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Performance of footing with single side micro-piles adjacent to slopes

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Abstract This research was initiated in order to investigate the capability of rigid strip one side micro-piles footings in stabilizing sand slopes. A physical model was designed and constructed for micro-piles footings resting on dense sand. Measuring devices were arranged; load-settlement measurements of the model footings were recorded; photos were captured and observations were documented. Different footing configurations located at variable distances from slope edge were tested; five groups of micro-piles depths were inspected and different eccentric vertical so as oblique loads were examined to investigate its capability of stabilizing the slopes. Measurements were plotted and analyzed. Comparison was carried out among the inspected cases. Results indicated that a significant enhancement to the bearing capacity of single side micro-piles footing was documented with the increase of micro-piles depth. It reached about 7.9 times that of footing without micro-piles.

1. Introduction

In terms of the importance of stabilizing the slopes, different techniques are available. Micro-piles are one of the most economical solutions for improving footing behavior nearby slopes. Footings might be located on/or nearby slopes according to the architectural requirements or according to the permitted space such as bridge abutments, retaining walls, foundations next to excavations and foundations built on mountain slopes [1]. Also, cost savings might be achieved if the footing is located as close as possible to the edge of the slope with keeping it as steep as possible. Therefore; this research was initiated in order to perceive a better understanding to use the micro-piles on slopes.

2. Literature review

Literature in the field of micro piles was revised. From the literature, it was stated that there are several theoretical methods for predicting the bearing capacity of shallow footings located in or on the top surface of a slope. Some of these bearing capacity theories are based on the method of stress characteristics [2] and others are based on limit equilibrium and limit analysis approaches [3,4]. Based on experimental data it was reported that the ultimate bearing capacity is reduced as the footing get closer to the slope crest [5–7]. Based on the

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literature, it was documented that several researchers conducted laboratory-model scaled centrifuge tests for shallow foundations located on or nearby slopes [8]. A Full-scale field test was carried for investigating the bearing capacity of inclined footing with anchors on granular slopes [9]. Generally the bearing capacity decreases with an increase in slope angle as well as a decrease in the distance between the footing edge and the slope crest.

These theories gave widely varying answers for identical footing locations and same soil conditions. Moreover; all of the above mentioned analytical and experimental works assumed that the load was vertically applied and was concentric to the footing base which is far from reality. However, for most practical cases, the resultant load acts on the footing with a certain inclination and sometimes with certain eccentricity [10,11]. Moreover, the load bearing capacity of shallow foundations located on sand slopes can be improved by reinforcement or stabilization. Experimental work in this area of research was carried out for a reinforced sandy slope [12,13].

3. Micro-piles

Micro-piles can be installed in a variety of challenging subsurface conditions. They provided an improving resistance to driving forces resulting in a higher factor of safety. Micro-piles are installed using the same drilling and grouting equipment as used for the installation of tiebacks or soil nails. This approach is based on the use of "micro-piles" fixed to the edges of the footing. This method does not need a wide excavation of soil, and hence it is not restricted by the presence of high water tables.

Many studies were conducted to investigate the effectiveness of micro-piles installation on load transfer mechanisms and the deformation behavior of soil subjected to additional surface loading. The micro-piles effects on soil behavior were explained. The soil response under surface loading was significantly improved by micro-piles installation [14–16]. Tests on micro-piles were carried out [17–19].They concluded that the bearing capacity and stiffness of the subgrade reaction of soil were increased considerably and the ground settlement also was decreased. A design of micro-piles for tunnel face reinforcement was done [20]. The deviations in the research results might be attributed to the difference in the assumed rupture surface, lack of the evaluation process or underestimation of governing parameters especially that affecting soil bearing capacity. As a result, the foundation bearing capacities should be selected conservatively.

To date, literature lacks data on the behavior of micro-piles footing on or nearby slopes crest under different loading conditions represented a motivation to carry out the proposed research. This study improved the understanding behavior of this promising soil improvement technique. Also the available solutions for the bearing capacity problem of footings on slopes are based mostly on experimental considerations, and give widely varying answers for identical footing configuration and soil conditions.

4. Experimental work

An experimental physical model was designed and prepared. Measuring devices were arranged and experiments were executed. An experimental program was designed and different loading tests were conducted on the designed physical model.

4.1. Physical model

The physical model consists of a tank, footing of micro-piles, loading system and a settlement measuring device. The rigid steel tank has inner dimensions of $2000 \times 300 \times 800$ mm length, width, and depth, respectively. The tank consists of four sided perspex ply stiffened all around with rigid steel sections to allow for limited deformation during loading process. The footing model is prepared using a stiff steel plate $150 \times 12 \times 295$ mm width, thickness and length, respectively. The footing length with its longitudinal direction fits within the tank width with a 2.5 mm recess at both sides. Any deformation is prevented to occur along the footing longitudinal direction, which leads to achieve a plain strain condition throughout the tests. The base of footing was made to have a rough surface.

A vertical plate ($100 \times 50 \times 4$ mm) is welded at the top of the footing to provide reference for the dial gauge in lateral direction. The load is transmitted at the top of the footing through a loading ball of 16 mm diameter. The ball is fitted between the rigid bar and the footing. A recess from the center of the footing plate and at the required eccentricities is achieved. The recess to accommodate a ball bearing through which the loads were applied to the footing.

4.2. Designed experimental program

An experimental program was designed. It included five groups of high tensile steel bars with 20 mm diameter and with different heights. Each group contains five micro-piles with the same height. The depths of the micro-piles after fixation on the footing base were 75, 150, 300, 450, and 600 mm i.e. $L/B = 0.5, 1.0, 2.0, 3.0$ and 4.0, respectively. In order to ensure rigid fixation, between the micro-piles and the footing, five holes with the full footing depth were drilled at equal spacing of 60 mm in the specified position to support the micro-piles. Each hole was 20 mm diameter. The micro-piles were connected to the footing by steel bolts.

A rigid loading frame was used to apply the load to the model strip footing through hydraulic jack and 50 KN proving ring. Dial gauges were used to measure the footing movements. The details of the loading frame are indicated in Fig. 1. Fig. 2 presents the examined micro-piles and footing. A schematic diagram of this study is shown in Fig. 3.

Where:

B: Footing width.
e: Load eccentricity.
X: Distance of the footing edge to the slope crest.
L: Micro-piles length.
i: Load inclination angle.
θ: Slope inclination angle.

It is to be noted that a model strip footing with/without single side micro-piles tests on sand slopes was inspected at two slope angles of 2H: 1V ($\theta = 26.6°$) and 3H: 2V ($\theta = 33.7°$) with different footing edge distances from slope crest to the footing width ratio, X/B, of 0, 1.0, 2.0, 3.0, 4.0 and 5.0 for five