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Effect of installation methods on granular pile response

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ABSTRACT: The effect of the method of installation-cased and uncased bore holes, number of lifts and compactive energy per lift given to granular piles and spacing, are studied in the field for single piles and in the laboratory for large groups. The paper describes the test methods, results, and the conclusions. The experimental results bring out the advantages of cased bore holes and larger compactive effort, in improving the behaviour of granular piles.

INTRODUCTION

Many sites which were considered to be uneconomical for development as stable and adequate support for conventional foundations and structures, can now be economically treated by the installation of granular piles (stone columns). Moderate increase in allowable bearing pressures and considerable reduction of settlement are the primary benifits of this method of ground improvement. In addition, by virtue of their high perviousness, granular piles act as free drains and permit rapid dissipation of excess pore pressures due to static and/ or seismic loading. Seed and Booker (1977) and Tatsuoka and Yoshimi (1980) recommend their use for improving resistance to liquefaction of alluvial deposits.

Granular piles are installed by the vibroflotation technique(Greenwood, 1970). In India, the rammed stone column and the preassembled stone column methods are popular (Datye, 1975). These two methods are labour intensive and are cost effective. No costly plant or equipment is required. Simple pile driving rigs can be adapted to install these piles. Mitchell (1982), Datye (1982a,b), Madhav (1982) and Barksdale and Bachus (1983) review the design, construction and analysis of the granular piles.

TEST DETAILS AND PROCEDURES

The soil that was used in both the in situ and the laboratory studies, is the local Kanpur silt available adjacent to the Geotechnical Engineering Laboratory in the academic area of IIT, Kanpur. The bore hole profile is given in Fig.1. The physical and the mechanical properties of the soil are Grain size : Sand 10-12 percent Silt 75-80 percent Clay 10-15 percent.
Liquid Limit: 30 Plasticity Index 13-15; I.S. classification: CL or ML.
Undrained strength: $C_u=0.35 kg/cm^2$ $\phi_u=7.5°$.
$C_c=0.33$; $p_c'=0.65 kg/cm^2$, $C_v=(0.6-1)\times10^{-4} cm^2/sec$. The granular pile material consisted of a mix of gravel and sand of the following grain size distribution.

Table 1: Grain size distribution of granular materials.

	Percent Finer					
Sieve size mm	6.25	2.0	1.0	0.6	.425	0.16
Gravel	95.60	17.4	1.7	1.6	1.4	1.4
Kalpi Sand	100	90.0	70.0	54.0	35.0	8.0

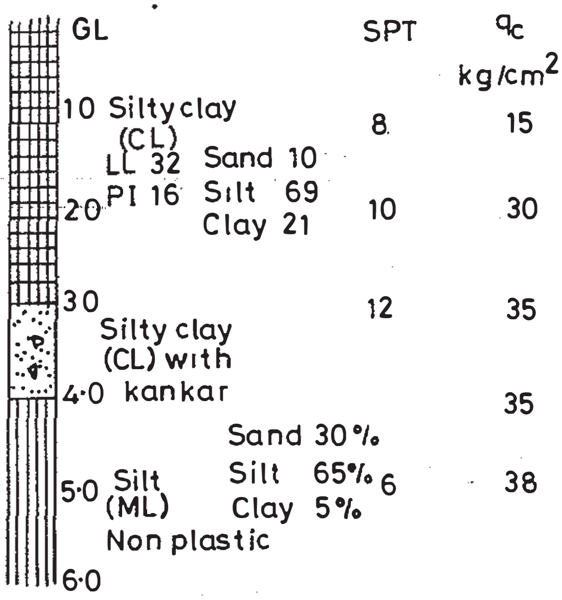

Figure 1. Soil Profile.

Angle of shearing resistance $\emptyset_s$ = 40°–45°.

FIELD SET-UP

A test pit 1.5m x 1.5m by 1.0m deep was dug. Water was poured into the pit and allowed to stand for several days, to saturate the soil. For installing the pile, a bore hole 10cm dia and about 1m long was dug by gradual augering and removal of the soil. Prepared granular mix (2 gravel:1 sand) was poured into the hole in two or three lifts. Each lift was compacted by 5 or 10 blows from a standard penetration test hammer falling freely from a height of 35 cm. The set or the reduction in thickness of the pile length for each lift was measured. Care was taken to make the top surface of the pile as flat as possible. Loads were increased by 30 kg. each time, dial gauge readings being taken till there was no change. The piles were loaded to failure. The parameters varied were the method of installation of the pile-uncased and cased bore holes with angering, number of lifts, and compactive effort (number of blows per lift).

LABORATORY SET-UP

Keeping in view the constraints and limitations of small scale model tests, a C.B.R. mould (15 cm dia and 17 cm high) was used. Undisturbed soil samples were collected from the site adjacent to the Geotechnical Engineering Laboratory and kept in water for about a week for saturation. The mould was taken out of water, excess water drained and a bore hole made in the centre of the sample. The hole was filled with gravel-sand mixture in the ratio of 2:1, in two lifts, each lift being compacted by 5 or 10 blows from 2.5 kg. weight falling through a height of 25 cm.

The standard consolidometer frame was modified to accommodate the mould. The load from the lever was applied through a rigid plate. A dial gauge placed on top of the frame measured the settlement due to the loading. The loads were increased in stages and dial readings taken continuously till constancy. The test was continued till a stress level of 2.12 kg/cm² was reached. The parameters studied were the installation methods uncased and cased bore holes, diameter of the pile (5.1 cm, 6.1 cm, 7.62 cm or S/d = 3, 2.4 and 2.0), number of blows per lift(5 and 10).

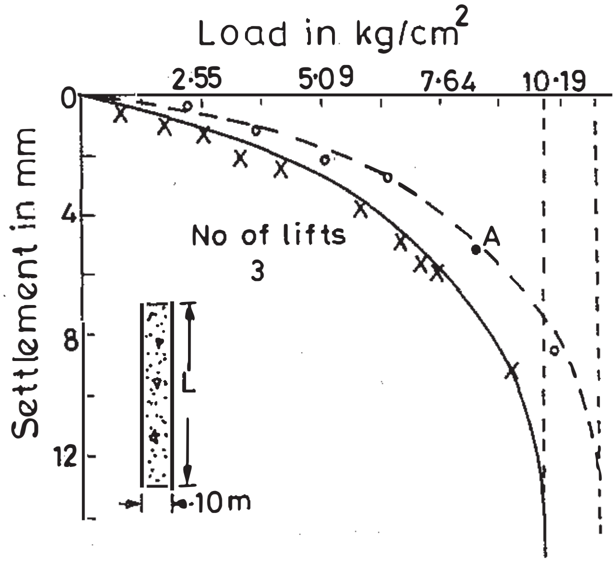

Figure 2. Load-Settlement Relation: In Situ Tests.

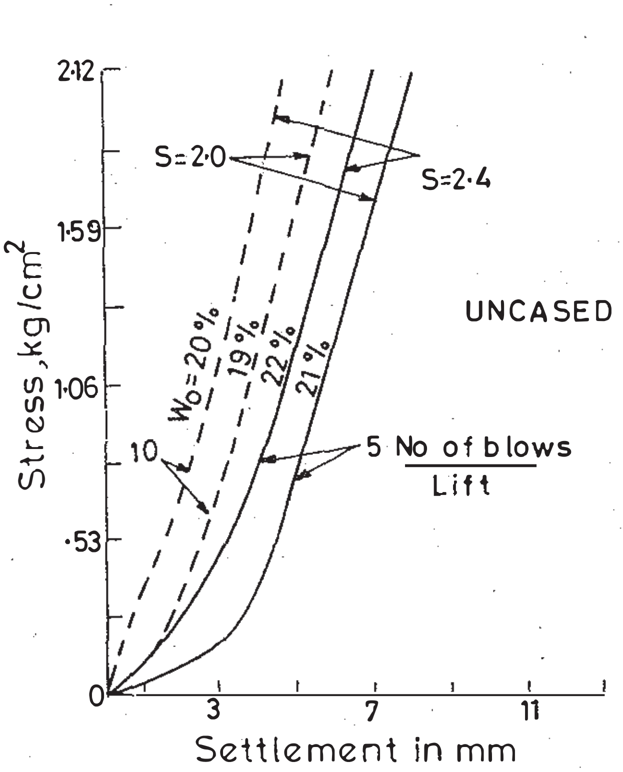

Figure 3. Stress-Settlement Relation: Model Tests; Uncased Hole.

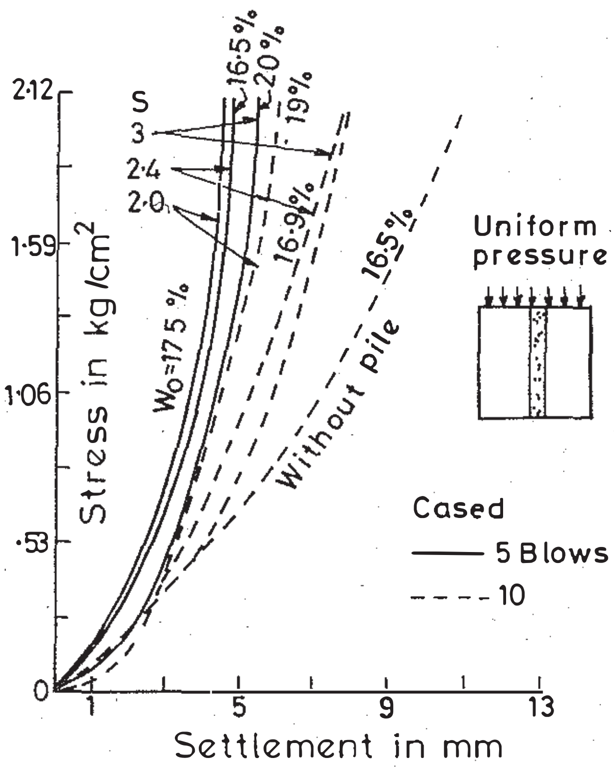

Figure 4. Stress - Settlement Relation: Model Tests; Cased Hole.

RESULTS

The load or stress versus settlement relation obtained from in situ tests is shown in Fig.2 for uncased bore hole with 2 and 3 lifts. The stress-settlement graph from the plate load test exhibits the typical local shear failure. The ultimate stress of about 1.15 kg/cm^2 corresponds to 6 C_u = 0.19 kg/cm^2 a value close to the one from undrained test. The load or stress-settlement graphs exhibit a linear trend at the lower stress level and become steep and nearly parallel to settlement axis at high stress levels. The ultimate loads in case of uncased hole are 800-825 kg if the pile is compacted in two lifts, 775-875 kg. for three lifts, and about 1450 kg. in case of cased borehole.

Cased bore hole causes densification of the in situ soil as the pipe is driven first, causing an increase in the strength of soil. Consequently the load carrying capacity is also very high. There is a possibility of loosening of soil in case of uncased bore hole and a reduction in strength resulting in a smaller load carrying capacity. If the number of lifts is increased, the granular pile is compacted better and a higher load carrying is observed.

Table 2 compares the observed ultimate loads with those predicted based on pile type and bulging failure. The ultimate load based on pile formula is

$$Q_u = d\ l\ C_u + \frac{d^2}{4}\ 9\ C_u \qquad (1)$$

while the ultimate load for bulging type failure according to Hughes and Withers (1975) is

$$Q_u = \frac{d^2}{4}\left(\frac{1+\sin\phi'}{1-\sin\phi}\right)\ C_u\ N_c + \sigma_o \qquad (2)$$

where l and d are the length and diameter of the pile, C_u - undrained cohesion of in situ soil, and ϕ - the angle of shearing resistance of the pile material. It appears from the table that the pile formula predicts loads closer to observed ones indicating pile type failure rather than bulging failure. The length to diameter ratio of the piles is 8 to 9 and possibly bulging would govern failure for longer pile lengths.

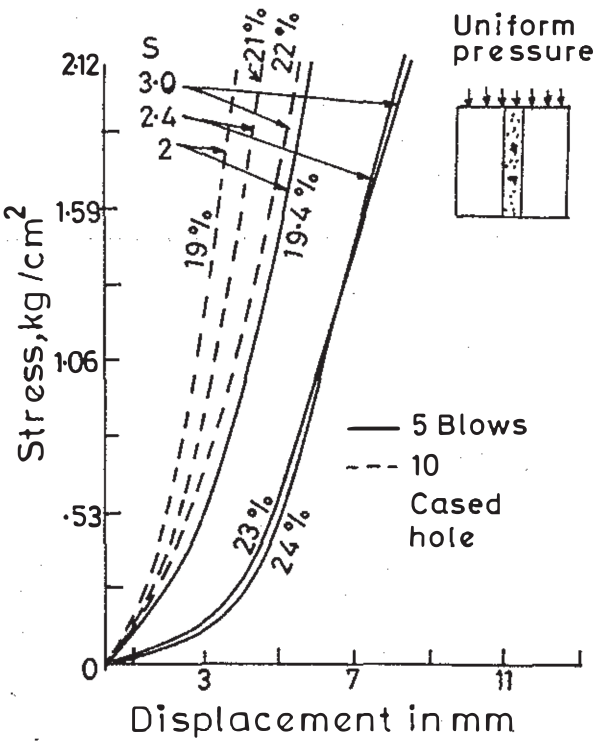

Figure 5. Stress-Settlement Relation: Model Tests; Cased Hole.

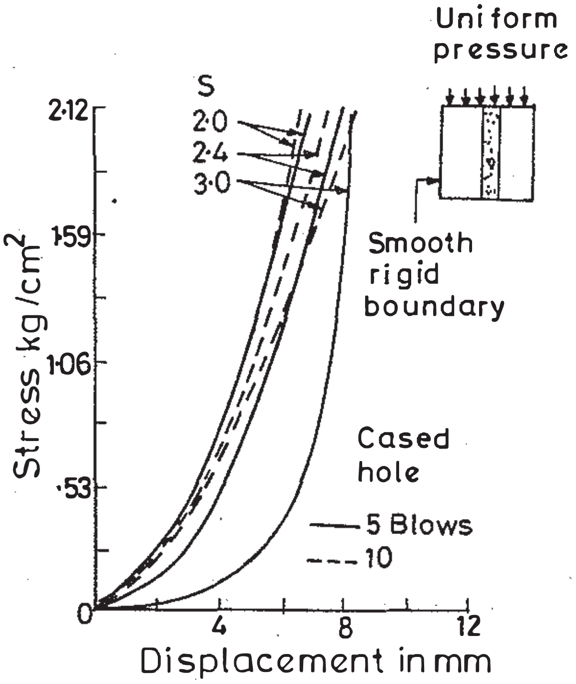

Figure 6. Stress-Settlement Relation: Model Tests, Cased Hole.

LARGE PILE GROUPS

As mentioned earlier, a typical unit is representative of the behaviour of granular pile reinforced soil. It is observed that settlements terminate within 24 hours of each stress increment.

The stress-settlement graphs shown in Figs. 3-6, depict a flatter initial portion of the curves at low stress levels and a steep line at higher stress levels. An yield stress, q_y, can easily be established beyond which the granular pile reinforced soil behaves as a very stiff material. The effect of pile diameter and compactive energy on the unit cell behaviour is shown in Fig.3 for uncased hole. The larger the diameter of the pile closer is the spacing and lesser will be the settlements. If the pile is installed by heavier compaction 10 blows per lift compared to 5 blows per lift, the settlement response is better i.e., lesser settlements are mobilised due to higher unit weights achieved for the granular pile material. Thus with 5 blows per lift, the unit weights are 1.4 to 2.55 g/cm^3 while with 10 blows they range between 1.9 to 2.8 g/cm^3. A denser granular pile is stiffer. The settlements will naturally be smaller. Similar results are observed for a cased bore hole (Fig.4). The curve for untreated soil is also shown in this graph for comparison.

The behaviour of granular pile consisting of gravel alone is shown in Fig.5. The pile is installed in a cased hole. If the angular gravel is replaced by peastones and sand, the behaviour shown in Fig.6 is observed.

The settlement reduction ratio, S_R, is calculated as

$$S_R = \frac{\text{Settlement of treated ground}}{\text{Settlement of untreated ground}}$$

It is observed that the settlement ratio is smaller for closer pile spacing (larger pile-diameter), larger compactive effort (10 blows per lift) and for angular material than rounded pea gravel. The differences between the effects of uncased and cased methods of installation could not be established clearly. Cased hole installation however appears to be slightly better than the uncased method. The settlement reduction factors are in the range 0.34 to 0.74 a range on the higher side because of the small l/d ratio (2.3 to 3.45).

CONCLUSIONS

The effect of method of installation on the behaviour of granular pile reinforced soil is studied. The behaviour of a large group represented by a single unit consisting of a pile surrounded by soil influenced by it, is studied in the laboratory. Cased and uncased bore holes, amount of compactive energy, number of lifts, spacing of piles in case of groups, are the factors studied. The load carrying capacity of single piles and pile groups is more and the settlements are less in case of cased than uncased bore holes. Similarly larger the compactive energy, more the number of lifts, and closer is the spacing, the better will be response of the granular piles.

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APPENDIX I

The rammed stone columns and preassembled stone columns are two techniques developed by Datye (1975). They are described briefly below.

Rammed stone columns is a technique in which either closed end or an open pipe is driven into the ground. The hole may be created by boring also. Stone and sand are poured into the hole in two or three lifts and each lift is compacted by a heavy weight dropped through a fixed height a given number of times. The casing pipe is withdrawn gradually during the ramming phase.

Datye (1982) describes the preassembled stone columns through uncased bore holes. The casing if used is of short length only. An enclosure of bamboo strips into which stone is placed, is lowered, and the stone compacted. When the length of the granular pile to be installed is 8-10 m only, this method of installation is economic and rapid.