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Numerical Analysis of the Bearing Capacity of Strip Footing Adjacent to Slope

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Abstract- In some cases, such as the foundations of high-rise buildings adjacent the excavation, bridge abutments and tower footings for electrical transmission lines, foundations may be built near a slope. In these cases, the behavior of the mentioned foundation will be affected by the slope. In this study, a numerical model was developed by finite element software, Plaxis Version 8., to investigation the bearing capacity of the strip foundation near the slope. The developed model was validated by some of the existing theories. After that, the parametric studies was performed to determine the geometrical effective parameters and their impacts on behavior of this type of infrastructure. Results indicated that behavior of the foundations adjacent to a slope, is function of the geometric characteristics, such as distance from the slope crest, height and angle of slope. The lowest value of bearing capacities was observed in the case of that foundation located without any distance from the slope crest. By evaluation of the results it was found that value of bearing capacity decrease with increasing of angle and height of the slope.

Keywords*- Bearing Capacity, Strip Footing, Slope, Numerical Analysis*

I. INTRODUCTION

Foundations are a fundamental pillar to any structure, which transmit the load of the superstructure to the layers of the soil. Due to the space constraints as well as economical and architectural objectives in a project, the foundation may be built near a slope. Some common examples of these foundations include basement excavations for high-rise buildings, bridge abutments and tower footings for electrical transmission lines. Slope stability and bearing capacity of foundation are important factors in such projects. When a foundation is constructed near a slope, one side of the foundation will be subject to the slope and plastic regions will be developed and significant changes will be occurred in the slope stability and subsequently bearing capacity of the foundation. Bearing capacity is a major concern in geotechnical engineering and correct determine of bearing capacity of the foundation near a slope is a challenging task for an engineer. For a footing near the slope, the ultimate bearing capacity may be governed by either the foundation bearing capacity or the overall stability of the slope. Hence the combination of these two factors makes the problem difficult to solve [1]. The bearing capacity of a shallow strip footing resting on level homogenous ground is generally evaluated using the superposition formula proposed by Terzaghi [2]. After Terzaghi, further studies on bearing capacity of the foundation on level ground developed by other researchers such as Meyerhof [3], Hansen [4] and Vesic [5].

Meyerhof investigated general failure mechanisms for bearing capacity of footings placed on purely cohesion-less or cohesive soils adjacent to slopes [6]. After Meyerhof, Hansen [4] and Vesic [7], evaluated the bearing capacity for the condition that the foundation is located at the slope crest. After them, numerous researchers have studied this problem via various method and solutions, including limit equilibrium techniques [8, 9], yield design theory [10], finite element method [11], upper bound technique [1, 12] and lower bound technique [1].

In this paper a numerical simulation carried out on the strip footing near the slope and effects of geometrical characteristics of the model as also as mechanical characteristics of the soil on the bearing capacity, were investigated.

II. NUMERICAL ANALYSIS

Two-dimensional plane strain FE numerical simulations were performed using Plaxis commercial program [13]. The left and right boundaries were only permitted to move vertically and the bottom of the model was constrained against both horizontal and vertical movements. To eliminate boundary effects due to loading, the horizontal and vertical boundaries must be located at a suitable distance from the foundation. In this study, a sensitivity analysis was conducted on influence of boundaries and it was found that a distance of 30 meters is appropriate. Description of the geometric parameters and distance of boundaries is presented in Fig. 1.

It was assumed that foundation is rigid. Hence, a uniform settlement applied in the vertical direction to all nodes at the soil-footing interface. The model mesh was generated using 15-node triangular elements. Due to the stress concentration around the foundation, the mesh size was locally refined in these regions. Typical adopted mesh is shown in Fig. 2. An elastic-plastic Mohr Coulomb (MC) model was selected for the soil beneath the foundation. Material properties that have been adopted in this study are presented in table 1.

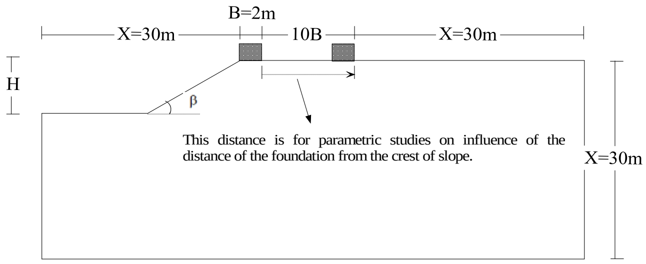

Figure 1. Description of the geometric parameters and distance of boundaries

Accuracy of the developed model was verified by bearing capacity equations proposed by other researchers [2-7] in two ways: 1. Strip foundation on level ground and 2. Strip foundation on purely cohesion-less soils adjacent to slopes.

In the level ground, it was assumed that the properties of materials are in accordance with table 1 and foundation width is equal to 2 meters. Table 2 shows the results of this verification.

In the sloped cohesion-less ground, material properties was taken according to table 1, except the cohesion of the soil that was equal to 0. The verification results for sloped ground are shown in Fig. 3. It should be noted that in this figure, b and N_γ are distance of the foundation from the slope crest and bearing capacity factor, respectively.

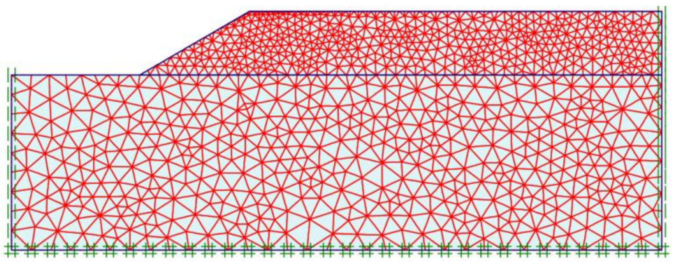

Figure 2. Typical mesh shape for numerical analyses

TABLE I. MATERIAL PROPERTIES

Properties	Soil
$E\ (kPa)$	20000
υ	0.3
$\varphi'(°)$	25
$\psi(°)$	-
$C'(kPa)$	9
$\gamma\ (kN/m^3)$	18

TABLE II. VERIFICATION OF DEVELOPED MODEL FOR LEVEL GROUND

Method	Parameters		
	N_c	N_γ	q_u (kPa)
Terzaghi[2]	25.13	8.34	376.29
Meyerhof[3]	20.72	6.77	307.34
Hansen[4]	20.72	6.76	308.16
Vesic[5]	20.72	10.88	382.32
Plaxis	-	-	365

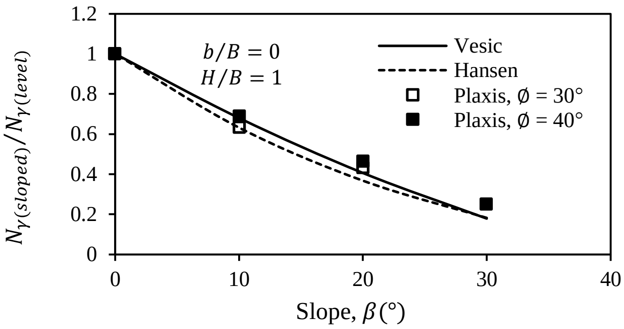

Figure 3. Verification of developed model for cohesionless sloped ground (foundation at slope crest)

III. RESULTS

Pressure-settlement characteristics for different edge distances of the foundation from the slope crest (b) are shown in Fig. 4. From this figure, it is clearly seen that the bearing capacity increases with increasing distance of the foundation from the slope crest. The failure mechanism for different distances of the foundation from the slope crest is shown in Fig. 5. It can be said that when the foundation is located in the vicinity of a slope, the soil beneath the foundation, tend to move toward the slope, so less shear resistance is supported by the soil. With increasing distance of the foundation from the slope, soil movement toward the slope decreases and therefore shear strength and bearing capacity increases.

In the parametric analysis of the this section, behaviour of the foundation near the slopes, assess through a dimensionless parameter (λ), which is defined as follows:

$$\lambda = \frac{q_u}{q_{u_{horizontal-ground}}} \quad (1)$$

Where, q_u and $q_{u_{horizontal-ground}}$ are ultimate bearing capacities of the foundation on sloped ground and on level ground, respectively. It is noteworthy that in this study, the ultimate bearing capacity was considered equal to pressure at a settlement of 10 % of the footing width, unless before this settlement, the maximum pressure is observed.

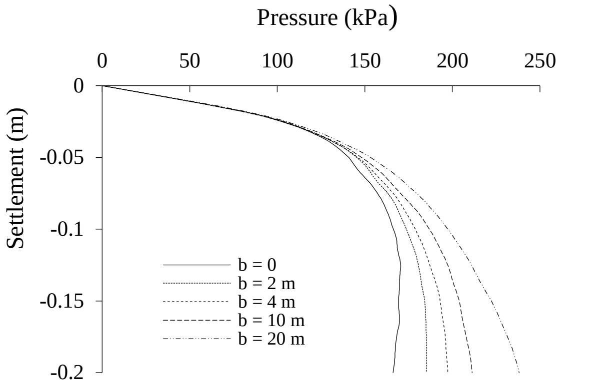

Figure 4. Pressure versus settlement curves for different distances of the foundation from the slope crest (b)

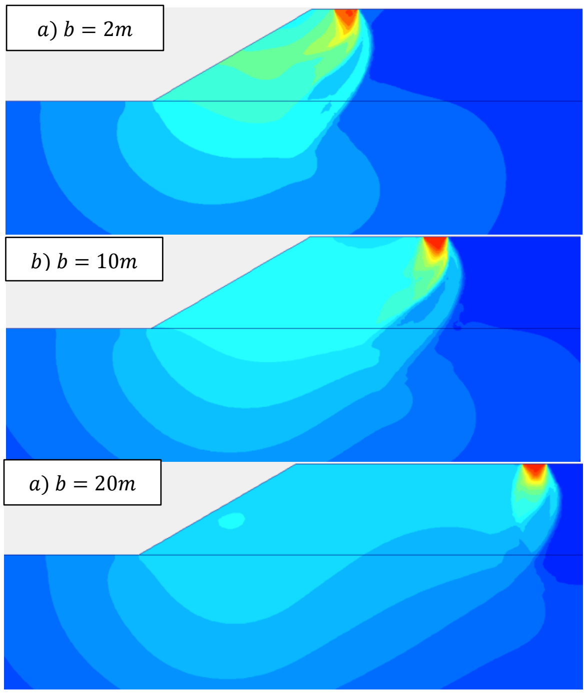

Figure 5. Displacement increment contours for different distances of the foundation from the slope crest (b)

A. *Influence of slope angle (β)*

A series of FEM analysis were conducted to investigate the effect of slope angle (β) on the bearing capacity of the foundation. Analysis were performed for (β) values of 10°, 20°, 30°, 40° and 50°. For each slope angle analysis, the foundation was placed at different distances from the slope crest. The failure mechanism for different slope angles, for foundation at the slope crest (b/B = 0), shown in Figure 6. According to this figure, can be said that slope stability decreases with increasing the slope angle, and thus the tendency of the soil beneath the foundation to move to the slope increases, therefore failure occurs due to the slope instability and reduces the bearing capacity.

Fig. 7 shows the variation of the λ with b/B ratio for different values of the slope angle (β). According to this figure, λ always decrease with increasing the β, that this decrease is lower in the greater amounts of b/B ratio. Because by increasing the distance of the foundation from the slope crest, behaviour of the foundation on sloped ground tend to behaviour of the foundation on level ground, thus, the geometric properties of the slope is not effected on the bearing capacity.

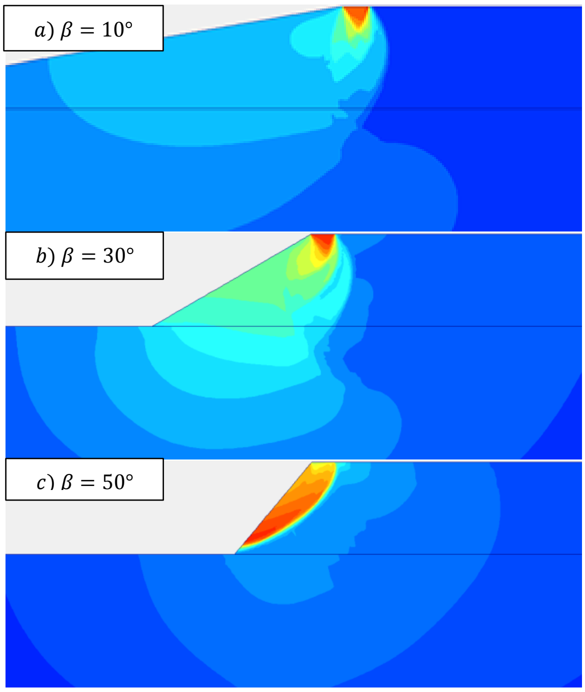

Figure 6. Displacement increment contours for different slope angle (β)

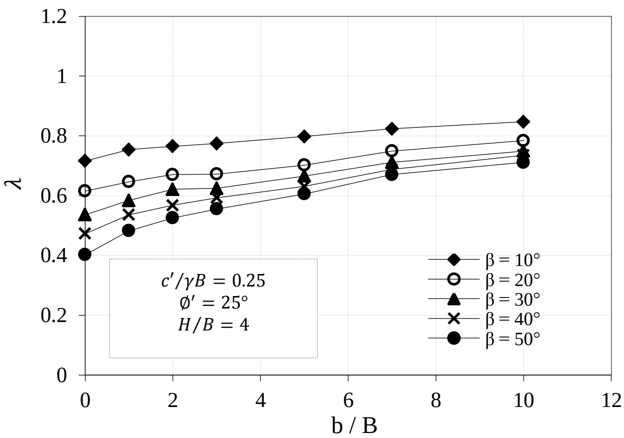

Figure 7. λ versus b/B for different values of β

B. Influence of normalized slope height (H/B)

The Influence of dimensionless normalized parameter of H/B on the bearing capacity was investigated by fixing the foundation width value (B) and changing the slope height (H). Fig. 8 shows the failure mechanism for different H/B ratios, for foundation at the slope crest (b/B = 0). With increasing the foundation height, slope stability decreases and the soil beneath the foundation tends to move to the slope, therefore the bearing capacity decreases. The variation of the λ with b/B ratio for different values of the (H/B), is shown in Fig. 9. According to this figure, can be seen that for small amounts of H/B, λ coefficient increases rapidly initially with increasing the distance from the slope crest and then the rate of increase decreases. Especially in the case of H/B = 0.25, that λ value related to it, is equal to 1 in b/B = 1 and with further increases in b/B amount, no increase is observed in λ. In fact, its behavior will be similar to the foundation behavior on level ground.

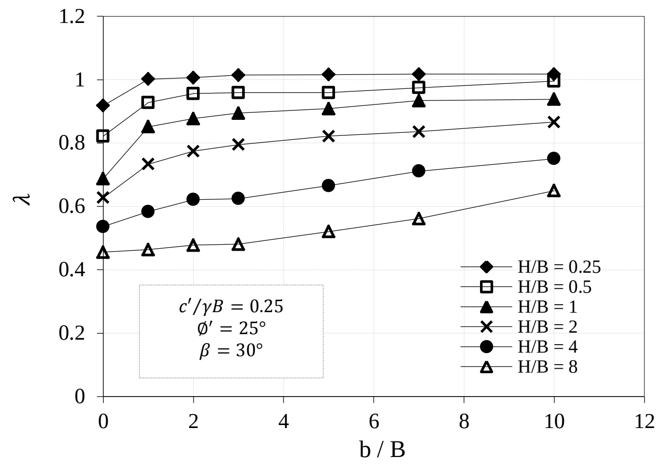

Figure 9. λ versus b/B for different values of H/B

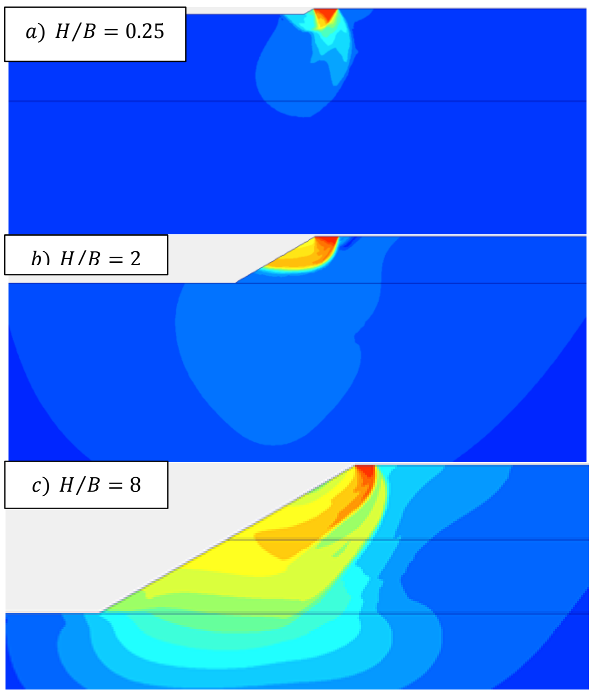

Figure 8. Displacement increment contours for different values of H/B

IV. CONCLUSIONS

Numerical investigations were performed to study the strip foundation behaviour near the slope. Mohr–Coulomb failure criterion considered for the soil beneath the foundation. Based on performed analyses, the following conclusions are drawn:

- The lowest bearing capacity value was observed in the case that the foundation is located at the slope crest (b/B=0). Depending on the geometric properties of the model, up to 60 percent decrease compared to the level ground, was observed in this study.
- By increasing the distance of the foundation from the slope crest, behaviour of the foundation on sloped ground tend to behaviour of the foundation on level ground and the bearing capacity increases.
- Slope stability decreases with increasing the slope angle, and thus the tendency of the soil beneath the foundation to move to the slope increases, therefore failure occurs due to the slope instability and reduces the bearing capacity.
- For small amounts of H/B, λ coefficient increases rapidly initially with increasing the distance from the slope crest and then the rate of increase decreases.

REFERENCES

[1] J. Shiau, R. Merifield, A. Lyamin, and S. Sloan, "Undrained stability of footings on slopes," International Journal of Geomechanics, vol. 11, pp. 381-390, 2011.

[2] K. Terzaghi, Theoretical soil mechanics: Wiley, 1943.

[3] G. Meyerhof, "The ultimate bearing capacity of foudations," Geotechnique, vol. 2, pp. 301-332, 1951.

[4] J. B. Hansen, "A revised and extended formula for bearing capacity," 1970.

[5] Vesic, "Analysis of Ultimate Loads of Shallow Foundations," in Journal of the Soil Mechanics and Foundations Division vol. 99, ed, 1973, pp. 45-73.

[6] G. Meyerhof, "The ultimate bearing capacity of foundations on slopes," in Proc., 4th Int. Conf. on Soil Mechanics and Foundation Engineering, 1957, pp. 384-386.

[7] A. S. Vesic, "Bearing capacity of shallow foundations," Foundation Engineering Handbook., pp. 121-147, 1975.

[8] A. S. Azzouz and M. M. Baligh, "Loaded areas on cohesive slopes," Journal of Geotechnical Engineering, vol. 109, pp. 724-729, 1983.

[9] F. Castelli and E. Motta, "Bearing capacity of strip footings near slopes," Geotechnical and Geological Engineering, vol. 28, pp. 187-198, 2010.

[10] P. d. Buhan and D. Garnier, "Three dimensional bearing capacity analysis of a foundation near a slope," Revue Française de Géotechnique, vol. 38, pp. 153-163, 1998.

[11] K. Georgiadis, "Undrained bearing capacity of strip footings on slopes," Journal of geotechnical and geoenvironmental engineering, vol. 136, pp. 677-685, 2010.

[12] O. Kusakabe, T. Kimura, and H. Yamaguchi, "Bearing capacity of slopes under strip loads on the top surfaces," Soils and foundations, vol. 21, pp. 29–40, 1981.

[13] R. Brinkgreve, Plaxis: finite element code for soil and rock analyses: 2D-Version 8:[user's guide]: Balkema, 2002.