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Analysis of the feasibility of applying reinforcement for laying direct foundations

Analyse de la faisabilité de l'application de renforcements pour la pose de fondations directes

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ABSTRACT: With urban expansion, the need to build in massifs with low support capacity and high deformability is increasingly common. A solution to this geotechnical problem is soil manipulation to improve its performance. In this sense, geosynthetics have been playing a prominent role in replacing conventional reinforcement solutions. The bibliography shows that the use of these materials, particularly in the case of shallow foundations, increases the load capacity and decreases the magnitude of settlements. The present study aims to analyze the technical feasibility of applying reinforcement for laying shallow foundations, with emphasis on the use of geosynthetics, as well as the parameters with the greatest influence on increasing the load capacity and reducing the magnitude of the settlement of the soil- reinforcement. The main parameters studied include: the characteristics of the foundation mass and the reinforcement, the geometry of the foundation and the nature of the loading. From an analytical model, variations of these parameters were simulated, within an acceptable range, seeking to estimate the load capacity based on Terzaghi's theory. In addition, a sensitivity analysis was carried out using the First-Order Second-Moment. The results make possible to determine under what conditions of stiffness of the foundation and reinforcement the execution of the technique is safely efficient. According to the analysis of the data in reduced models, it can be stated that the reinforcement ensured greater stability, enabling the construction in soils of low resistance.

RÉSUMÉ: Avec l'expansion urbaine, la nécessité de construire dans des massifs à faible capacité de support et à forte déformabilité est de plus en plus courante. Une solution à ce problème géotechnique est la manipulation du sol pour améliorer ses performances. En ce sens, les géosynthétiques jouent un rôle de premier plan en remplacement des solutions de renforcement conventionnelles. La bibliographie montre que l'utilisation de ces matériaux, notamment dans le cas de fondations peu profondes, augmente la capacité de charge et diminue l'ampleur des tassements. La présente étude vise à analyser la faisabilité technique de l'application de renforcements pour la pose de fondations superficielles, en mettant l'accent sur l'utilisation de géosynthétiques, ainsi que les paramètres ayant la plus grande influence sur l'augmentation de la capacité de charge et la réduction de l'ampleur du tassement du sol. renforcement. Les principaux paramètres étudiés comprennent : les caractéristiques du massif de la fondation et du ferraillage, la géométrie de la fondation et la nature du chargement. A partir d'un modèle analytique, les variations de ces paramètres ont été simulées, dans une plage acceptable, en cherchant à estimer la capacité de charge selon la théorie de Terzaghi. De plus, une analyse de sensibilité a été réalisée en utilisant le Second-Moment du Premier Ordre. Les résultats permettent de déterminer dans quelles conditions de rigidité de la fondation et du renforcement l'exécution de la technique est efficace en toute sécurité. Selon l'analyse des données en modèles réduits, on peut affirmer que le renforcement a assuré une plus grande stabilité, permettant la construction dans des sols de faible résistance.

Keywords: Reinforcement; shallow foundation; geosynthetic.

1 INTRODUCTION

Currently, with urban expansion, it is very common to build in masses that have low support capacity and high deformability. The solution to this geotechnical problem is the use of techniques to improve the performance of the mass.

Conventional treatment methods range from replacing part of the weak soil with a suitably thick layer of stronger granular fill, increasing the size of the foundation base, or a combination of the two methods, for example. However, a more economical alternative is the use of geosynthetics to reinforce the soil.

In the soil-structure-geosynthetic interaction mechanism, the synthetic material, which deforms according to the structure's request, adds a portion of tensile strength to the soil due to the friction developed. Particularly, in the case of shallow foundations laid on masses with low load capacity and high compressibility, the introduction of geosynthetics provides an increase in support capacity and a significant reduction in settlements.

2 OBJECTIVES

The main objective of the article is to define the stiffness conditions of the mass and reinforcement in which the application of the technique, in the case of direct foundations, is efficient with safety and economy.

3 METHODOLOGY

The concept of soil reinforcement was initially published by Vidal (1969) and was consolidated in the pioneering work of Binquet and Lee (1975a, 1975b) with an evaluation of the behavior of sand mass reinforced with metal strips. Over time, with new requirements and technologies in relation to material, shapes and sizes, metallic strips were replaced by geosynthetics.

The Figure 1 below shows the configuration and parameters of a foundation reinforced with geosynthetic. The main parameters studied include depth of the first reinforcement layer (u), geosynthetic width (b), number of reinforcements (N), spacing between layers (h) and total reinforcement thickness (d).

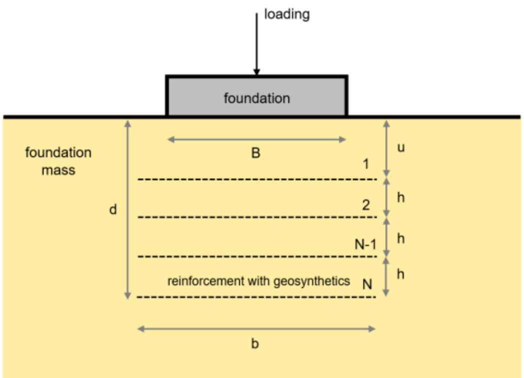

Figure 1. Configuration and parameters of a foundation reinforced with geosynthetic.Source: Adapted from Corrêa, 2021.

The performance of the reinforcement element, in this case, the geosynthetic element, is related to its sizing and the specification of the values of its relevant properties. In the case of reinforcing a shallow foundation, the following properties are worth highlighting: the tensile strength, the deformation at failure, the tensile stiffness modulus and creep behavior, as well as the adhesion and the friction angle of the soil-soil interface. geosynthetic.

The methodology for calculating the load capacity was defined based on the bibliography, considering the models proposed by Sharma et al. (2009). Initially, it was considered that the reinforced mass behaves similarly to a foundation on a mass with two types of soil.

Figure 2 presents the schematic section of a shallow foundation placed on soil.

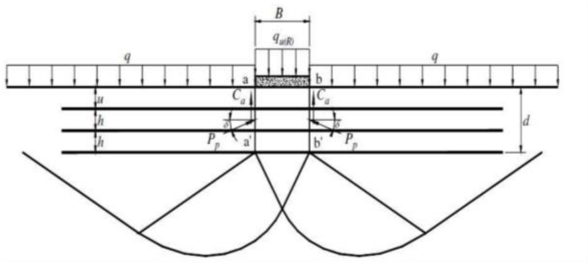

Figure 2. Similar failure in foundations laid on solid ground with two types of soil. Source: Sharma et al., 2009.

The failure mechanism is characterized by punching in the reinforcement layer followed by general shear failure in the unreinforced mass.

$$q_r = q_0 + \frac{2(C_a + P_p sen\delta_p)}{B} - \gamma_t d + \Delta q_t \quad (1)$$

where, q_r is the load capacity of the reinforced soil, q_0 is the load capacity of the unreinforced soil, C_a is the adhesion force, P_p is the force resulting from the passive thrust of the soil, δ_p is the angle of the passive force with the horizontal, which can be adopted as $0{,}5\varphi_r$, where φ_r is the angle of friction of the soil used as reinforcement, B is the width of the foundation, , γ_t is the specific weight of the layer of reinforced soil, d is the thickness of the layer reinforced and Δq_t is the increase in load due to the tension in the reinforcement.

The load capacity of a shallow square foundation on reinforced soil is then determined by the equation:

$$q_r = q_0 + \frac{4c_a d}{B} + 2\gamma_t d^2\left(1 + {}^{2D}/_{d}\right)\frac{K_s tan\varphi_r}{B} + \frac{4\sum_{i=1}^{N} T_i tan\delta_p}{B} - \gamma_t d \quad (2)$$

where, K_s is the punching thrust coefficient, T_i is the tensile force in the synthetic material and N is the number of reinforcement layers.

It is worth mentioning that, for this estimate, the traction of a geogrid of the Fortrac model, from Huesker, was considered, which has a traction resistance of up to 2500kN/m.

The punching thrust coefficient was obtained using the abacus proposed by Chen (2007), which relates K_s as a function of the friction angle.

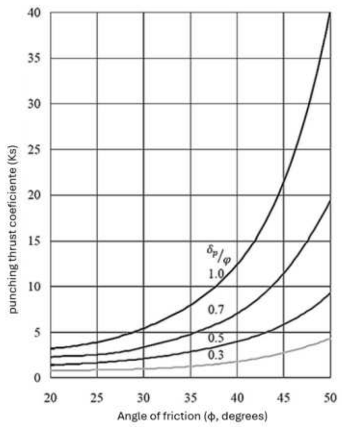

Figure 3. Punching thrust coefficient as a function of friction angle. Source: Adapted from Chen, 2007.

For the acceptability criterion of probabilistic analysis, the Brazilian standard does not specify numerically. The bibliography shows model evaluation criteria regarding the reliability index and probability of rupture. The tables below show the relationships found.

Table 1. Risk acceptability scale using the MIL – STD – 882 standard. Source: Adapted from Clemens (1983) adapted by Aoki (2011).

β	Occurrence	Recurrence Time	Frequency	Risk Level	Prob. Level	p_f
-7,94	Certainty	1 day	All day		1	1,00
0,00	50% probability	2 days	Every 2 days		2	0,50
0,52	frequent	1 week	Every week	A	$3x10^{-1}$	0,30
1,88	likely	1 month	Every month	B	$3x10^{-2}$	0,03
2,75	Occasional	1 year	Every year	C	$3x10^{-3}$	0,003
3,43	Remote	10 years	Every decade	D	$3x10^{-4}$	0,0003
4,01	Very remote	100 years	Every century	E	$3x10^{-5}$	0,00003
4,53	Unlikely	1000 years	Every millennium		$3x10^{-6}$	0,000003
7,27	Never	5,47E+12	Age of the Universe		0	1,83E-13

Table 2. Reliability assessment considering a useful life of 50 years according to the ELT 1110-2-547 standard. Source: Adapted from U.S. Army Corps of Engineers (1997).

Expected performance level	β	Probability of ruin
High	5,0	0,0000003
Good	4,0	0,00003
Above average	3,0	0,001
Below average	2,5	0,006
Low	2,0	0,023
Unsatisfactory	1,5	0,07
Risky	1,0	0,16

4 RESULTS AND DISCUSSION

In this sense, the first considering a medium-sized building, with an allowable load capacity $qadm = 200kPa$ and a 1 meter square footing and the other considering a large building, with a permissible load capacity $qadm = 500kPa$ and a 3 meter square footing.

It is worth mentioning that, for both cases, a rigid, square foundation was considered, based on a sand mass, reinforced with a geogrid. In the applied method, the input data are the average values and variances of the soil parameters, the geometric characteristics of the foundation, and the estimated values of the other soil parameters necessary for the deterministic analysis.

Therefore, the thickness of the minimum reinforcement layer was 0.5m and the maximum was 3m, varying from 0.5m to 0.5m. In addition, the base width (B) and specific weight (γ) were also considered.

From this, the First Order Second Moment method is applied, verifying the effect of varying the number of layers (N) and the thickness of the reinforced layer (d) on the probability of rupture and the reliability index.

The analysis considers that the foundation mass can be sand that is not very compact and moderately compact.

Some considerations are made in the literature about the massive configuration for this case. It was observed that the load capacity of the soil suffers an insignificant increase for conditions with more than six layers of reinforcement, a result confirmed by Das (1989) and Omar et al. (1993), which was also observed in this work.

Considering a soft mass, for the situation in question, the best reinforcement contribution occurs when the number of layers is equal to 2. From the graph below, it is also possible to see that the increase in the number of layers after this number, has not a significant effect.

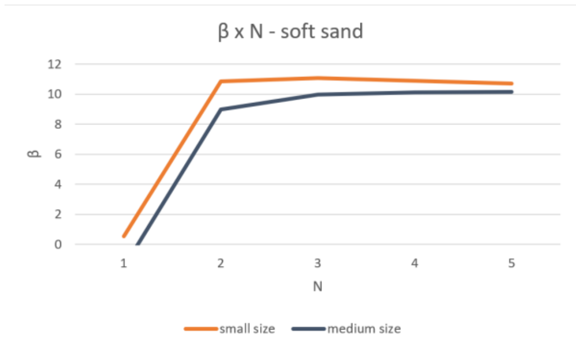

Figure 4. Behavior of the foundation mass vs. reliability index considering a soft mass in a small building and medium-sized building.

There is a consensus in the literature that the reinforcement length should be around 5B and the ideal number of layers is normally limited to up to 5. For higher numbers of layers, it has been demonstrated in the literature that there is no significant gain in capacity of the soil, only generating an increase in costs for the enterprise.

For the mass and reinforcement configurations considered in this analysis, it was possible to notice that, for all types of soil considered, and for the two loading conditions, when the number of layers is above

3, no significant increases in the index were generated. of reliability.

The graphs below show the behavior of the number of reinforcements for a less compact massif, a significant increase in the reliability index can be seen when including reinforcement (with just one layer).

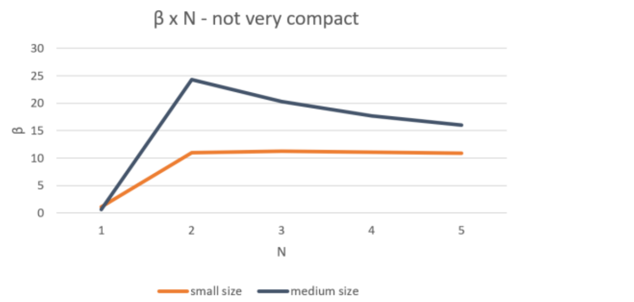

Figure 5. Behavior of the foundation mass vs. reliability index considering a less compact mass in a small building and a medium-sized building.

Furthermore, tests also demonstrated that for reinforcement to be efficient, the last layer must never be located at a depth greater than 2B. In this analysis, the depth of the reinforcement layer thickness reached 3 meters in both cases. Thus, it is possible to see graphically that, when a small building is considered, and therefore, the foundation is 1 meter wide, when the reinforcement exceeds 2 meters in thickness, there is no major influence on the reliability index.

The graphs below show the relationship between the reliability index and depth for the types of soil considered.

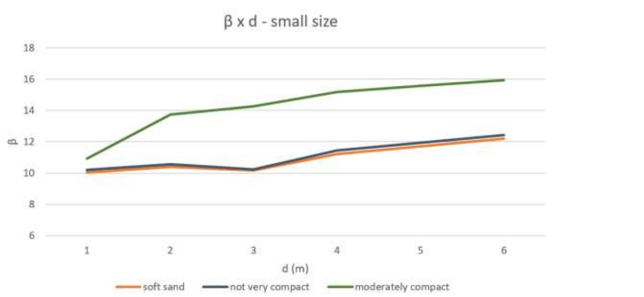

Figure 6. Behavior of the foundation mass vs. reliability index for a small building of a soft sand, not very compact and moderately compact.

The literature also shows that for direct foundations based on clay soils, Shin et al. (1993) and Omar et al. (1993) concluded that a good depth for the first layer of reinforcement is 0.4B, regardless of the anchorage length. The ideal length for anchoring was defined within the range of 4.5B to 5B. According to the authors, to influence the improvement of load capacity, the number of layers of reinforcement must be limited to 5, in addition the first layer of reinforcement must not be located at depths greater than 1.8B.

5 CONCLUSIONS

According to the analysis carried out, it is possible to state that the reinforcement substantially increases the load capacity and reduces the magnitude of settlements, allowing better behavior of the foundation from the point of view of resistance and deformability. The results suggest that the effectiveness of reinforcement is greater in masses with low support capacity.

However, increasing the number of reinforcement layers and the thickness of that layer beyond a specific number, 3 layers and 2.5m, does not produce a significant increase in load capacity.

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