Ground Improvement Using Displacement Type Sand Piles

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ABSTRACT

Stone columns are widely adopted to improve weak/loose ground to achieve adequate bearing capacity. Displacement type stone column/granular piles can densify loose sand/silty sand and strengthen the ground. In present a laboratory investigation has been made to investigate the improvement on the ultimate bearing capacity due to installation of a group of displacement type granular piles on loose sand bed. Effect of improving the surrounding region of the footing on the Ultimate bearing capacity has also been examined. Ultimate bearing capacity has been computed from Plate load tests results conducted on loose sand bed and also on improved sand bed. Two types of material sand itself and gravelly sand were used as granular pile material. Comparison has also been made between the two types of materials used in stone column in term of load carrying capacity. A method also suggested for estimating the ultimate bearing capacity of the stone column improved ground which is supported by experimental result.

1. INTRODUCTION

Lack of suitable sites for construction forced the building industry to look for cheaper land for construction. Stone column method of ground improvement can be employed successfully in both loose cohesionless soil and soft cohesive soil to improve its strength and deformation behavior. In past many researchers have carried out extensive research to study the behavior of soft soil deposit reinforced with stone column. Various theories given by different researchers is there to estimate the ultimate bearing capacity and compressibility characteristics of the stone column improved soft soil [Greenwood 1970, Hughes & Withers 1978, Madhav & Vitkar 1978]. Effect of various parameters i.e. stone column length, stone column material property, stone column diameter and spacing on the improvement of soft soil has also been reported by various researchers [Bergado et al. 1990, Priebe 1995, Poorooshash & Meyerhof 1997].

Most of the works reported in literature are reported to understand behavior and predict the bearing capacity and compressibility characteristics of soft soil reinforced with stone column. Very less study has been made to examine the efficacy of the stone column to improve/densified the loose cohesionless soil deposit. As it is not uncommon to encounter a loose cohesionless soil deposit upto shallow depth over a stiffer stratum where shallow foundation can deposit. In small project where using of vibroflot or dynamic compaction will not be economical and shallow foundation can be placed after improving/densifying the top loose soil affordable dynamic compaction will not be economical and be placed after improving/densifying the top loose soil affordable which brings the necessity to study the effectiveness of the stone column to improve the loose soil deposit and developed an approach to estimate the ultimate bearing capacity of the improved soil strata which can be employed in the subsequent design without details subsurface investigation.

In present an experimental study have been taken up to examine the effect of installation of group of driven insitu granular piles/stone columns on load carrying in loose sand bed only below loaded region and also below and surrounding the loaded region.

2. EXPERIMENTAL STUDY

Materials Used
Sand passing through 4.75 mm was used to prepare the sand bed. From grain size distribution curve the values of Coefficient of curvature (C_c) and Uniformity coefficient (C_u) are 1.16 and 1.67. Max.dry unit weight= 16.17 kN/m^3, Min.dry unit weight= 13.37 kN/m^3, specific gravity=2.62. The test bed was prepared at 20% relative density with corresponding angle of shearing resistance =30.5° and Cohesion is zero.
Gravelly sand used was artificially crushed stone material used for stone column construction. The fraction passing through 6mm sieve was used to construct granular pile. From grain size distribution curve the values of Coefficient of curvature (C<sub>c</sub>) and Uniformity coefficient (C<sub>u</sub>) are 1.02 and 2.2. Max.dry unit weight= 18.45 kN/m<sup>3</sup>, Min.dry unit weight= 15.3 kN/m<sup>3</sup>, specific gravity=2.73. Angle of shearing resistance @90% relative density is 42.6<sup>o</sup> and Cohesion is zero.

**Preparation of Loose Sand Bed**
All the tests have been conducted on a square test tank of size 1.15m×1.15m×1m. Loose sand bed of R.D=20% was prepared by rainfall technique. Rainfall technique consists of filling the sand in test tank through a sieve from a fixed height to maintain constant density of filled sand bed. A specially designed sieve of same size as test tank having 3mm dia. hole @ spacing of 5mm c/c was used for this purpose.

**Preparation of Granular Pile/Stone Column**
Steel pipe having external dia 50 mm has been used to prepare stone column. The stone columns were installed in loose sand bed by statically driving the steel pipe by a mechanical jack. Steel pipes were attached with a detachable conical shoe at the tip to prevent entry of the sand into the pipe during driving. During the installation of pile two dial gauges were fixed just adjacent to pile position to measure the heave which shows no heave during the installation. The length of the stone column (40cm) was two times the width of the footing. Special care has taken to maintain the verticality of the stone column/granular pile during installation. The compacted relative density of stone column material was achieved 90% of its maximum density. 4 no’s(2 x 2 group) and 16 no’s(4 x 4 group) of granular pile in square pattern at a c/c spacing of 2.5 times the diameter of granular pile were installed in this process.

**Test Procedure**
5 no’s of load test have been carried out, one on loose sand bed and other four test on groups of 2 x 2 and 4 x 4 with combination of sand itself and gravelly sand as stone column material. load test was carried out on a square model footing of size 20cm×20cm. Load was applied in equal increment (0.2kN) and each increment of load has been allowed until very little change(less than 0.002 mm/min) in settlement was observed. The details of arrangement of columns in group and their length, spacing are shown in Fig. 1 and Fig. 2.

**Final Void Ratio of Improved/Densified Ground**
Theoretically the final void ratio of the improved ground was calculated based on the assumption that single stone column in a group assume to act within its tributary area called unit cell. Based on this the final void ratio of the improved ground is calculated on the assumption that the displacement of the soil particle due to stone column installation limited only to the corresponding influence area (i.e. unit cell) of that stone column and amount of reduction in volume of voids in unit cell equal to the volume of installed stone column in that unit cell. For the properties of sand and initial relative density of sand bed of 20% the final void ratio in a unit cell for square pattern of stone column arrangement can be related to diameter and spacing of stone column as follows.

\[ \text{Final Void Ratio}=0.892-1.482(d/s)^2 \]  

For 50mm dia stone column/granular and @ 2.5d c/c spacing and for square arrangement of stone column in a group results a 90% relative density of the improved ground.

**3. RESULTS AND DISCUSSIONS**
Results of the load test on the loose sand bed and also after installation of displacement type sand pile , effect of stone column/granular pile material , improving soil just below and surrounding the loaded region on improvement have been discussed below.

**Effect of Displacement Type Pile on Ultimate Bearing Capacity**

**Sand Pile**
Fig.3 shows the effect of installation of displacement type sand pile in loose sand bed in terms of ultimate bearing...
capacity of footing. For both the 4 no’s and 16 no’s of piles pressure vs. settlement curves are above the loose sand bed. An increase in ultimate bearing capacity 5.5 times w.r.t loose sand bed is observed when the 4 no’s sand pile are installed and 7 times when 16 no’s sand piles installed.

**Gravelly Sand Pile**

Fig.4 shows the effect of installation of displacement type gravelly sand pile in loose sand bed in terms of ultimate bearing capacity of footing. For both the 4 no’s and 16 no’s of piles pressure vs. settlement curves are above the loose sand bed. An increase in ultimate bearing capacity 5.84 times w.r.t loose sand bed is observed when the 4 no’s sand pile are installed and 8.2 times when 16 no’s sand piles installed.

**Effect of Materials of Pile on Ultimate Bearing Capacity**

Two types of material used to prepare the stone column, sand (ϕ=37.5) and gravelly sand (ϕ=42.6). Load test reveals on both type of stone column improved ground that stone column material property i.e. shears strength parameter have significant influence on the ultimate bearing capacity of the stone column improved ground. Material having higher friction angle, gravelly sand shows higher ultimate bearing capacity in both 4 no’s and 16 no’s of stone column improved ground than sand pile improved ground. For both types of stone column improved ground due to improvement failure is shifted from local shear failure towards the general shear failure. Improving the soil below and surrounding the footing up to a distance of 0.4375 times the width of the footing from footing edge increase the ultimate bearing capacity about 1.5 times when the soil just below the footing is improved.

**Method to Estimate Ultimate Bearing Capacity of Improved Ground**

A method is described to determine ultimate bearing capacity based on the improved strength parameter of the of the displacement type granular pile improved sandy soil. Theoretically final void ratio of the improved ground has been calculated using equation 1. In present experimental work, a sand bed of relative density at 20% is improved to a relative density of 90% due to installation of 50mm dia. displacement sand piles at spacing of 2.5 times dia of piles (Eq. 1). Direct shear test has been conducted on sand and gravelly sand at their corresponding R.D. The composite strength parameter of the improved ground is calculated as follows

\[
\phi_{comp} = \tan^{-1}[a_s \times \tan \phi_p + (1 - a) \times \tan \phi_m] \tag{2}
\]

\[
C_{comp} = c_p \times a_s + c_m (1-a_s) \tag{3}
\]

Where

\( \phi_{comp} \) = angle of internal friction of improved/composite zone.

\( c_{comp} \) = cohesion of improved/composite zone

\( a_s \) = area replacement ratio

\( \phi_p, \phi_m \) = angle of internal friction of stone column material and sand bed respectively.

\( c_p, c_m \) = unit cohesion of stone column material and sand bed respectively.

Improved strength parameter of the sand bed \( \phi_{comp} \) has been calculated using Eq. (2) & (3) and Ultimate bearing capacity of tested footing resting on surface is calculated using Terzaghi’s bearing capacity factor corresponding to composite angle of internal friction.

**Comparison of Estimated and Experimental Result**

A comparison of estimated and experimental ultimate bearing capacity has been made. Experimental ultimate bearing capacity for 4 no’s and 16 no’s sand piles are 71.5 and 100.5 kN/m² respectively and estimated ultimate bearing capacity for 4 no’s and 16 no’s sand piles are 88.71 kN/m² & 88.71 kN/m² respectively. Experimental ultimate bearing capacity for 4 no’s and 16 no’s gravelly sand piles are 82 and 120 kN/m² respectively and estimated ultimate bearing capacity for 4 no’s and 16 no’s gravelly sand piles are 100.95 kN/m² & 100.95kN/m² respectively. From the above comparison it can be concluded that when there is improvement in the ground up to a distance of 0.4375 times
the width of footing from footing edge (16 no’s of column) the above method can be employed to estimate the ultimate bearing capacity of the improved ground for both sand pile and gravelly sand pile improved ground. When the soil just below the foundation is improved the above methods overestimate the ultimate bearing capacity of both sand pile and gravelly sand pile improved ground.

4. SUMMARY AND CONCLUSIONS

This paper discusses the effectiveness of driven insitu granular pile to improve loose cohesionless soil. For a situation loose soil deposit of shallown depth over stiff/dense soil where the dynamic compaction or Vibrofloation is not affordable and economical owing to small volume of work there this method can be effectively employed. The method to estimate ultimate bearing capacity involves small scale laboratory test to estimate the shear strength parameter and hence minimize the detailed subsurface investigation and hence leads to economy of the project. The proposed method of estimating the ultimate bearing capacity compare well with the experimental study when soil surrounding the footing also improved and this value can be employed in subsequent design. Based on the result obtained from the test following conclusion can be drawn.

1. Strength parameters of the stone column/ granular pile material have an influence on load carrying capacity of the improved ground and load carrying capacity of the improved ground increases with increasing the value of the strength parameter of the pile material.

2. Load carrying capacity of the improved soil also increases when the soil below and surrounding the loaded region also improved.

3. Ultimate bearing capacity of the stone column improved ground can be estimated without load est when the soil upto a distance of 0.4375 times the width of footing from footing.

REFERENCES

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