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Technical note

Experimental study on the behaviour of geogrid-reinforced slopes with respect to aggregate size

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A B S T R A C T

This paper investigates the influence of geogird reinforcement on slope deformations and its stability under a limited width of surcharge (strip footing with width of 140 mm) on the crest. A series of reduced scale plate load tests were conducted to cover different parameters including two sand-particle sizes (namely fine and coarse sands), three different lengths of geogrid reinforcement and three positions of strip footing from crest of the slope namely "edge distance". Bearing capacity of the footing, failure mechanisms and factor of slope influence are discussed and evaluated. It is found out that the particle size of sands has great influence on the behaviour of reinforced slope and leads to change its modal behaviour especially at failure state. Based on experimental results, to achieve "plane" status conditions, regardless of the edge distance, the proper length of geogrids for fine and coarse sands were obtained 6 times of footing width (L = 6B) and 4 times of footing width (L = 4B), respectively. Also, it was observed that for fine sand, the safe edge distance of footing can be considered D = 3B. However, for coarse sand, this value might be increased to more than 3B. Particularly, critical values of studied parameters for providing maximum reinforcing effects are established.

1. Introduction

Structures are often constructed near the edge of slopes. Examples include buildings near river banks, footings on embankments, bridge abutments. However, in the case of situating a footing near the edge of slope, the bearing capacity of the footing may be significantly reduced depending upon the location of the footing from the crest of slope and the slope angle (Meyerhof, 1957; Shields et al., 1977; Borthakur et al., 1988; Javankhoshdel and Bathurst, 2016).

Use of polymeric reinforcements to improve load-bearing capacity of foundation has been extensively reported by researchers by using different foundation material (Rowe and Taechakumthorn, 2011; Tavakoli Mehrjardi et al., 2012, 2013; 2015; Chen et al., 2014; Biabani and Indraratna, 2015; Miyata et al., 2015). Ferreira et al. (2015) investigated the influence of soil moisture content, soil density and geosynthetic type (uniaxial and biaxial geogrids and high-strength geotextile) on the behaviour of the soil–geosynthetic interface. They found out that the soil moisture content and soil density had a remarkable influence on interface shear strength, particularly when geogrids were used. Also, it was concluded that the biaxial geogrids was the most effective reinforcement for this particular type of soil, concerning the direct shear mechanism. Knowledge of the treatment of reinforced slopes, loaded with a surface footing, is of practical importance to geotechnical engineers. Recently, the beneficial effects of using geosynthetic reinforcements to increase the bearing capacity of footing located near the edge of slope, has been clearly demonstrated by several investigators (Zornberg et al., 1998; Yoo, 2001; http://www.sciencedirect.com/science/article/pii/S0266114403000451 Viswanadham and König, 2004; El Sawwaf, 2007; Alamshahi and Hataf, 2009; Choudhary et al., 2010; Hu et al., 2010; Turker et al., 2014; Rajabian and Viswanadham, 2016).

Results of previous studies have shown that the load-settlement behaviour and ultimate bearing capacity of the footing could be considerably improved by applying the inclusion of a reinforcing layer at the appropriate location in the fill slope (Lee and Manjunath, 2000; El Sawwaf, 2007; Alamshahi and Hataf, 2009; http://www.icevirtuallibrary.com/author/Ferreira%2C+F+B, Ferreira et al., 2016a,b). Choudhary et al. (2010), in

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particular, presented the results of laboratory model tests on bearing capacity behaviour of a strip footing resting on the top of a geogrid reinforced fly-ash slope. The results showed that the efficiency of fly-ash geogrid system was increased with increasing the number of geogrid layers and edge distance of footing from the slope.

In spite of the fact that other researchers have studied the effect of geogrid-reinforced slopes and its benefits on the bearing capacity of footing situated on the slope, but there is still a lack of investigations into the effect of soil particle size on the behaviour of reinforced slope. This paper seeks to aid understanding of the reinforcement mechanisms, and to suggest an optimal length of reinforcement and effect of edge distance between the footing and the crest of the slope.

2. Test materials

2.1. Soil

Two types of silica granular soil with angular particle shape, namely "fine sand" and "coarse sand" are used to provide two sizes of soil particles. The properties of these soils, which are classified as SP in the Unified Soil Classification System (ASTM D2487-11), are given in Table 1. The maximum, minimum and effective particle size of fine sand are 2, 0.07 and 0.27 mm, respectively and for coarse sand are 10, 1.2 and 3.2 mm, respectively.

2.2. Geogrid reinforcement

The geogrids which are expanded over the slope's backfill were made of high-density polyethylene with aperture size of 27×27 mm^2. Fig. 1 illustrates the aspect ratios which is defined the ratio of the geogrids' aperture size to the medium grain size of soils. In fact, the geogrids were selected to provide two different aspect ratios of 8.4 and 100 for coarse and fine sands, respectively, besides having reasonable tensile strength in the considered physical modelling. The mechanical characteristics of the geogrids used in this study are given in Table 2.

3. Test setup, instrumentation and test procedures

A physical model, developed at Kharazmi University, was used to perform the experimental tests. Fig. 2 shows the schematic representation of the test setup including test box made of a steel frame, having inside dimensions of 1300 mm × 700 mm in plan (1300 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 fibreglass, 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 back wall of the tank was braced on the outer surface and all were fixed by steel columns at equal spacing.

In all tests, firstly, soil embankment with plane surface was constructed in layers of 120 mm-lift thickness to reach 50 cm height. In order to compact the backfill, a small vibrating plate compactor was used to achieve 70% relative density of the soils. Then, the embankment was trimmed to achieve slope's backfill with angle of 45° (see Fig. 2(b)). The major obstacle to not selection of the slope's angle less and more than 45° was scale effect difficulty and instability of the slope. Also, Leshchinsky (2015) showed that the bearing capacity factor got reduced in slope with angle of 45°. To have a better assessment of the backfill compaction, in some installations and after backfill placement, soil densities were measured according to ASTM D1556-07. According to Table 3, there is a 95% probability that actual density in a test varied no more than 5% about the average backfill density. Also, moisture contents of the backfill, just before the loading, have been measured. The average moisture content was obtained 5.9%.

The monotonic loading system consisted of a hand-operated hydraulic jack and pre-calibrated load ring mounted on a horizontal steel strip plate, with 650 mm in length, 140 mm in width and 20 mm in thickness. The two ends of the footing plate were polished to minimize their friction effects. A rough base condition was achieved by patching a thin layer of sandpaper on the base of the footing. The plate was located on the slope with specific distance from the edge of slope. To ensure rigidity of the footing, a steel beam with profile of IPE20 was used to transfer loading from hydraulic jack onto the footing. The hydraulic jack applied loading via a pre-calibrated load ring with capacity of 5000 kg and accuracy of ±0.01% of full range, located between the loading shaft and loading plate. To avoid any undesired loading eccentricity and inclination, some sort of careful actions have been applied during loading systems' installation. Throughout the tests, to investigate any possible rocking or tilting of the footing, settlements were monitored by two dial gauges with an accuracy of 0.01% of full range (60 mm), located on opposite edges of the loading plate. Average of the recorded settlements was reported as settlement of the footing at each loading step.

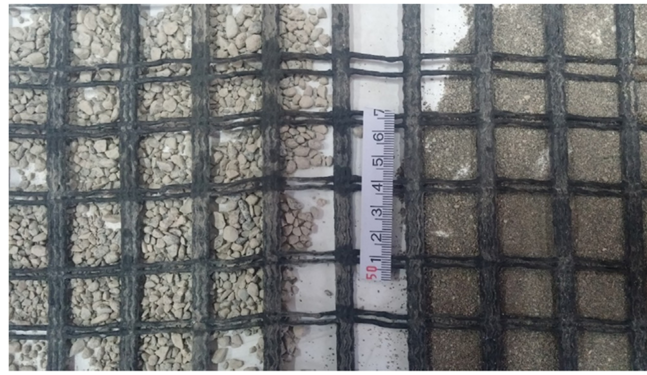

Fig. 1. A view of geogrid and sands used.

Table 2
Mechanical properties of geogrids.

Aperture size (mm)	Thickness (mm)	Weight per unit area (kg/m^2)	Ultimate tensile strength (kN/m)	
			Longitudinal	Transverse
27 × 27	2	0.52	58	30

Table 1
Physical Properties of coarse and fine sands.

Description	Coarse sand	Fine sand
Coefficient of uniformity, C_u	11.1	11.0
Coefficient of curvature, C_c	1.44	2.00
Effective grain size, D_{10} (mm)	2.20	0.18
Medium grain size, D_{50} (mm)	3.20	0.27
Moisture content (%)	6	6
Maximum void ratio	0.80	0.94
Minimum void ratio	0.62	0.70
Specific gravity, G_s	2.65	2.40
Friction angle at D_r = 70% (degree) (obtained by direct shear test)	33	30

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