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The Modeling of Ground Improvement with Stone Columns

Bahador Reihani[1], Masoud dehghani[2]
[1]Department of Civil Engineering, Pardis of Gheshm, Iran
[2]Department of Civil Engineering, University of Hormozgan, Iran
Emails: [1]b_reihani@yahoo.com, [2]dehghani@hormozgan.ac.ir

Abstract- Stone columns in soft soil improve bearing capacity because they are stiffer than the material which they replace, and compacted stone columns produce shearing resistances which provide vertical support for overlying structures or embankments. In this article, the analysis was carried out using the commercially available finite-element program PLAXIS, to compare the load settlement behavior with the model test. A parametric study is carried out to investigate the behavior of standard and encased floating stone columns in different conditions. Different parameters were studied to show their effect on the bearing improvement and settlement reduction of the stone column. In this modeling, the effect of friction angle and the effect of elasticity modulus of the stone column and the surrounding soil material on the load settlement curve and the settlement ratio (SR) have been paid.

Keywords- Stone columns, Settlement ratio, Finite element method, ground improvement

I. Introduction

Stone column construction involves the partial replacement of unsuitable subsurface soils with a compacted vertical column of stones that usually completely penetrates the weak strata. The presence of the stiffer column creates a composite material of lower overall compressibility and higher shear strength than the native soil alone. Stone column system in soft, compressible soils are somewhat like pile foundations, except that pile caps, structural connections, and deep penetration into underlying firm strata are not required, and the stone columns are, of course, more compressible (Mitchell 1981). When loaded, the stone columns deforms by bulging into the subsoil strata and distributes the stresses at the upper portion of the soil profile rather than transferring the stresses into deeper layer, unlike in case of pile foundation, thus causing the soil to support it (Bergado et al. 1994).

Abusharar et al. (2011) were investigate on Two-dimensional deep-seated slope stability analysis of embankments over stone column-improved soft clay. Based on the numerical results, a reduction factor was proposed to account for the difference in the FS when the individual column model is converted to the equivalent area model. The effects of the influence factors on the reduction factor were also investigated. The comparative study shows that the FS values obtained by the equivalent area model are higher than those by the individual column model. The results of these analyses are summarized into a series of design charts, which can be used in engineering practice.

Castro et al. (2011) survey on Deformation and consolidation around encased stone columns. The solution is presented in a closed form and is directly usable in a spreadsheet. Parametric studies of the settlement reduction, stress concentration and consolidation time show the efficiency of column encasement, which is mainly ruled by the encasement stiffness compared to that of the soil. Column encasement is equally useful for common area replacement ratios but columns of smaller diameters are better confined. Furthermore, the applied load should be limited to prevent the encasement from reaching its tensile strength limit. A simplified formulation of the solution is developed assuming drained condition. The results are in agreement with numerical analyses.

Fattah et al. (2012) were investigate on Finite Element Analysis of Geogrid Encased Stone Columns. They show that the bearing improvement ratio and the settlement reduction ratio are increased with decrease in undrained shear strength of the surrounding soil for all end bearing soil undrained shear strengths.

Hassen et al. (2010) were investigate on Finite element implementation of a homogenized constitutive law for stone column-reinforced foundation soils, with application to the design of structures. The closed-form expressions derived for such a constitutive law allow for its implementation into a f.e.m-based numerical procedure. The computational code so obtained is then applied to simulating the response of a foundation soil reinforced by a group of floating columns, expressed in terms of load–settlement curves drawn up to the ultimate bearing capacity.

Six et al. (2012) were investigate on Numerical Analysis of Elastoplastic Behavior of Stone Column Foundation. Their paper deals with the influence of the earth pressure at rest coefficient K0 on stone columns behavior. This parameter is related to the initial stresses caused by the compression of in situ soil and by the installation (expansion of column material).

II. Analysis

The initial vertical stress due to gravity load has been considered in the analysis. The stress caused by column installation depends on the method of construction and type of soil. In this investigation for considering the stress due to column installation, initial horizontal stress (K0) is increased. Groundwater was supposed to be more than 10 m below the ground surface. Hence, there was no need to enter groundwater condition. In this analysis, the improvement of the stiffness (reduction of settlement) of the treated ground was evaluated. Improvement of a soft soil by stone columns is due to three factors. The first factor is inclusion of a stiffer column material (such as crushed stones, gravel, and so on...) in the soft soil. The second factor is the densification of the soft soil surrounding the stone columns during the installation of stone column. The third

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factor is the vertical drainage provided by stone columns (Guetif et al. 2007). Therefore, the insertion of stone columns into weak soils is not just a replacement operation and stone column can change both the material properties and the state of stresses in the treated soil mass. In this analysis, the effect of stiffness of column material and the densification of the surrounding soft soil during the installation of stone column were considered. A uniform vertical displacement (ε =2%) was prescribed to the model. The average settlement (Se) can be calculated by the following equation (Christian and Carrier 1978):

$$S_e = \mu_0 \mu_1 \frac{q.B}{E} \tag{1}$$

Where q is the applied footing load, E is elastic Modulus of the soil, and μ0 and μ1 values depend on the depth of the footing and the thickness between the footing base and hard strata, respectively. Assuming the whole soil medium to be homogeneous, the equivalent secant modulus values (Eeq) have been calculated as

$$E_{eq} = \frac{\sigma}{\varepsilon} \tag{2}$$

Where

$$\varepsilon = \frac{S}{L} \tag{3}$$

Where, σ is the average applied stress, ε is the average strain, S is the settlement of the footing, and L is the thickness of the clay bed (=10 m). Figure 3 shows typical axial stress versus settlement behavior for improved ground based on finite element analysis at different friction angle of stone columns material. The vertical stress versus settlement relation is almost linear. The equivalent Young's modulus of the composite ground can be obtained from average slope of the plot. Settlement ratio (SR), settlement of the composite ground divided by settlement of ground without stone column at the same stress level, was calculated. Using Eq. 1, SR can be expressed as

$$SR = \frac{E_0}{E_{eq}} \tag{4}$$

Where, E_0 is Young's modulus of ground without stone column.

A. Numerical analysis

The analysis was carried out using the commercially available finite-element program PLAXIS, to compare the load settlement behavior with the model test. Properties of different materials are shown in Table 1. An axisymmetric analysis was carried out using Mohr-Coulomb criterion. A drained behaviour was assumed for all materials. The improved soil is modeled with 15 nodes triangular finite elements in the area of reinforced ground, because stresses and displacements are higher in this area, the considered medium mesh size was refined.

Table 1: Properties of materials

R_{inter}	$\gamma(kN/m^3)$	c(kPa)	ψ(˚)	φ(˚)	υ	E(kPa)	
0.7	17	5	0	21	0.35	4000	clay
0.9	19	0	10	43	0.3	55000	stone column
-	16	0	4	30	0.3	20000	sand

The basic axisymmetric finite-element mesh and boundary conditions used to represent the stone column and the surrounding clay and the typical deformed mesh for single column is shown in Figure 1.

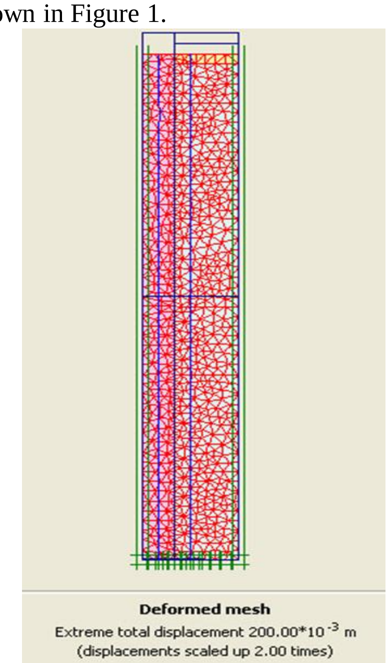

Figure1: Finite-element discretization for clay with single column, Typical deformed mesh

After applying settlement of the soil, plastic Points are shown in Figure 2. It can be concluded that in this region, further strain and deformations occur.

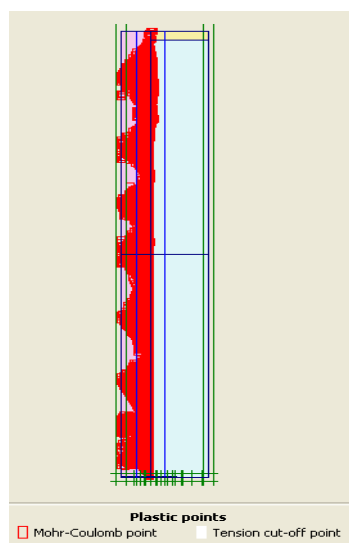

Figure 2: plastic Points in the unit cell model

In this modeling, the effect of friction angle and the effect of elasticity modulus of the stone column and the surrounding soil

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material on the load-settlement curve and the settlement ratio (SR) have been paid.

B. Effect of friction angle:

In this section, firstly the effect of changing the friction angle of stone columns materials has been studied, and then friction angle of clay have been investigated. According to the conducted modeling. By increasing the friction angle of stone columns materials, the bearing capacity of stone columns increases, that shown in Figure 3.

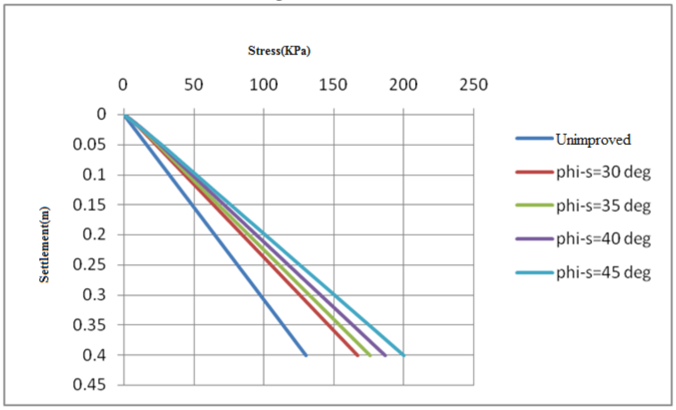

Figure 3: Stress settlement behavior under loading for different friction angle of stone columns material

Also by increasing the friction angle of clayey soil, the bearing capacity of stone columns increases, that shown in Figure 4.

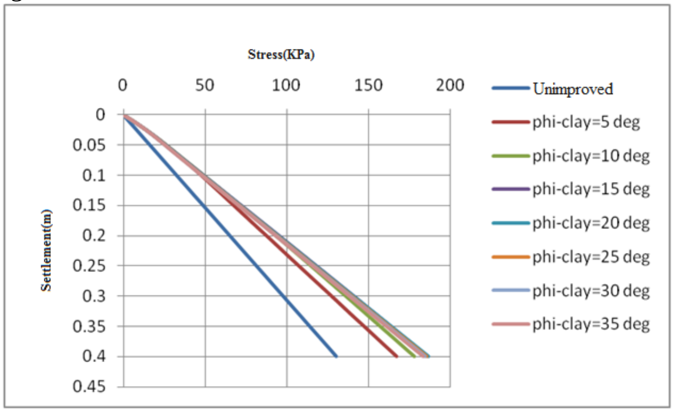

Figure 4: Stress settlement behavior under loading for different friction angle of clayey soil

C. Effect of modulus of elasticity:

In this section, initially the effect of changing the modulus of elasticity of stone columns materials has been studied and then moduli of elasticity of clay have been investigated. According to the conducted modeling. By increasing the modulus of elasticity of stone columns materials, the bearing capacity of stone columns increases, that shown in Figure 5.

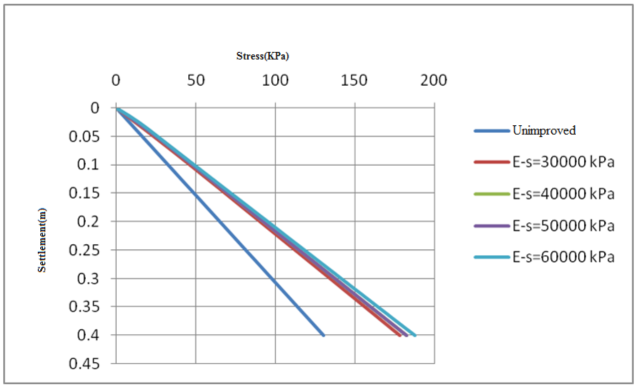

Figure 5: Stress settlement behavior under loading for different modulus of elasticity of stone columns material

Also by increasing the friction angle of clayey soil, the bearing capacity of stone columns increases, that shown in Figure 6.

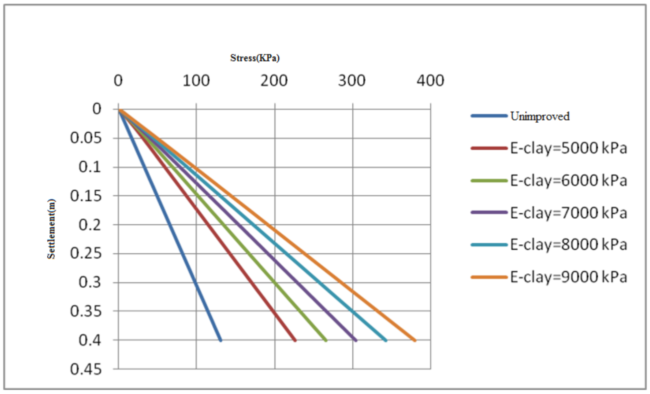

Figure 6: Stress settlement behavior under loading for different modulus of elasticity of clayey soil

For quantify the results, the SR parameter that calculation described above is used. As can be seen in Figure 7, with increasing the elasticity modulus of stone columns from 30,000 kPa to 60,000 kPa, the SR is reduced approximately 5 percent.

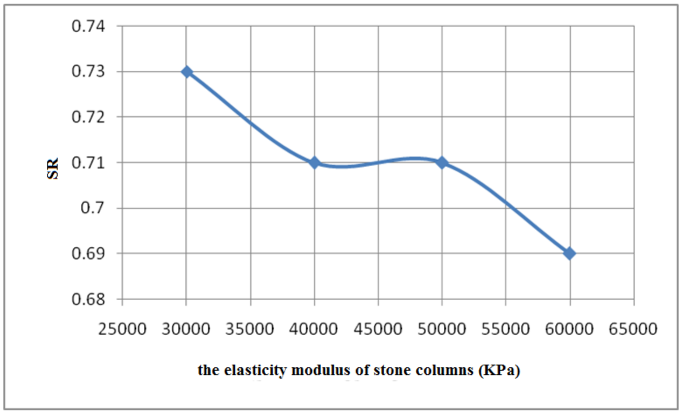

Figure 7: SR changes with changes in the elasticity modulus of stone columns

III. Conclusion

From the finite element analysis, the following conclusions can be drawn:

1- The bearing improvement ratio and the settlement reduction ratio are increased with decrease in undrained shear strength of the surrounding soil for all end bearing soil undrained shear strengths.
2- With increasing the friction angle of clayey soil, the bearing capacity of stone columns increase.
3- With increasing the modulus of elasticity of stone columns materials, the bearing capacity of stone columns increase

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