Bearing capacity of encased stone columns with different materials in soft clay

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ABSTRACT: Advantages of using stone columns in soft clay are recognized as an applied method to improve bearing capacity of shallow foundations. In order to study behavior of stone columns in soft clay a foundation simulating setup manufactured included a large test box (1.20×1.20×0.90 m) and hydraulic loading system. Twelve experimental tests were carried out to investigate effects of three different diameters of stone columns (63, 80 and 92 mm) on bearing capacity of them. Also, geotextile with both full-length and ringed forms were applied for encasing columns. Using ringed form of geotextile for encasement give the opportunity to investigate the possibility of use of similar encasing materials such as worn out tires. Diameters of 63, 80 and 92 mm with a ratio of length to diameter of 5 for both ordinary and encased columns were chosen. Results are shown to compare effectiveness of diameter variations and encasement.

Keywords: Stone column, Soil improvement, Geotextile, Experimental test, Worn out tire

1 INTRODUCTION

In soft soils, the construction of structures such as a building, liquid storage tanks, earthen embankments, etc. cause excessive settlement that ends up stability problems. To solve or reduce settlement problems, out of several available techniques, stone columns (also known as granular piles) have been widely used. (Watts et al. (2000), Gniel and Bouazza (2009), Najjar et al. (2010), Sivakumar et al. (2011), Fattah et al. (2011), Dash and Bora (2013) and Miranda and Da Costa (2016)). Under compressive loads stone columns fail in different modes, such as bulging described by Hughes and Withers (1974), general shear failure described by Madhav and Vitkar (1978), and sliding described by Aboshi et al. (1979). Also punching failure mechanism was investigated by Aboshi et al (1979). Murugesan and Rajagopal (2010) carried out some laboratory tests to compare the shear load capacity of ordinary stone columns and encased stone columns. The results from the load tests indicated that using geosynthetic material for encasing leads to increase in the bearing capacity of encased columns. Shahu and Reddy (2011) performed 1-g tests (large test box) of stone columns on fully drained model in a cylinder tank with diameter of 300 mm and the depth of 600 mm. Ghazavi and Afshar (2013) performed some laboratory tests with a large test box on different diameters of ordinary and encased stone columns. Columns were constructed in the soft soil using replacement method.

As a new procedure for encasement, tires can be used. In this paper efforts are made to investigate properties of this form of encasement.

In this paper, using a large test box, bearing capacity of single stone columns in soft clay are investigated. Stone columns were tested in 3 procedures: OSC (ordinary stone column), ESC (encased stone column), RESC (ringed encased stone column).

2 EXPERIMENTAL STUDY

2.1. Materials

2.1.1. Clay and gravel

The soft clay used was of CL classification, excavated from the depth of 1 m where the clayey soil was not included vegetation, air-dried, and pulverized particles. Crushed stones aggregates of sizes between 2 to 10 mm also have been used to form stone column. Table 1 gives some properties of clay and gravel.

Table1. Properties of clay and gravel

Material	Specific gravity	Bulk unit weight for test (kN/m^3)	Modulus of elasticity (kPa)	Poisson's ratio (ϑ)	Unified system classification
Gravel	2.7	15.5	40000	0.3	GP
Clay	2.7	19	400	0.25	CL

Some unconfined compressive strength tests (UCS) on cylindrical specimen with 38 mm diameter and 76 mm height were carried out for determining the moisture content of the clay corresponding to undrained shear strength of 13 kPa. It was determined 21%.

2.1.2. Reinforcement

In the current research, large body stone columns with diameters of 63, 80 and 92 mm were reinforced using nonwoven polypropylene geotextile with ultimate tensile strength 9 KN/m and its tensile modulus (J) is16 KN/m. These values are chosen based on law scale. The relationship between prototype-scale reinforcement stiffness (J_P) and model-scale stiffness (J_m) can be calculated as $J_P = J_m\lambda^2$, where 1/L is the model scale. In the current study, this is equal to 10 (Ghazavi and Afshar (2013)). For all tests, an overlapping width of 15 mm was taken and overlapping seam was stuck with special polypropylene glue.
Beside ordinary columns (Figure 1a) and full-length encased columns (Figure 1b), columns encased by ringed geotextiles (Figure 1c) tested to investigate the possibility of using similar form of encasing materials such as worn out tires in practise.

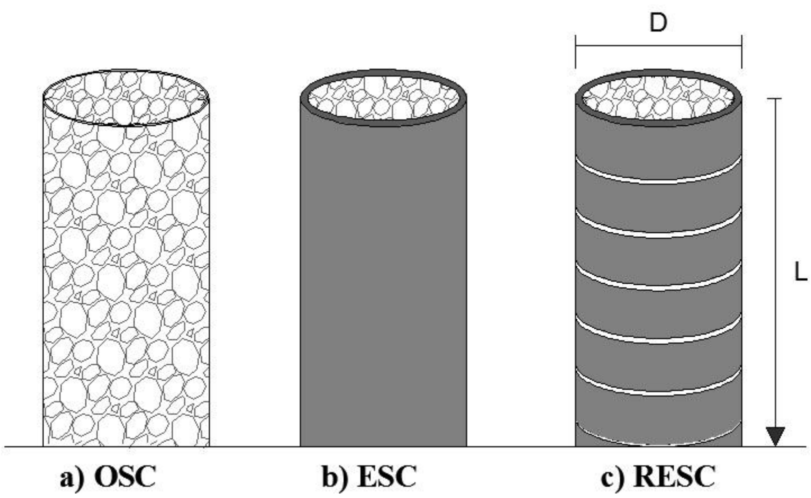


Figure 1: Different types of columns used. (Lajevardi et al. (2016))

2.2 Test setup and procedure

This test included a rigid loading box with plan dimensions of 1.20×1.20×0.90 m height, that provides enough space for soft soil and stone columns in a way that boundary of the box do not effect on bearing capacity of columns (Figure 2).

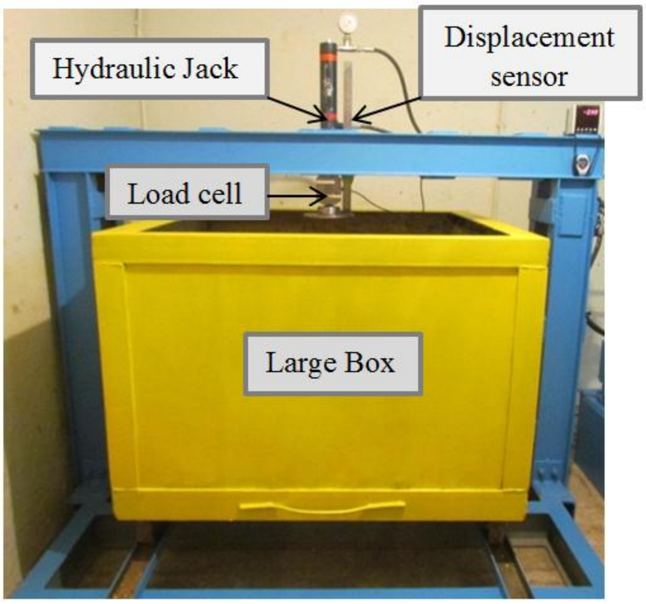


Figure 2: Large test box and loading frame

The loading system is based on displacement control which is powered by electrohydraulic system that applied vertical load on the centre of single columns. Load applying to reach the 50 mm settlement continued and its speed was kept fixed by a special valve on the rate of 2 mm/min in all tests. In this study, 12 tests were performed on single stone columns (Table 2).

Table 2. Single stone column tests

Test description	Plate size (mm)	Diameter of stone columns (mm)			Total number of tests
		63	80	92	
Clay bed	180	1	1	1	3
OSC		1	1	1	3
ESC		1	1	1	3
RESC		1	1	1	3

While the loading plate was on top of columns tests were performed on single columns with diameters of 63, 80 and 92 mm and lengths of 315, 400 and 460 mm, respectly. These amounts are based on the ratio of length to diameter of 5 which were satisfied minimum L/D = 4 is required for controlling of bulging failure mode (Barksdale and Bachus, 1983). Also, the area ratio defined as area of the stone column divided by loading area obtained 12.25%, 19.75% and 26.1% for columns with diameters of 63, 80 and 92 mm, respectly.

2.3. Preparation of materials

2.3.1 Soft clay bed

Clay bed was prepared in a large test box with plan dimensions of 1.2 m×1.2 m in layers each of which was 50 mm thick. In order to prepare the moisture content of 21% corresponding to 13kPa undrained shear strength, the amount of additional water calculated based on initial natural water of clay was added. To keep this moisture away from vaporization and also reach to uniform moisture, mixture was kept for 5 days in a large box covered by nylon sheets from inside. The clay was placed in the box with measured weight. A uniform compaction provided with a tamper to achieve a 60 mm height for each layer and uniform density to reach a certain bulk unit weight of 19 kN/m^3. In all tests, moisture changes controlled and its variations kept less than 1%. To ensure that the undrained shear strength remained the same, 3 unconfined compression tests were performed on the specimens taken from different depths of the clay bed.

2.3.2. Stone columns

All stone columns were constructed by a replacement method at the centre of the large box, to ensure that test results wouldn't be affected by walls of box. In order to replace the clay, 3 thin seamless steel pipes with outer diameters of 63, 80 and 92 mm and wall thickness of 2 mm were prepared and used to push into the clay. The clay within each pipe was scooped out using an auger. After excavating of the whole clay inside the columns, Pipes were taken out slowly ensuring that no major soil movement occurred around the top level of stone column. Stones were charged into the pipes with measured weight and a compaction provided with a tamper to achieve a 50 mm height and uniform density to reach a certain bulk unit weight of 15.5 kN/m^3.

3 RESULTS

3.1 Deformation and failure mode

After tests, in order to check the deformed shape of stone columns soft clay around the columns were cut softly. (Figure 3). The bulging failure usually occurs at the top of the column to depth of 2D. The shape of bulging was axisymmetric. It is observed that encased materials in single columns caused a smaller bulging in ESCs and RESCs rather than OSCs.

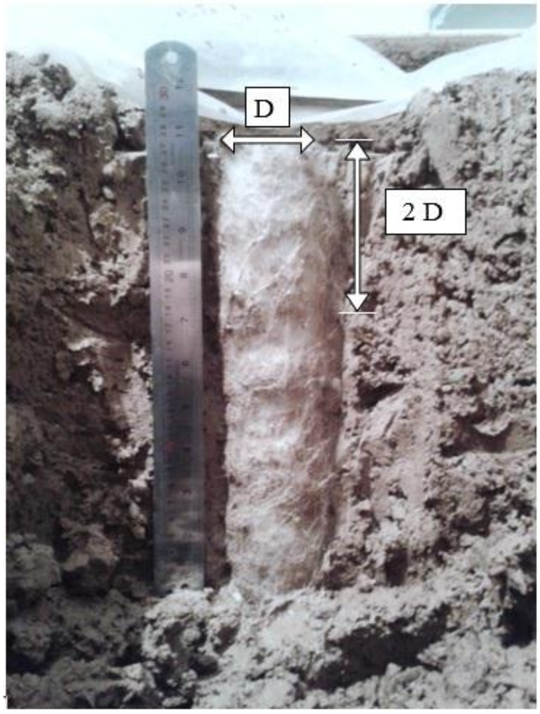
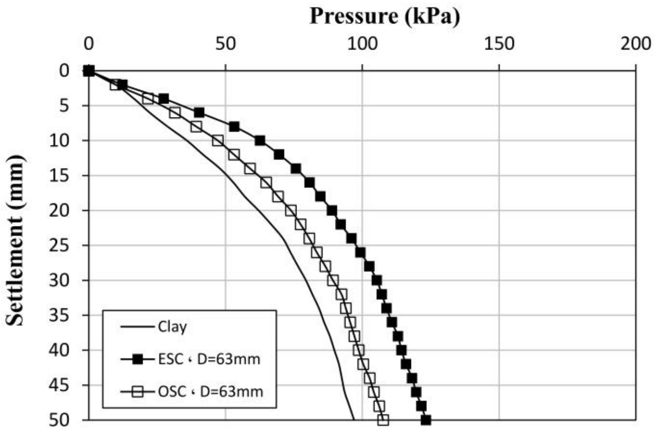


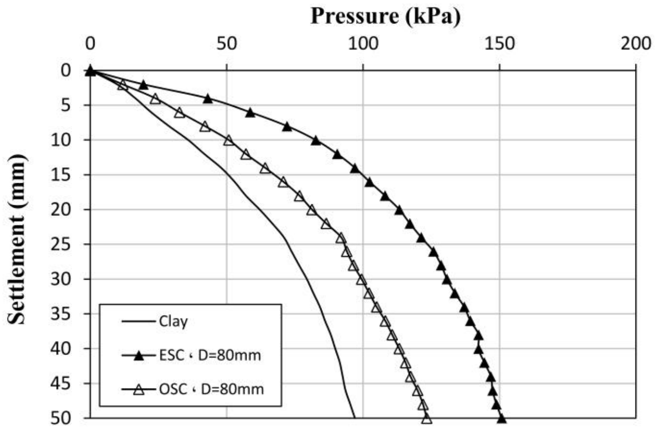
Figure 3: Deformation of encased stone columns after test

3.1.2 Load-settlement behavior

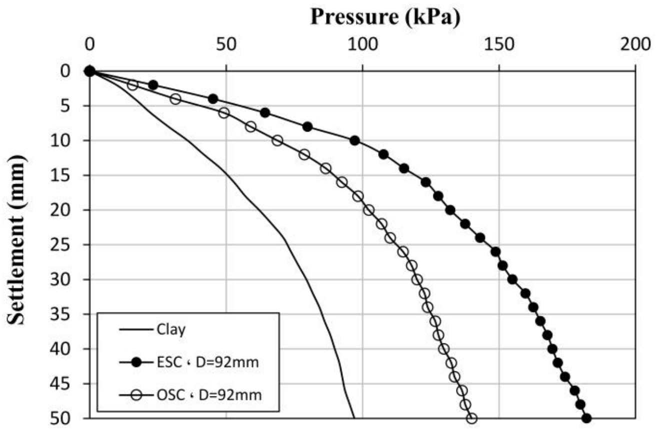
Figure 4 illustrates the load-settlement behaviour of OSCs and ESCs with diameters of 63, 80 and 92 mm. Using stone columns in all tests; lead an increase in the ultimate load-carrying capacity of the soft clay. In addition, by increasing the diameter of stone columns the ultimate capacities of OSCs were increased. It is seen that the ultimate capacity also improved by vertical encasement due to reducing the bulging failure of stone columns. Increseaings on bearing capacities of stone columns were 14.6%, 22.2% and 30.1% for columns with diameters of 63, 80 and 92 mm, respectly. Furthermore, effect of geotextile encasement on bearing capacity of stone columns increased by raise in columns' diameters.



(a)



(b)



(c)

Figure 4: Load-settlement behavior of stone columns with diameters : (a) 63 mm, (b) 80 mm, (c) 92 mm

3.1.3 Ringed encased stone columns

3.1.3.1 Bearing capacity

Some tests were performed on ringed encased stone columns (RESC) to investigate performance of these shape of reinforcement. Load-settlement behaviour of RESCs for different diameters are shown in Figure 5. By changing in shape of the encasing material (full-length to ringed), the ultimate bearing capacity of column decreased 7% in average and showed a raise rather than OSCs.

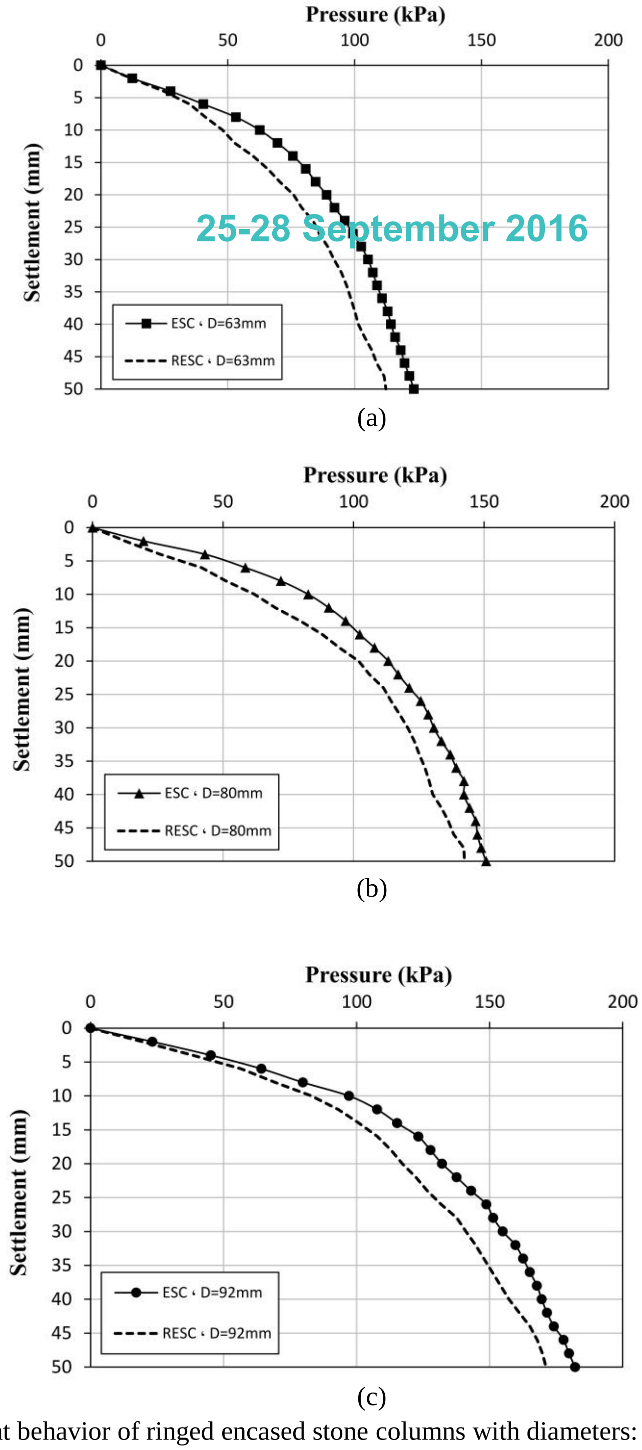


Figure 5: Load-settlement behavior of ringed encased stone columns with diameters: (a) 63 mm, (b) 80 mm, (c) 92 mm

3.1.3.2 Load ratio (LR)

To determine the efficiency of stone columns on the ultimate bearing capacity of the soft clay during loading, the load ratio (LR) parameter is defined as: Ultimate load obtained from reinforced soil by stone columns divided by the ultimate load obtained from soft soil without stone column. The variation of LR for RESCs with diameter of 63 mm obtained from 1.13 to 1.57 and for diameter of 80 mm is 1.45 to 1.88 and finally for diameter of 92 mm is 1.75 to 2.55 (Figure 6). Amounts of LR for ESCs are 1.30 to 1.85, 1.55 to 2.50 and 1.81 to 2.88 for diameters of 63, 80 and 92mm, respectively.

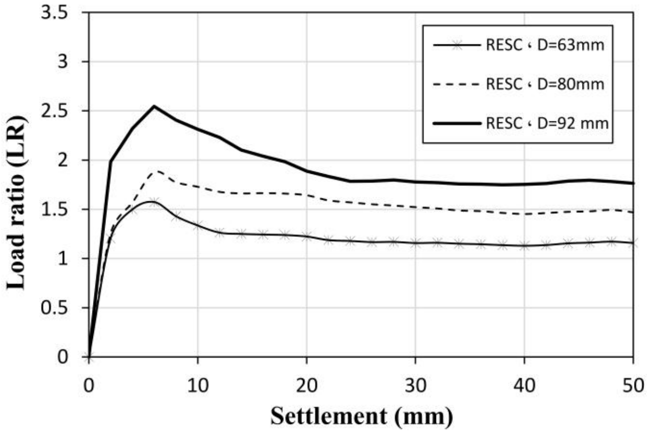


Figure 6: Variation of load ratio for stone columns.

4 CONCLUSIONS

In this research, laboratory tests have been performed on single stone columns with diameters of 63, 80 and 92 mm. ESCs (encased stone columns), and RESCs (ringed encased stone columns) with full length encasement were used in tests and the results were compared with those obtained from tests on OSCs (ordinary stone column).

Based on results from tests on, the following conclusions may be extracted:

1. Using OSCs the ultimate load carried by the system increased. Using columns with bigger diameters resulted in higher ultimate loads.
2. By encasing columns in both ESCs and RESCs bulging failure was reduced due to more lateral confinement provided by geotextile, therefore ultimate load increased.
3. In single stone columns bulging failure mode always governed. The bulging failure usually occurs at the top column to depth of 2D.

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