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Scale effect on the behaviour of geogrid-reinforced soil under repeated loads

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A R T I C L E I N F O

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A B S T R A C T

One of the most useful geosynthetics in soil reinforcement is geogrid due to its high tensile strength, having a great influence on soil skeleton reinforcement and eventually, increasing bearing capacity of the foundation. In this research, a series of 36 repeated plate load tests have been carried out to investigate the scale effect on geogrid-reinforced soil, tending to further understanding of the behaviour of geogrid-reinforced soil system. Four different soil grains sizes, two different geogrid's aperture sizes (with roughly the same tensile strength) and three different loading plate sizes are the variables considered. During the tests, the applied loading and soil surface settlements were recorded to evaluate the systems' response. As it was expected, the reinforced soil exhibited higher bearing capacity than the unreinforced status, up to 635%. The results show that increasing loading plate size and soils' particle size fortify the response of foundation, especially in reinforced status, against the loading plate penetration. The results further focused on the important role of scale effect on the response of reinforced foundation. It was understood that the optimum nominal aperture size of geogrids should be about 4 times of medium grain size of soil. Also, it was found out that in order to acquisition of highest reinforcement benefits, the footing's width should be in the range 13–25 (20 in average) times of medium grain size of the backfill. Finally, to achieve the best results, it is recommended that the aperture size of geogrids should be selected roughly 0.2 times of footing width.

1. Introduction

Geogrids have been successfully utilized as reinforcements in geotechnical projects such as embankments over soft subgrades, road construction, slopes, retaining walls and railroads (Brown et al., 2007; Indraratna et al., 2013; Nair and Latha, 2014; Miyata et al., 2015; Moghadas Tafreshi et al., 2015; Das, 2016; Ferreira et al., 2016; Palmeira and Góngora., 2016; Tavakoli Mehrjardi et al., 2016; Wang et al., 2016; Moghadas Tafreshi et al., 2016; Suku et al., 2017; Esmaeili et al., 2017; Cardile et al., 2017). For instance, Tavakoli Mehrjardi et al. (2016) investigated influence of geogird reinforcement on slope deformations and its stability under a limited width of surcharge on the crest. With installation of geogrid layeres in the slope beneath the footing, bearing capacity of the footing was increased, at the maximum, by 250% and 760%, for fine and coarse sands, respectively compared with those in the unreinforced slope. The interface shear behaviour of coarse silica soil against geogrid was examined by Wang et al. (2016). The results indicated that in cyclic direct shear, an interface with a larger particle size has a higher contraction value. In the monotonic condition, the apparent adhesion and friction angle at the interface both increased with increasing soil particle size.

Existing studies confirmed that from an engineering point of view, the response of geogrid-reinforced soil is directly influenced by soil's grains, geogrid's characteristics and surface loading geometries. DeBeer (1965) believes that bearing capacity factor reaches an approximate constant value at $\gamma B \geq 2.45 - 2.9\ \mathrm{kN/m^2}$ (γ and B are unit weight of soil and footing with, respectively). In this regard, if the average unit weight of sand is assumed to be about $16\ \mathrm{kN/m^3}$, then the footing with would be at least 150 mm in order to determination of the ultimate bearing capacity. Furthermore, Das and Omar (1994) due to their studies indicated that the bearing capacity ratio of the sand-geogrid system decreased with an increase in foundation width. However, above a certain foundation width (130–140 mm) bearing capacity ratio reached a constant value. Also, Hsieh and Mao (2005) found out that using biaxial

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geogrids with apertures equal to D_{50} of the soil provided the best reinforcement effect for coarse granular materials. Also they showed that the ratio between the loading plate size and soil grains sizes have a significant effect on the plate load test reliability. Based upon these test results, the load plate diameter should be larger than 15 times the D_{50} of the test soil. Many experimental studies in the field of reinforced embankments have been carried out with small or large scale physical modeling at which the scale effects are rarely fully considered. However, one of the most challengeable matters in this area is how the reduced scale model and prototype model tests can be bridged. Góngora and Palmeira (2016) investigated the performance of unreinforced and reinforced low fills on a loose sand subgrade, with particular emphasis on the behaviour of the fills after surface maintenance. Different types of geosynthetics (12 geogrids and a woven geotextile) were tested in large equipment where the fills were subjected to cyclic loading. This study identified optimum ranges for the ratio between geogrid aperture dimension and fill particle diameter for which less fill particle breakage and greater load spreading angles were obtained. They observed that for the ration of equal aperture size of geogrids (a_{eq}) to maximum aggregates size (D_{max}) between 0.7 and 1.35, less breakage took place. A discrete element model has been developed for geogrid-reinforced ballast by McDowell et al. (2006). A model for unreinforced ballast has been developed and evaluated using simulations of large-scale triaxial experiments and comparing with available data. They certified that a ratio of aperture size to particle diameter of about 1.4 gives optimum interlock and peak resistance mobilized at the smallest displacement in pull-out conditions. Also, Brown et al. (2007) described a series of experiments involving the full-scale simulation of geogrid reinforcement for railway ballast, which allowed the key parameters influencing the reduction in vertical settlement (permanent deformation) under repeated loading to be studied. The results demonstrated that grid geometry, stiffness, rib cross-sectional shape and junction strength are all influential. They stated that the geogrid aperture size in relation to the nominal size of the ballast particles is a very important parameter for effective reinforcement. Regards to this fact, they found out that, for the 50 mm ballast that was used, the optimum aperture size was 60–80 mm. Recently, Cuelho et al. (2014) conducted full-scale tests to compare the relative operational performance of geosynthetics used as subgrade stabilization. For the broad graded fill material (coefficient of uniformity, $C_u = 123$), the most efficient a_{eq}/D_{50} ratio was obtained about 3.9 (Palmeira and Góngora, 2016).

Although some sorts of relevant research have been carried out, the development of practical and reliable design methods and of the correct grid specifications for particular applications are still required to provide a well-based background for the development of reinforced soil design. Taking into account the scarcity of studies on the scale effect on the response of geogrid-reinforced soil, a series of plate load tests have been carried out to investigate the sensitivity of reduced scale geogrid-reinforced soil to variation of loading plate size, soil grain size and geogrid's aperture size.

2. Test materials

2.1. Soils

Four types of uniformly graded soils as backfill materials with the medium grain size of 3, 6, 12 and 16 mm were considered. The physical properties of these backfill materials which are classified as SP and GP in the Unified Soil Classification System (ASTM D2487-11) are summarized in Table 1. Also, the grading of backfill materials is graphically illustrated in Fig. 1. It should be mentioned that these materials can be use in railroad as ballast and in retaining walls as fill materials.

2.2. Geogrids

The geogrids, exploited in the backfill, were made of coated polyester with aperture sizes of 20 × 20 mm^2 and 25 × 25 mm^2. According to Fig. 2, the provided aspect ratio (defined as the ratio of geogrid's aperture size (b) to the medium grains size (D_{50})) varies from 1.3 to 8.3. The mechanical characteristics of the geogrids used in this study are given in Table 2. Tavakoli Mehrjardi et al. (2016) stated that ratio of soil's elastic modulus to that of geogrid is a key parameter in the response of reinforced foundations. Therefore, the efforts have been applied to select the geogrids with the same tensile strength, besides having reasonable tensile strength in the considered physical modeling.

3. Test setup, instrumentation and test procedures

A physical model, developed at Kharazmi University, was used to perform the experimental tests (Fig. 3). In this figure, “u” is the burial depth of geogrid; “B” is loading plate's diameter; “L” is the width of geogrid and “H” is height of the backfill in the box. The following sections are assigned to present test setup and the procedures.

3.1. Model of test box

Fig. 3 shows the schematic representation of the test setup including test box, made of a steel frame, having inside dimensions of 1200 mm × 700 mm in plan (1200 mm in length, in X direction and 700 mm in width, in Z direction) and 700 mm in height (Y direction). The sidewalls of the test box were made of 20 mm-thick fiberglass, supported directly by two steel columns. The glass sides allowed the sample to be seen during the test installation and testing. To ensure the rigidity of the tank, the surrounding walls of the tank were braced on the outer surface and all were fixed by steel columns at equal spacing.

Table 1
Physical properties of backfill materials.

Description	Sand 3 mm	Gravel 6 mm	Gravel 12 mm	Gravel 16 mm
Coefficient of uniformity, C_u	2.125	2.14	1.33	1.27
Coefficient of curvature, C_c	1.19	1.08	0.95	0.96
Medium grain size, D_{50} (mm)	3.1	5.9	12.5	16.5
Maximum particles size (mm)	4.75	9.50	19	25
Specific gravity, G_S	2.419	2.494	2.546	2.604
Moisture content (%)	0	0	0	0
Percentage of fractured particles (%)	85	80	83	82
Friction angle by direct shear test (degree)	42.5	44	47	48
Classification (USCS)	SP	GP	GP	GP