Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 55(9) (2023) 387-390
DOI: 10.22060/ceej.2023.21741.7812

The effect of combined loading on the bearing capacity of strip footings located on two-layered clayey soils adjacent to geogrid-reinforced slopes

M. Mahboubi Niazmandi[1] , S.Mirassi[2], Mehdi Hashemi jokar[3], Mohammad Momeni [2]

[1] Department of Civil and Environmental Engineering, Shiraz University of Technology, Shiraz, Iran
[2]Faculty of Civil Engineering, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran
[3]The main member of the specialized geotechnical commission, Organization of the construction engineering system

ABSTRACT: The present paper aims to determine the undrained bearing capacity of strip footings located on two-layered clayey soil in the vicinity of a geogrid-reinforced slope under the effect of combined loading by applying horizontal (H), vertical (V) and bending moment (M) loads. To this aim, by finite element modeling in ABAQUS based on the controlled load-displacement method, the failure envelopes and the failure mechanism of the subsoil of strip footings under the effect of combined loadings were determined in V-H, V-M and V-H-M loading spaces. The results obtained in two cases of unreinforced and reinforced slopes with geogrids were compared by performing parametric studies regarding the effect of changes in undrained shear strength ratios of clayey layers (Cu1/Cu2) and the ratio of the thickness of the first clay layer to the width of the strip foundation (H1/B). The results showed that by increase Cu1/Cu2 in V-H loading spaces, the vertical bearing capacity increased, which is caused by the increase in the undrained cohesion of the first layer. Furthermore, in scenarios involving both vertical-horizontal (V-H) and vertical-moment (V-M) load combinations, when subjected solely to vertical loading, a greater volume of soil experienced failure. The results showed that reinforcing the slope with geogrid increases the vertical and the moment bearing capacity by 31 and 35%, respectively. In general, the findings of this study provide a new insight into the failure mechanism of strip foundations based on two-layered clayey soils in the vicinity of geogrid-reinforced slopes under the effect of combined loads.

Review History:

Received: Sep, 01, 2022
Revised: Aug. 12, 2023
Accepted: Aug. 16, 2023
Available Online: Aug. 26, 2023

Keywords:

Finite element analysis
strip footings, two-layer clayey soil
geogrid-reinforced slope
combined loading

1- Introduction

Placing a foundation near a slope significantly reduces its bearing capacity. In such situations, the use of polymer reinforcements, such as geogrids, offers a viable solution to increase the foundation's bearing capacity [1]. Moreover, real-world foundation conditions involve the simultaneous application of vertical (V), horizontal (H), and bending moment (M) loads. Conventional designs estimate the foundation's bearing capacity under the influence of combined loads by making a series of simplifying assumptions [2]. However, recent studies [3,4] have demonstrated that such analyses are overly cautious and do not possess sufficient accuracy in determining the foundation's actual response to combined loads. Therefore, it is crucial to focus on understanding the behavior of foundations when subjected to combined loads, particularly in proximity to sloping terrain [4]. This area of research has attracted substantial interest from geotechnical experts, resulting in numerous studies conducted in this field. Examples include investigations into the bearing capacity of strip foundations on two-layered clay soils [4] and sandy soils [5], the behavior of skirted foundations [6], the effect of spatial variability in soil shear strength on foundation bearing capacity [7], and the bearing capacity of strip foundations on frictional-clay soil layers [8] under V-H-M combined loads.

Despite an extensive review of technical literature, it is noteworthy that the issue of undrained bearing capacity of clay soils near slopes under the influence of combined loads remains unexplored. Consequently, the present paper is aimed to evaluate the bearing capacity of a strip foundation on a two-layer clayey soil profile near a slope reinforced with geogrid, considering the simultaneous effect of combined loads.

2- Materials and Methods

In the present paper, the bearing capacity of strip foundations on clay soils adjacent to a slope reinforced with geogrid under different combined loading conditions (V-H, V-M, and V-H-M) was investigated using numerical modeling based on finite element analysis (FEA) in ABAQUS [9]. To determine the bearing capacity and draw the failure envelopes, FEA approaches based on the Probe technique for two-dimensional loads (V-H and V-M) and the Load-Probe for V-H-M loading were used [10,11]. Figure 1 illustrates the geometry of the modeled problem. According to this figure, a strip foundation with a width of B is placed on a two-layer clayey soil profile with undrained shear strengths C_{u1} and C_{u2} adjacent to the geogrid-reinforced slope.

*Corresponding author's email: m.mahboubi@sutech.ac.ir

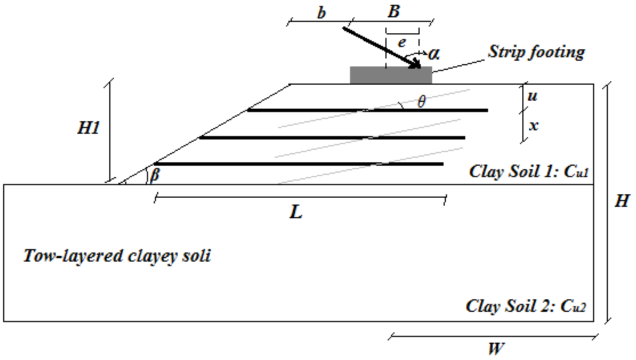

Fig. 1. Schematic of the modeled problem

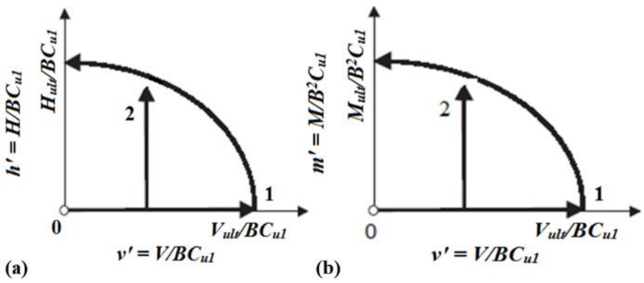

Fig. 2. Determination of failure envelopes using Probe and Load-Probe FEA in (a) V-H loading and (b) V-M loading

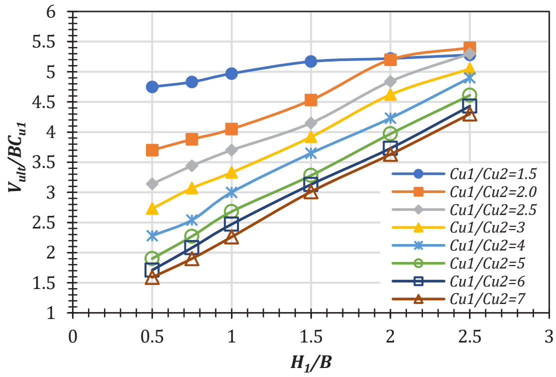

Fig. 3. Changes of V_{ult}/BC_{u1} versus H1/B in V-H loading

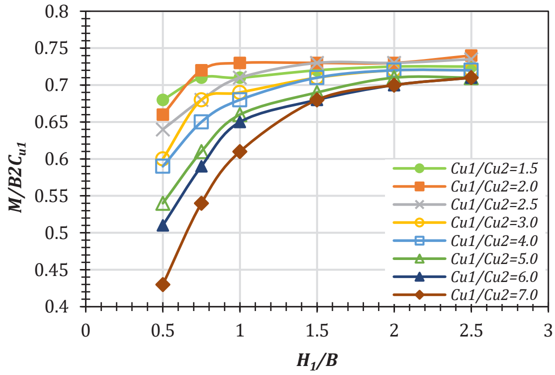

Fig. 4. Changes of M_{ult}/B^2C_{u1} versus H1/B in V-M loading

The mechanism of determining the failure envelopes using Probe and Load-Probe analyzes in different loading modes is shown in Figures 3(a) and 3(b), respectively.

The focus of the parametric studies in this research is on the influence of the ratio of undrained shear strength of the clay layers (C_{u1}/C_{u2}) and the ratio of the thickness of the first clay layer to the width of the strip foundation (*H1/B*) on the bearing capacity of the foundation. The results will be compared and evaluated in terms of failure envelopes, changes in vertical load capacity, and the failure mechanism in different loading situations.

3- Results and Discussion

Figure 3 shows the changes of the maximum points of failure envelopes of the vertical bearing capacity (V_{ult}/BC_{u1}) versus *H1/B* for different C_{u1}/C_{u2} in V-H loading. As can be seen, by increase in C_{u1}/C_{u2}, the failure envelopes become smaller. The reason for this can be attributed to the increase in the vertical bearing capacity of the foundation with an increase in the undrained shear strength of the first layer. These changes occur more strongly at lower *H1/B* ratios. This means that the lower the thickness of the first layer, the more the vertical bearing capacity decreases with an increase in the resistance of this layer.

Figure 4 displays the changes of the maximum points of failure envelopes of the bending moment bearing capacity (M_{ult}/B^2C_{u1}) versus *H1/B* for different C_{u1}/C_{u2} in V-M loading. By comparing the results, it can be seen that with the increase of C_{u1}/C_{u2}, the failure envelope becomes smaller. However, this change in the failure envelope occurs more intensely at lower *H1/B* ratios. This means that the smaller the soil thickness of the first layer is, the less bending anchor is needed for the foundation to break as the strength of this layer increases.

4- Conclusions

The important and practical results of the present research can be stated as follows:

With the increase in C_{u1}/C_{u2} in V-H loading, the failure envelopes are more distant from each other because the vertical bearing capacity increases with an increase in the undrained adhesion of the first layer. Additionally, with the increase in C_{u1}/C_{u2} in V-H loading, the failure envelope becomes smaller.

The soil failure mechanism under the foundation, under the effect of V-H and V-M combined loadings, shows that in the case where there is only vertical loading, a larger volume of soil is failed.

A comparison of foundation failure envelopes in two cases (slope without reinforcement and slope reinforced with geogrid) under the effect of V-H and V-M combined loadings shows that slope reinforcement has a significant effect on vertical bearing capacity.

References

[1] R. Sharma, Q. Chen, M. Abu-Farsakh, S. Yoon, Analytical modeling of geogrid reinforced soil foundation, Geotextiles and Geomembranes, 27 (2009) 63–72.

[2] M.F. Bransby, G.J. Yun, The undrained capacity of skirted strip foundations under combined loading". Geotechnique, 59(2) (2009) 115–125.

[3] L.C. Hung, S.R. Kim, Evaluation of undrained bearing capacities of bucket foundations under combined loads, Marine Georesources & Geotechnology, 32(1) (2014) 76–92.

[4] P. Rao, Y. Liu, J. Cui, Bearing capacity of strip footings on two-layered clay under combined loading, Computers and Geotechnics, 69 (2015) 210–218.

[5] C. Tang, K.K. Phoon, K.C. Toh, Effect of footing width on Nγ and failure envelope of eccentrically and obliquely loaded strip footings on sand, Canadian Geotechnical Journal, 52(6) (2014) 694–707.

[6] B. Bienen, C. Gaudin, M.J. Cassidy, M. Rausch, A. Purwana, H. Krisdani, Numerical modeling of a hybrid skirted foundation under combined loading, Computers and Geotechnics, 45 (2012) 127–139.

[7] A. Hentati, M. Selmi, T. Kormi, N. Bel Hadj Ali. Probabilistic HM failure envelopes of strip foundations on spatially variable soil, Computers and Geotechnics, 102 (2018) 66–78.

[8] A. Haghighi, P. Hu, J.G. Tom, K. Krabbenhoft, Combined loading of strip footings on sand-over-clay with layers of varying extents, Soils and Foundations, 59(2) (2019) 433–442.

[9] ABAQUS, (2011), ABAQUS user's manual, Version 6.13.1.

[10] M.F. Bransby, M.F. Randolph, Combined loading of skirted foundations, Geotechnique, 48(5) (1998) 637–655.

[11] S. Gourvenec, Randolph, M.F. Effect of strength non-homogeneity on the shape and failure envelopes for combined loading of strip and circular foundations on clay, Geotechnique, 53(6) (2003) 575–586.

HOW TO CITE THIS ARTICLE

M. Mahboubi Niazmandi, S.Mirassi, Mehdi Hashemi jokar, Mohammad Momeni, The effect of combined loading on the bearing capacity of strip footings located on two-layered clayey soils adjacent to geogrid-reinforced slopes, Amirkabir J. Civil Eng., 55(9) (2023) 387-390.

DOI: 10.22060/ceej.2023.21741.7812