Numerical Analysis And Experimental Study on Reinforcement Using PVC Rod In The Vicinity of Pressure Bulb In Sand

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Abstract. Owing to the scarcity of land, Geotechnical Engineers are working round the clock for the technique to improve the existing land. One of the technique used by the engineers which helps to improve the engineering characteristics of soil is soil reinforcement. Inclusion of reinforcement in the vicinity of pressure bulb using PVC rods in sand below the footing is a novel approach in ground improvement technique. This paper endeavors to show some aspects on the effects of combined vertical and inclined reinforcement using PVC rods in sand. Both laboratory investigation and numerical analysis using ABAQUS software were carried out. PVC rods were arranged in an array with varying length. The effects of reinforcement within the periphery and outside periphery of the base plate were compared. To achieve the objective, a set of plate load tests were performed on sea sand in its natural grain size and optimum length was found out. The optimum length was found out to be 2.5B, where B is the base of the footing. The test results reveals that the reinforcement using PVC rods improved the mechanical properties of the soil.

Keywords: Ground improvement, PVC rods, Combination of vertical and inclined reinforcement

1 Introduction

1.1 General

Improvement of ground is an imperative method before Geotechnical Engineers everywhere throughout the world. Shortage of land alongside exceptionally frail sub soil conditions of the current ground constrained the geotechnical engineers to work round the clock to discover appropriate solutions. Idea of support of soil including the usage of suitable material has been utilized since before years. Ground improvement procedures are highly favored methods for load bearing applications as low and moderate intense in soft as well as loose soils. Soil reinforcement is one of the method in which tensile components can be placed in the soil to improve the stability and consequently control deformation of the soil structure and foundation also hence there by reducing the settlement of soil. To be more effective, the reinforcement must pass or meet the potential failure surfaces in the soil mass. Strains in soil mass produce strains in the reinforcements, which in turn generate tensile loads in the reinforcements. These tensile loads act to limit soil movement and in this manner grant extra shear strength. This outcomes in the composite soil/reinforcement system having altogether more noteworthy shear strength than the soil mass alone.

This study intends to investigate the chance of utilizing PVC rods and use it in sandy soils to improve the all over stability and improving the mechanical properties like compressibility, shear strength, density. In general, the increase of strength is proportional to the amount of reinforcing material. Use of PVC rods as reinforcement is a smart thought that these are astounding corrosion resistant and climate safe material and it has high compressive strength. It is likewise a decent electrical and thermal insulator. These are effectively accessible in bars and tubing. The soil properties can be improved using PVC rods as reinforcement. Inclusion of reinforcement in the vicinity of pressure bulb enrich the shear strength of soil. Also it aid the use of poorer quality soils to be used as structural component. The stability can be improved by a combination of inclined and vertical insertion of PVC rod. PVC rods can be used to underpin foundations resting on sandy soil. The surrounding soil achieves strength by the densification process where the soil gets densified into a tighter configuration, resulting in increased density. Thus the shear strength of the soil increases and results in the enhancement in engineering properties of the soil. The use of combination of vertical and inclined insertion of the PVC rod gives additional strength when compared to the vertical insertion.

2 Experimental Program

In this study PVC rods are inserted in a combination of vertical and inclined reinforcement in two arrays in the vicinity of the pressure bulb. Here the variables used for the study are the length of reinforcement, diameter of reinforcement, extent of reinforcement. The Plate load test implemented in the laboratory is simulated using 3D software. PVC rod with varying length are compared and optimum length is found out. The length was varied to 1.5B, 2B, 2.5B where B is the base of the footing The load versus settlement graph are evaluated based on plate load test as well as numerical analysis.

2.1 Materials used

The soil sample was collected from Menamkulam beach, Trivandrum. Sea sand is selected for this study. Various tests are conducted on the sand according to the IS specification. Dry sieve analysis is conducted and soil is classified as uniformly graded sand as per IS 2720. Table 1 shows the properties of the soil.

Table 1. Properties of soil

Soil Property	Values
Specific Gravity	2.665
Max. dry density (kN/m3)	17.48
Min dry density (KN/ m3)	14.69
D_{10}	0.21
D_{30}	0.28
Uniformity coefficient, Cu	1.57
Cc	1.131

PVC rods were purchased from Yogdeep Enterprises Pvt ltd, Mumbai. The rods are intruded by checking the angle of orientation as constant as 450. PVC rods were placed symmetrically at 8 points in inclined manner & vertically at 3 points.

Table 2. Properties of PVC rod

PVC rods Property	values
Density	1580Kg/
Modulus of Elasticity	3174 Mpa
Temperature Resistance	70^0 c
Yield Strength	45Mpa

2.2 Test setup

The plate load tests were conducted on sand filled in a circular tank of diameter 0.6 m and 0.4m height. Cast iron tank was used so that its wall do not deform during tests. A rough mild steel plate of 12cm diameter and 2cm thickness was used as footing. Sand was filled in the tank at required density using the raining technique at a height of fall of 30 cm. The points of intrusion of rods were equidistance from the center point of the tank. Sand was filled in the tank in 35% of relative density. Manually operated hydraulic jack used for loading circular footing. The hydraulic jack was mounted on a self-reacting frame. Proving ring which is pre calibrated was used to measure the load applied on the footing. The proving ring was placed between hydraulic jack and the footing with a ball- bearing arrangement. Loading was applied using hydraulic jack of 10 T capacity and the applied load was measured using a proving ring of 30 KN capacity. Two dial gauges of 0.01mm least count were placed diametrically opposite to each other for measuring the settlement of plate. The test load was increased gradually till the plate settle at constant rate. The ultimate load bearing capacity of the soil was calculated by dividing the value of total load on the plate by area of steel plate.

Fig. 1. Photograph of the test setup

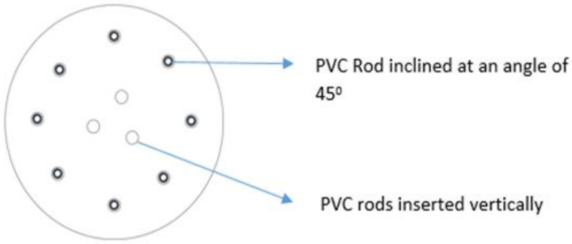

Fig. 2. Arrangement of PVC rods

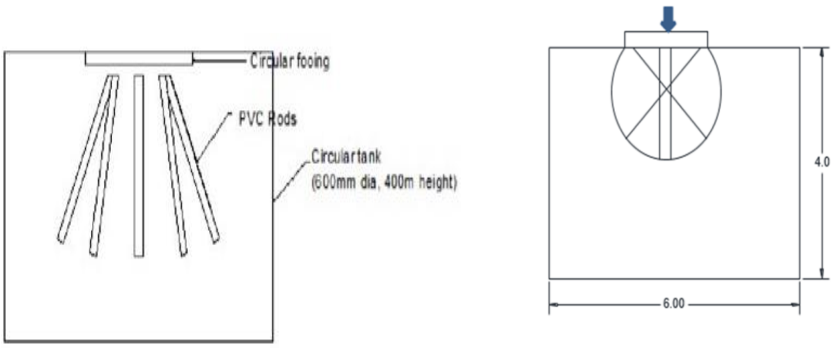

Fig. 3. Schematic diagram of orientation of reinforcing rods in to the sand

2.3 Modelling and analysis

Modeling and analysis is carried out using the ABAQUS 6.14.2- 3D Software to study the behavior of sand when combination of vertical and inclined reinforcement with PVC rods are used and also of sand without any reinforcement. The experimental results were also cross checked through finite-element analysis using ABAQUS software The size of the numerical model is kept equivalent to the trial arrangement, where boundaries were kept 5 times away from the center of the footing. A versatile completely plastic Mohr-Coulomb constitutive model was considered for sand, and a linear elastic model was picked for the PVC rods. The PVC rods are inserted into the sand using the interaction module. A 3D deformable part is created for the soil specimen, material properties are assigned and section is defined as solid, homogeneous. A Uniform Pressure load of 300Kpa is applied. The boundary conditions are given such that as only vertical movements are allowed.

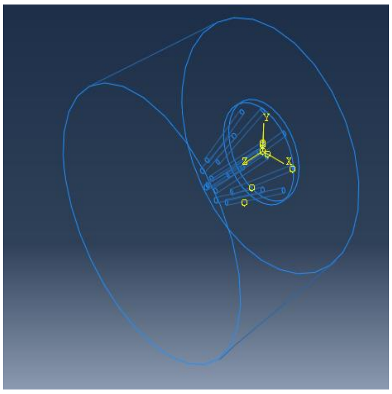

Fig. 4. PVC rods arranged in 2 arrays of 1.5B length and 6 mm diameter.

Table 3. Variables of study used

Type of test	Variables
Type of the test tank	Circular
Size of the test tank	0.6m diameter x 0.4m
Type of footing	Circular
Size of footing	0.12m diameter x 0.02m
Length of reinforcement	1.5B, 2B, 2.5B, 2.75B
Diameter of reinforcement	6mm, 8mm

3 Results and Discussion

From the series of plate load test results, load- settlement curves are plotted. The improvement in performance due to the provision of PVC rods is significantly noticeable. The load settlement response of reinforced and unreinforced sand bed is illustrated in the following figures. Here the reinforcement was applied in the vicinity of the pressure bulb. When the pressure bulb criteria was concerned, it can be seen that we can effectively reduce the cost of consumption of the PVC rods. Since PVC rod being the denser material nearly equal to the sand we can completely utilize the soil for load transferring.

The main objective of this study is to determine the efficiency of the combined vertical and inclined reinforcement of the PVC rods. The results are presented with the reference of the unreinforced soil. For this purpose the pressure settlement graphs are plotted. The ultimate bearing capacity was determined by double tangent method since there was no definite failure point. The bearing capacity improvement was represented by a factor called Bearing Capacity Ratio (BCR) defined as bearing capacity of the reinforced soil to the unreinforced soil.

The length of insertion is varied as 1.5B, 2B, 2.5B where B is the base of the footing. The optimum length was found out. Comparing the curves of 6 mm dia and 8 mm dia reinforcement, curve corresponding to 8 mm dia bar has lesser slope than 6 mm dia bar. It indicates that as the diameter of the reinforcing rod increases, bearing capacity increases and settlement reduces and enhances the overall stability.

3.1 Effect of length and diameter on pressure settlement response using plate load test

Length of the PVC rod is a governing factor to influence the behavior of reinforced sand bed. In the cost effective point of view it helps to reduce the wastage of the reinforcement and thereby reduce the cost.

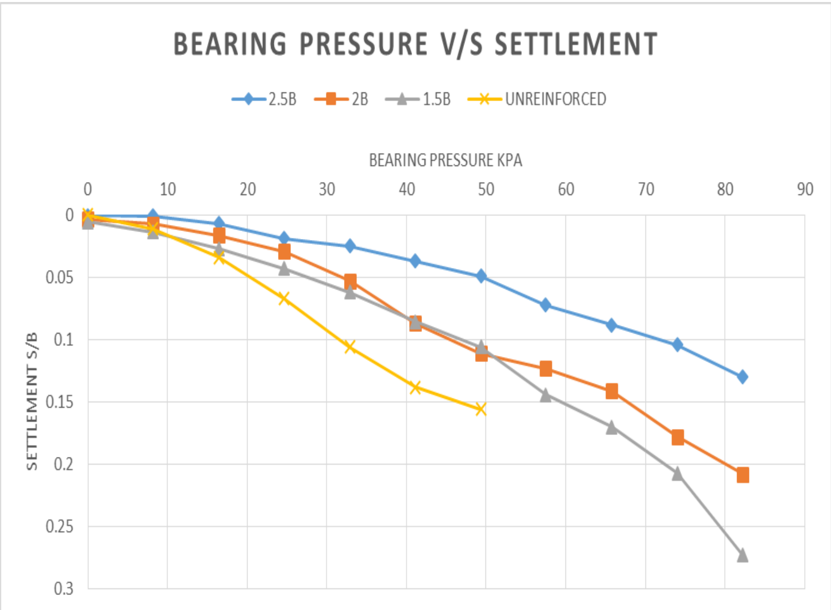

Fig. 5. Pressure-settlement response of footing on reinforced sand bed with varying length having diameter 6mm.

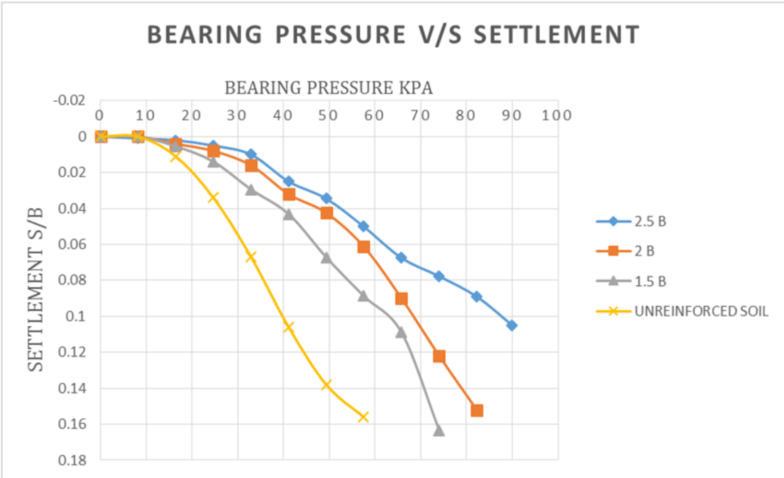

Fig 6. Pressure-settlement response of footing on reinforced sand bed with varying length having diameter 8 mm.

From the figure it can be seen that the slope of the curve decreases with addition of Combination of inclined and vertical reinforcement in the vicinity of the pressure bulb. It indicates that strength has got improved and settlement has got reduced with addition of reinforcement. This may be because of the fact that as a result of the introduction of a stiffer material into the soil the stiffness of the PVC rod–soil system increased, i.e., PVC rod into the loose– medium dense sand.

Diameter of the rod were selected as 6 mm and 8 mm. From the pressure settlement graph, it is becomes apparent that for the same spacing ratio and test condition reinforcement having thicker diameter gives lower magnitude of displacement. Increase in diameter increase the stiffness of the reinforcing element and reduces the lateral movement which in turn reduces the settlement.

3.2 Effect of length and diameter on pressure settlement response using Numerical Analysis

On comparing the displacement contour of the PVC rod reinforced soil with varying length it can be seen that embedded part of the reinforcement in the stable underlying soil increases as the length of the reinforcement increases thus imparting resistance to the lateral movement. This improved resistance enhances confinement of the soil resulting in the decrease in the vertical movement.

On further studies it can be inferred that when a length greater than 2.5B was used there was no considerable improvement. Hence in order to reduce the cost of consumption, the optimum length of the PVC rod was taken as 2.5B, where B is the base of the footing.

Stress contours of reinforced and unreinforced soil are given below. It can be seen that when the reinforcement is added to the soil, the stress values get decreases.

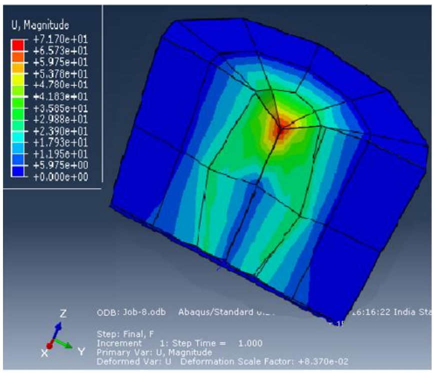

Fig. 7. Displacement contour of the Unreinforced soil

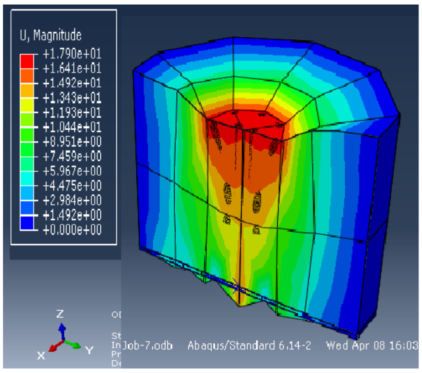

Fig.8. Displacement contour of the PVC rod reinforced soil (1.5 B)

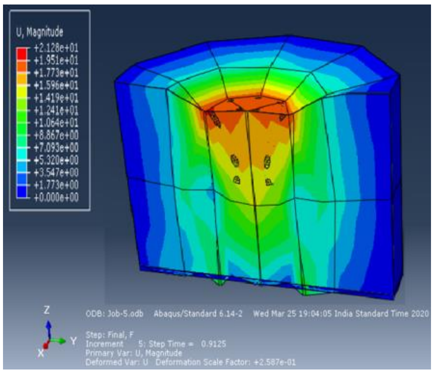

Fig.9. Displacement contour of the PVC rod reinforced soil (2.0 B)

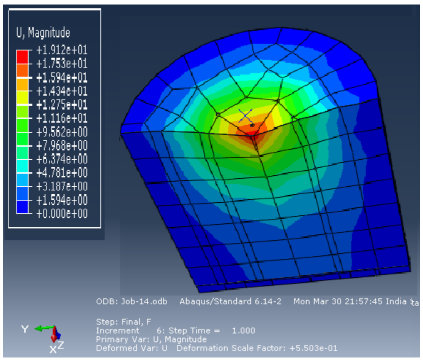

Fig.10. Displacement contour of the PVC rod reinforced soil (2.5 B)

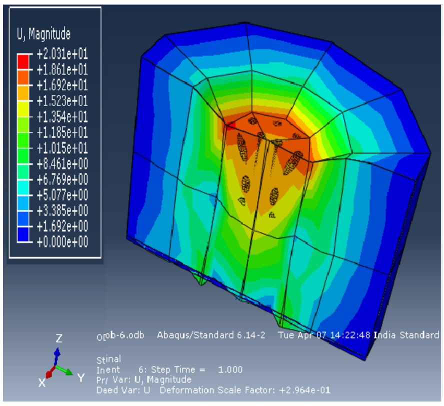

Fig.11. Displacement contour of PVC rod reinforced soil (L=1.5B, d=8 mm)

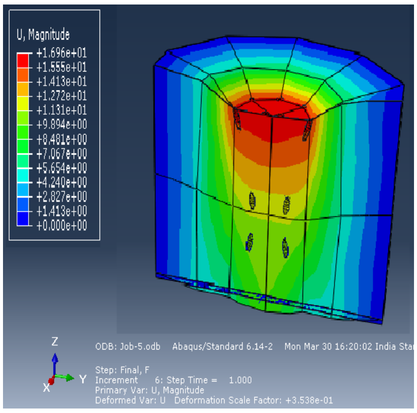

Fig.12. Displacement contour of PVC rod reinforced soil (L =2B, d = 8mm)

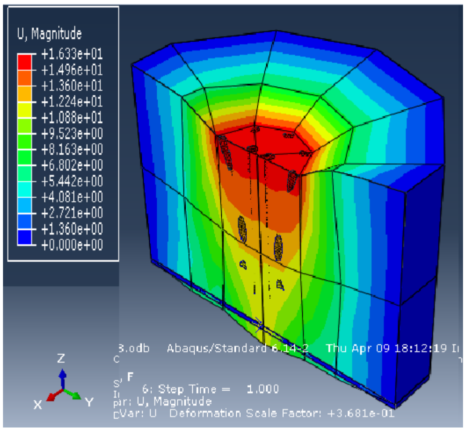

Fig. 13. Displacement contour PVC rod reinforced soil (L= 2.5B, d=8mm)

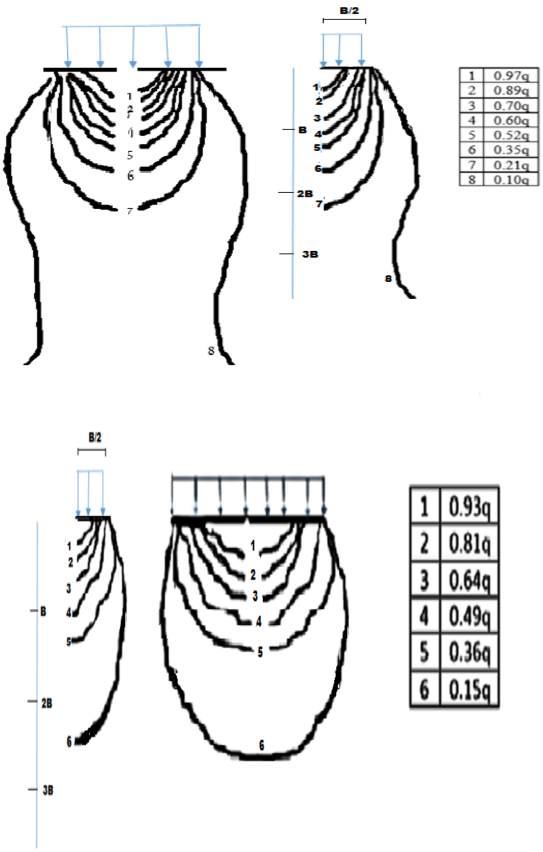

Fig.14. Pressure Bulb

3.3 Validation

Numerical model is compared with the experimental values using stress settlement curve for reinforcement with PVC rods. The results of the experimental program are analogous with the FEM analysis results. It is observed that the experimental and numerical simulation shows a similar trend.

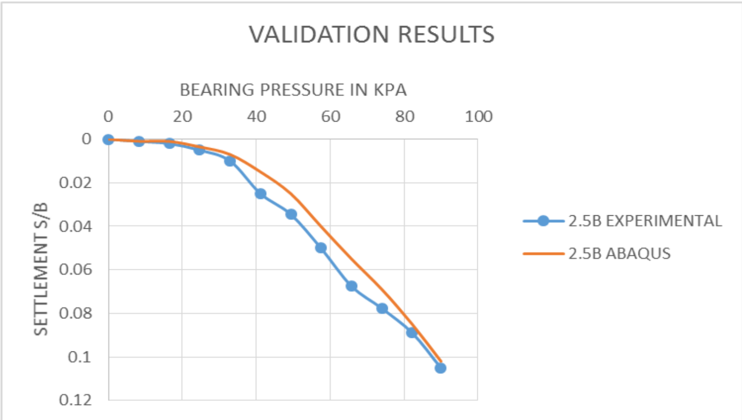

Fig. 13. Validation graph for reinforcement with PVC rods ABAQUS results and experimental results are compared.

4 Conclusions

On evaluating the experimental program and numerical analysis results, the following conclusions about the response of footing placed over PVC rods – soil system are made:

1. PVC rod reinforcement in the vicinity of pressure bulb will enhance the strength and stiffness of soil.
2. Confinement of the soil can be achieved by placing the reinforcement with different length, diameter, spacing and extent of reinforcement leading to significant improvement in the load settlement response.
3. As the length of the PVC rod in the vicinity of the pressure bulb increases, there is a considerable decrease in the deformation of the soil structure.
4. When the length increases considerably, there is no much effects on the deformation. Thus from the cost effective point of view, the optimum length of PVC rod is 2.5B , where B is the base of footing

5. FEM analysis with Mohr-Coulomb constitutive behavior for sand can be used to solve the bearing capacity problem of the footing placed over the PVC rod –soil system.
6. Settlement is reduced to 65.2% for 6 mm diameter PVC rod (2 array) compared to unreinforced soil.
7. Settlement is reduced to 67.1% for 6 mm diameter PVC rod (2 array) compared to unreinforced soil.
8. Various stress contours are plotted, it is clear that when the reinforcement are added to the sand bed, at a particular depth the stress values get decreased.
9. Substantial improvement in the bearing capacity of the sand can be derived by reduced stress values. Thus it is proved that a combination of vertical & inclined reinforcement gives better results.

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