



Technical note

Load-settlement characteristics of large-scale square footing on sand reinforced with opening geocell reinforcement

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ABSTRACT

This paper describes load-carrying characteristics of a series of large-scale steel square footing tests performed on sand reinforced with two types of reinforcement methods. These are full geocell reinforcement (FGR) and geocell with an opening reinforcement (GOR). A thick steel square plate with 500 mm by 500 mm dimensions and 30 mm thickness was used as foundation. The parameters varying in the tests include the depth of geocell mattress (u), width of opening in geocell in the GOR type (w), relative density of sand (D_r) and number of geocell layers (N). The results revealed that the use of GOR and FGR methods enhances significantly the footing load carrying capacity, decreases the footing settlement and decreases the surface heave. It has been found that the use of GOR with an opening width of $w/B < 0.92$, has the same improvement effect on the footing load-carrying response as the FGR has (B = footing width). Furthermore, with increasing the number of geocell layers from 1 to 2 in both GOR and FGR methods, the footing bearing pressure increases and footing settlement, surface heave and difference of performance between FGR and GOR mattress decrease.

1. Introduction

Geosynthetic materials have been used in practice due to their costs, performance, tensile resistance, durability and ease of application for e.g., construction of footing over soft soil, embankments, road construction and in general for improvement of weak ground supporting variety constructions. The behavior of geosynthetic reinforcement has been investigated extensively (Binquet and Lee, 1975; Khing et al., 1993; Dash et al., 2001a,b,2007, Dash, 2012; Yoon et al., 2004; Ghosh et al., 2005; Chung and Cascante, 2007; El Sawwaf, 2007; Sharma et al., 2009; Latha and Somwanshi, 2009; Boushehrian et al., 2011; Lavasan and Ghazavi, 2012; Lavasan et al., 2017; Koerner, 2012; Chen et al., 2013; Demir et al., 2013; Badakhshan and Noorzad, 2017; Shahin et al., 2017).

Over recent last decades, many investigators have confirmed the benefits of planar reinforcement on enhancement of load-carrying characteristics of footings. Binquet and Lee (1975), Fragaszy and Lawton (1984), Khing et al. (1993), Hataf et al. (2010), Demir et al. (2013) and Roy and Deb (2017) performed model tests to investigate such characteristics. Ghazavi and Lavasan (2008) and Lavasan and Ghazavi (2012) conducted tests to evaluate the behavior of two closely spaced footings on geogrid reinforcement. They reported that the influence of the interference on the settlement of closely spaced footings

at a given load decrease by increasing the number of geogrid layers. They also performed numerical analyses to evaluate the performance of footing on planar geosynthetic reinforcement.

In recent years, three dimensional geocell reinforcement has been used, resulting in better enhancement of footing, embankment and subballast load-carrying characteristics (Rea and Mitchell, 1978; Shimizu and Inui, 1990; Adams and Collin, 1997; Dash et al., 2001a,b,2003; Biswas et al., 2013; Biabani et al., 2016; Oliaei and Kouzegaran, 2017; Kargar and Mir Mohammad Hosseini, 2017). Dash et al. (2003, 2004) carried out model tests on circular footing supported by geocell reinforced soil overlying soft clay. Dash (2012) carried out tests to investigate the influence of geocell on load-carrying mechanism of strip footings. Sitharam and Hegde (2013) and Hegde and Sitharam (2015a, b, c, 2017) have conducted comprehensive numerical and experimental studies to evaluate the behavior of the footings on geocell with additional basal geogrid reinforced soil and bed reinforced with the bamboo cells. They showed that planar geogrid at the base of the geocell mattress enhanced the load carrying capacity significantly. Ngo et al. (2016) studied the load-deformation behavior of geocell-stabilized subballast subjected to cyclic loading using a novel track process simulation. The results indicated that the geocell decreased the vertical and lateral deformation of subballast assemblies at any given frequency.

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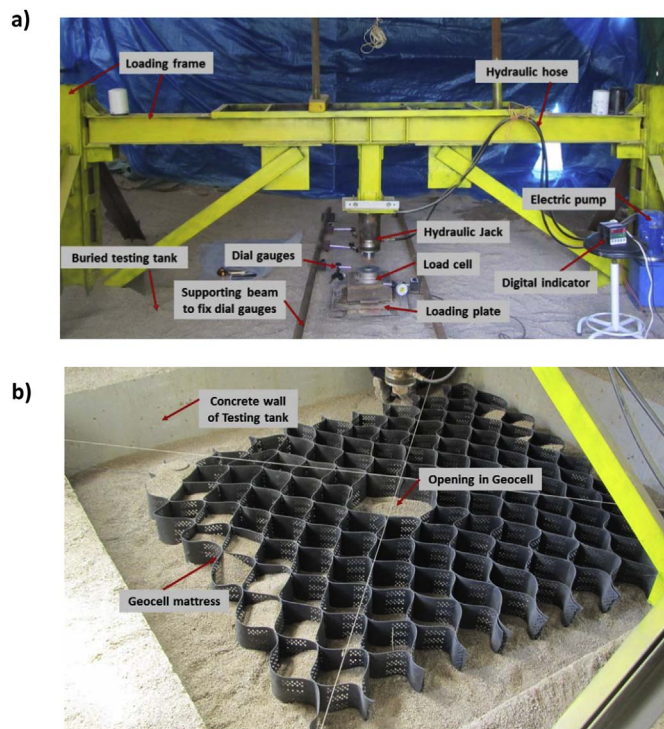


Fig. 1. Test setup: (a) General arrangement of test setup; (b) Test tank and geocell mattress.

In almost all past studies, the footing size has been small and results may not be applicable to large size footings especially when geocell is used as soil reinforcement. Adams and Collin (1997) conducted only one test on a 910 mm square plate placed beside six plates in a tank. They did not consider boundary effects and interaction effects of each footing on neighboring footings which is quite important, as stated by Lavasan and Ghazavi (2012). Thus, it is necessary to understand more comprehensively the behavior of larger scale footings on geocell-reinforced soil.

In the present study, a total number of 18 large-scale tests were performed using a thick square plate with 500 mm width and 30 mm thickness as footings supported by both unreinforced and geocell-reinforced sand. In this research, for the first-time, geocell with an opening reinforcement (GOR) was used as the bed for large steel square plate as footing. The current research has three strong features: 1) the use of large footing; 2) the use of GOR for the first time and 3) the use of geocell with dimensions close to real condition. For GOR type reinforcement, geocell layers were used around the footing bottom level which is named here as ‘Geocell with an Opening Reinforcement’ (GOR), as shown in Figs. 1b and 2b. To evaluate the performance of GOR, several large-scale tests were conducted on unreinforced sand and normally geocell reinforced which is called ‘Full Geocell Reinforcement’ (FGR), as shown in Fig. 2a. As will be shown, the GOR method can be an appropriate alternative to FGR method in cases where access to the footing bottom is difficult or limited. The various parameters studied in this research include the depth of the first geocell layer (u), the number of geocell layers (N), the width of opening in geocell reinforcement (w) and relative density of sand (D_r).

2. Large scale tests

A series of large scale model tests were conducted by a loading set up consisting of a rigid loading frame, test tank, loading system, steel plate as footing and load and settlement measuring devices. The general arrangement of the test setup is shown in Fig. 1. As seen, the loading frame supports a hydraulic jack and provides reaction loads to apply on

the footing. The loading frame was designed to deflect slightly under 250 kN maximum applied load. Some diagonal elements were used to control undesirable deflections of columns and foundation of loading frame.

The soil bed was prepared in a steel reinforced concrete test tank with inside dimensions of 3000 mm length, 3000 mm width and 2000 mm height. In order to reduce the boundary effects, the size of the test tank was in conformity with that used by Ueno et al. (1998). Also, a numerical model was applied for this purpose. The sidewall friction effects on the model test results were reduced by coating the inside of the walls with petroleum jelly. The test tank was built underground. This facilitates easily to fill and evacuate sand in the tank due to large size of the tank (Fig. 1).

The load is applied on the footing using a hydraulic jack that has a maximum stroke of 15 cm and 220 kN maximum load. The loading steel plate was square with 500 mm width and 30 mm thickness. To provide enough flexural rigidity for the footing, two identical plates with dimensions of 500 mm × 500 mm × 30 mm were welded together. To prepare a rough surface for the footing bottom, coarse sand paper was adhered to the plate.

The loading shaft was tipped to a half-sphere shape sitting mounted on the load cell. This zone was completely lubricated with grease to decrease the friction on the surface as much as possible. The load was applied on the footing while it remained vertical during tests to prevent the footing from tilting.

To measure the settlement of the footing, three dial gauges with an accuracy of 0.01% of full range (100 mm) were attached to two reference beams and their tips were placed about 10 mm inwards from the edge of the plate, as shown with DG1, DG2 and DG3 in Fig. 2c. In addition, to measure heave or settlement of the soil surface at points 1.5B and 2.5B (B = footing width) to the either side of the footing center, four dial gauges were used as represented by DG4, DG5, DG6 and DG7 in Fig. 2c. A compression load cell with an accuracy of $\pm 0.02\%$ full-scale was placed between the loading shaft and center of the footing plate.

3. Test materials

3.1. Sand

The sand classified as SP in the Unified Soil Classification System (USCS) is relatively uniform silica with grain size ranging 0.08–10 mm. To have negligible size effect, according to Kusakabe (1995), the sand grain size is small enough than the footing width ($\frac{B}{D_{50}} > 50 \sim 100$). The friction angles of the sand at two relative densities were determined using drained triaxial compression tests. The sand properties are shown in Table 1.

3.2. Geocell reinforcement

In the past research work, geocell was fabricated in two methods. In the first method, geocell mattresses are prepared by cutting geogrid to required lengths and heights from full rolls and placing them in transverse and diagonal directions on the soil bed with bodkin joints (plastic strips) inserted at connections (Bush et al., 1990). In the second method, geocell is made of a type of planar geotextile thermo-welded to form a honeycomb structure with an open top and bottom. In the current research, due to having large footing size, none of two methods has been used and instead, to achieve uniformity in reinforcement, prefabricated factory produced geocell was used. The pocket size of geocell (d) is taken as the diameter of an equivalent circular area of the pocket opening (A_g). In all tests, the pocket size of the geocell (d), the height of the geocell layer (H) and the width of the geocell layer (b) were kept 220, 150 and 2500 mm, respectively. Thus d/B , H/B , and b/B were considered 0.44, 0.3 and 5, respectively.

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