ARTICLE IN PRESS

Engineering Science and Technology, an International Journal xxx (2017) xxx–xxx

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Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

Estimation of bearing capacity of floating group of stone columns

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A R T I C L E I N F O

Article history:
Received 10 September 2016
Revised 6 January 2017
Accepted 12 March 2017
Available online xxxx

Keywords:
Bearing capacity
Floating stone column
Empirical equation
Experiments

A B S T R A C T

Stone column is one of the ground improvement techniques. This technique has a proven performance, short time schedule, durability, constructability and low costs. The stone column technique has been used as a method of reinforcement of soft ground over the past 30 years. The bearing capacity of the stone column still has high level of uncertainties because the existing formulas for the estimation of the bearing capacity are general and do not take into consideration the type of the stone column whether if it's floating or end bearing and the method of the implementation of the stone columns and the length to diameter ratio of the stone column (L/D) and many other factors that affect the bearing capacity of the stone column.

In the present study, a general equation was obtained by carrying out statistical analysis using the SPSS (Statistical Package for the Social Sciences) program from the present experimental work and previous studies. The equation is used to estimate the bearing capacity of floating stone column group installed in clays of different undrained shear strengths between (4–25) kPa and with different diameters and L/D ratios constructed by cased bored method. The equation indicates that the most controlling parameter in the prediction of stone columns bearing capacity, q_u, is the area replacement ration, As, where q_u increases considerably with increase of As, i.e. decrease of spacing between columns.

1. Introduction

Granular piles including stone columns are used as a ground improvement method. These compression elements introduced into the ground, although they cannot resist tensile stresses, possess high compressive strength and stiffness. Thus such columnar inclusions carry a substantially greater proportion of applied loads with significantly smaller deformation compared to the in-situ soft clay.

Stone columns not only serve the primary functions of reinforcement and drainage but also enhance the bearing capacity and reduce settlement of the composite ground. Also, as a consequence of the installation processes, the lateral stresses in the original ground conditions around the inclusions tend to be higher than its values at rest.

Construction of stone columns in soft clay under an embankment is a common economical ground improvement method when shear strength increase, settlement reduction and acceleration of consolidation are needed above the vertical stresses, which remain approximately constant. The stone column derives its axial capacity from the passive earth pressure developed due to the bulging effect of the column and increased resistance to lateral deformation under superimposed surcharge load, [29].

Several experimental studies have been proposed to predict the bearing capacity of stone columns.

Al-Qyssi [5] conducted model tests to improve the behavior of stone columns by using different patterns of reinforcement consisting of two and three discs connected to a central shaft. Different parameters were studied; spacing between stone columns, effect of shape of footing, effect of area replacement ratio, As and the number of stone columns. It was found that circular footing demonstrates a higher bearing ratio at failure followed by the square then by the rectangular model footings. The bearing ratio increases with increasing spacing from 2D to 2.5D and 3D c/c (D is the stone column diameter) for all the three shapes of model footing. The area replacement ratios showed an insignificant influence on the efficiencies of the single stone column.

Ambily and Gandhi [9] carried out experiments on behavior of single stone column and group of columns by varying parameters like spacing between the columns, shear strength of soft clay and loading conditions. The results indicated that columns arranged with spacing more than 3 times the diameter of the column do not give any significant improvement. The stiffness improvement factor was found to be independent of the shear strength of the

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Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2017.03.005
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surrounding clay soil, however it depends on the spacing of the stone columns and friction angle of the stone aggregates.

The group efficiency of 24 model stone columns installed in soft clay was considered by Shlash et al. [31] and Fattah et al. [23]. These groups consisted of 2, 3 and 4 columns. The tests were conducted on stone columns with length to diameter ratio (L/D) of 6 and 8. A laboratory setup was manufactured in which two proving rings were used to measure the total load applied to the soil-stone column system and the individual load carried directly by the stone column. The foundation steel plates have 220 mm diameter and 5 mm thickness. These plates contain 1, 2, 3 and 4 holes, respectively. The spacing between all holes equals twice the stone column diameter (D), center to center. The stone column capacity was taken as the load corresponding to a settlement equals to 50% of the diameter of stone column. The results illustrated that the group efficiency decreases with increasing the number of stone columns, also the stone columns with L/D of (8) provided higher efficiency than those with L/D of (6).

Bouassida et al. [18] described the use of some new software (Columns 1.0) to undertake the design of foundations on soils reinforced by columns. First, the main advantages of columnar-reinforced systems are briefly reviewed: namely the increase of bearing capacity, the reduction of settlement, the acceleration of consolidation and the prevention of liquefaction potential. These advantages are usually predicted from analytical calculations and quantified after recorded field data. Second, the design methodology incorporated in this new software is described. Based on results obtained essentially by the 'group of columns' model and by the composite cell model, this methodology aims to optimise design which makes it possible to avoid overestimated quantities of column material under rigid or flexible foundation. Different types of reinforcement by columns such as the most frequently used stone columns, sand compacted columns, deep mixing soil method, etc. can be simulated by this new software.

Bora and Dash [20] carried out an experimental investigation to ascertain the behavior of stone column under load in soft clay bed. The group effect of the stone column was also studied as the stone column reinforced bed was prepared in group. Based on the experimental results, the pressure-settlement response of the stone column reinforced clay was studied. The experimental data were further used for regression analysis to fit the equation for bearing capacity of the improved soft clay bed. Both linear and nonlinear regression were carried out and the best suited regression model was presented. It was observed that the nonlinear regression model is best fitted for the stone column reinforced clay bed.

Table 1
Physical and chemical properties of the natural soft soil.

Index property	Value	Specification
Liquid Limit (L.L) (%)	44	ASTM D 4318-00 [14]
Plastic limit (P.L) (%)	19	ASTM D 4318-00 [14]
Shrinkage limit (S.L) (%)	14	ASTM D 4318-00 [14]
Plasticity index (P.I) (%)	25	ASTM D 4318-00 [14]
Activity	0.96	ASTM D 4318-00 [14]
Specific gravity (Gs)	2.69	ASTM D 854-00 [15]
Gravel (%)	0	ASTM D 422-00 [13]
Sand (%)	17	ASTM D 422-00 [13]
Silt (%)	35	ASTM D 422-00 [13]
Clay (%)	48	ASTM D 422-00 [13]
Classification (USCS)	CL	ASTM D 2487-00 [10]
Organic matter (O.M.) (%)	0.39	ASTM D 2974-00 [11]
Calcium oxide (CaO) (%)	0.36	BS 8004 test No. 8 [21]
SO_3 content (%)	0.52	BS 8004 test No. 9 [21]
Total dissolved salts% (TDS)	1.02	BS 8004 test No. 10 [21]
pH value (%)	9.17	BS 8004 test No. 11 [21]

Fattah et al. [24] investigated the behavior of embankment models resting on soft soil reinforced with ordinary and encased stone columns (ESCs). Model tests were performed with different spacing distances between stone columns and two length-to-diameter ratios (L/D) of the stone columns, in addition to different embankment heights. A total of 39 model tests were performed on soil with an undrained shear strength of 10 kPa. The system consisted of a stone column-supported embankment at different spacing-to-diameter ratios (s/D) of stone columns. For embankment models constructed on soft clay reinforced with ESCs, it was found that whether a column was floating or end bearing (resting on a rigid stratum), encasement of the column by a geogrid was most effective in improving the bearing ratio of reinforced soil by approximately 1.29, 1.39, and 1.63 times and 1.4, 1.57, and 1.83 times that of untreated soil, reducing the settlement by approximately 0.71, 0.67, and 0.62 times and 0.63, 0.6, and 0.45 times that of untreated soil for 200, 250, and 300 mm embankment heights with L = d = 5 and 8, respectively, and spacing s = 2.5d. The bearing improvement ratio (bearing capacity of treated-to-untreated soil) increased with decreasing spacing of stone columns for a given embankment. A higher improvement ratio was achieved for the models reinforced with stone columns at s = 2.5d at any embankment height.

It is concluded from the previous studies that there is no general relationship for predicting the baring capacity of single and group of stone columns that take into account several factors affecting the stone column behavior such as L/D ratio, spacing between columns

Fig. 1. Four stone column group models.