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Bearing capacity of strip footings on sand slopes reinforced with geogrid and grid-anchor

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ABSTRACT

This paper presents the effect of a new type of geogrid inclusion on the bearing capacity of a rigid strip footing constructed on a sand slope. A broad series of conditions, including unreinforced cases, was tested by varying parameters such as geogrid type, number of geogrid layers, vertical spacing and depth to topmost layer of geogrid. The results were then analyzed to find both qualitative and quantitative relationships between the bearing capacity and the geogrid parameters. A series of finite element analyses was additionally carried out on a prototype slope and the results were compared with the findings from the laboratory model tests and to complete the results of the model tests. The results show that the bearing capacity of rigid strip footings on sloping ground can be intensively increased by the inclusion of grid-anchor layers in the ground, and that the magnitude of bearing capacity increase depends greatly on the geogrid distribution. It is also shown that the load-settlement behavior and bearing capacity of the rigid footing can be considerably improved by the inclusion of a reinforcing layer at the appropriate location in the fill slope. The agreement between observed and computed results is found to be reasonably good in terms of load-settlement behavior and optimum parameters.

1. Introduction

The use of geosynthetics to improve the bearing capacity and settlement performance of shallow foundations has proven to be a cost-effective foundation system (Basudhar et al., 2007; El Sawwaf, 2007; Ghazavi and Lavasan, 2008). In marginal ground conditions, geosynthetics enhance the ability to use shallow foundations in lieu of the most expensive deep foundations. A reinforced soil foundation (RSF) consists of one or more layers of a geosynthetic reinforcement and controlled fill placed below a conventional spread footing to create a composite material with improved performance. A composite reinforced soil foundation (CRSF) is an RSF that also includes a geosynthetic fabric separating native soil from the fill used to construct the RSF.

RSFs may be used to construct shallow foundations on loose granular soils, soft fine-grained soils, or soft organic soils. Most RSF's are constructed with the reinforcement placed horizontally; however, there are cases in which vertical reinforcement may be used. The reinforcement may consist of geogrids, geofabrics, geocells or other geosynthetics. The fill placed between layers of reinforcement is usually a clean coarse road base material that is compacted to a minimum relative density of about 75%, but may also consist of compacted sand. There are a number of factors that may influence the performance of an RSF, including: (1) type of reinforcement; (2) number of reinforcing layers; (3) depth below the footing to the first layer of reinforcement; (4) spacing between reinforcing layers; (5) dimensions of the reinforcement beyond the dimensions of the footing; and (6) type and placement of the fill.

Over the past 20 years, considerable advances have been made into the understanding of the behavior of RSFs and on the applications and limitation of using geosynthetics to improve the performance of shallow foundations. Detailed investigations have been performed using small scale and large scale model footings to evaluate the performance of RSF's and to develop rational methods for design.

The subject of reinforcing soil underneath footings has acquired considerable attention in the past few years (e.g. Dash et al., 2003; Boushehrian and Hataf, 2003; Ghosh et al., 2005; Bera et al., 2005; Patra et al., 2005, 2006). Through the possible applications, the use of foundation reinforcement to excellence load bearing capacity has attracted a great deal of attention, and there have been numerous studies on this subject (e.g. Binquet and Lee, 1975a, b; Akinmusuru and Akinbolade, 1981; Fragaszy and Lawton, 1984; Das et al., 1994, etc.). These investigations have demonstrated that both

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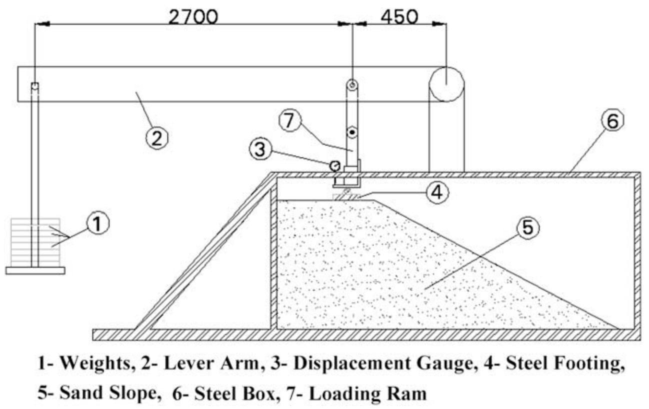

Fig. 1. Schematic view of the experimental apparatus.

the ultimate bearing capacity and the settlement characteristics of the foundation can be improved by the inclusion of reinforcements in the soil. There are many situations where footings are located on sloping fills (e.g., footings for bridge abutments on sloping embankments). When a footing is constructed on a sloping ground, the bearing capacity of the footing may be significantly reduced, depending on the location of the footing with respect to the slope.

As mentioned, foundations are sometimes built on slopes or near the edges of slopes. Examples of such practice are buildings near river banks, foundations on embankments, bridge abutments resting on granular fill slopes and roads constructed in hilly regions. The stability of the slope and the bearing capacity of a foundation constructed close to the edge of a slope are important factors in the performance of the structure. When a shallow footing is located on top of a slope and subjected to axial loading, it results in a reduction of ultimate bearing capacity as compared to that constructed on a horizontal ground surface. The stability of a foundation located on top of a slope is further affected by the edge distance and the slope angle (Meyerhof, 1957; Shields et al., 1977; Borthakur et al., 1988). Therefore, the investigation of the means to improve the bearing capacity and stability of foundations on top of a slope is one of the main aspects in the design of such structures, as they are more liable to failure than other types of structures.

One of the possible ways to improve the bearing capacity would be to reinforce the foundation ground with layers of geogrid. Introduction of high tensile strength reinforcing materials to stabilize embankments or existing slopes to sustain loads from traffic or heavy structures has been broadly adopted in practice. In addition, the concept of a reinforced steep slope has been performed with great success for various applications such as road broadening and the repair of failed slopes. Knowledge of the treatment of reinforced slopes loaded with a surface footing is of practical importance to geotechnical engineers. Although there are several research studies on reinforced level ground (Binquet and Lee, 1975a, b; Basset and Last, 1978; Fragaszy and Lawton, 1984; Milligan et al., 1986), investigations of footings on reinforced slopes are rather limited (Selvadurai and Gnanendran, 1989; Yoo, 2001; El Sawwaf, 2005; Lee and Manjunath, 2000). When a footing is constructed on a reinforced slope, the bearing capacity of the footing would be significantly increased by the presence of correctly placed reinforcements. To design a footing on a reinforced slope requires a thorough knowledge of both the bearing capacity behavior of the footing and the mechanical behavior of the reinforced slope. Most of the previous studies dealing with the reinforced slope have achieved at developing limit equilibrium-based design methods (e.g. Zhao, 1996; Lesniewska, 1993; Mandal and Labhane, 1992; Schmertmann et al., 1987; Michalowsk, 1997; Zornberg et al., 1998a, b; Sawicki and Lesniewska, 1991; Schneider and Holtz, 1986; Leshchinsky and Boedeker, 1990, etc.).

Few studies on the bearing capacity behavior of strip footings on a reinforced slope include works done by Selvadurai and Gnanendran (1989) and Huang et al. (1994), Yoo (2001), Jahanandish and Keshavarz, 2005, El Sawwaf, 2005 and Lee and Manjunath (2000), in particular, the reported results of an experimental study of strip footings located on a geogrid-reinforced sloping fill. It must, however, be noted that most of their study was basically focused on the influence of depth of a single geogrid layer on the load-settlement response of a footing located near the crest of a slope.

The bearing capacity determination technique is an important part of any correct design of footings on a reinforced slope. Numerical analyses such as the finite difference or finite element analysis have become popular in design practice, in recent years. However, despite many attempts which was done by many researchers, still no obvious method for the determination of ultimate bearing capacity of a strip footings on reinforced slopes is available to date, and therefore, much still remains to be investigated. This study tries to find both qualitative and quantitative relationships between the bearing capacity and the ordinary geogrid in particular grid-anchor, a new type of geogrid parameters (Mosallanezhad et al., 2008) and forming a database for future development of an obvious design/analysis method.

The main purpose of this investigation was to examine the effect of using ordinary and the new geogrid on increase and improvement of bearing capacity behavior. In this study, 43 laboratory model tests were carried out to investigate the bearing capacity of a rigid strip footing placed on top of an air-dried sand slope with and without layers of ordinary geogrid and grid-anchor reinforcement. Numerical analysis was executed using a commercially available finite element program PLAXIS (Bringkgreve and Vermeer, 1998) to ascertain the model test results. The merits of developing such a finite element model are that it can be used to model various conditions which have not been examined experimentally in the study.

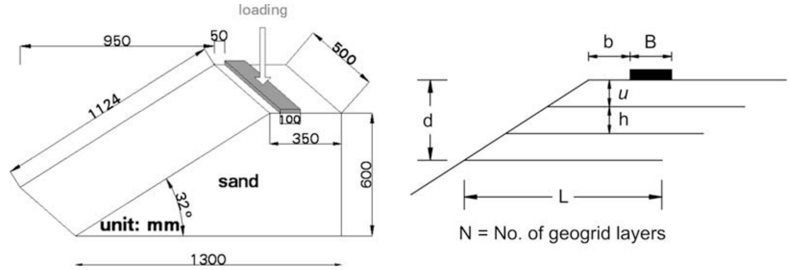

Fig. 2. Schematic view of test parameters.