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Experimental and numerical study on the bearing capacity of soils reinforced using geobags

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ABSTRACT

In this study, the soil bearing capacity improvement using geobags is investigated. The bearing capacities of shallow foundations on reinforced and unreinforced soil under vertical loads are determined experimentally and numerically. Different sizes of geobags, as well as number and arrangement of geobags, were used in physical models and the load-settlement curves have been obtained. In the next step, laboratory conditions were simulated employing a 3D finite element computer code. Having validated the numerical modeling, the influence of other factors such as the scale effect on soil improvement and failure mode under a footing are investigated. Results of this study show that using geobags under footings significantly increases the bearing capacity of foundation. It was also found that the number and arrangement of geobags are the most important factors in the increase of bearing capacity and decrease of settlements of foundations.

1. Introduction

Geobags, soilbags; sandbags, etc. are bags usually made from textiles having high tensile strength and filled with materials such as gravel, sand and even construction wastes. Advantages of soil reinforcement by geobags summarized as follows [9]:

(i) Geobags are light.
(ii) Their transportation and relocation are very easy.
(iii) Compatibility with the environment due to no use of any chemicals and there is no noise during construction.
(iv) No special or heavy construction equipment is needed.
(v) The materials inside geobags may be any granular remains and construction wastes such as recycled concrete, asphalt, tire and tile.

Use of geosynthetics and geobags for protection against flood and controlling erosion of river and sea shores, especially sand beaches was known for decades [7,8]. Recently, geobags have found many other applications as temporary and permanent structures in engineering projects. Bearing capacity and settlements of shallow foundations have always been great concerns for engineers and researchers in geotechnical and civil engineering projects. The use of geobags to increase bearing capacity of soft soils is one of these new applications to increase bearing capacity and reduce settlement. Confining the soil by geobag leads to increase in its bearing capacity. This advantage has encouraged the engineers to use geobags for geotechnical improvement of sites with low bearing capacity. Building retaining walls, constructing small temporary buildings, reducing vibrations due to the movement of vehicles and earthquakes are some other applications of geobags.

Hence investigations on geobags behavior are carried out in the last decades worldwide, theoretically, experimentally and numerically. The aim of this study is to investigate the role of geobags in increasing the bearing capacity of soils through a series of experimental and numerical modeling.

2. Previous studies

Chen [4] investigated the geobags' behavior under two-dimensional space. Matsuoka and Liu [9] studied the effect of geobags connections on their bearing capacity by performing a series of experimental tests and found that the bearing capacity increased by connecting geobags horizontally. Aqil et al. [2] investigated the failure mechanism and deformation of overlapping geobags under lateral shear. Tantono and Bauer [11] studied the two-dimensional behavior of geobags. Pu et al. [10] studied the behavior of geobags theoretically. They presented the effect of geobag improvement using the concept of apparent cohesion, C_a. Using Mohr–Coulomb failure criterion for predicting the apparent cohesion and ultimate strength of geobag was employed by following equations:

$$\sigma_{1f} = K_p\sigma_{3f}+2C_a\sqrt{K_p} \rightarrow \sigma_{1f} = 2C_a\sqrt{K_p} \quad (1)$$

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$$C_a = \frac{K_p \Delta\sigma_3 - \Delta\sigma_1}{2\sqrt{K_p}} \tag{2}$$

In these equations σ_1 and σ_3 are representing stresses in filling soil. σ_{1f} and σ_{3f} are external stresses on geobag, $\Delta\sigma_1$and $\Delta\sigma_3$ are average of excess stresses due to tension in geobag and K_p is Rankine's passive earth pressure coefficient.Yamamoto and Jin [12] obtained a three-dimensional relationship for the stress - strain behavior of geobags. Chew et al. [5] achieved consolidation rate of clay geobags under various tests and compared the results with the one dimensional consolidation theory. Ansari et al. [1] simulated three-dimensional model of geobag numerically and they compared the models with the concluded relationship for geobags in two-dimensional space under static and dynamic vertical loads. Javahari and Hataf [6] simulated the geobags mechanical behavior under vertical load using finite element method numerically. They also studied the behavior of geobags in the three dimensional environment. They developed the following equation to determine the apparent cohesion employing Drucker-Prager yield criterion as follows:

$$c_a = \frac{T}{2R\sqrt{K_p}}\left(\sqrt{d^2 + \frac{4d - 16R/H}{1 - R/H}} + d\right) \tag{3}$$

In this equation, T is the tensile stress developed in bag material, B, L and H are geobag dimensions and $d = \frac{1 + \frac{R}{H}}{\frac{1}{3} - \alpha^2} - 4$ and $\frac{1}{R} = \frac{1}{B} + \frac{1}{L} + \frac{1}{H}$.

3. Experimental study

3.1. Materials and apparatus used

In order to perform laboratory model tests a box with dimensions of 1.0 × 1.0 × 1.0 m was used, Fig. 1. The dimensions of the box should be selected in such a way that the boundary conditions do not affect the test results. In other words, the effect of geobag should not continue to the boundaries of the container. For this purpose, an initial analysis using software PLAXIS 3D was performed and the range of induced stresses and displacements around geobag was determined. Floor and two opposite walls of the box were made from steel plates and two other walls were covered by glass with a thickness of 6 mm. To apply static load a servo hydraulic loading system was used. The system has the possibility of applying a controlled pressure stepwise up to 95 kN. Displacement measuring system consisted of 3 LVDTs, data recorder and a computer.

In this study, two foundation models were built from hard plastic having dimensions of 10 × 10 × 4 cm and 15 × 15 × 5 cm. These thicknesses were used to achieve acceptable rigidity.

Fig. 1. The test box.

Fig. 2. The geobags used.

To make geobag models geotextile sheets were used. In this way, geotextile sheets cut to the required size and then three sides were sewn forming a bag and one side was sewn after filling the bag with soil. Fig. 2 shows geobag physical models.

The soil used was sand its properties are given in Table 1. The geotextile strength parameters are determined according to the standard ASTM D4595-09 [3]. Properties of used geotextile in this study are shown in Table 2.

3.2. Test procedure

The test box was first filled using the sand in 5 layers. Each layer, twenty centimeters thick, was poured by rain method. In all tests, soil was poured from about 15 cm height and to increase unit weight, each sand layer was rammed by dropping a weight from a specified height. To reach the uniform unit weight throughout the box, the amount of energy applied to the entire surface of the soil kept constant in each layer. A standard Proctor hammer and a piece wood, with a dimension of 20 × 20 cm, was used to ram the layers.

Before loading, a small load was applied on the foundation model and displacements were set to zero and then loading was started. Increasing of the loading was considered 2 bars on each stage and each stage continued, till displacement reached a constant amount. Since in some loading experiments, the load limits have not been reached, for a more accurate and detailed examination of the load tolerated by the foundation and a better comparison, the results of the force input into the system at different settlement to the width of the foundation ratio were considered.

4. Numerical study

Similar to the conditions of the tests in the laboratory, numerical

Table 1
The properties of sand used.

D_{10} (mm)	0.065
D_{30} (mm)	0.419
D_{60} (mm)	2.214
Coefficient of uniformity (C_u)	34.06
Coefficient of curvature (C_c)	1.22
Unit weight (kN/m^3)	17.6
Minimum unit weight (kN/m^3)	16.6
Maximum unit weight (kN/m^3)	20.6
e	0.43
e_{min}	0.29
e_{max}	0.59
Cohesion (kPa)	2.1
Friction angle (degree)	32.2