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ORIGINAL ARTICLE

Bearing capacity of shell strip footing on reinforced sand

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ABSTRACT

In this paper, the ultimate load capacities of shell foundations on unreinforced and reinforced sand were determined by laboratory model tests. A series of loading tests were carried out on model shell footing with and without single layer of reinforcement. The tests were done for shell foundation at different shell embedment depth and subgrade density. The results were compared with those for flat foundations without reinforcement. The model test results were verified using finite element analysis using program PLAXIS. The experimental studies indicated that, the ultimate load capacity of shell footing on reinforced subgrade is higher than those on unreinforced cases and the load settlement curves were significantly modified. The shell foundation over reinforced subgrade can be considered a good method to increase the effective depth of the foundation and decrease the resulting settlement. Also the rupture surface of shell reinforced system was significantly deeper than both normal footing and shell footing without reinforcement. The numerical analysis helps in understanding the deformation behavior of the studied systems and identifies the failure surface of reinforced shell footing.

Introduction

Shell foundation has been considered the best shallow foundation for transferring heavy load to weak soils, where a conventional shallow foundation undergoes excessive settlement, due to its economic advantage in area having high material-to-labor cost ratio. Kurian [1] and Fareed and Dawoud [2]. The conical shell raft foundation, which is a combined foundation, is suitable for water tanks and tower like structures. Concept of shell is not new in foundation design, considering construction in past with inverted brick arch foundation in this category. The use of inverted brick arches as foundation has been in practice in many parts of the world for a long time. Shells are essentially thin structures, thus structurally more efficient than flat structures. This is an advantage in situation involving heavy super structural loads to be transmitted to weaker soils. Shell footing is limited to a few geometries, such as conical, pyramidal, hyper and spherical footings. The structural performance of the shell foundation with respect to membrane stresses, bending moment, shear, deflection and ultimate strength of the shell itself was investigated in a wide range as stated by Paliwal and Rai [3], Paliwal and Sinha [4] and Melerski [5]. However, the geotechnical behavior of shell foundation to determine the soil response with respect to settlement, bearing capacity, contact pressure distribution

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and deformation within the soil mass has taken little attention. The experimental and numerical investigations that carried out to determine the geotechnical behavior of shell foundation were restricted. Abdel-Rahman [6], Hanna and Abdel-Rahman [7] reported experimental results on conical shell footings on sand for plain strain condition. Maharaj [8], Huat and Mohamed [9] and Kentaro et al. [10] conducted a finite element and experimental analysis for shell foundation to study the effects of increasing soil modulus in addition to investigating the geotechnical behavior of shell foundation. Most papers in literature were only studied the behavior of a variety of shell foundation on unreinforced sand without considering the existence of a reinforced element below this type. All works were done only on flat foundation placed on single or multi layers of reinforcement as discussed by many investigators as Latha and Somwanshi [11] and Patra et al. [12], except for Shaligram [13], who studied the behavior of shell triangular footing on reinforced layered sand. His investigation presents a surface study which explained only the effect of such technique on the bearing capacity without identification the stress and deformation of the adopted system. Consequently, in this research a new approach was adopted to study the geotechnical behavior of strip shell foundation resting on single layer of reinforcement to validate the reinforcement effect in the conjunction of adopting shell foundation. The present study was done using both experimental and numerical analysis to confirm the model test results and identify the deformation characteristics of the studied system.

Experimental

Testing tank

Fig. 1a shows a schematic view of the experimental model steel apparatus used in this research. The test box, having inside dimensions of 90×30 cm in plane and 120 cm in depth, the walls thickness of the tank is 6 mm. The tank box was built sufficiently rigid to maintain plane strain conditions by minimizing the out of plain displacement in all directions. The tank walls were braced from the outer surface using horizontal steel beam fitted at the mid depth of the tank. The inside walls of the tank are polished smooth to reduce friction with the soil as much as possible by using galvanized coat in the inside wall.

The loading system consists of a hand-operated hydraulic jack and pre-calibrated load ring to apply the load manually to the footing soil system and the settlement was measured by dial gauges fixed at footing surface.

Foundation models

The strip shell footing models were made of steel plates with constant width (B = 150 mm) in horizontal projection, with different embedment depth, a (a = 60, 75 and 112.50 mm) and 20 mm thickness. The transverse footing length is 29 cm to satisfy the plain strain condition. Sketches of the foundation models are illustrated in Fig. 1b. A rough base condition was achieved by fixing thin layer of sand onto the base of the model footing with Epoxy glue. The load is transferred to the footing through a steel loading arm which was fixed rigidly by welding at the mid of foundation models as shown in the relevant Fig. 1b.

Testing materials

The sand used in this study is medium to coarse silica sand. A homogenous bed of dry silica sand was formed. The mean grain size $D_{50\%}$ = 0.33 mm and the uniformity coefficient is 3.5. The physical properties of tested sand are: Specific gravity was determined using gas jar method and it was found to be 2.65; the maximum and minimum dry density were obtained using Japanese method and were found to be 17.96 and 15.6 kN/m^3, respectively.

To prepare the compacted sand bed, the Japanese method [14] was adopted, using manual compactor. The sand depths were kept constant during the tests. Three test series were carried out on loose, medium and very dense sand. The unit weight of sand and thus the required relative density was controlled by pouring a pre-determined weight of sand into the testing tank, to fill each layer, and then the sand surface was leveled and compacted. A loose sand deposit was achieved by a placement soil layers 50 mm thickness in zero fall height. In order to obtain a compacted sand structure, the sand is placed in layers, each layer has 50 mm thickness and compacted using manual compactor 35 N. The numbers of compaction passes are pre-evaluated for each layer at the beginning of the program to achieve the required sand density. For medium and dense case, the falling height is $_{40\ \mathrm{cm}}$ and 90 cm respectively. The relative density achieved during the tests was monitored and evaluated by collecting samples in small cans of known volume placed at different arbitrary locations in the test tank. The relative densities during the testing program were found to be 50%, 72% and 83%. The corresponding angles of shear resistance are 31°, 36° and 41°, respectively, which were obtained by applying a series of direct shear box tests at the corresponding relative density under different normal stresses.

In order to prepare the soil core under the shell model, the space under the shell was filled with sand according to the required unit weight as stated by Hanna and Abdel-Rahman [7]. The sand filling process of a shell model was done by placing a thin steel plate on the bottom of the shell model before placing it on its location. The steel plate was then slowly pulled out horizontally underneath the shell from the side.

The reinforcement adopted in the present research was a heat bonded nonwoven geotextile (Typar-3857) manufactured from polypropylene multifilament fibers. According to the manufacturer's data, it has a nominal thickness of 2 mm and mass per unit area of 290 g/m^2. The wide-width tensile strength from the strip test method is 20.1 kN/m and the elongation at maximum load is 10%.

Experimental testing program

A total number of 34 tests were conducted on prearranged foundation models using three different sand densities and under different embedment depth (a/B). A series of loading tests were done for the foundation on both unreinforced and reinforced sand subgrade using Geotextile that was placed at fixed distance equal to 0.5B below the foundation tip with constant length equal to 4B as stated by Androwes [15], Abdel-Baki and Raymond [16] and Abu-Farsakh et al. [17]. In all testing program both plate sides of the shell foundations were embedded in the sand.