Experimental Study of the Effect of Stress Concentration Ratio on the Shear Strength of Loose Sand Reinforced by Stone Column

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Extended Abstract

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Introduction

Stone column installation method is one of the popular methods of ground improvement. Several studies have been performed to investigate the behavior of stone columns under vertical loads. However, limited research, mostly focused on numerical investigations, has been performed to evaluate the shear strength of soil reinforced with stone column. The stress concentration ratio (n) is one of the important parameters that uses in soil improvement by stone column method. Stress concentration ratio is the ratio of the stress carried by stone column to that carried by the surrounding soil. In this paper, the results of a laboratory study were used to examine the changes in the stress concentration ratio when normal and shear stress applied. Direct shear tests were carried out on specimens of sand bed material, stone column material and sand bed reinforced with stone column, using a direct shear device with in-plane dimensions of 305*305 mm and height of 152.4 mm. Experiments were performed under normal stresses of 55, 77 and 100 kPa. In this study, three different area replacement ratios (8.4%, 12%, 16.4%), and three different stone column arrangements (single, square and triangular) were considered for investigation. Loose sand and crushed gravel were used to make the bed and stone columns, respectively. In this study, the equivalent shear strength and equivalent shear parameters measured from experiments were also compared with those predicted by analytical relationships at stress concentration value of 1 and stress concentration value obtained from experiments.

Material Properties

Fine-grained sand with particle size ranging from 0.425 to 1.18 mm was used to prepare loose sand bed, and crushed gravel with particle size ranging from 2 to 8 mm was used as stone column material. The sand material used as bed material had a unit weight of 16 kN/m^3 and a relative density of 32.5%, and the crushed stone material used in stone columns had a unit weight of 16.5 kN/m^3 and a relative density of 80%. The required standard tests were performed to obtain the mechanical parameters of bed material and stone column material. As the diameters of model scale stone columns 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.

Testing Procedure

In this study, large direct shear device was used to evaluate the shear strength and equivalent shear strength parameters of loose sand bed reinforced with stone column. Experiments were performed under normal stresses of 55, 75 and 100 kPa. Two class C load cells with capacity of 2 tons were used to measure and record vertical forces and the developed shear forces during the experiments, and a Linear Variable Differential Transformer (LVDT) was used to measure horizontal displacement. The main objectives of this study was to calculate the stress concentration ratio of stone columns in different arrangement. Stress concentration ratio is the ratio of the stress carried by stone column to that carried by the surrounding soil, and can be calculated using Equation 1. For this purpose, the direct shear device was modified. Two miniature load cells with capacity of 5 kN were employed. The load cells were mounted on the rigid loading plate with dimensions of 305*305 mm^2 and thickness of 30 mm, as shown in Figure 1, All achieved data from the experiments including data on vertical forces, shear forces and horizontal displacements were collected and recorded using a data logger, and an especial software was used to transfer data between the computer and the direct shear device. All specimens were sheared under a horizontal displacement rate of 1 mm/min.

$$n = \frac{\sigma_c}{\sigma_s} \quad (1)$$

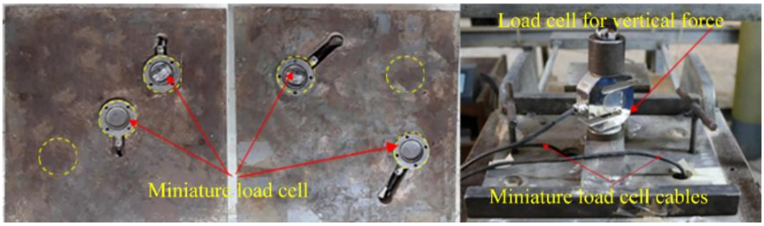

Figure 1. Loading plate designed for (a) single and square arrangement of stone columns (b) triangular arrangement of stone columns (c) installation method of S class and miniature load cells

Testing Program

Experiments were performed on single stone columns and group stone columns arranged in square and triangular patterns. The selected area replacement ratios were 8.4, 12 and 16.4% for single, square and triangular stone column arrangements. To eliminate boundary effects, the distance between stone columns and the inner walls of the shear box was kept as high as 42.5 mm. In total, 11 direct shear tests were carried out, including two tests on loose sand bed material and stone column material, and 9 tests on stone columns with different arrangements. From the tests performed on group stone columns, 3 tests were performed on single stone columns, 3 tests on stone columns with square arrangement and 3 tests on stone columns with triangular arrangement. Hollow pipes with wall thickness of 2 mm and inner diameters equal to stone column diameters were used to construct stone columns. To prepare the specimens, first, the hollow pipes were installed in the shear box according to the desired arrangement. Then, bed material with unit weight of 16.5 kN/m^3 was placed and compacted in the box in 5 layers, each 3 cm thick. Stone material was uniformly compacted to construct stone columns with uniform unit weight.

Results and discussion

1. The SCR value increases for settlement up to 3 mm and then decreases with increasing the horizontal displacement and then approaches almost a constant value. Results also show that stress concentration

ratio decreases with increase of stone column diameter. Results show that the value of stress concentration ratio in square pattern is higher than that in single and triangular pattern. Moreover, results show that stress concentration ratio decreases with increase of normal stress.

2. The value of the internal friction angle in (peak) state, for loose bed increases from 33 to 40 degrees in square arrangement and in the corresponding state of displacement of 10 % from 30 degrees in a loose bed increase to 32 degrees, for loose sand reinforced with stone column. Shear strength increases with the increase of modified area ratio in all stone column installation patterns in both the peak and the corresponding state of the horizontal displacement of 10%.
3. For stone columns with the same modified area ratio, the installation pattern has an effective role in defining the shear strength. Group stone columns mobilize higher shear strength compared to single stone columns. Among the installation patterns investigated in this study, stone columns with square arrangement experienced the highest increase in shear strength value while single stone columns experienced the lowest.
4. The equivalent shear strength values measured from experiments are higher than those obtained from analytical relationships. Accordingly, it is conservative to use analytical relationships to calculate shear strength parameters. It is worth explaining that these relationships assume that the value of stress concentration ratio is equal to 1. Results from this study show that the value of stress concentration ratio should be accurately calculated and used in the relationships.
5. Comparison between shear strength parameters obtained from experiments and those predicted by analytical relationships shows that in single stone columns, the value of stress concentration ratio should be 3 to 4.5, and in square and triangular patterns, this value should be 6 to 7 and in triangular patterns 4.5 to 5, respectively, to achieve good agreement between experimental and analytical results in peak condition. In horizontal displacement 10% the value of stress concentration ratio should be 2.5 to 3, in single, square and triangular patterns, to achieve good agreement between experimental and analytical results.

Keywords: Stone Column, Stress Concentration Ratio, Equivalent Shear Strength, Direct Shear Test

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