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STABILITY ANALYSIS OF ISOLATED SQUARE FOOTINGS WITH LIMITSTATE: GEO2D®

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ABSTRACT

In the design of foundations, analysts have various applications that allow them to determine parameters of ultimate load capacity and safety factors. This article presents a study that seeks to analyze the results obtained from the modeling of foundations with geotechnical software of finite elements that integrate additional aspects of modeling that can vary with some degree of sensitivity the results of the design parameters. State-of-the-art modelers such as the one used in this study allow to involve in the analysis of foundations, characteristics about the boundary conditions of the land, the foundation materials and/or the width of the column. Several models of surface foundations were developed in stratified soil with the high performance geotechnical software LimitState:Geo2D (restricted version) and the formulation of Meyerhof and Hanna was used to validate the results. In order to analyze the impact on the design parameters, variations were made in the width of the foundation floor block, the foundation material and the section of the column, in all cases finding interesting differences in the results of the safety factor that in terms of engineering practice would mean impacts on construction costs, safety and risk, structural redundancy, reliability and vulnerability.

Keywords: parameter calibration, creep, asphaltmix, optimization, dirichlet series.

1. INTRODUCTION

The foundation of a building fulfils the main function of adequately transmitting the loads coming from the structure to the support terrain; the success of the sizing of these elements is a combination of a good interpretation of the characteristics of the ground and the characteristics of the building to be built. At first, the engineers only had the empirical methods that they used to analyze complex geotechnical problems, however, at the present time a great variety of computational applications have been developed that support the calculation work of the engineer. For the analysis of geotechnical problems, there are computational modelers based on the classic finite element method, among which stands out the well-known and robust software Plaxis® used by the majority of engineers engaged in geotechnical calculation. Other less complex and very interesting options specialize in analyzing the stability of geotechnical structures through advanced algorithms, such as LimitState:Geo2D®, which, through an intelligent algorithm for optimizing areas of discontinuity, allows rapid realization a stability analysis (critical failure mechanism and safety factor) in footings / foundations, cantilevered walls, reinforced soil, slopes, gabions, gravity walls and deep excavations. Taking advantage of the simplicity and versatility of the tool, a typical case of geotechnical analysis (surface foundation) was implemented in this software with the purpose of showing the incidences that certain characteristics of the foundation environment have on the calculation of the design parameters. Carrying out an analysis of these characteristics will provide elements that allow stopping in the stability analysis due to certain variations that occur in the values of the security factors. The use of intelligent calculation tools allows designs with safety factors more adjusted to reality and also recreate multiple geotechnical situations that does not include empirical formulation.

2. METHODS

The intelligent algorithm of optimization of the areas of discontinuity of the LimitState: Geo2D®program finds the critical slip line that characterizes the failure mechanism, using a four-step methodology:

a) Nodes are distributed throughout the domain of the problem (Figures 1a and 1b).
b) Connect the nodes that define slip lines that represent possible discontinuities (Figure-1c).
c) The optimization algorithm is applied to identify the discontinuities that make up the critical failure mechanism (Figure-1d).
d) The corresponding failure load factor is determined.

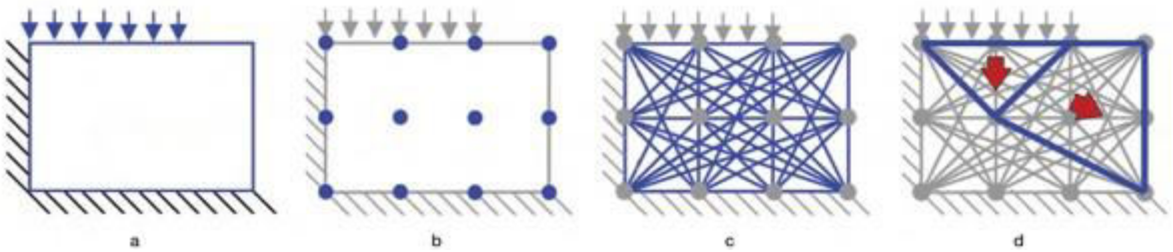


Figure-1. Procedure executed by LimitState:Geo2D® in a geotechnical analysis of stability.

In summary, the process of calculation of the program requires the definition of the problem characterized by an area of overload near a vertical cut and the discretization of the soil domain by means of nodes. With these inputs, the program calculation engine realizes the interconnection of the nodes with potential discontinuities and identifies the critical subset of potential discontinuities through optimization, obtaining as a result the critical failure mechanism and the design safety factor.

According to the calculation methodology proposed, the problem of stability analysis of a surface foundation consisting of a square footing supporting a 200 KN load on a terrain formed by two saturated clay layers (strong clay on weak clay) is defined. The characteristics that are summarized in Table-1,

Table-1. Characteristics of ground.

Layer	**Cu** [kN/m^2]	**ϕ** [°]	**γ_{sat}** [kN/m^3]
1	60	0	20
2	30	0	19

Table-2. Geometric data of foundation.

B [m]	**D$_f$** [m]	**l** [m]	**H** [m]
1	1	1	0.835

The analysis is performed using the Meyerhof ultimate load capacity equations and the LimitState:Geo2D® software.

2.1 Empirical formulation (Meyerhof y Hanna 1978 and Meyerhof 1974)

The problem is solved using the equations of Meyerhof and Hanna 1978 and Meyerhof 1974 (Das [1], [2], [3], [4] and [5]) for foundations on stratified soils (strong clay on soft clay) according to the Equations (1), (2) and (3),

$$q_u = \left(1+0.2\frac{B}{L}\right).(5.14).C_2 + \left(1+\frac{B}{L}\right).\left(\frac{2.C_a.H}{B}\right) + \gamma_1.D_f \leq q_t \tag{1}$$

$$q_t = \left(1+0.2\frac{B}{L}\right).(5.14).C_1 + \gamma_1.D_f \tag{2}$$

$$\frac{q_2}{q_1} = \frac{5.14\,C_2}{5.14\,C_1} = \frac{C_2}{C_1} \tag{3}$$

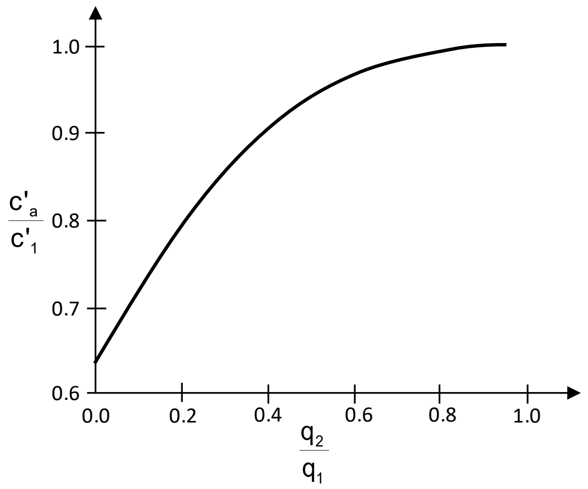


Figure-2. Variation $\frac{C'_a}{C'_u}$ and $\frac{q_2}{q_1}$ based on the theory of Meyerhof and Hanna (1978). Source: Das B., 2011, Principles of foundation engineering.

2.2 Computational model

Several foundation models were made using the Limit State:Geo2D® software to find the safety factor. The results of the modeling were validated with the empirical formulation using the soil and foundation characteristics described in Tables (1) and (2). Other data from Tables (3) and (4) were necessary to develop computational models. Table-3 shows characteristics of rigid footing and Table-4 shows additional characteristics for the problem.

Table-3. Material characteristics for rigid footing.

Cu [kN/m^2]	**γ** [kN/m^3]
0	0

Table-4. Additional characteristics of problem.

Width of column b [m]	**Width of soil block or Soil domain L** [m]
0,40	5

Due to the modeler's restrictions, a size medium nodal density was used. The discretized model is shown in Figure-3.

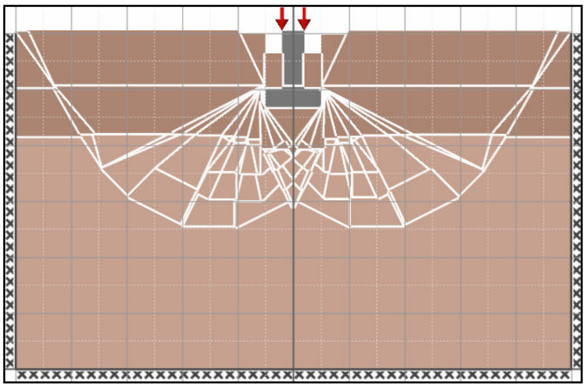


Figure-3. Finite element model-LimitState:Geo2D®. medium nodal density.

2.3 Sensivity analysis

In order to observe which factors can be sensitive in the analysis, that is, which characteristics can vary the results of the problem; we propose a modification of some parameters of the model (limited by the possibilities of modeling the software). These factors are: nodal density, width of the foundation soil block, foundation material and section of the column

2.3.1 Variation of the nodal density

The nodal density of the modeled domain was varied, that is, the number of nodes used to represent the area of analysis (discretization). The software's possibilities in terms of density are: thick, medium, fine, very fine and personalized. Nodal density represents the degree of refinement of the cloud of points on which the solution to the problem is obtained. In the modeled problem thick and medium density is adopted due to the limitations imposed by the trial version; the analysis is carried out for the two nodal density situations and results are obtained. We expect the results with the average mesh to be more adjusted; however, we consider the importance of observing the variations between the densities of the two meshes in order to conclude about the justification of possible increases in computational cost due to refinement.

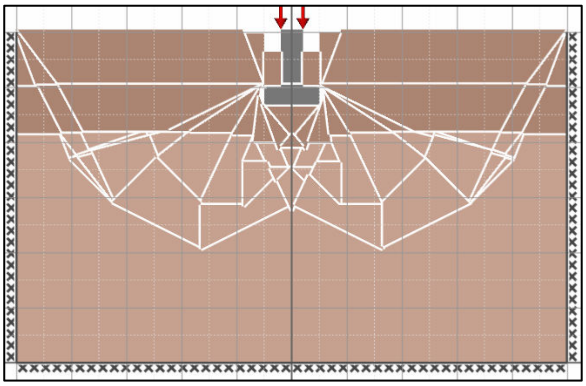
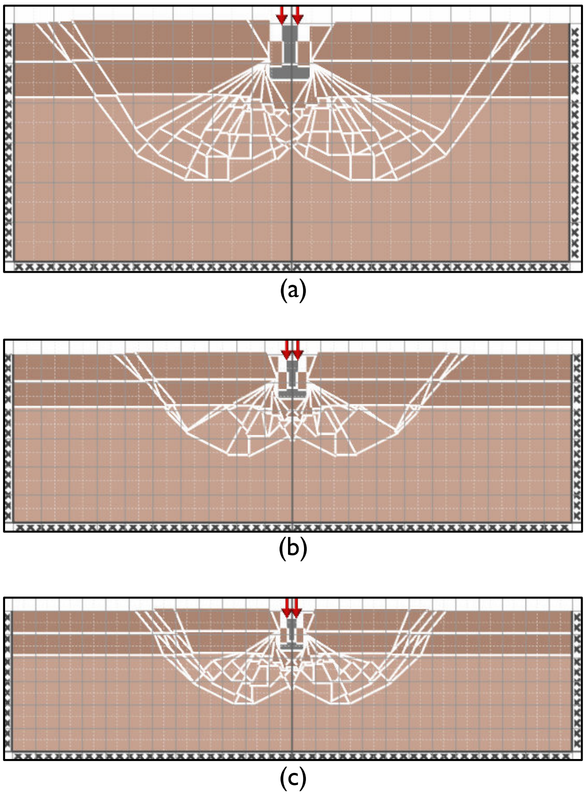


Figure-4. Finite element model-LimitState:Geo2D®. Coarse nodal density.

2.3.2 Variation of the soil domain

The domain of the problem was increased, that is, the width of the modeled soil block to observe the incidence of the proximity of the domain boundaries on the results of the analysis. The block widths used were 7, 10 and 12 (m). For the analysis of the three situations we work with medium-sized nodal density.



(a)

(b)

(c)

Figure-5. Finite element model-LimitState:Geo2D®. Expansion of border boundaries: (a) 7m (b) 10m (c) 12m.

2.3.3 Variation of the foundation material

Different types of material for the foundation are considered taking advantage of the software in this aspect. Three types of material are used. Concrete 1 (γ=23 kN /m^3 and Cu= 10000 kN/m^2), Light concrete 2 (γ = 0 kN /m^3 and Cu=10000 kN/m^2) and steel (γ=78 kN /m^{3}and Cu=125000kN/m^2). This analysis is done to find the effect on the results of the safety factor due to the rigidity of the foundation. One analysis for medium-sized nodal density is executed in each case.

2.3.4 Variation of the column width

Column widths of 0.35, 0.30 and 0.25 (m) are considered, in order to evaluate the possible incidence of the punching of the column and the load distribution of the shoe on the safety factor. Medium nodal density models are developed in each case.

Once the results of each analyzed situation are determined, the information is recorded in tables to determine percentages of variation.

3. RESULTS AND DISCUSSIONS

Table-5 shows the results of the Safety Factor obtained from the theoretical solution of Meyerhof and Hanna -taken as a reference- and the initial model used as a validator. Table-2 shows the results of the two alternatives and the variations.

Also, we show the percentages of variation respect to the theoretical Meyerhof solution for the others alternatives: nodal density, soil domain width, material of foundation and column width.

Table-5. Results of the alternatives and comparison.

		Safety Factor	Variation %
Reference solution (Meyerhof)		**1,95**	**---**
Model of validation			
Material γ=0 KN/m^3			
Cu=0 KN/m^2			
Column width b=0.40 m			
Domain width L=5 m			
Medium nodal density		2.204	13,03
Coarse nodal density		2.248	15.28
Domain width*	L=7 m	2.211	13.38
	L=10 m	2.236	14.67
	L=12 m	2.239	14.82
Type of material*	γ=23 KN/m^3 Cu=1000 KN/m^2	2.12	8.72
	γ=0 KN/m^3 Cu=10000 KN/m^2	2.212	13.44
	γ=78 KN/m^3 Cu=125000 KN/m^2	1.9	(-) 2.56
Columnwidth*	b=0.35 m	2.201	12.87
	b=0.30 m	2.198	12.72
	b=0.25 m	2.195	12.56

*Medium nodal density

As we expected, the density of the mesh is a relevant factor in the approximation of the results. However, it is important to observe the sensitivity of the results objectively within the ranges of variation shown which are acceptable. In general, this means in general that the geometric characteristics of the footing, the dimensions of the domain, the distance of the borders and the properties of the material can affect the results of the design factors. So more exhaustive analyzes will lead us to tentatively more approximate answers to the reality of the phenomenon and this task can only be carried out with robust calculation tools such as packages that are based on finite elements..

4. CONCLUSIONS

In general, we observed that the safety factors increased slightly, suggesting the need to give greater importance to the parameters that characterize the superficial foundations, since when greater analytical conditions are involved, higher values of the safety factor are obtained. This situation may suggest that classical methods based on empirical formulations tend to increase the dimensions of the foundations.

The empirical formulations developed by Terzaghi, which were modified by Meyerhof and other researchers in the field of foundation engineering, have been the basis for the development of different methods and computational applications of geotechnical analysis. However, these equations do not consider aspects such as boundary conditions of the land, foundation materials and width of the column. The introduction of these characteristics in the analysis of foundations warns variations of the safety factor; for the case study, the Meyerhof safety factor was lower than the one calculated with the Limit State software:Geo2D®, which suggests that the foundations that have been designed with empirical methodologies could be oversized, especially considering that the value of control of the safety factor in the software is greater than one (> 1), that is, if the safety factor obtained from the analysis is less than one, the foundation is susceptible to collapse. On the other hand, the Meyerhof equations establish a control value of the higher safety factor (greater than 2) when working with brute load.

The introduction of new variables can lead to a reduction in construction, safety and risk costs.

This is just the beginning of a great research on the subject, since modeling seeks precisely to improve the design of structures. With this study it was demonstrated that the inclusion of design variables that are not present in the classical theories modifies the results of a stability analysis of superficial foundations of the isolated footing type.

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REFERENCES

[1] Das B. 2011. Principles of foundation engineering, SI. 7a. ed. Cengage Learning. EE.UU. pp. 133-195.

[2] Das B. 2007. Principles of foundation engineering. 6a. ed. Thomson. EE.UU. pp. 177-185.

[3] Das B. 2006. Principles of Geotechnical Engineering. 5a. ed. Thomson. EE.UU. pp. 530-538.

[4] Das B. 1999. Princípios de Ingeniería de Cimentaciones. 4a. ed. Thomson. EE.UU. pp. 187-194.

[5] Das B. 2009. Shallow foundations, Bearing Capacity and Settlement. 2a. ed. CRC Press Taylor & Francis Group. EE.UU. pp. 128-141.

[6] Desai C. 2007. Unified DSC constitutive model for pavement materials with numerical implementation, Int. J. Geomech. 7, 83-101.

[7] LimitState Ltd. 2014. LimitState: GEO Manual. Version 3.1. c, LimitState Ltd. Reino Unido. pp. 13-15, 25-56.

[8] Meyerhof G. and Hanna A.1978. Ultimate Bearing Capacity of Foundations on Layered Soil under Inclined Load. Canadian Geotechnical Journal. 15(4): 565-572.

[9] Meyerhof G. 1974. Ultimate Bearing Capacity of Footings on Sand Layer Overlying Clay. Canadian Geotechnical Journal. 11(2): 224-229.

[10] Ottosen N.S., Ristinmaa M. 1961. The Mechanics of Constitutive Modeling, Elsevier, Amsterdam. 2005.

[11] Prager W. Introduction to the Mechanics of Continua. Ginn & Co., Boston, Mass.

[12] Prat P. 2000. Leyes de Comportamiento de Materiales. Master en Métodos Numéricos para Ingeniería. Universidad Politécnica de Cataluña.