Use of woven geogrids under shallow foundations

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ABSTRACT: During the process of selecting foundation solutions it is necessary to determine what load level is bearable by the local soil. In many cases this type of determination includes choice of foundation depth due to the fact that the load bearing capacity of the soil may be insufficient to stabilize some types of shallow foundations. However, in some cases this kind of solution is not possible due to factors as cost, space and access. As an alternative approach an application using geogrids as tension distribution elements has been considered to provide improvement the bearing capacity of shallow foundations. The main points that must be studied are the resistance parameters like reinforcement stiffness and deformation and the type of criteria could be used. A key issue is how the design can be validated when woven geogrids of high elastic modulus are used. They need to be able to be placed in layers to resist large loads and ensure rupture by shear stress does not occur. The paper presents a theory that validates this application through a real case study and confirms the equilibrium limit method that is commonly used in shallow foundations on soft soil. Although this method does not consider the reinforcement elongation; the results obtained in the calculations were compatible with the executed work.

1 INTRODUCTION

In most cases the foundation designers consider a load bearing capacity of soil trying to conduce a specific work to shallow foundation solution, for obvious reasons as cost, executive velocity and in some cases, technical challenge.

The problem comes when the bearing capacity of soil is not sufficient to propose a shallow foundation. When simulating the conditions of a soil stratum with low bearing capacity to a superficial loading, it is possible to realize ruptures tendencies under critical surfaces of shear strength where the resistance of the soil is insufficient.

There are many kind of method to determine the critical failure surface; however most of theses methods do not present much variability of resistance parameters (friction angle, cohesion) what disables the use of different types of geosynthetic reinforcement. In this paper will be presented a method developed by Hopkins et al (2005) to solve the real problem of shallow foundation under base of high equipment (industrial machine), where the definition of equilibrium limit is used to evaluate a stability of reinforced granular base with geosynthetic reinforcement.

2 PROPOSED METHODOLOGY

2.1 *Hopkins Limit Equilibrium Model*

The Hopkins limit equilibrium model developed in previous research and used to calculate the factor of safety against failure is a generalized limit equilibrium procedure of slices (Janbu, 1957 and Bishop, 1966). The mathematical model has been formulated in such a manner that the safety factor of a multilayered flexible soil system may be calculated. In the procedure, the potential failure mass is divided into a series of vertical slices; the equilibrium of each slice and the equilibrium of the entire mass is considered. In the approach, the ultimate strengths of the materials in each soil layer are used.

2.1.1 *Basic Assumptions*

- A line or thrust line passing the points of action of the interslice forces is known or assumed.
- For each cross section, the stability problem is treated as two dimensional. The shear strength of the soil layers may be expressed in terms of effective stress or total stress (Terzaghi, 1943).

2.1.2 *Shear Surface Used in Bearing Capacity Analysis*

Shear surfaces of various shapes or failure patterns may be assumed in performing bearing capacity analysis. However, basic bearing capacity solutions show that the failure pattern should consist of three distinctive zones as shown in Figure 1.

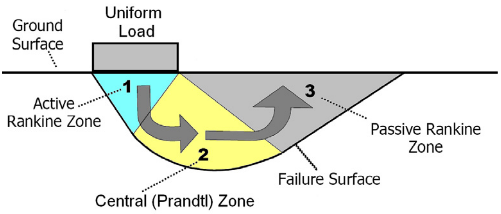

Figure 1. Assumed failure patterns and block movements, Hopkins et al. (2005).

These three zones are identified as zones 1, 2, and 3. Zone 1 is an active Rankine zone. This zone pushes the radial Zone 2 sideways and the passive Zone 3 in an upward direction as shown in Figure 1. Basic failure patterns and equations for one, homogeneous layer and a multi-layered system are described as follows.

The shear surface assumed in the model analysis for a homogeneous layer of material consists of a lower boundary, identified in Figure 2, as **abcd**. This surface consists of two straight lines, **ab** and **cd**. The portion of the shear surface shown as line **ab** is inclined at an angle, α_1 to the horizontal, where, ϕ is friction angle of foundation soil.

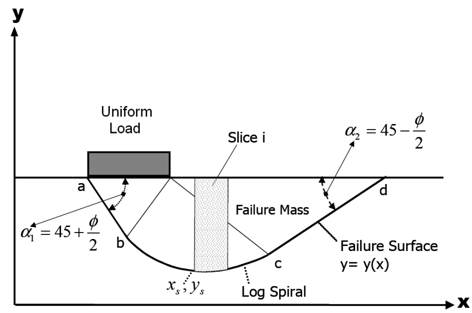

Figure 2. Exit and entry angles for a homogeneous bearing media, Hopkins et al. (2005).

To use the procedure that describes the shear surface used in Bearing Capacity is necessary to define the shape of the shear surface **abcd** in Figure 2, where the x- and y- coordinates of points **a**, **o**, **b**, **c**, and **d** must be established according to Figure 3. After these points have been defined, the coordinates, x_s (the x-coordinates of the sides of the slices) and y_s (the y-coordinates of the shear surface at the sides of the slices) may be determined. The coordinates of point **a**, x_a, and y_a are assumed. The x- coordinate of point (0, x_o) is assumed and depends on the width of the footing, $C = x_o - x_a$. The y- coordinate, y_o, is arbitrarily selected, or assumed. The coordinates of point **b**, x_{tn}, y_{tn}, may be defined by first computing the radius, r_1

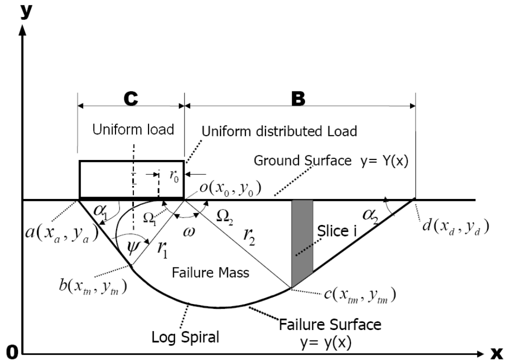

Figure 3. Geometric quantities defining the shape of the shear surface in a homogenous bearing media, Hopkins et al. (2005).

After the coordinates **a, b, c,** and **d** are defined, the y-coordinate, y_s, of the intersection of the x-coordinate of the side of any given slice **i** and the shear surface may be determined. The potential failure mass is divided into a selected number of slices, n.

2.2 *Shallow foundation on cohesive soil*

Consider a shallow continuous foundation supported by layer of granular soil on cohesive soil, which the width of the foundation is B, and the interface between the granular and cohesive soil is located at a depth H measured from the bottom of the foundation. It is assumed that the failure surface was cylindrical when the center of the trial failure surface was at O. Thus, it is possible to provide the limit equilibrium procedure of slices (Janbu, 1957 and Bishop, 1966) to calculate the factor of safety against failure.

2.3 *Wayne Method et al.*

Wayne et al. (1998) propose to use a filling soil on a geosynthetic reinforcement when this reinforcement is positioned on the soft soil and the failure occur by puncture load, where ultimate bearing capacity of soil is computed from the expression:

Rectangular loading condition:

$$q_{ult} = c.N_c + \left[2.c_a + \gamma.H\left(1+\frac{2.D}{H}\right).\frac{K_p.\tan\alpha}{B}\right].\frac{H.(B+L)}{B.L} + \gamma.H + 2.T.\frac{B+L}{B.L}$$

Infinite loading condition:

$$q_{ult} = c.N_c + \left[2.c_a + \gamma.H\left(1+\frac{2.D}{H}\right).\frac{K_p.\tan\alpha}{B}\right].\frac{H}{B} + \gamma.H + .\frac{2.T}{B}$$

where, c is soft soil cohesion, N_c is adopted 5.14 when it use synthetic reinforcement, ca is cohesion of filling soil, α is 2/3 of friction internal angle of filling soil, γ is bulk unit weight to filling soil, K_p is passive thrust coefficient, H is filling soil height, D is depth of shallow foundation, T is Tensile Strength of reinforcement.

3 CASE STUDY

It will be presented two work cases which it will be possible to analysis the behavior of shallow foundation on cohesive and no cohesive soil layer.

3.1 *Cohesive soil case*

This case study focuses on the application of geogrid reinforcement under shallow foundation to support a uniform load on granular soil surface. For this work it was used the following design information:

Filling soil parameters:
(bulk unit weight) γ_a = 18 kN/m³
(friction angle) ϕ_a = 40 degrees
(height of filling soil) H = 0.30m
Uniform load on surface (high equipment):
(distributed load) Q = 150 kPa
(width of equipment base) B = 1.00m
Foundation soil parameters:
(bulk unit weight) γ_f = 18 kN/m³
(friction angle) ϕ_f = 0 degrees
(cohesion) c = 15kPa

The ultimate bearing capacity required for stabilizing the soil foundation with or without geogrid reinforcement is obtained through software MacStars® 2000. This software has been developed to check the stability of reinforced soils through Limit Equilibrium Method using reinforcing units that are able to absorb the tensile stress. The idea is obtain a safety factor equal 1 for specific failure surface, and load surface, concluding that the soil has the load bearing capacity equal load surface used. It was used a woven high strength geogrid composed of high tenacity, multifilament polyester yarns woven in tension and PVC coated to form a stable fabric. Geogrid mechanical properties have been tested in accordance to published standards, and it presented in Table 1.

Table 1. Woven geogrid reinforcement properties

Tensile Strength (Ultimate)	T_{ultMD}	kN/m	ASTM D6637	40.00
Ultimate Strain at failure	ε	%	ASTM D6637	12.00
CREEP reduction factor	RF_{CR}		ASTM 5262	1.90
Long Term Design Strength		kN/m	ASTM 5262	21.00

Analytically it obtain critical surface and using the software of slope stability is possible to check the safety factor of reinforced soils. The result obtained in Figure 4 and 5 showed that it is possible to improve the load bearing capacity of soil through analytical failure surface checking. The reinforced shallow foundation condition is 2.90 times (435kPa against 150kPa) higher than shallow foundation without geosynthetic reinforcement (Figure 4 and 5). It was provided three layers of geogrid reinforcement spaced to each 10 centimeters.

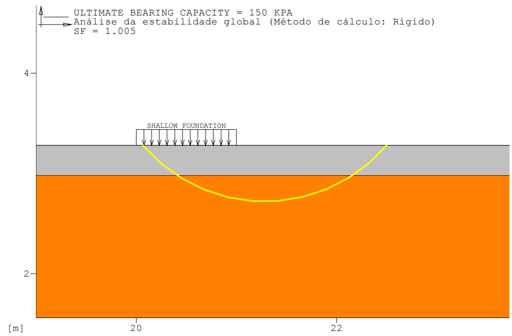

Figure 4. Safety factor value about 1 obtained without reinforcement to ultimate bearing capacity equal 150kPa.

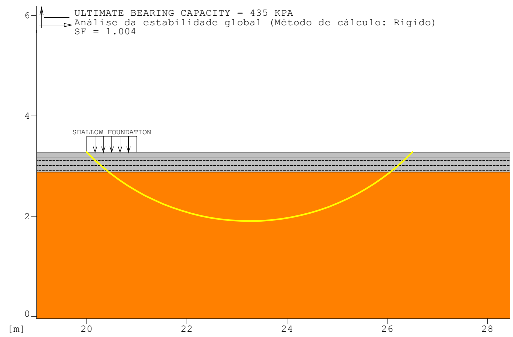

Figure 5. Safety factor value about 1 obtained with reinforcement to ultimate bearing capacity equal 435kPa.

Considering Wayne Method and using the design information, geogrid reinforcement properties, and applying equation to infinite loading condition to different depths of geogrid layers, where it was used the design stregth to geogrid equal, T = 40/1.90 = 21.00 kN/m.

Depth of geogrid layer	Ultimate bearing capacity
0.10m	121.32 kPa
0.20m	124.36 kPa
0.30m	128.24 kPa

The total ultimate bearing capacity of reinforced soil foundation is 373.92 kPa. This value result is 14% lower than the value found to the circular failure surface method obtained by slope stability software and 2.50 times higher than shallow foundation without geosynthetic reinforcement.

3.2 *No cohesive soil case*

For this case study it was used the following design information:

Filling and foundation soil parameters
(bulk unit weight) γ = 18 kN/m³
(friction angle) ϕ = 40 degrees
Uniform load on surface (high equipment)
(distributed load) Q = 550 kPa
(width of equipment base) B = 1.00m

The ultimate bearing capacity required for stabilizing the soil foundation without geogrid reinforcement is obtained through software of slope stability and the log spiral failure surface refers to distributed load of 550.00 kPa and Hopkins, 2005, which safety factor value equal 1 determines the ultimate bearing capacity of the soil foundation (Figure 6).

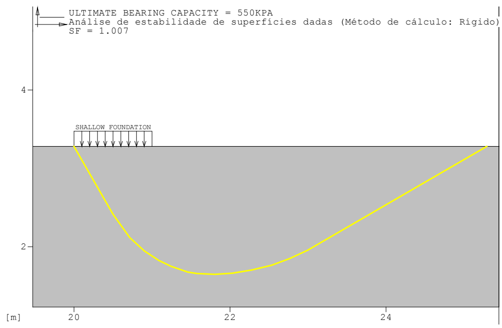

Figure 6. Safety factor value about 1 obtained without reinforcement to ultimate bearing capacity equal 550kPa.

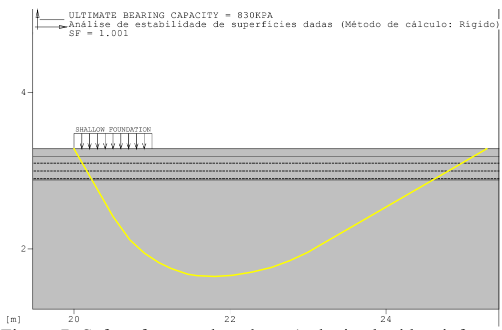

Figure 7. Safety factor value about 1 obtained with reinforcement to ultimate bearing capacity equal 830kPa.

The reinforced shallow foundation condition is 1.50 times (830kPa against 550kPa) higher than shallow foundation without geosynthetic reinforcement (Figure 6 and 7). It was provided three layers of geogrid reinforcement spaced to each 10 centimeters.

4 CONCLUSION

This paper has brought a suggestion that relates the geogrid mechanical characteristic with particular characteristic of shallow foundation and bearing capacity analysis considering the three levels to sliding surface, active zone, log spiral curve and passive zone to no cohesive soil foundation and circular failure surface to cohesive soil foundation.

The model proposed by Hopkins, which are based on limit equilibrium and are operated together, can be used to analyze the load bearing capacity, or stability, of early construction of loads on a homogeneous layer of base aggregate material and subgrade of soft soil. In this case considering shallow foundation is necessary to consider initial mobilization of geogrid strength before receives the shallow foundation, in other words, during the construction soil operation the geogrid must be working.

Wayne's Method specifies the position of a reinforcement to a certain depth without taking in account which the maximum length under the shallow foundation should be adopted, that the makes useful when it needs to know, like initial parameter, which the load bearing capacity of soil reached with the reinforcement, however it is limited when it introduce wide foundations, as the presented in this paper. Already Hopkins's Method complements the one of Wayne, once that when establishing a failure surface also criticizes establishes which the area that will be asked under the foundation. Regarding the safety factor obtained by traditional methods according to of analyzes of slope stability as Janbu or Bishop Method, just it makes attractive these method in terms of manipulation of the safety factor adopted for geosynthetic materials and softwares of slope stability analysis.

REFERENCES

Bishop, A.W. (1966). "Strength of soils as engineering materials", Geotechnique , 16, 89-130.

Das, B.M. (1999). Shallow Foundations - Bearing Capacity and Settlement, 1th Edition, CRC Press LLC.

Hopkins, T.C., Sun, L., and Slepak, M.E. (2005). Bearing Capacity Analysis and Design of Highway Base Materials Reinforced with Geofabrics, University of Kentucky, College of Engineering, Kentucky Transportation Center.

Janbu, N. (1957). "Earth pressures and bearing capacity calculations by generalised procedure of slices", Proceedings of the 4th International Conference on Soil Mechanics and Foundation Engineering, London, 2, 207-212.

Terzaghi, K., (1943). Theoretical Soil Mechanics, John Wiley and Sons, Incorporated, New York, NY.

Wayne, M. H.; Han, J. y Akins, K. (1998) The design of geosynthetic reinforced foundations. *Geosynthetics in foundation reinforcement, pp 1-18, ASCE.*