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Experimental study on Equivalent shear strength of cohesive soils improved with Stone columns by Triaxial Testing

J. Nazariafshar[1,*] , M. Aslani[2], N. Mehrannia[3]

1 Assistant Professor, Department of Civil Engineering, Shahr-e-Qods Branch, Islamic Azad University, Tehran, Iran
2 Department of Civil Engineering, Lenjan Branch, Islamic Azad University, Isfahan, Iran
3 Department of Civil Engineering, Shahr-e-Qods Branch, Islamic Azad University, Tehran, Iran

ABSTRACT: The use of stone column is an effective method in modifying of poor soils. One of the methods of studying the behavior of soils improving with stone columns is homogenization method. In this method, the stone column and the surrounding soil are replaced with a homogenous soil. In homogenization method the equivalent parameters are calculated by means of weighted average of soil and column parameters with linear relations. In this study, equivalent shear strength and shear strength parameters of the soil improved with stone columns was calculated based on the analytical relationships and the accuracy of the relationships used was evaluated through triaxial tests. In this study with help of simulation of the unit cell in the laboratory scale and investigating the shear strength of soil improved with stone columns, behavior of stone columns was investigated. The laboratory experiment consisted of series of the triaxial tests with a diameter of 100 mm and height of 200 mm and sand column with diameter of 37.5 and 51 mm and 3 confining pressure 50,100,200 kPa. The results of this study shows that with the use of a stone columns in soft soil, the undrained shear strength and the stiffness of the sample is increased and with increased confining pressure, the percentage of undrained shear strength increased. The difference between shear strength parameters obtained from experiments and those predicted by analytical relationships with the increase in the stress concentration ratio increased and decreased with increasing undrained shear strength of the surrounding soil.

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1. INTRODUCTION

Using the triaxial apparatus to model the concept of unit cell is considered one of the common methods of investigating the behavior of stone columns. In this method, the stone column and surrounding soft soil is modelled through making a cavity in the center of the clay sample in the triaxial sample. In most of the methods proposed to investigate the behavior and design of the stone columns, the concept of unit cell has been used to model the stone column and surrounding soft soil. There are two general methods of calculating the effect of reinforcing stone columns on the increase in soil bearing capacity and shear strength of soil. In the first method, the soft soil and stone column are considered separately. The second method applies homogenization method. Stone column and the surrounding soil together form a heterogeneous medium. For simplification, the heterogeneous until cell is converted to a homogenous one. For this purpose, the stone column and the surrounding soil are replaced with an equivalent homogenous soil with improved properties. One of the methods of calculating equivalent soil parameters is to average soil and column parameters weighted by their corresponding area. This method is a common method in estimating bearing capacity, settlement and especially slope stability. The accuracy of the linear relationship used to homogenize of stone columns has not been examined through any laboratory tests, and most of the studies into the analytical comparison and real use of the concept of homogeneous unit cell, have been analytical and numerical[1-8]. Therefore, considering the current shortcomings, the present paper has simulated the unit cell and investigated the hybrid shear strength of the stone column materials and the surrounding soil on small laboratory scale. For this purpose, the present paper investigates the effect of stone column presence on shear strength of soft soil, stress–strain behavior of soft soil sample reinforced with stone column, effect of confining pressure on equivalent shear strength and the accuracy of the linear relationship used for homogenizing the soft soil reinforced with granular column.

*Corresponding author's email: j.nazariafshar@qodsiau.ac.ir

2. MATERIAL PROPERTIES OF SOFT BED, STONE COLUMN and SAMPLE PREPARATION

The low-plasticity silt (ML) with LL=43% and PI=8% has been used to form soft soil bed. Two undrained shear strength values of 15 kPa (ML1) and 30 kPa (ML2) are considered for

Table 1- Summary of experimental tests

Test No	Test Name	Ar (%)	(kPa)$\boldsymbol{\sigma_3}$			Number of Test
			50	100	200	
1	ML1	0	1	1	1	3
2	ML2	0	1	1	1	3
3	S	100	1	1	0	2
4	ML1-S-14%	14	1	1	1	3
5	ML1-S-26%	26	1	1	1	3
6	ML2-S-14%	14	1	1	1	3
7	ML2-S-26%	26	1	1	1	3

the shear strength of bed. In the present study, the moisture of fine-grained soil should be 36.5% and 32.2% respectively to reach the undrained shear strengths of 15 kPa and 30 kPa. Poorly graded angular sand (SP) with particle size ranging from 1 to 4 mm were used as stone columns materials. The internal friction angle and apparent cohesion of sand are 43 degrees and 18 kPa in the relative density of 63%. As for the aggregates that are tested examination, 18 kPa of cohesion has been gained as well as internal friction angle, and this cohesion results from internal interlock between the angular particles of aggregates that is known as apparent cohesion in technical notes that is different from the type of cohesion in fine grains. As the diameters of model scale stone columns and equivalent trench were smaller than the diameters of stone columns installed in the field, the particle dimensions of stone column material were reduced by an appropriate scale factor to allow an accurate simulation of stone columns behavior [9-12]. The required soft soil samples are made through the method of tamping soil layers with the same thickness and the given bulk density of 19 kN/m². In all tests, the diameter of the soft soil sample has been determined as 100 mm and the stone column diameter has been determined as 37.5 mm and 51 mm. Considering the fact that the diameter of the soft soil sample has been constant in the triaxial tests and the changing diameter of granular column, it can be said that the area replacement ratio (A_r) for the stone columns with the diameter of 37.5 mm and 51 mm were 14% and 26% respectively in the conducted tests. A steel pipe with a wall diameter of less than 2 mm was placed in the center of the sample within the bed. Both the internal and external surfaces of the pipe are covered by a thin film of oil, then the pipe is placed in the soft soil vertically, gently and carefully in order to decrease the friction between the pipe and soil, and to decrease the effect of disturbance on fine-grained soil. The soft soil inside the pipes has been removed only in the pipes with a maximum diameter of 25 mm because it was not possible to remove the cohesive soil of the pipes with a diameter of greater than 25 mm in practice, moreover, the excessive removal of the cohesive soil at one phase will result in soft soil suction and disturbance to the soil. A special auger, made to be used in this study, was used to remove the soil [13].

3. TESTING PROCUDURE

A fully automatic triaxial apparatus with a diameter of 100 mm and a height of 200 mm was employed for modelling and conducting the relevant tests. Also, the tests were conducted based on the controlled displacements in unconsolidated-undrained conditions according to ASTM D2850-03a standard. The tests were conducted in two area replacement ratios (14%, 26%) and in three confining pressures of 50 kPa, 100 kPa and 200 kPa. The applied displacement was measured using a linear variable differential transformer (LVDT) and the axial force was measured by a load cell. An automatic device has been employed to apply the confining pressure making it possible to maintain the amount of applied pressure constant during the test with an error of less than 2 kPa. The data obtained from the tests were transferred to a computer by a data logger where the data were collected, recorded and analyzed by a specific program. All specimens were sheared under a vertical displacement rate of 1 mm/min.

4. TESTING PROGRAM

Nine tests were conducted in the bed with an undrained shear strength of 15 kPa (ML1), 9 tests were conducted in the bed with the undrained shear strength of 30 kPa (ML2), and two triaxial tests were conducted on aggregates (S), and the relevant details have been presented in Table 1. Five triaxial tests were conducted at a confining pressure of 100 kPa to draw the undrained shear strength diagram of bed soil with changing moisture, and the total number of the tests will be 25 when including these tests. Some abbreviations have been used in Table 1 to name the tests where the first letter indicates subgrade, the second letter indicates the materials of stone column and the last letter indicates the area replacement ratio.

5. RESULTS AND DISCUSSION

The present study conducts a laboratory examination of the equivalent shear strength of improved soft soil to stone columns in the biaxial apparatus. The behavior of stone columns in the triaxial apparatus was examined in two area replacement ratios (14% and 26%) and in three confining pressures of 50 kPa, 100 kPa and 200 kPa, and the following results were obtained according to the received data.

1-The undrained shear strength and sample stiffness increase along with the increase in the area replacement ratios in all tests. In the tested samples, involving a soft soil with the undrained shear strength of 15 kPa gained through a granular column with a diameter of 37.5 mm in confining pressures of 50 kPa, 100 kPa and 200 kPa, the ratio of the ultimate deviator stress between soil and the stone column to the unimproved soil are 1.9, 2.2 and 2.6 respectively. Also, this ratio, in the case when the diameter of the granular column is 51 mm, will be 2.7, 3.2 and 3.6. In the tested samples, involving a soft soil with a undrained shear strength of 30 kPa through using a stone column with a diameter of 37.5 mm in lateral stress of 50 kPa, 100 kPa and 200 kPa, the ratio of the ultimate deviator stress between soil and the stone column to the unimproved soil are 1.4, 2.0 and 2.8 respectively. Also, this ratio, in the case when the diameter of the stone column is 51 mm, will be 1.8, 2.6 and 4.4.

2-The amounts of shear strength and the shear strength parameters obtained from the tests in the ML1 bed will be less than the amounts of equivalent shear strengths obtained from analytical relations, and the same amounts in the ML 2 bed will be greater than the equivalent amounts of shear strength obtained from further analytical relations. The results show that the use of analytical relationships for the soft soils with a decrease in the shear strength is conservative. In fact, it can be said that the adequate confining pressure has been provided to apply the shear strength of stone column materials when the undrained shear strength of subgrade increases.

3-Generally, the percentage of undrained strength increases along with the increase in confining pressure; however, the slope of changes in the percentage of increase in undrained strength of soil with the undrained shear strength of 15 kPa is milder than that of the soil with the undrained shear strength of 30 kPa, and this slope is milder when the confining pressure is less than 200.

4-The comparison between the parameter of shear strength of the soil reinforced with granular column with analytical relationships suggests that the difference between the internal friction angle parameter of the results obtained from the analytical and lab relationship increases according to the value of n; however, the cohesion remains constant because the parameter of the equivalent cohesion does not depend on n value.

5-Comparison between the parameters of shear strength resulting from the test and the analytical relationships suggest that the equivalent shear strength parameter will be equal to 1 in ML1 subgrade considering the ratio of stress concentration, and it is equal to 2 in ML2 subgrade considering the ratio of stress concentration.

6-The difference between the analytical results and laboratory results decreases along with the increase in the undrained strength of the surrounding soil. The main reason resulting in this is that the adequate confining pressure has not been provided to apply the shear strength of stone column sand materials along with further softening of the clay around the stone column when the undrained shear strength of subgrade increases, while the complete shear strength of the stone column materials is used in the relations. However, it will be possible to apply the shear strength of stone column materials along with the increase in subgrade strength and confining pressure, resulting in the increase in the parameters of shear strength.

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