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Enhancement of Load Bearing Capacity of Soft Silty Clay Soil by Pressure Grouting

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Abstract- The load bearing capacity of loose silty clay soil was found to be 15.8 KN/m^2 there at Byrnihat, Meghalaya, India site which was the experimental target location. After proper sub soil investigation, it was decided that, to increase the bearing capacity, pressure grouting technique shall be the most appropriate ground improvement technique. After applying pressure grouting at the selected site, the load bearing capacity was enhanced by 3-4 times of the original. This paper concentrates on the enhancement of load capacity derived from a driven cast in situ single pile, more specifically “compaction pile” with steel casing after retrofitted/post grouted with cement slurry.

Keywords- Compaction pile, loose silty clay soil, Pressure Grouting, fracture grouting technique.

I. Introduction

Target site consists of loose silty clay soil upto a depth of 13m, with an average void ratio (e) is 0.723 with porosity (n) of 42 %, hence the soil mass was ***loose*** enough with 42 % void volume. Besides, N value was found to be between 2-4. Hence the soil was termed as soft silty clay soil.

The primary objective of this paper is to try to compare the load carrying capacities of un grouted and grouted driven cast in situ single pile [1] by performing vertical compression test and pull-out test on post grouted piles which were pressure grouted with cement slurry. There are many techniques to enhance load bearing capacity of loose silty clay soil like micropiling [2], various grouting techniques, compaction piling and so on. The un grouted pile capacity in clay soil has been calculated on static analytical methods.

From the above study it has been observed that grouting mechanism in soft silty clay soil by fracture is quite different in situations where grout cannot be permeated into the voids. Fractures in such soils are initiated by applying pressure higher than the overburden/vertical pressure which is then filled up by grout mass. The fractures filled with grout follows the plane with the minor principal stress and forms in layers making grout bulb all around the grouted pile. This intrusion of cement slurry into the sub-soil increases the adhesion between the pile – soil interface. Besides, the stiffness of soil matrix also increases due to heaving and mechanical rearrangement of soil particle.

The main contributions of this paper can be:

- To study the mechanism in our problem site, we have decided to install perforated steel casing of length 12 m and subsequently inserted into the sub-soil up to a depth of 11.70 m keeping 30 cm of its portion above EGL.
- The test piles consist of the steel casing bearing holes (ϕ=12mm to 16mm) up to 6m from the bottom @ 30cm c/c all around and 6 m without holes from the top. Each test pile was prepared by pouring dry aggregates (20 mm down stone chips.) up to a depth of 8.00 m from pile toe.

II. MATERIAL & METHODS

In this paper, pressure grouting has been discussed elaborately which was conducted for this research work. **Pressure Grouting** [3] is the process of pumping a cement or chemical grout into soft or weak strata of soil or voids. This grout fills these voids, thus stabilizing and strengthening the soil. It has many applications; some of these include support for existing structures where foundations have shifted and soil stabilization for new structure foundations.

A. Pile Driving For Post Grouting

- A conventional method of pile driving was adopted for three numbers of test piles involved in our study. The test piles consisting of steel casing of outer diameter (O.D.) of 150 mm were inserted vertically into the proposed locations by blowing at the pile head with the bucket of a JCB having capacity of 10 M.T.[4].
- The steel casings were inserted up to a depth of 11.70 m (30cm above the EGL). A cutting edge fitted at the pile top helped in the driving operation. Also, a steel plate was fitted at the pile head to carry the blows made by the bucket of JCB excavator.

A. Grouting Methodology Adopted in the Site

Pressure grouting method was adopted for the fracture grouting of the given test piles which was already inserted.[5] In order to examine the clearance of the casing we at first conducted a test by lowering a weight tied to a thread into the steel casing before filling up the steel casing with aggregates. We found that mud entered through the casing holes up to a height of 3.30 m from the bottom, and also, we found the water depth to be at 1.20 m above the top level of the mud.

A centrifugal pump was fitted with the grouting machine, the inlet pipe of which consists of three numbers of washers, one valve and one pressure gauge. A grouting gauge pressure of $2kg/cm^2$ (200 $kN/m^{2)}$ was maintained during the grouting process. Grout machine was started at about 4 p.m. on 17/05/2014 and that was continued as long as the pressure in the pressure gauge was reduced i.e. for a period of 30 in.. [6]During the grouting process we see that grout feeding rate was very slow and non-continuous (observed by stopping the inlet valve and opening by the outlet pipe valve). After 20 minutes of grouting, 10 litre of water was added in the solution to decrease the consistency. During the operation, agitation was made to keep the cement grout in solution state.

B. Vertical compression pile load Test

Objective- Initial vertical compression pile load test is carried out for one or more purposes-

1. Determination of ultimate load capacities and arrival at safe load by application of factor of safety.
2. To provide guidelines for setting up the limits of acceptance for routine tests.
3. To study the effect of piling on adjacent existing structures and take decision for the suitability of the type of piles to be used, to get an idea of suitability of piling system, and to have a check on calculated load by dynamic or static approaches.

III. RESULT & DISCUSSION

Three numbers of steel pipes of O.D. = 150 mm, Length (L) =12m, were used as casing for the test piles which were inserted at different proposed locations. The test piles consist of the steel casing bearing holes (ϕ=12mm to 16mm) up to 6m from the bottom @ 30cm c/c all around and 6 m without holes from the top.

A. *Test Procedure*

The test is conducted following guidelines as per IS 2911 (Part 4)-1985. A static loading test is performed by loading a test pile with a gradually or stepwise increasing load, while monitoring the movement of the pile head [7]. Compression load is applied to the pile top (after proper preparation of the pile head) by means of a hydraulic jack against rolled steel joist or suitable load frame capable of providing reaction. Corresponding settlement is recorded by 3 dial gauges of 0.01 mm sensitivity, each positioned at equal distance around the pile and held by datum bars resting on immovable supports at minimum distance of 1.5 m from the edge of the pile.

- The reaction for the jack is obtained from the kentledge placed on the platform supported clear of the test pile [8]. The centre of gravity of the kentledge is kept on the axis of the pile and the load applied by the jack is made coaxial with this pile within the limits of engineering accuracy. The available reaction for the test is kept more than 25 % above the final proposed test load.
- Vertical downward load for the test is applied in steps of 4.7 tons and the equilibrium total settlement corresponding to each increment of load is recorded [9].

B. *Vertical Compression Pile Load Test Result, Pile 01*

Diameter of test pile : 150 mm
Date of testing : 09-05-2014
Pile Length : 12.0 m from E.G.L.
Type of test : Initial Vertical Compression Grouted Pile Load Test
Capacity of jack use : 150.0 M.T.

Time in hours	Load applied in M.T.	Dial gauge reading (mm)			Average Settlement (mm)
		Dial gauge No-1	Dial gauge No-2	Dial gauge No-3	
11:30		0.00	0.00	0.00	0.00
11:30	4.7	0.52	0.56	0.35	0.48
11:45		0.52	0.56	0.36	0.48
12:00		0.52	0.59	0.37	0.49
12:00	9.4	0.89	1.78	1.05	1.24
12:15		0.92	1.86	1.12	1.30
12:30		0.92	1.88	1.15	1.32
12:30	14.1	11.01	12.59	10.79	11.46
12:45		11.17	12.73	10.94	11.61
13:00		11.23	12.80	10.98	11.67
13:00	18.8	33.56	32.97	33.18	33.24
13:30		33.73	35.1	33.31	34.06

			3		

Table 1: Load- Settlement (Data of testing 09-05-14)

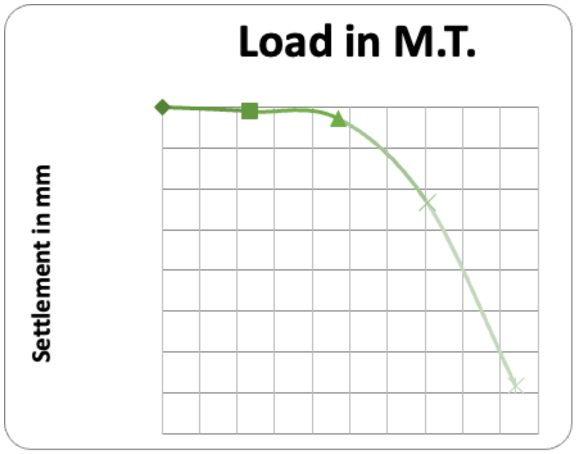

Fig 1: Load-Settlement curve.

Based on the field results of load and the corresponding final settlement, a load- settlement curves plotted as shown in Fig 1. From test result it has been observed that under an applied load of 14.1 M.T., [10]observed settlement reaches a value of 11.67 mm which is less than the limiting settlement of 12mm. Hence as per IS: 2911(part 4)- 1985, from the available test results the safe load of the given test pile may be taken as two-third of 14.1 M.T. i.e**.** *a safe load of 9.4 M.T. may be adopted for the design purpose.*

C. Vertical Compression Pile Load Test Result, Pile 02

Diameter of test pile : 150 mm
Date of testing : 11-06-2014
Pile Length : 12.0 m from E.G.L.
Type of test : Initial Vertical Compression Grouted Pile Load Test
Capacity of jack used : 150.0 M.T.

Time in hours	Load applied in M.T.	Dial gauge reading (mm)			Average Settlement (mm)
		Dial gauge No-1	Dial gauge No-2	Dial gauge No-3	
11.30		0.00	0.00	0.00	0.00
11.30	4.7	0.75	0.24	0.72	0.57
11.45		0.75	0.24	0.72	0.57
12.00		0.75	0.24	0.72	0.57
12.00	9.4	2.25	0.95	2.05	1.75
12.15		2.26	0.98	2.09	1.78
12.30		2.26	0.98	2.09	1.78
12.30	14.1	3.31	3.11	3.06	3.16
12.45		3.33	3.15	3.10	3.19
13.00		3.34	3.16	3.10	3.20
13.00	18.8	9.95	9.74	9.76	9.82
13.15		9.98	9.76	9.79	9.84
13.30		9.99	9.77	9.79	9.85

13.30	23.5	14.98	14.65	14.92	14.85
13.45		15.	14.68	14.95	14.87
14.00		15.04	14.70	14.96	14.90
14.00	28.2	39.40	38.96	39.32	39.23
14.15		39.44	38.99	39.36	39.26

Table 2: Load -Settlement Data (Date of testing 11-06-2014)

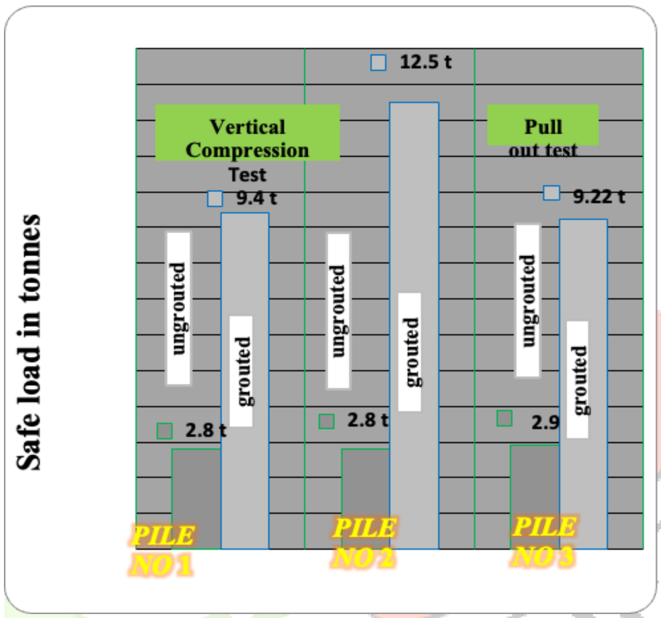

Fig 2: Comparison of ungrouted pile capacity with grouted initial pile load test result.

Based on the field results of load and the corresponding final settlement, a load- settlement curves plotted as shown in Fig 3. From test result it has been observed that under an applied load of 18.8 M.T., observed settlement reaches a value of 9.85 mm which is less than the limiting settlement of 12mm. Hence as per IS: 2911(part 4), 1985,[10-11] from the available test results the safe load of the given test pile may be taken as two-third of 18.8 M.T. i.e. *a safe load of 12.53 M.T. may be adopted for the design purpose.*

A. *Comparison Analysis*

The safe load carrying capacity of the piles, both in compression and uplift has considerably increased after grouting was being done. For the untreated ground, the safe load carrying capacity obtained for compression and uplift by the analytical method was found to be 2.8 M.T & 2.9 M.T**.** respectively. The ultimate load carrying capacity of the piles were increased by the post grouting methodology adopted for the given site conditions and thereby safe load carrying capacities were finally increased to a value of 9.4 M.T. & 12.5 M.T. in vertical compression and to a value of 9.22 M.T. in vertical uplift/pull out respectively [12].

Hence in the vertical compression test the percent increase of safe load carrying capacity after grouting, for test piles no 1 & 2 were found to be about 70% & 78% respectively. For the pull-out test carried out for pile no 3, the percent increase of safe pull out resistance after grouting was found to be about 68%.

The average safe load carrying capacities both in compression and uplift can be summarized as 10.37 M.T. So, the percent increase of safe load carrying capacity after grouting was found to be about 72%.

Pile No	Analytical		Pile Load Test	
	Vertical (kN)	Pull-Out (kN)	Vertical (kN)	Pull-Out (kN)
01	2.8	2.9	9.4	-
02	2.8	2.9	12.5	-
03	2.8	2.9	-	9.22

Table 3: Summary of Load Capacities from Analytical and Field Pile Load Test

IV. CONCLUSIONS

A considerable increase in the adhesion factor can be obtained if grout is injected under pressure at the pile/soil interface after a waiting period of 24 hours or more. Two-to threefold increase in adhesion factor when post-grouting was undertaken around the shafts of 150mm diameter micro piles in London clay, has been reported by Jones and Tuner. It also opined that, the feasibility of achieving such increases should be checked by loading tests before using them for design purposes. Lastly, it can be concluded that an average three to four times of load capacity has been observed to increase by pressure grouting that has been adopted for the soil profile under consideration.

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