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INFLUENCE OF FOOTING SHAPE ON UNDRAINED SEISMIC BEARING CAPACITY OF SURFICIAL FOUNDATIONS NEAR COHESIVE SLOPES

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ABSTRACT

This paper focuses on assessing the impact of different footing shapes on the undrained seismic bearing capacity of surficial foundations located near slopes. The study employs the PLAXIS 3D finite element software to conduct a comparative analysis, aiming to provide valuable insights for geotechnical engineers involved in foundation design in such scenarios. For this purpose, numerical models are created to simulate the behavior of surficial foundations under seismic loading. Various footing shapes are examined during the analysis, considering the undrained soil properties, slope characteristics, distance between the slope and footing, and seismic loading parameters. The research findings highlight the substantial influence of footing shape on the undrained seismic bearing capacity of surficial foundations near slopes. As a result of the study, design charts specific to each footing shape are developed, offering engineers a tool to estimate the bearing capacity in similar scenarios. These design charts provide practical guidance for optimal foundation design and enhance the understanding of how footing shape impacts the seismic performance of surficial foundations near slopes.

Keywords: *bearing capacity, footing shape, cohesive slope, design chart, Plaxis.*

1. INTRODUCTİON

The recent earthquake in Kahramanmaraş, Turkey, which occurred in February 2023, has highlighted the vulnerability of structures in seismic-prone regions. Given Turkey's sloping terrain and high seismic activity, it is crucial to have a comprehensive understanding of the seismic behaviour and bearing capacity of foundations located near cohesive slopes. A key aspect in ensuring the safety and stability of structures during earthquakes is evaluating the influence of footing shape on the seismic bearing capacity.

The seismic bearing capacity of foundations plays a vital role in protecting structures during seismic events. Accurate assessment of seismic bearing capacity is essential to prevent potential failures and mitigate risks to both human life and infrastructure. With advancements in numerical modeling techniques, such as the Finite Element Method (FEM), it is now possible to investigate the effects of various parameters on the seismic behavior of foundations near cohesive slopes. FEM, widely used for geotechnical analyses (Gourvernec, 2006), provides a powerful tool for simulating the complex interaction between foundations, soil, and slopes. Utilizing FEM-based software like PLAXIS 3D, researchers can conduct detailed investigations into the influence of footing shape on the seismic bearing capacity. This approach enables a comprehensive understanding of the response and stability of foundations in cohesive slope environments under seismic forces (Cinicioglu&Erkli, 2018).

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The objective of this paper is to explore the impact of footing shape on the seismic bearing capacity of foundations near cohesive slopes using FEM-based PLAXIS 3D analysis. Through a systematic study of various footing shapes and their interaction with cohesive slopes, valuable insights can be gained regarding their influence on the seismic performance and stability of foundations. The research outcomes will contribute to the development of improved design charts and recommendations for foundations in seismic-prone areas near cohesive slopes which can provide invaluable guidelines for hazard risk assessment and/or urbanization planning studies.

2. PROBLEM DEFINITION

The influence of footing shape on the undrained seismic bearing capacity of surficial foundations near slopes is tested by performing a parametric study with different variables using the Finite Element method. The reason for preferring the finite element method over the limit equilibrium method is that it provides a solution without any presumptions about the failure surface. Moreover, the finite element method doesn’t require slices, which means assuming the slice forces is unnecessary. In this study, the surficial foundation case, which is the most critical case, is represented by ignoring the embedment influence. In this study, the footing is represented by a rectangular rigid plate with different footing length L values and constant width B values to cover different foundation dimensional properties, with the rough interface between the footing and soil. An elastic – perfectly plastic model with the Tresca failure criterion is used to model the soil behavior. The soil is purely cohesive, with no change in soil properties depending on the depth. The pseudo-static approach is used to define the seismic activity, where k_h is the horizontal component of seismic acceleration. The vertical component k_v is taken as zero due to its ignorable influence on seismic bearing capacity. In the horizontal component, the component through the third direction, the y-axis, was set as $k_y = 0$ to consider the most critical case where the whole seismic force is toward the slope, which acts along the x-axis. The inertia force of the structure is assumed to act at the foundation base. In addition, a set of analyses with $k_h = 0$ values were performed to represent the static conditions response with varying foundation shapes and provide a basis of comparison to interpret the influence of seismic action. The parametric analyses were conducted for rectangular surficial footings with rough bases. The dimensions of the footings are chosen as two meters on the short side (B) and L= 0.5, 2, 4, and 8 m on the long side. Dimensionless parameter L/B = 0.25, 1, 2, 4 ∞ is used to define the variations in dimensional properties where the infinity sign corresponds to the continuous footing case, as indicated by Cinicioglu&Erkli 2018. Mohr-Coulomb elastic-perfectly plastic constitutive soil model with $\varphi = 0$ and $\gamma = \gamma_{sat} = 20$ kN/m^3 is used for all the analyses. Soil strength c_u values are varied as 25, 50, 100, and 200 kN/m^3 to test the response of soft, stiff, and hard soils. The equation $E_u = 200\ c_u$ is used to find the undrained stiffness, while the undrained Poisson’s ratio was assumed as 0.495 to avoid the singularity in the stiffness matrix. The footing is located at various distances, s from the slope crest, and this distance is normalized by the footing width B, which is defined as $\lambda = s/B = 0$, 0.5, 1, and 2. The height of slope H is normalized by the footing width B as H/B = 1, 2, and 4, while the slope angle values β were 15°, 30°, 45°, and 60°, which are used to define the slope shape. The model used in this study is presented in Table 1.

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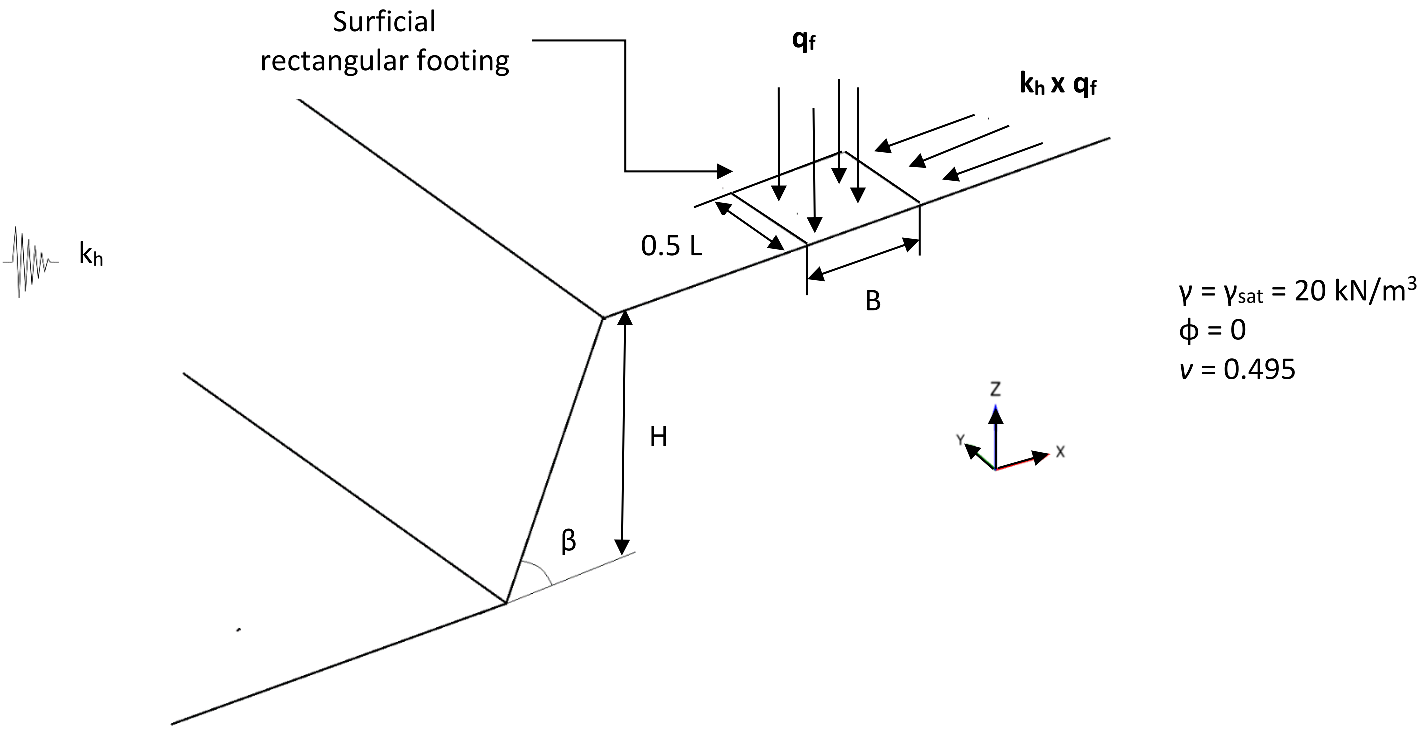

Figure 1. Schematic of the problem investigated in this study.

3. FEM MODEL EXPLANATİON

An axisymmetric view of the FEM model is shown in Figure 2. In this study, the model geometry proposed by (Erkli 2015) for plane-strain conditions is adopted and modified for three-dimensional problems. As illustrated in Figure 2, the boundary along the x-axis is located at 8B from the edge of the footing, while the boundary along the y-axis is positioned at 8L from the edge of the footing. The front and bottom boundaries along the x-axis and z-axis are positioned at 12.5B and 6B from the slope toe to eliminate any possibility of size effects.

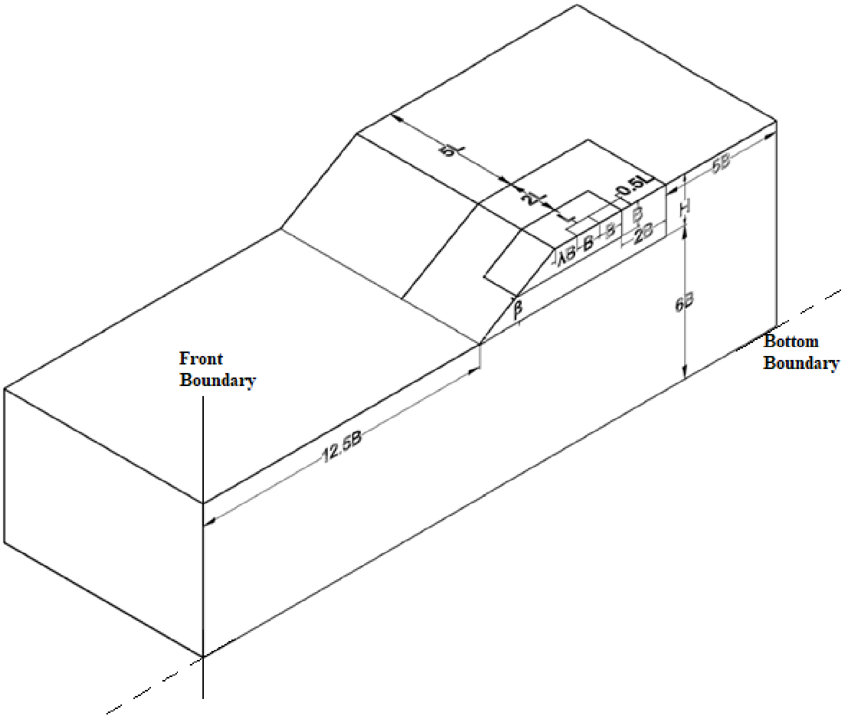

Figure 2. Schematic of FEM model used in this study.

The model is divided into two halves with a symmetric surface over the xz surface passing through the center of both the slope and the rectangular footing, as only one half is used during the analysis due to the symmetry to optimize the calculation time. The mesh optimization method proposed by (Georgiadis 2011) is applied with some modifications to obtain the most practical meshing in terms of calculation time. The mesh settings used in this study are obtained by performing different model analyses. The previous mesh optimization method is tested to find the undrained static bearing capacity factor N_c of strip footing on level ground (Prandtl 1920) using both 3D and 2D models, and the result obtained is 5.27 and 5.14, with a 2.5% and 0% error values, respectively. According to Equation 1, bearing capacity factor N_{cs} is calculated for all the models by dividing the ultimate pressure q_u, obtained by the FEM analyses, by undrained soil strength c_u to get a normalized value.

$$q_u = N_{cs} c_u \qquad \textit{Equation 1}$$

4. RESULTS

Due to the lack of studies in the literature that focus on the influence of footing shape on the seismic bearing capacity of foundations located near slopes, the studies that investigated the level ground case were used to verify the validity of this study's approach and results. Various methods have been utilized in the literature, such as empirical approaches (Skempton, 1951), numerical finite element analysis (Michalowski, 2005 and Gouvernec, 2006), and finite element limit analysis (Salgado et al. 2004 and Yang et al., 2019). As presented in Figure 3, the variation of $s_c N_c$ values, which indicates the bearing capacity factor multiplied by the shape factor representing the N_{cs} value calculated in this study, with B/L values, is compared to the results obtained by other researchers. It can be observed that the results obtained by this study compared with those obtained in previous

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studies are consistent. FE results obtained by Gouvernec (2006) for the level ground case are almost identical to those obtained by this study, except for the B/L=0 case. The deviation for B/L=0 is that this study used 2D plain-strain conditions to represent the strip foundation case, which provides more realistic results than those found by Gouvernec (2006) using a 3D model.

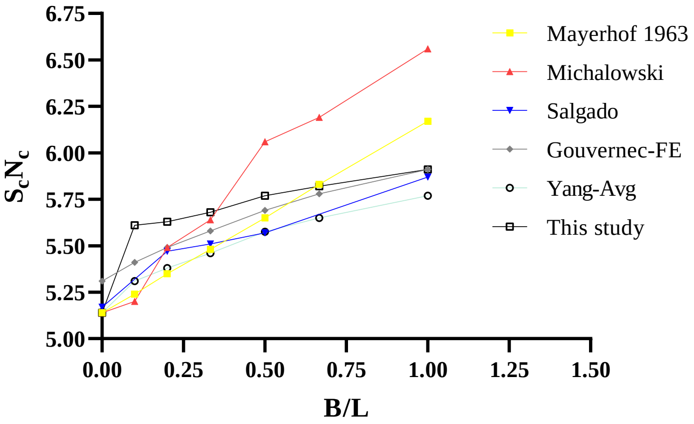

Figure 3. Variation of S_cN_c with B/L of this study compared to previous studies.

After conducting a comprehensive study on the impact of various parameters on the seismic bearing capacity of a foundation near a cohesive slope, it became necessary to develop a design methodology to assist geotechnical engineers in predicting the seismic bearing capacity for such scenarios. Design charts were created to achieve this, incorporating the relationship between N_{cs} and λ for each footing shape considered in this study. The N_{cs} value initially increases with λ until it reaches a critical point, λ_o. Beyond this critical point, the N_{cs} remain constant since the slope no longer affects the failure mechanism. By integrating these findings, the design charts offer a practical tool for geotechnical engineers.

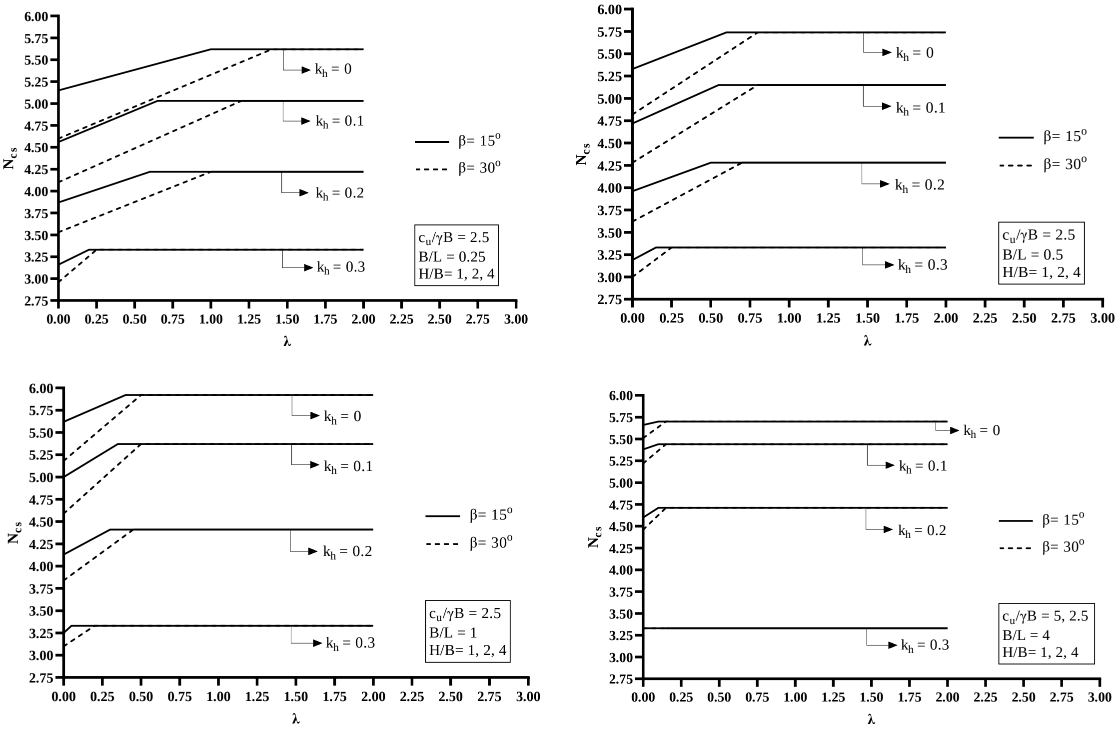

Figure 4. Design chart for seismic bearing capacity factor of rectangular surficial footings near cohesive slopes (β= 15°, 30°, cu/γB= 2.5, H/B= 1, 2, 4).

5. CONCLUSION

The seismic bearing capacity of foundations located next to cohesive slopes is significantly influenced by the shape of the foundation, as indicated by the parameter B/L. However, this study only explored a limited number of footing dimensions due to the extensive analysis required. To gain more comprehensive insights, future research should consider expanding the range of B/L values and investigating the impact of circular footing shapes. By doing so, more precise and accurate results can be obtained concerning the effect of the footing shape on seismic bearing capacity. It can be observed that the critical point λ_o is decreased while increasing the B/L value. The reason for this behavior is that increasing the B/L will reduce the length of the footing, resulting in a decrease in the stress applied from the footing onto the slope. Therefore, the footing becomes less influenced by the slope effect, particularly at shorter distances.

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