Cyclic Response of Stone Columns

K.V.S.B. Raju, L.Govinda raju, Chandrashekhar A.S

Abstract- Stone column is a proven ground improvement technique to improve the stiffness of ground in weak soils. It is found from the literature that lot of studies was confined on static behavior of stone columns but studies were limited on the cyclic behavior of stone columns. The necessity of cyclic behavior arises when the improved ground is to resist dynamic loads such as machine loads, seismic loads and cyclic loads. In this paper an attempt is made to study the behavior of stone columns subjected to cyclic loading to improve the characteristics of black cotton soil. The cyclic behavior was investigated by conducting a number of cyclic plate load tests on end bearing and floating stone columns. Also studies were also extended to encased stone columns with geosynthetic material. From the cyclic plate load tests a parameter known as coefficient of elastic uniform compression was found which is used in the design of machine foundations. It is found that as compared to untreated black cotton soil alone, the coefficient of elastic uniform compression (C_u) increases with inclusion of stone columns and further when compared to floating stone columns the parameter (C_u) increases for end bearing stone columns. Also when compared to single stone columns the parameter (C_u) increases for group of stone columns, and further it more in case of encased stone columns due to increased lateral stiffness due to encasement.

Index Terms— Stone columns, Geotextile, Dynamic load, Lateral stiffness, Black cotton soil, Coefficient of elastic uniform compression, Cyclic plate load tests.

1. INTRODUCTION

SEVERAL researchers have worked on theoretical, experimental and field study on behavior of stone columns. Ambily and Gandhi (2007) carried out experiments to evaluate the behavior of stone column by varying spacing, shear strength of soft clay, moisture content etc. Ayadat et al. (2005) conducted a series of laboratory tests on the geofabric encapsulated stone column to investigate its performance in a collapsible soil. The load carrying capacity and the deformation characteristics were studied. From this investigation, it was found that the load carrying capacity of the encapsulated sand columns increased with the increase of geofabric material stiffness. The increase of column rigidity and column length increase the load carrying capacity of the collapsible soil. Dipty and Girish (2009) studied the influence of column material on the performance of stone column through laboratory experiments on model stone columns installed in clay. Five reinforcement materials were studied: stones, gravel, river sand, sea sand and quarry dust. Load versus settlement response was obtained. The grain size of the stone column material is one of the prime controlling parameters in the design of stone columns. It was found that stones are the most effective stone column material. Quarry dust, though a waste product is effective in improving the load deformation characteristics of the soil used. Deb et al. (2010) conducted a series of laboratory test to investigate the effect of geogrid-reinforced sand bed on stone column. From this investigation, it was found that the load carrying capacity of the soft clay was significantly increase by including the geogrid in the sand bed above the stone column on the soft clay and also the bulge diameter was significantly reduced and the bulge depth was increased. Malarvizhi and Ilamparuthi (2004) studied load versus settlement response of the stone column and reinforced stone column i.e. geogrid-encased stone column in the laboratory. Load tests were performed on soft clay bed stabilized with single stone column and reinforced stone column having various slenderness ratios and using different type of encasing material.

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The response of foundations due to dynamic stress application produced by earthquakes, blasting, machine vibrations resting on poor ground is a subject of interest in recent times due to increased cost of land and lack of availability of firm strata at or near to ground surface. Due to increased infrastructure development taking place in many parts of the country the availability of land is scarce particularly in urban areas. This necessitates the use of land which has weaker strata, where in geotechnical engineers are challenged by presence of different problematic soils having varied engineering characteristics. Concrete pile foundations are not economically and technically feasible for moderately loaded structures such as storage tanks and industrial structures. In addition, their environmental constraints greatly encourage the improvement of weak soils by some ground improvement techniques. Out of several techniques of ground improvement, the stone columns have been used to a large extent for several applications. Of course, a number of researchers have studied and substantially contributed in the field of ground improvement using stone columns but such studies were mainly confined to the static loading conditions only. Studies pertaining to cyclic behavior of stone columns are required when a machine foundation is proposed to rest on a weaker stratum. Machine foundation require the special attention of a foundation engineer as in addition to static loads due to weight of machine and the foundation, loads acting on such foundations are dynamic in nature. In this type of foundation, a dynamic load is applied repetitively over a very large period of time and many loading cycles. While the magnitude is small, it is therefore necessary the soil behavior will be elastic, or else deformation will increase with each cycle of loading until the foundation displacements becomes practically unacceptable. In designing a machine foundation, the coefficient of elastic uniform compression of soil (C_u) is the most important parameter which can be obtained by conducting a cyclic plate load tests.

In the present study a series of cyclic plate load tests were conducted for floating and end bearing single and group of stone columns, with and without encasement of geosynthetics to evaluate a dynamic parameter namely coefficient of elastic uniform compression (C_u) which is used in the design of machine foundations. In the present study the ratio between the size of the model tank and size of plate is not equal to five, hence it is expected to have some boundary effects. However an attempt is made to conduct a series of cyclic plate load tests in addition to static tests to evaluate coefficient of elastic uniform compression.

2 EXPERIMENTAL INVESTIGATIONS

2.1 Properties of materials

The clay used was collected from Harpanahalli, Davanagere district, Karnataka state. In order to maintain uniformity of test results block sample was taken at a depth below 2m.The other properties are specific gravity=2.72, liquid limit=83%, plastic limit=32.5%, maximum dry density=14.4 kN/m^3, and optimum moisture content=28.5%.

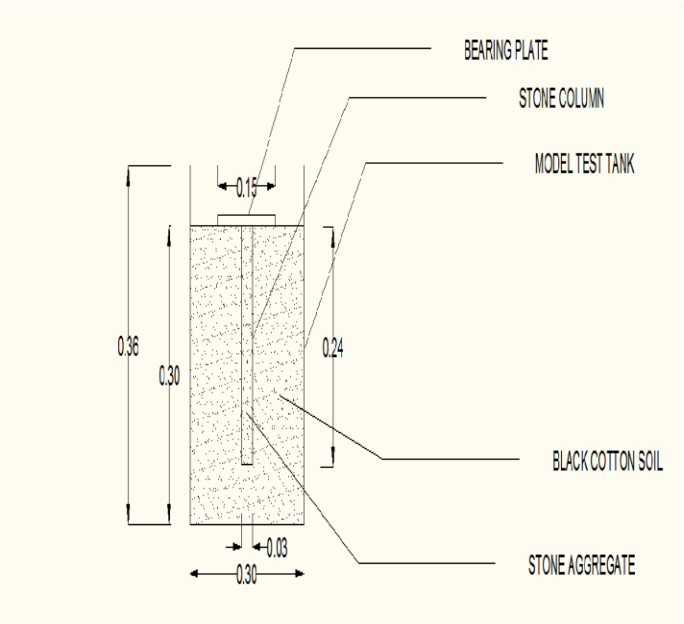
Crushed stones (aggregates) of sizes between 10 and 2mm have been used to form stone column. The stones were compacted to a density of 16.6kN/m^3 while constructing stone columns for the experiments. Quarry dust is also used as stone column material to fill the voids between the aggregates. Quarry dust is a cohesionless material which consists mainly of sand size particle. Properties of quarry dust are specific gravity=2.79, D10=2.7mm, Cc =0.9, and Cu =1.37.

The geotextile used was Polyester woven multifilament TFI 3000, with the net of 1mm x 1mm aperture size as the encasement material of the stone column.

2.2 Procedure

In continuation of author's recent work on load settlement response of black cotton soil using stone columns with and without encasement of geosynthetics, cyclic plate load tests were carried out with rammed stone columns surrounded by black cotton soil placed in a square tank of 300 mm side and 360 mm height. Schematic diagram of floating and end bearing stone columns are shown in Fig.1. Single and group of columns with square pattern of arrangements were adopted. The detailed experimental procedure and test results for static loading were not repeated herein as it is provided in Raju et.al (2012).

The cyclic plate load test was performed in a model test tank. The equipment is same as used in static plate load test. A square bearing plate of thickness 10mm and size of 150mm*150mm was used. To commence the test, a seating pressure is first applied to the plate. It is then removed and dial gauges are set to read zero.



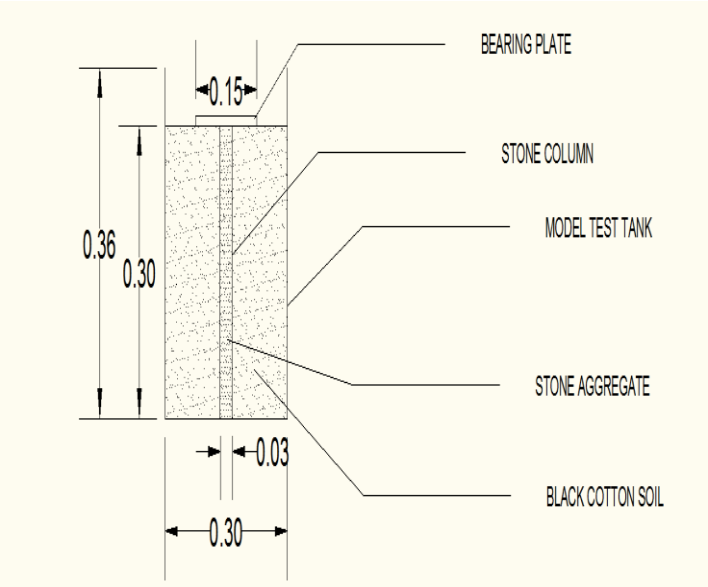


Fig.1. Schematic diagram showing floating and end bearing stone columns.

In cyclic plate load test, each incremental load is maintained constant till the settlement of the plate is complete. The load is then released to zero and the plate is allowed to rebound. The reading of final settlement is taken. The load is then increased to next higher magnitude of loading and maintained constant till the settlement is complete, which again is recorded. The load is then reduced to zero and the settlement reading taken. The next increment of load is then applied. The cycles of unloading and reloading are continued till the required final load is reached.

From the data, the load intensity versus elastic rebound is plotted, and the slope of the line is coefficient of elastic uniform compression.

$$C_u = P/S_e \ldots\ldots\ldots\ldots\ldots (kN/m^3)$$

Where P = Load intensity in kN/m^2

S_e = Elastic rebound corresponding to P in m

3 Results and discussion

Variation of load intensity Vs settlement are shown in Fig.2 to Fig.6 for the case of L/D =8 (Floating stone column) only where as all other figures for the case of L/D =10 (End bearing stone column) are not presented herein just for restricting the size of the article.

From the load intensity Vs settlement, elastic settlement was found and from which load intensity and elastic rebound for each pressure increment was plotted as shown for a typical case of four stone columns with encasement in Fig.7. The coefficient of elastic uniform compression (C_u)was found from the slope of pressure intensity Vs elastic settlement and it is tabulated in Table1. It is found that the parameter C_u varies from 0.24 x10^{5}kN/m^3 for the case of untreated black cotton soil to 1.27x 10^{6}kN/m^3 for the case of group of stone columns with geosynthetic encasement. It is found that coefficient of elastic uniform compression was found to be higher for end bearing stone columns and further it is found to be more for geosynthetic encased stone columns due to increase in lateral stiffness of encased stone columns.

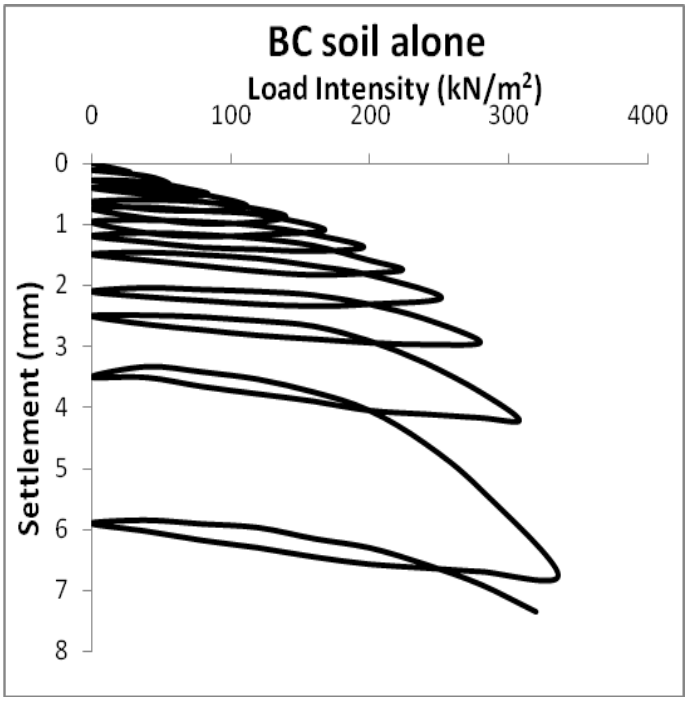


Fig.2. Load intensity versus settlement of BC soil alone in a cyclic plate load test.

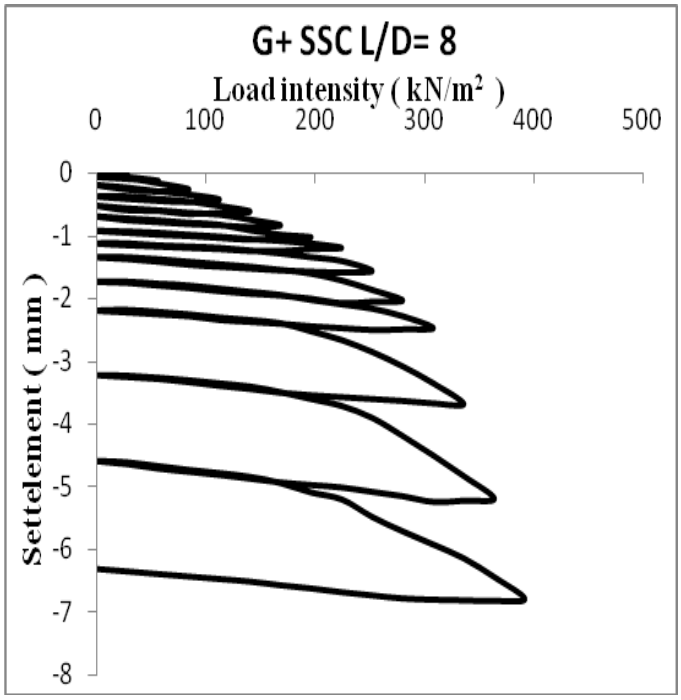


Fig.4. Load intensity versus settlement of Encased single stone column for L/D=8 in a cyclic plate load test

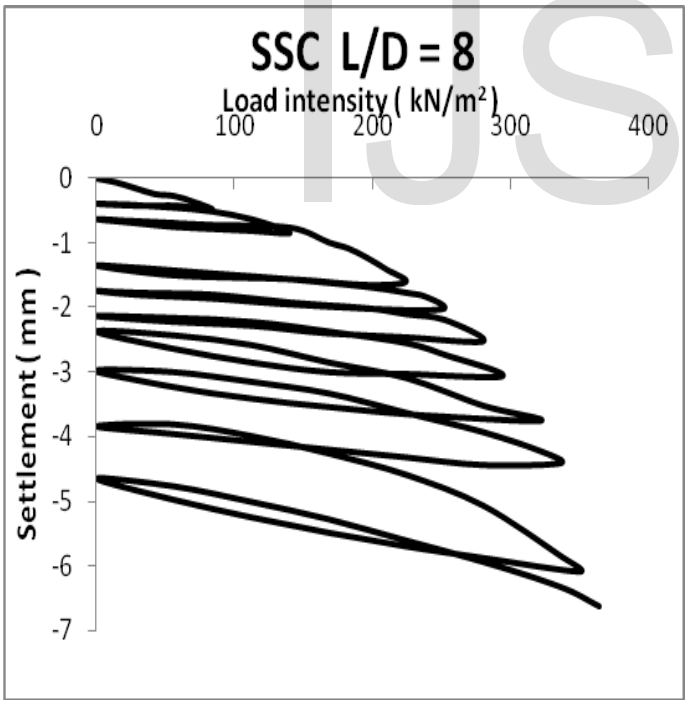


Fig.3. Load intensity versus settlement of single stone column for L/D=8 in a cyclic plate load test

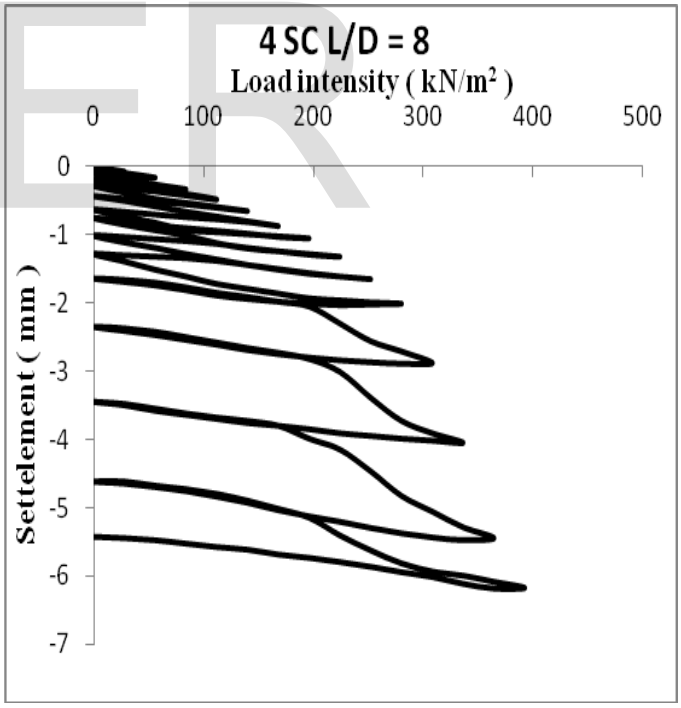


Fig.5. Load intensity versus settlement of four stone columns for L/D=8, S= 2D in a cyclic plate load test

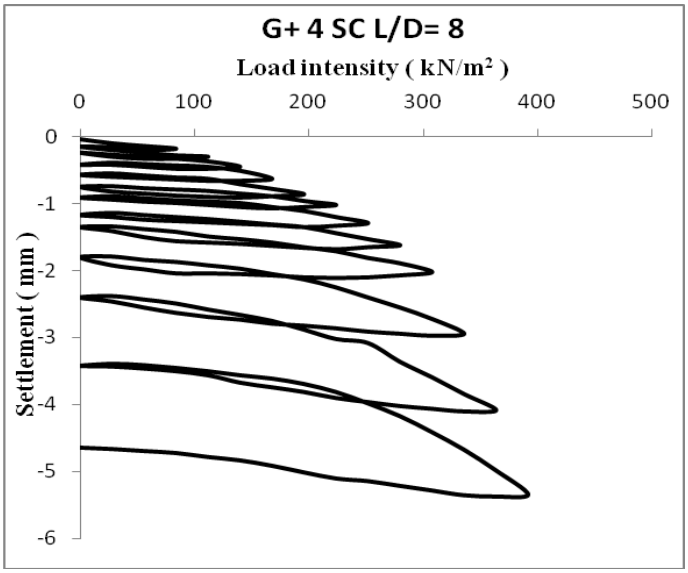


Fig.6. Load intensity versus settlement of four encased stone columns for L/D=8, S=2D in a cyclic plate load test

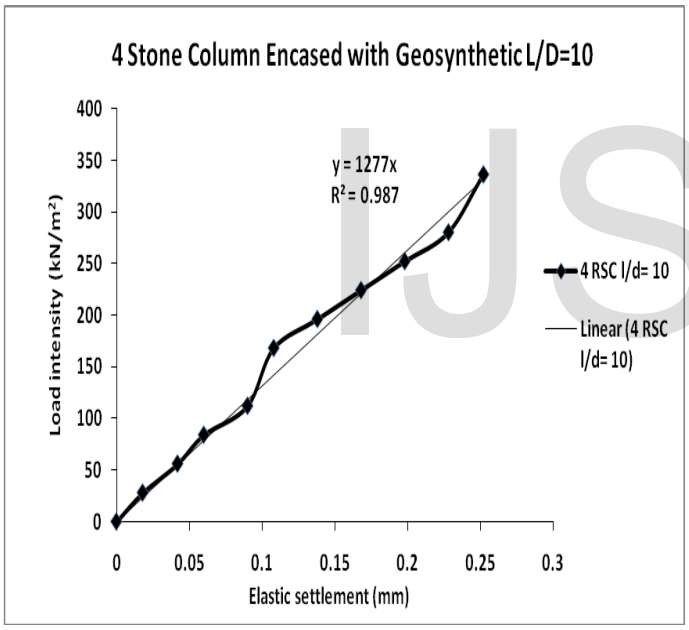


Fig.7. Load intensity versus elastic rebound from cyclic plate load test for four encased stone columns for L/D=10, S=2D

Table 1: Variation of coefficient of elastic uniform compression.

Sl. No	Description	Coefficient of elastic uniform compression Cu (kN/m^3)
1	Soil alone	$0.24*10^5$
2	Single stone column (L/D=8)	$0.34*10^5$
3	Single stone column with encasement (L/D=8)	$0.39*10^5$
4	Single stone column (L/D=10)	$0.63*10^5$
5	Single stone column with encasement (L/D=10)	$0.77*10^5$
6	4 SC square pattern (L/D=8,S=2d)	$0.91*10^5$
7	4 ESC square pattern (L/D=8,S=2d)	$0.93*10^5$
8	4 SC square pattern (L/D=10,S=2d)	$1.04*10^6$
9	4 ESC square pattern (L/D=10,S=2d)	$1.27*10^6$

4. Conclusions

In this paper an attempt is made to study the cyclic response of stone columns by conducting series of cyclic plate load tests on single, group and geosynthetic enacased stone columns. From cyclic plate load test a dynamic parameter called coefficient of elastic uniform compression(C_u) was found which can be used in the design of machine foundations constructed on treated ground with stone columns. It is found that as compared to untreated black cotton soil alone, the coefficient of elastic uniform compression (C_u) increases with inclusion of stone columns and further when compared to floating stone columns the parameter (C_u) increases for end bearing stone columns. Also when compared to single stone columns the parameter (C_u) increases for group of stone columns, and further it more in case of encased stone columns due to increased lateral stiffness due to encasement

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