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Behavior of circular footing resting on laterally confined granular reinforced soil

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Abstract Three dimensional physical laboratory models were examined to investigate the influence of soil confinement on circular footing behavior resting on granular soil. A total of 23 model footing tests were performed. Nine hollow cylinders with various heights and diameters were installed around the footing model for soil confinement purpose. Square geogrid layers were placed at different depths beneath the bottom edge of the cylinder. Different parameters such as height, diameter, and depth of the cylinder were studied. Moreover, number, width, and position of the geogrid layers were, also, investigated. The response of a non-confined footing model was set as reference for comparison purpose. The results showed enhancement in the bearing capacity of the soil as well as a reduction in its settlement in all used configurations compared with the reference case. It is, however, observed that on increasing the number of geogrid layers more than one layer had a small significant effect on the footing behavior. Moreover, placing geogrid layers underneath the cylinders improves the bearing capacity up to 7.5 times that of the non-confined case. Footing with cylinder of a diameter nearly equal to the footing diameter behaves as one unit like a deep foundation. This behavior pattern was no longer observed with large cylinder diameter and small height. Finally, the study ends up with recommendations for selection of cylinder dimensions to maximize the bearing capacity. The benefits of using geogrid layers were also highlighted.

Introduction

Several methods for soil improvement have been applied to improve soil characteristics. Confinement of soil in shallow depths might have a significant effect in enhancing soil bearing capacity. Skirted foundations form an enclosure where the soil is strictly confined. This allows the confined soil to work as one unit transferring the superstructure loads to the soil at the skirt tip level. For foundations resting on cohesive soil, [1] concluded that increase in bearing capacity due to the presence of rigid walls was small. On the other hand, several

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investigators reported that a significant increase in bearing capacity and a reduction in settlement of footing models were obtained by confining the sand. Results of [2] showed that the existence of skirt leads to enhancement of soil bearing capacity and reducing footing settlement. Mahiyar and Patel [3] found that the bearing capacity of circular footings on sand increases with rising of the confinement depth. They observed that the effectiveness of confinement decreased by increasing its diameter. Confined soil underneath the footing resists its lateral displacement which consequently leads to an improvement in the load-settlement behavior; all the details are shown in reference [4]. The effect of confinement on the bearing capacity of sand was studied by [5]. They found an improvement in bearing capacity up to 17 times higher than that of unconfined case with noticeable reduction in settlement values. Inserting discontinuous vertical dowels around existing foundation was carried out by [6]. The dowels were close enough to prevent the escaping of soil through the gaps. A marked increase of 20% in the bearing capacity and a reduction of settlements were found. Al-Aghbari and Zein [7] carried out tests on strip footings with structural skirts resting on sand. They observed that the skirts improved the bearing capacity by a factor up to three. A large number of triaxial compression tests on confined sand were done by [8]. Enhancement in granular soil strength and stiffness was found due to the influence of geocell confinement. Tests on strip footing resting on homogeneous dense sand beds of 70% relative density were conducted [9]. They indicated that an 8 times increase in bearing capacity was achieved with the provision of geocell. Model tests were performed on a circular footing supported on a dense sand layer overlying a soft clay bed [10]. Results showed about a six times rise in bearing capacity with the provision of geocell.

Limited literature is available on numerical simulations of confined foundation beds. The results revealed that soil confinement upgrades the footing load-settlement behavior. The soil confinement conduits using GEOFEM program were simulated [11,12]. The confinement layer has been modeled as an equivalent composite material having higher stiffness and shear strength. The effect of introducing a skirt in the soil around the footing by using SAPIV package program was studied analytically [13]. The analysis concluded that insertion of a skirt leads to a substantial gain in bearing capacity and reduction in settlement. Regarding the skirt thickness, the benefit of skirting is realized substantially even at lower thickness. Also, the skirt benefit was found to be rather insensitive to skirt material. Finite element method is used to study the effect of skirted foundation shape on the response of various loads [14]. The analyses indicated that the vertical circular footing capacity was higher than that of the strip footing.

The aim of the present study is to investigate experimentally the behavior of soil footing system due to installing hollow cylinder surrounding isolated circular footing model on granular soil. The effect of adding geogrid layers with the confinement cylinder was also studied. To achieve this objective, 23 model plate loading tests were carried out with a wide range of variables.

Materials and methods

The materials used in this study were clean sand, circular footing model, plastic hollow cylinders with different height and diameter, and geogrid inclusion having the following properties:

Sand: it was brought from Khatatba city, north of Cairo, Egypt. The specific gravity as determined by the pycnometer method as per IS: 2720, 1980, was 2.63. The grain size distribution is 27% coarse sand, 52% medium sand, and 15% fine sand. The sand is classified as SP according to the USCS and has a maximum and a minimum dry density of 19.3 and 15.6 kN/m^3, respectively. The effective size (D_{10}), the mean grain size (D_{50}), coefficient of uniformity (C_u), and coefficient of curvature (C_c) were 0.19 mm, 0.50 mm, 2.9 and 1.0, respectively. The bulk density of the sand was kept constant during model tests at 18.0 kN/m^3 with a relative density of 70%, for which the friction angle from direct shear test was found to be 36°.

Footing model: circular stiff steel footing model with 200 mm diameter and 20 mm thickness having a rough base was used in all tests.

Plastic hollow cylinders: nine plastic hollow cylinders of thickness 5 mm open at both ends were used to confine the soil under the circular footing model. The cylinders having different heights and diameters are shown in Fig. 1.

Reinforcement: the inclusion used in this research is a geogrid sheet which is made of high density polyethylene produced by El-Sherif Company, commercially known as CE131, which is shown in Fig. 2. It is manufactured in a sheet form of 2.0 m width and 30.0 m length, with unit mass = 6.6 N/m^2, mesh opening size = 27×27 mm, mesh thickness = 5.2 mm, tensile strength at maximum load = 5.8 kN/m, load at 10% extension 5.2 kN/m, strain at maximum load = 16.5%, and strain at 1/2 peak strength 3.7%.

Test set-up: the model steel circular footing, 200 mm diameter, was tested in a three dimensional stiffened framed tank of inner dimensions of 1000 mm length, 1000 mm width, and 600 mm depth. The tank's height and width were chosen equal to three and five times the footing width, respectively. The tank dimension was designed to minims its boundary effect on the footing pressure settlement behavior, as stated by [15]. Two opposite sides of the tank were made of perspex, 18 mm thickness, and the other two sides were made of stiff wood, 12 mm thickness. The outer sides of the tank were fixed by rigid steel frames and restrained by steel stiffeners to prevent deflection in the tank sides during tests. The vertical load was transmitted axially to the footing through a hydraulic jack

Fig. 1 Plastic cylinders.