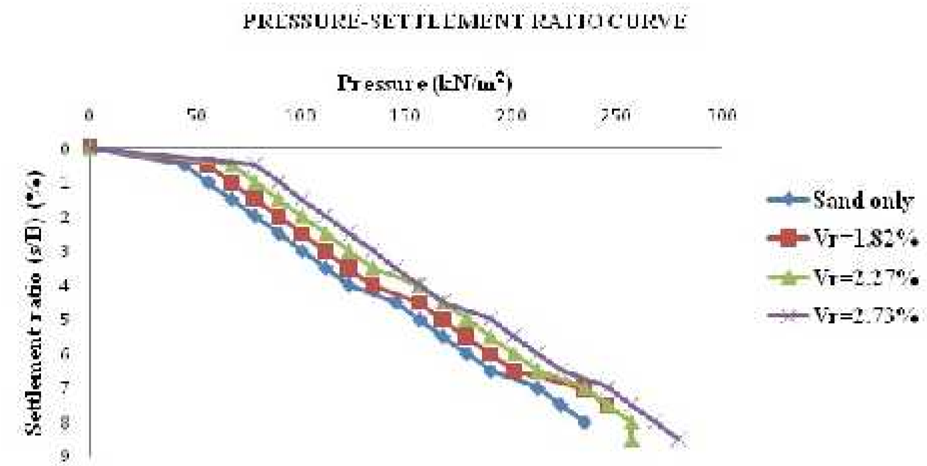

Figure 6. Pressure settlement ratio curves for sand pile reinforced with tetrapod for different volume contents

Table 4. Effect of volume content of tetrapods on bearing capacity (RD 50%)

Test condition	Bearing capacity at s/B of 4% kN/m^2)
Sand only	122.76
Tetrapod (Vr=1.82%)	133.92
Tetrapod (Vr=2.27%)	156.24
Tetrapod (Vr=2.73%)	167.40

4.3. Effect of Volume content of Pentapod (RD 50%)

Figure 7 and table 5 show the effect of volume content of pentapod on the bearing capacity of footing resting on pentapod reinforced sand pile at a relative density of 50%. Volume content

(Vr) is varied as 1.82%, 2.27%, and 2.73%. From the pressure – settlement graphs it was found that as in the case of tetrapod, for pentapod reinforcement also as the volume content increases the bearing capacity of reinforced soil also increases. The optimum volume content is 2.73%. Comparing the increment in volume contentfrom 1.82% to 2.27%, the percentage improvement in bearing capacity is 38 % at a settlement ratio of 4%.Similarly for the increment of volume content from 2.27 % to 2.73%, the percentage improvement is 5%. There is a marginal increase only in the second case.

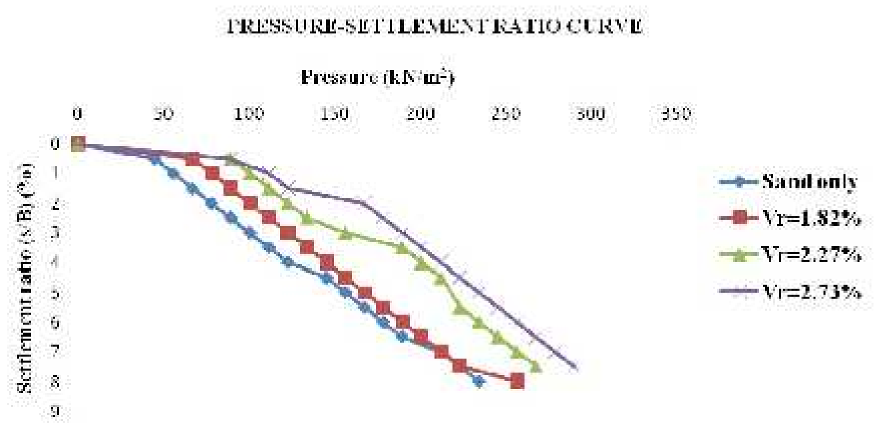

Figure 7 Pressure settlement ratio curves for sand pile reinforced with pentapod for different volume contents

Table 5 Effect of volume content of pentapods on bearing capacity (RD 50%)

Test condition	Bearing capacity at s/B of 4% (kN/m^2)
Sand only	122.76
Pentapod (Vr=1.82%)	145.08
Pentapod (Vr=2.27%)	200.88
Pentapod (Vr=2.73%)	212.04

4.4 Effect of Shape of Reinforcement (RD 50%)

From the pressure–settlement ratio curves it was found that when comparing each volume content of pentapod and tetrapod, pentapods are more effective, and the maximum value for bearing capacity is obtained for pentapod at a volume content 2.73%. This is because of the fact that when comparing tetrapods and pentapods, the quantity of soil confined between the jacks will be more in case of pentapods owing to its geometry.

5. Conclusions

➢ The bearing capacity of soft soil improved by 29% from unreinforced condition to reinforced condition with sand pile of relative density 50%.Similarly there was an improvement in bearing capacity of soil by 41 % when comparing unreinforced condition to reinforced condition with sand pile of relative density of 70%.

➢ The bearing capacity of soil reinforced with sand piles and 3D elements increased as the volume content of elements was increased. But the percentage increment in improvement decreased as volume content of 3D elements was increased. Considering this volume content of 2.27 % is considered as the optimum percentage of 3D reinforcements for both tetrapods and pentapods.

➢ The soft soil having tetrapod reinforced sand pile at optimum volume content showed an improvement in bearing capacity of about 76% in comparison to the unreinforced condition. Also the improvement in bearing capacity was about 36 % when soil reinforced with sand pile and 3D elements was compared with soil reinforced with sand pile only.

➢ Similarly for soft soil reinforced with pentapod and sand pile, the improvement in bearing capacity is 123 % in comparison with unreinforced soil and 72 % when compared to that of soil and sand pile only.

➢ Comparing the shapes, pentapods are more effective than tetrapods as reinforcing elements .There is around 26 % additional improvement in bearing capacity of soil when pentapods are used instead of tetrapods as reinforcing elements in sand piles at optimum content.

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