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Effect of Soft Lens on the Behavior of Ordinary and Reinforced Stone Columns Located in Saturated Sandy Bed

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ABSTRACT: One of the effective methods to improve the behavior of problematic beds containing soft lens is using stone columns. The capability of this soil improvement method increases by simultaneous use of the stone column and geosynthetic encasement, especially in the presence of soft lens near the ground surface or where the possibility of bulging failure is probable. In this research, the efficiency of using stone column embedded in a saturated sandy bed containing soft lens has been numerically investigated in terms of bearing capacity and failure mode. Also, the efficiency of reinforcing the stone column has been investigated in the presence of soft lens with different thicknesses and placement level. The results of numerical analysis obtained by finite element software (Abaqus) and validated by laboratory results of small-scale physical model experiments in real stress conditions shows that in the presence of soft lens, the change in the length of a stone column does not affect the occurrence of bulging failure and decreasing placement level of the soft lens, increases the bulging failure occurrence proportional. On the other hand, increasing the thickness of the soft lens reduces the bearing capacity of the ordinary and reinforced stone column. The phenomenon of bulging can occur at the level of the lens placement and up to a depth of about 4 times the diameter of the ordinary column because of the existence of a soft lens in a relatively loose sandy bed, while the mechanism of failure is not bulging anymore if using encasement.

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1- Introduction

Dealing with beds composed of soft/loose materials during the construction of engineered structures (buildings, road embankments, etc.) exhibiting insufficient soil-bearing capacity and settlement exceeding permissible limits is a constant challenge.

The implementation of stone columns is one way of increasing the bearing capacity and reducing settlement in such soil. Stone columns can be used for soil reinforcement in soft and loose soil up to a depth of 20 m. In this method, 15% to 35% of the volume of the loose sand is replaced with gravel or crushed stone that is poured into a well of a specific diameter and depth to increase the soil bearing capacity and reduce settlement [1].

2- Numerical Model Specifications

The current study examined the effect of a soft lens on the failure mode and defects in ordinary and geotextile-encased stone columns located in a saturated sandy bed containing a soft lens using Abaqus finite element software. The dimensions of the model are based on the site dimensions of the stone column which are being used in the bed containing the soft lens. The sand used to model the bed is the relatively loose poor graded sand. Based on the model‹s geometric conditions, axisymmetric modeling has been used.

Also, the behavior of sand, clay and stone column materials were determined based on the Mohr-Coulomb elastic-perfectly plastic failure mode which is widely used for geotechnical analysis and flow law is also assumed to be independent. The water table is at the same level as the natural ground level and linear elastic behavior is considered for geotextile materials [2, 3].

3- Model Geometry and Boundary Conditions

Figure 1 is a 2D schematic view of the properties of the axisymmetric model showing the dimensions and materials used for numerical model.

The vertical displacement is applied to the rigid plate uniformly and the stone column failure criterion is assumed as 45 cm settlement (vertical displacement) rate in all the analyzed models. This value is equal to 0.25 of the diameter of the loading plate, which is considered as the ultimate failure limit in some references [2]. According to the behavior and related failure mechanism, in the stone columns analysis the soil interaction or interface with the stone column and/or geotextile is not considered [3].

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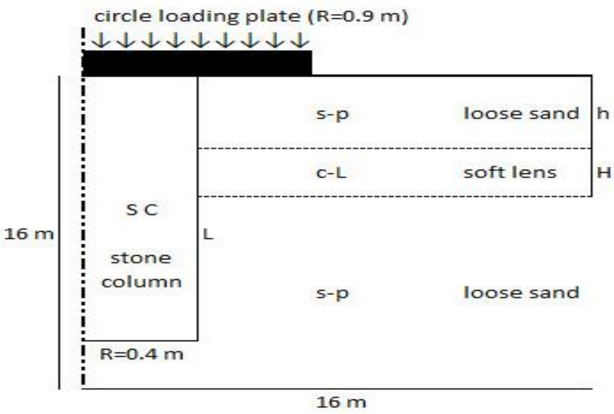

Fig. 1. 2D schematic of model properties

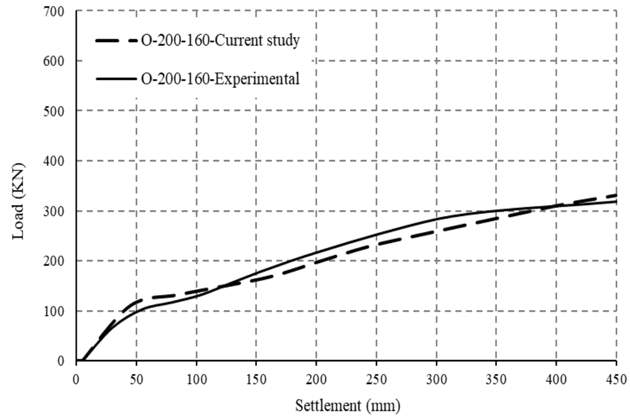

Fig. 2. Load-settlement of ordinary stone column in lens with a thickness of 160 cm embedded at -200 cm

4- Numerical Model investigated

72 numerical models were analyzed on the whole, which 36 models were ordinary and 36 models were reinforced. In these models, a stone column with three lengths of 600, 800 and 1000 cm also a soft clay lens in four levels of -160, -200, -240 and -280 cm with three thicknesses of 80, 120 and 160 cm are considered. The analyzed models have been investigated on failure mode (bulging) and bearing capacity of the stone column.

5- Numerical Model validation

In the current research, conforming to the conditions of the numerical models two physical models were built with a scale of 1:10 in the Frustum confined vessel (FCV)4]], and the results were used to validate and calibrate the results of the numerical models.

Considering the scale effect, the results of two physical models have been used to validate the results of numerical modeling. The materials specifications defined in the validation models are not similar to the same materials defined in the numerical models. Figures 2 and 3 show the load-settlement curves obtained from physical and numerical models with similar conditions, respectively.

6- Frustum confined vessel(FCV)

Testing of a full-scale model that is conducted on-site produces the best results. However, the heavy cost of full-scale testing and the inability to repeat tests under exactly equal conditions have led to the popularity of small-scale physical model tests. A physical model is, in fact, a smaller version of an actual geotechnical structure. For small-scale physical modeling of geotechnical structures such as stone columns, the scale selected is usually 1:10 so that the model is not unduly large to complicate working with it and not unduly small to cause a considerable difference in the behavior of the model and the prototype.

In conventional small-scale physical models (1g), limitations concerning stress conditions exist because the

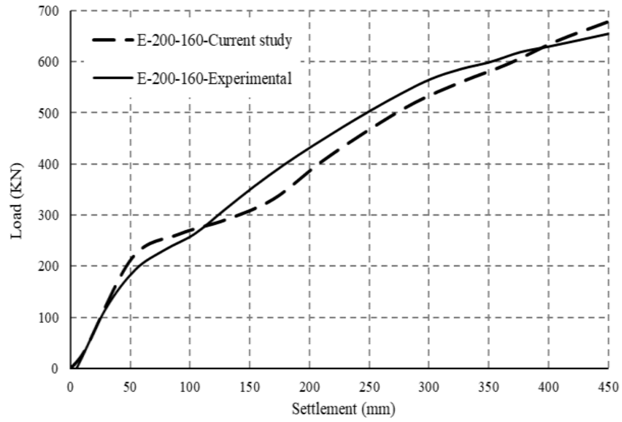

Fig. 3. Load-settlement of the reinforced stone column in lens with a thickness of 160 cm embedded at -200 cm

stress level is much lower than the actual stress. Moreover, the small dimensions of a centrifuge model can complicate the installation of measurement tools having fixed volumes and weights, which would, thus, change the soil behavior [4].

7- Results and Discussion

In this research, different parameters such as the length of the stone column, the placement level of the soft lens, the thickness of the soft lens, and the reinforcing effect have been investigated. By related graphs, the effect of these parameters has been shown.

8- Conclusions

With the existence of soft lens increasing the length of the stone column has no effect on reducing the maximum radial displacement and its failure mode, also, the stone column with different lengths, with the existence of soft lens has bulging failure.

With the existence of soft lens, increasing the length of the stone column has no effect on increasing of bearing capacity, and increasing the length of the stone column does not increase its bearing capacity. Only reinforcing stone column with geotextile increases the bearing capacity.

In ordinary stone columns, by reducing the placement level of the soft lens, the level of bulging failure is reduced proportionately, and also the maximum radial displacement of the stone column is also reduced. In reinforced columns, by reducing the placement level of the soft lens the maximum radial displacement of the stone column is reduced.

Bearing capacity of ordinary and reinforced stone columns increases by reducing the placement level of the soft lens. The rate of increase for reinforced stone columns is about 35% more than the ordinary one.

The existence of soft lens in a loose sandy bed causes the bulging failure to occur at the level of the lens placement and up to a depth of about 4 times the diameter of the ordinary column, while in loose homogeneous soils, the bulging failure occurs up to a depth of 2 times the diameter eventually.

The bearing capacity of ordinary and reinforced stone columns decreases by increasing the thickness of the soft lens. The rate of decrease for the ordinary stone column is about 35% more than the reinforced one.

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