Experimentally Studying the Effect of Loading State on the Behavior of Shallow Footing in Sandy Soils

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ABSTRACT: In shallow footings depending on the type of structure which is located on it, such as urban buildings, marine structures, billboards, dams, etc.; it is influenced by different types of loads, such as vertical, horizontal, and bending moment. Depending on the type of structure, these loads can affect the shallow with different loading states. In this paper, by defining 32 experimental tests, the behavior of two circular and square shallow footings located on the sandy soil under the three loading states have been investigated and the failure envelope of each footing has been plotted in the V-H space (vertical load-horizontal load). Also, to study the effect of relative density on the failure envelope using the rainy method, sandy soil with two densities of 50 and 70 percent was developed. The results show that the failure envelope for shallow footing regardless of its shape in the V-H space, follows a second-order function, which the increase of density and consequently the increase of soil friction angle in the sandy soil has a direct impact on the failure envelope in the V-H space; the surface has a maximum point which is equivalent to 0.3 V_max. The square footing has a bigger ultimate load than the circular footing; that’s why the failure envelope in the V-H space for the square footing is larger. In general, the failure envelope in the V-H space for shallow footings depends on the ultimate load (V_max) and soil friction angle.

1. INTRODUCTION

All structures need to be built on footings to carry loads on Earth. These loads are usually applied in the vertical direction due to the weight of the structure. In this case, the soil bearing capacity is one of the fundamental factors in the design of the shallow footing. Vertical bearing capacity is considered by researchers [1, 2]. In some structures such as power towers, oil platforms, and marine structures, Footings may be affected by eccentric or inclined loads. Decomposition of load vector to components can be considered as vertical and horizontal loads. The behavior of footings under eccentric loading was investigated by [3-16]. To investigate the behavior of shallow footings under eccentric inclined loading a new perspective was proposed by Butterfield and Ticof (1979)[17] and Butterfield (1981)[18], in which the eccentric inclined load is turned into vertical (V), horizontal (H) and bending moment (M) components, and then the soil failure and its corresponding settlements under the shallow footing were studied about these loading components. We can now use vertical load (V), horizontal load (H), and bending moment (M) components to draw the 3D failure envelope. By using a 3D failure envelope, the behavior of shallow footing is examined under different loading states and loading passes. Inside the envelope area is a possible loading state, points on the boundary show the soil failure, and points outside the envelope are impossible loading state, in this paper regard to the negligence of relative density and footing shape effect on failure envelope, some laboratory tests are developed to examine the shallow footing behavior under vertical and horizontal loading with different loading paths, the results of these tests are presented as follows.

2. METHODOLOGY

To study the effect of the shape and relative density of soil on the behavior of shallow footing, two types of circular and square footings, as well as two different relative densities, are considered in this study. On the other hand, to examine the dependence of failure envelope on loading state, three different loading paths have been introduced:

- V-C Path: Vertical loading in the center of the footing to reach the failure.
- I-C Path: Inclined Loading in the center of the footing to reach the failure.
- V-H Path: Vertical loading up to a specified value then applying horizontal until it fails.

A total of 32 laboratory tests have been conducted on square and circular footings with 20 cm in diameter and thickness of 20 mm to ensure sufficient rigidity. The tested soil is standard Firoozkooh No. 161 sand, which is named (SP) in

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4. DISCUSSION AND RESULTS

By performing tests and plotting the load-settlement diagrams, the ultimate load for each experiment was obtained. A failure point in the two-dimensional space V-H is considered, and the failure envelope of the footing model is drawn. Each failure envelope is drawn using 9 points in the V-H space. The first point of this graph is based on the origin and indicates the unloaded state. The endpoint of the graph, which is located on the horizontal axis, is obtained using the V-C loading state, indicating the bearing capacity of the footing under central vertical loading. To obtain the other points, two other loading states have been defined; five points are obtained from the V-H loading state and two points from the I-C loading state. Now a parabolic curve is best fitted, predicting the shallow footing behavior, which shows the failure envelope under general loading. Fig. 2 illustrates a comparison between the failure envelope of circular and square footings with two density of 50 and 70%.

According to the experimental data and the results of analysis, to predict the shallow footing behavior under combined vertical and horizontal loading, the following relationship is presented:

\[ H = 2 \tan \varphi V \left(1 - \frac{V}{V_{\text{max}}} \right) \]

The coefficients of this relationship are derived from the results of 32 laboratory tests, and its diagram shows the footing failure envelope which is a parabolic curve, depends on the amount of ultimate load and the soil friction angle. In Figure 3, the proposed relationship diagram is presented for 50% relative density and compared with experimental results.

5. CONCLUSIONS

According to the results of experiments conducted on circular and square shallow footings under general loading on sandy soil with two different densities and with about the failure envelopes achieved, it can be concluded that increasing the amount of relative density of the soil and so increasing the angle of internal friction, increases the bearing capacity and the failure envelope in VH space, and failure envelopes under general loading in the VH space is a parabolic curve. This envelope holds a maximum of \( V = 0.5V_{\text{max}} \). The maximum horizontal load tolerated by shallow footing in this study is equivalent to 0.3\( V_{\text{max}} \), which depends on the material and density of the soil.

REFERENCES


