NUMERICAL ANALYSIS OF STONE COLUMNS IN SOFT CLAY WITH GEOTEXTILE ENCASEMENT AND LIME STABILISATION

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ABSTRACT

Stone columns have been widely accepted as a method of foundation to support large area loads over soft clay beds. Laboratory studies were carried out in test tanks to study the behavior of stone columns in soft clay with different initial consistencies. The study was conducted without and with geotextile encasement and also the influence of pretreatment of soft clay with lime on the behavior of stone columns was investigated. This paper presents the numerical analysis of the above stone column systems for load-settlement behavior and compared with laboratory test results. This analysis revealed that the numerical analysis using PLAXIS 3D software is useful to predict the behavior of stone columns under different field conditions.

Key Words: Stone Columns, Soft Clay, Geotextile Encasement, Lime Stabilization, PLAXIS 3D

1 Introduction

Soft clays are present in several world nations and these deposits are characterized by high natural water content, low shear strength and high compressibility. (Murugeshan and Rajagopal, 2010). Construction of infrastructure facilities in such deposits is a challenge to civil engineers. Deep foundations have been widely used in such deposits despite heavy investment (Priebe, 1995; Muir-Wood et al.,2000). Several ground improvement techniques such as preloading with vertical drains, electro- osmotic drainage and stone columns were promulgated to improve these soil deposits. Several project sites are immensely benefitted by these techniques; especially to support area loads such as embankments and even to support building foundations(Ambaly and Gandhi 2007). Stone columns not only improve the load carrying capacity of ground but also promote consolidation. However, in case of very low strength (Cu<25kPa) soils, difficulty in installation of stone columns was reported (Chummar, 2000). The load – settlement behavior of stone columns was studied previously in the test tanks without and with geotextile encasement. Also the influence of pretreatment of soft clay with lime on stone column behavior was studied. The present study is an effort to model the above systems in PLAXIS 3D software to predict the load-settlement behavior in relation to the laboratory test results.

2 Materials and Methodology

Analysis was carried out using PLAXIS 3D software to compare the load-settlement behavior of stone columns with different test conditions considering Mohr-Coulomb model. The dimensions of tanks used were 300 mm diameter and 300 mm height for installing single stone column and 500 mm*500 mm*500 mm for group of stone columns. The initial consistencies of clay bed adopted were 25% 40% and 55%. A stone column of 50 mm diameter and 280 mm height was made at the center of the clay bed with the help of a PVC pipe at a density of 1.6 g/cc corresponding to 70% relative density and at the top of it, a leveling course of 20 mm thick sand is placed and loaded with a plate having diameter twice the diameter of stone column. The tensile strength of geotextile (PD381) is 18 kN/m, which is used in the study. The clay properties are: gravel = 4%,sand = 26%, fines = 70%, liquid limit = 56% and plastic limit = 18%. Pressure-settlement plots were drawn and the ultimate capacity is obtained by drawing the tangents to the initial and final straight line portions. For the formation of group three stone columns in the test tank, three stone columns were placed at the spacing of two times the diameter of the stone column and the remaining process is similar to that for single stone column. The input parameters for modeling the stone columns in soft clay are given in tables 1 and 2. The bulging patterns of stone columns are shown in figures 2.1 and 2.2 without and with encasement.

Table 1: Input parameters for modeling stone columns in soft clay

Materials	Test consistencies (%)	W (%)	E (kPa)	Poissons ratio μ	C_u (kPa)	Φ (deg)	Ψ (deg)	ϒdry kN/m^3	ϒsat kN/m^3
Clay	25	46.5	1400	0.47	2.8			11.54	16.87
	40	38	2750	0.45	5.5			12.37	17.42
	55	35.1	4000	0.43	8			13.33	18.01
Stone Aggregate			55000	0.3		38	10	16.62	
Sand			20000	0.3		30	4	15.6	

Table 2: Input parameters for modeling stone columns in lime stabilized soft clay

Materials	Test Consistencies (%)	W (%)	E (kPa)	Poissons ratio μ	C_u (kPa)	Φ (deg)	Ψ (deg)	ϒdry (kN/m^3)	ϒsat (kN/m^3)
Clay	25	28	90000	0.3	180			14.7	18.85
	40	26	100000	0.3	200			15.18	19.15
	55	23.8	140000	0.3	280			15.7	20.68
Stone Aggregate			55000	0.3		38	10	16.62	
Sand			20000	0.3		30	4	15.6	

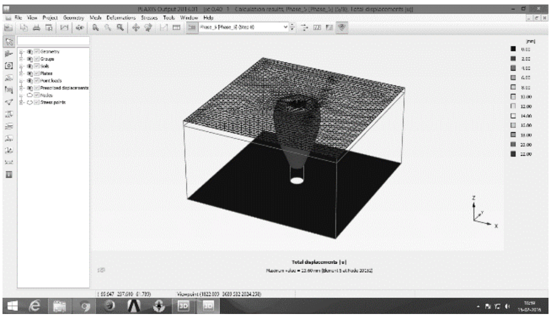

Fig 2.1 Stone Column in soft clay without geotextile encasement

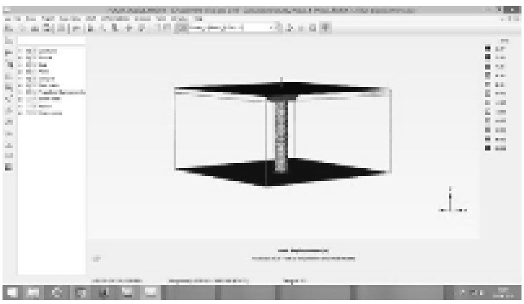

Fig 2.2 Stone Column in soft clay with geotextile encasement

3 RESULTS AND DISCUSSIONS

3.1 Pressure-Settlement behavior of individual stone columns at different consistencies of clay

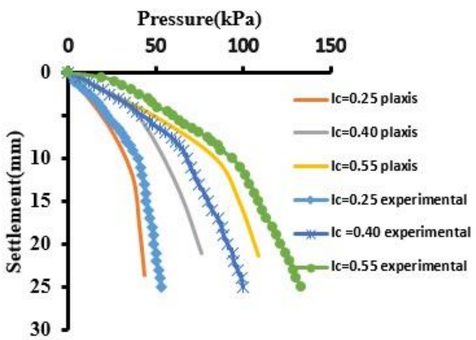

Fig 3.1 Pressure -Settlement plots of individual stone column at different consistencies of clay

Fig3.1 shows the load-settlement plot for single stone column without encasement. It can be inferred from this figure that at Ic=0.25, the ultimate load capacity is 20 kPa with the corresponding settlement of 7 mm. Similarly at Ic=0.40, the ultimate load capacity is 28kPa with corresponding settlement of 6 mm. At Ic=0.55, the load carrying capacity is 55kPa with corresponding settlement of 4 mm. These patterns indicate that the load capacity of stone columns increases with increasing consistency of clay bed. The relative variation of the load-settlement plots at different initial consistencies is also shown in figure 3.1for ready comparison of numerical analysis and laboratory test results

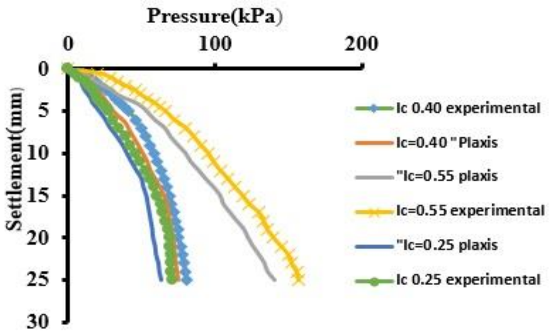

Fig 3.2 Pressure Settlement plots of individual encased stone column at different consistencies of clay

The load-settlement plots for individual encased stone column obtained through numerical analysis are presented in figure 3.2. It can be observed from this figure that the ultimate load carrying capacity of encased stone column is about 60 kpa at Ic=0.25 with the corresponding settlement of 6 mm. At Ic=0.40, the ultimate load carrying capacity is 75kPa with corresponding settlement of 4 mm. However, at Ic=0.55 the ultimate load capacity is 102 kPa with corresponding settlement of 3 mm. This can be attributed to the fact that as confinement increases, the load carrying capacity also increases. The relative variation of the load-settlement plots at different consistencies is also shown in fig 3.2 for ready comparison of numerical analysis and laboratory test results.

3.2 Pressure-Settlement behavior of three group of stone columns at different consistencies of clay

Figures 3.3 and 3.4 show the Pressure-settlement behavior of group of stone columns without and with encasement respectively. From figure 3.3, it can be observed that at Ic=0.25, the ultimate load is 36 kPa; at Ic=0.40, the ultimate load carrying capacity is 55 kPa and at Ic=0.55, the ultimate load capacity is increased to 92 kPa. In all these cases the settlement varied from 4 mm to 7 mm. Similarly, for encased stone column groups, the ultimate capacity is in the range of 85 kPa to 175 kPa with the corresponding settlements of 6 mm to 8 mm. From these observations, it is revealed that the group capacity is altogether different from the mere multiplication of single column capacity with the number of columns in a group. This behavior could be attributed to the mutual confining effect in groups compared to single stone column.

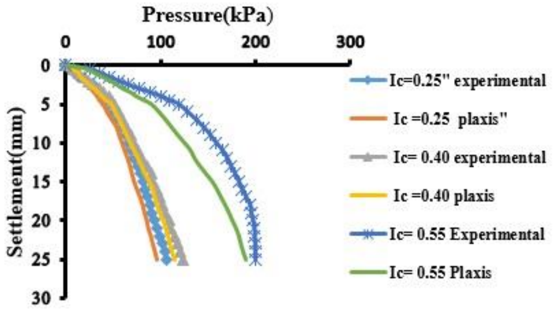

Fig 3.3 Pressure-Settlement plots of 3- stone column groups at different consistencies of clay

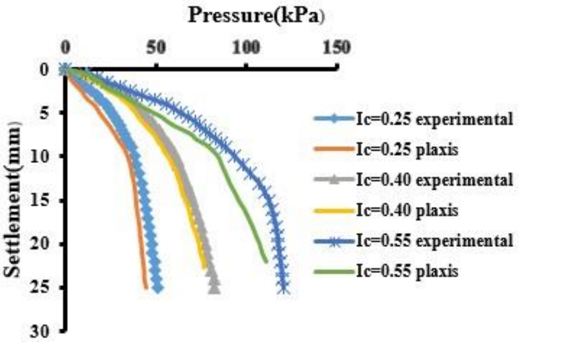

Fig 3.4 Pressure settlement plots for group of encased stone column at different consistencies of clay

3.3 Pressure-Settlement behavior of stone column groups in lime stabilized soft clay at different initial consistencies

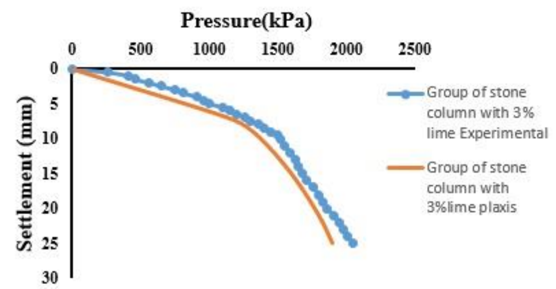

Fig 3.5 Pressure- Settlement plot for 3- stone column group in soft clay stabilized with 3% lime at Ic=0.25

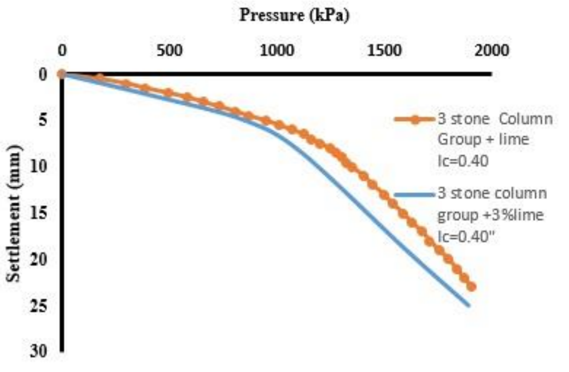

Fig 3.6 Pressure-settlement plot for 3- stone column group in soft clay stabilized with 3% lime at Ic=0.40

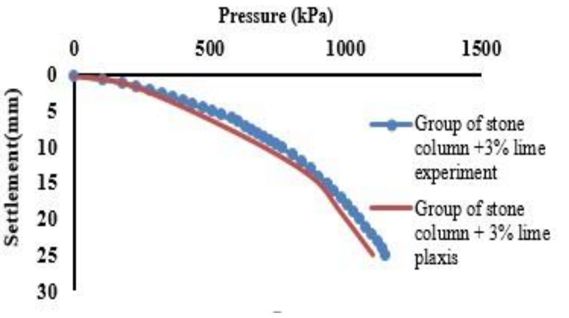

Fig 3.7 Pressure-settlement plot for 3- stone column group in soft clay stabilised with 3% lime at I_c = 0.55

Figs 3.5, 3.6 and 3.7 show the load-settlement behavior of group of three stone columns installed in 3% lime stabilized soft clay. It can be observed that at Ic=0.25, the ultimate load carrying capacity obtained from numerical analysis is about 1400 kPa, whereas the laboratory value is 1500 kPa. At Ic = 0.40, numerical analysis showed that the ultimate load carrying capacity is 1000 kPa and the laboratory value is about 1200 kPa. Also at Ic = 0.55, the ultimate load carrying capacity obtained from numerical analysis is around 700 kPa, whereas the value is 750 kPa from laboratory testing. For all these cases, the settlement corresponding to ultimate loads varied from 5 mm to 9 mm. In lime stabilised clay, similar trends are observed for individual stone column also. The decrease in degree of improvement in lime stabilized clay with increasing consistency could be attributed to transition of failure from bulging to vertical displacement of stone column in lime stabilised clay bed.From the above observations, it is understood that the behavior of stone columns under different field conditions can be predicted using PLAXIS 3D software.

4 Conclusions

The following conclusions are drawn based on numerical investigations carried out on stone columns installed in soft clay without and with lime stabilization and geotextile encasement.

The ultimate load capacity of stone columns is increased with increasing undrained strength Cu of soft clay.

The load carrying capacity of geotextile encased stone column is enhanced by almost 3 times that without encasement. The group capacity is not the multiplicative value of a single stone column capacity at any consistency with or without geotextile encasement.

The bulging of stone columns is reduced both with geotextile encasement and lime stabilization.

The degree of improvement in load carrying capacity of stone columns with lime stabilization is lesser in case of clay with high initial stiffness.

From PLAXIS 3D analysis, it is found that the load carrying capacity of stone columns is significantly increasing with increasing Young's modulus. This is true with increasing consistency of clay.

The load-settlement plots obtained from laboratory testing compared well with numerical method of finite element analysis for ordinary stone columns, geotextile encased stone columns and stone column in lime stabilized clay; indicating the potential use of PLAXIS 3D software to predict the behavior of stone columns in the field.

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