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Technical note

Effect of footing shape and load eccentricity on behavior of geosynthetic reinforced sand bed

Ehsan Badakhshan*,[1], Ali Noorzad

Geotechnical Engineering, Faculty of Civil, Water & Environmental Engineering, Shahid Beheshti University, Tehran, Iran

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ABSTRACT

This paper presents the results from a laboratory modeling tests and numerical studies carried out on circular and square footings assuming the same plan area that rests on geosynthetic reinforced sand bed. The effects of the depth of the first and second layers of reinforcement, number of reinforcement layers on bearing capacity of the footings in central and eccentral loadings are investigated. The results indicated that in unreinforced condition, the ultimate bearing capacity is almost equal for both of the footings; but with reinforcing and increasing the number of reinforcement layers the ultimate bearing capacity of circular footing increased in a higher rate compared to square footing in both central and eccentrial loadings. The beneficial effect of a geosynthetic inclusion is largely dependent on the shape of footings. Also, by increasing the number of reinforcement layers, the tilt of circular footing decreased more than square footing. The *SR* (settlement reduction) of the reinforced condition shows that settlement at ultimate bearing capacity is heavily dependent on load eccentricity and is not significantly different from that for the unreinforced one. Also, close match between the experimental and numerical load-settlement curves and trend lines shown that the modeling approach utilized in this study can be reasonably adapted for reinforced soil applications.

1. Introduction

For the last four decades in Civil Engineering, application of geosynthetics has been known as a common technique to increase the ultimate bearing capacity of soils and decrease the settlement of footings. Among the range of geosynthetics available in the market, geotextiles are the most preferred type of geosynthetic materials for reinforcing the foundation beds. Many researchers (Hughes and Withers, 1974; Binquet and Lee, 1975a, 1975b; Huang and Tatsuoka, 1988, 1990; Adams and Colin, 1997; Alawaji, 2001; Ghosh et al., 2005; Kumar et al., 2007; Mosallanezhad et al., 2007; Tafreshi and Dawson, 2010; Ghazavi and Afshar, 2013; Pinho-Lopes et al., 2015) reported when reinforcements were placed at an optimum depth below a footing (strip, square, rectangular foundations) the beneficial effect of reinforcement can observed. These studies were focused on the ratio of the first layer of reinforcement from the foundation base, u, the foundation size, B, (u/B); the ratio of the reinforcement width, b, to the foundation size (b/B); and the ratio of the total reinforced depth, h, to the foundation size (h/B) and critical ratios of them.

In the field of soil reinforcing with geosynthetic layers (in sand or clay) for circular foundations in centrally loaded, there has not been a lot of researches as compared to other foundations in the literature. Sitharam and Sireesh (2004) conducted a number of laboratory model tests to determine the bearing capacity of an embedded circular footing supported by sand bed reinforced with multiple layers of geotextiles. The test results demonstrated that the ultimate bearing pressure increased with embedment depth ratio of the foundation. Also, Basudhar et al. (2007) carried out experimental and numerical analyses on behavior of circular footings with different size resting on reinforced sand with geotextile and reported that with increase in number of reinforcement layers, the settlement value gradually decreased. Similarly, Boushehrian and Hataf (2003) found that for the circular footings on reinforced sand the maximum bearing capacity occurs at different values of embedment depth ratio depending on the number of reinforcement layers. For ratios of u/D greater than one reinforcement layers had no significant effect on bearing capacity. They also reported that choosing a rigid reinforcement did not always improve the effect on bearing capacity. Yetimuglu et al., 1994

* Corresponding author.
E-mail address: e_badakhshan@sbu.ac.ir (E. Badakhshan).
[1] http://www.sbu.ac.ir.

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conducted laboratory model tests to investigate the bearing capacity of rectangular footings on geotextile reinforced sand. For a single layer of reinforcement, the optimal placement depth was found to be 0.3 times the footing width.

Lovisa et al. (2010) studied behavior of pre-stressed geotextile reinforced sand bed supporting a loaded circular footing and found out that effects of the pre-stressed reinforcement configuration were evident for greater footing depths, in comparison with unreinforced and reinforced without pre-stressing. The results of the laboratory model tests for strip and square foundations supported on reinforced sand with geosynthetic layers demonstrated that for the development of maximum bearing capacity, the maximum depth of reinforced zone is about 2*B* for strip foundation and 1.4*B* for square foundation, where *B* is width of footing (Omar et al., 1993). The maximum depth of placement of the first layer of reinforcement should be less than about *B* to take advantage of reinforcement. In the same vein, Khing et al. (1994) conducted model tests on a strip footing supported by reinforced sand. Results showed that the maximum benefit of reinforcement in increasing the bearing capacity was obtained when the depth ratio of the first reinforcing layer to the foundation width was less than unity. Further, Latha and Somwanshi (2009) concluded that effective depth of the reinforcement zone below a square footing is twice the width of the footing, beyond which the inclusion of reinforcement layers will not result in significant improvement in the bearing capacity of the footing and, within the effective reinforcement zone, the optimum spacing of reinforcing layers is about 0.4 times the width of the footing. Moreover, Mandal and Sah (1992) revealed that the ratio u/B for the most efficiently possible condition of the reinforcement must be selected less than 0.3. Noorzad and Mirmoradi (2010) studied the behavior of cohesive soil reinforced with a geotextile by tri-axial compression tests and found that with increasing relative compaction, the peak strength of the sample and axial strain at failure increases. In another investigation, Mosallanezhad et al. (2007) dealt with the influence of a new generation of reinforcement (named by them as Grid-Anchor) on the increase of the bearing capacity of square foundation. They found that the critical value of u/B, h/B and b/B are equal to 0.25, 0.25 and 4.5, respectively. They also demonstrated that *BCR* for this system is greater than that of ordinary reinforcement.

Up to now, few studies are developed experimentally to identify the critical values of reinforcement layers for reinforcing of the soil under the strip and rectangular foundations, when loading has been applied with eccentricity (Sadoglu et al., 2009; Patra et al., 2006; Ornek, 2014; Turker et al., 2014; Sadoglu, 2015). Sawwaf and Nazir (2012) studied the behavior of eccentrically loaded small scale ring footings resting on sand. They reported that the behavior of an eccentrically loaded ring footing significantly improved with an increase in the depth and relative density of the replaced compacted sand layer. All the above model tests have been carried out in optimum condition, over which the highest efficiency of the reinforcing layers is expected. As it can be easily noted in the previous studies no attention has been paid to the effect of footing shapes and load eccentricities resting on unreinforced and reinforced soil. Hence, the present study has been aimed to investigate the effect of foundation shape with the same plan area (for circular and square footings) in central and eccentral loadings on the bearing capacity, settlement and tilt of footings in unreinforced and reinforced sand bed.

2. Materials

To investigate the effect of eccentric loading on a circular footing resting on reinforced sand with geotextile layers, the necessary details of the experimental studies are presented as follows:

2.1. Sand

Oven dried poorly graded medium sand from the west of Iran is used in this study. The particle size distribution is determined using the dry sieving method according to ASTM D 422-90. This sand can be classified as SP in the unified soil classification system (USCS) with coefficient of uniformity 2.89 (C_u), coefficient of curvature 1.05 (C_c) and effective size of 0.27 (D_{10}). The specific gravity of soil particles, maximum and minimum dry densities and maximum and minimum void ratios of the sand are found to be 2.65, 1.64 (g/cm^3), 1.44 (g/cm^3), 0.89 and 0.65, respectively. The angle of internal friction of dry sand at a relative density of 60% obtained from the direct shear box (6 cm $\times$ 6 cm) test is 38°.

2.2. Geosynthetic

In order to provide horizontal reinforcement material for the model test, geotextile layers is used with tensile strength of 7.68 kN/m. This type of reinforcement is an extruded polymer sheet made by using high density polyethylene (HDPE). The reason for selecting this type of reinforcement is almost the same peak tensile strength in every direction. The properties of this reinforcement are obtained from manufacture's manual of the product are given in Table 1.

2.3. Model footings

Model of the circular and square footings are made of steel plates of 15 mm thickness. The diameter of the circular footing and the width of square footing are selected as 120 mm and 106 mm (both footings had the same plan area equal to 11300 mm^2), respectively. The bases of both footings are made rough by gluing a layer of geonet on the bottom surface of them with epoxy glue so as to ensure uniform roughness in all tests. Cone shaped grooves are opened on the footings so that different load eccentricities can be applied. Under the grooves 2-mm thickness are left so that eccentricity cannot change during testing. Fig. 1 shows circular and square foundations and the footing's rough bases that are used in this study. The *Kern* of footing is defined as the part of footing where the whole footing undergoes compressive pressure when the load is applied in other places except for the center. Loading on the *Kern* boundary caused the pressure at edge of footing to become zero. For circular foundation, *Kern* boundary is $R/4$ and loading inside the *Kern* boundary, whole footing area is under pressure. In this study, one load eccentricity (on the *Kern* boundary) is selected for both foundations: $R/4$ for circular footing and $B/6$ (in one-way) for square footing. The load eccentricities can be applied on the model footing by small holes whose locations are shown in Fig. 2, where point 1 is repeated for both foundations and points 2 and 3 are loaded for circular and square model footing, respectively.

3. Test apparatus and experimental program

Laboratory tests are performed in a square test tank with inside

Table 1
Properties of geotextile.

Physical and mechanical property	Value
Polymer type	Polyethylene
Tensile strength (kN/m)	7.68
Extension at 1/2 peak load (%)	3.2
Extension at maximum load (%)	20.2
Tensile strength at 10% extension (kN/m)	6.8
Weight (g/m^2)	730