Segmental retaining wall: comparison between predicted and observed slip surface

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ABSTRACT: Reinforced soil structures as geotechnical and environmental works solutions are greatly considered in Brazil. Nowadays, design analyses are commonly used specially for segmental retaining wall design (SRW). These methods are mostly conservative, presenting a considerable security margin, depending on the adopted safety factors. However, literature shows cases where the structure has not attained the predicted safety factor which resulted in failure. In order to verify the main factors that influence the design of a SRW structure, this work shows the back analysis of two reported cases histories where the reinforced structure came to failure. Internal and global stability analyses for these cases were performed with the use of MACSTARS® 2000 program, according to Maccaferri (2004), which is based on limit equilibrium analyses. In these cases, it is possible to compare the predicted safety factor and the corresponding critical surface with the real observed slip surface. The analyses show values of safety factor close to the ones commented by the authors and the predicted critical surfaces were located at the same region observed in the field. However, the quality and reliability of analyses are directly related to the exact description of the existent conditions in the field and entrance parameters of each application. The case where this program is used, it is important to investigate different intervals to analyze the potential surfaces of rupture, as well as to choose the width of lamellas that can influence the results of stability analysis.

1 INTRODUCTION

The use of geosynthetics in Civil Engineering work and specifically in the geotechnical area has been frequently used today. It presents a low cost for some kind of works when comparing to other alternatives of the project and also other advantage as a reduced execution period and a low technical executive complexity.

The design methods for reinforced walls usually evaluate the security requirements for internal stability (connection and geosynthetic rupture) and the external stability (tilting, horizontal displacement and bearing capacity).

With the computer technology, different softwares (Plaxis, Slope, Stabl, Gawacwin, Macstars, and Forterrae) were developed in order to help in the design. These programs are quite different and use different approaches, which can explain some differences in the results obtained.

The quality and reliability of the analysis are being directly related to the entrance parameter used in each application. This reinforces the importance to represent the existent conditions in the field through a good geological-geotechnical field characterization and determination of parameters through appropriate laboratory tests.

These softwares can present conservative results according to several safety factors involved in the process: functional behavior of geosynthetic/soil/SRW. However, literature shows work cases in which the structure did not attain the performance expected turning out to a collapse. These facts proved the need of an intensive study in some areas.

The SPT is commonly used in Brazil to investigate the soil. Nevertheless, the reliability is based on the interpretation of the soil analysis parameters results.

At present, based on these facts, some safety factors are being adopted in all design phases of a reinforced work: the project, to determine the kind of reinforcement to be used in the softwares, and measurement and verification of stability, internal and external.

In order to study two rupture cases reported in the literature, this work will compare the results obtained from back analysis with those provided by the authors using the program MACSTARS 2000. The analysis consisted in verifying the input data, design method, hypothesis and results obtained. The reliability of these analyses is guaranteed by the work cases that attained a rupture. The safety factor is lower or equal to one and the real rupture surface is known.

2 METHODOLOGY

The program used in this work to perform stability analyses of slopes with reinforcement and in the condition of rupture is based in the limit equilibrium method. This method was selected due to its large use in the design reinforced works, the capacity to simulate different kinds of reinforcement and wall, as well as to verify the stability of a natural slope.

According to the program, it is possible to perform global and internal stability analyses, slip and verification of the wall shear stress. So, in this work, internal and global stability analyses were performed and the verification of the slip and wall shear stress was not done because there were no data reported by the authors in the cases observed.

For internal and external stability analyses it is possible to select random polygonal or circular surfaces. When there is homogeneous of the material analyzed, the surface selected is the circular one and when there is heterogeneous material formed by geosynthetics and the soil, the surface adopted is the random polygonal.

Moreover, it is necessary to decide for one of the available limit equilibrium methods: Janbu's simplified or Bishop' simplified. In this case, Janbu's method was selected because it is less conservative and leads to results closer to the real ones.

After analyzing all potential failure surfaces, the critical one was compared to the failure surface observed in the field. The respective safety factors were compared with the values found by the authors in their analyses and with the ones recommended in literature.

3 CASE STUDIES

3.1 *Case 1: "Lessons learned from a failure of geosynthetics-reinforced segmental retaining wall", YOO et al. (2004)*

According to Yoo et al. (2004), in the beginning of 2003, in the South of Seoul, Korea, a reinforced wall was built in the landfill destined to a road of the local Industrial Complex. Its total length was about 150 m distance, with a height of about 1.0 to 7.4 m. This wall was about 4 m from a road with presence of water.

In July 2004, however, during an intense storm, which attained a significant precipitation rate, the wall collapsed. According to the pictures taken after the disaster, it was observed a large amount of soil which moved down the slope in mass, affecting one part of the road located above the wall.

During a research after the collapse, it was noticed that the layers of reinforcement had 5 m extension displayed in a uniform separation distance of 0.6 m. The wall face was built with segmental blocks of 20 m height. The reinforcement consisted of a high density polyethylene Geogrid. The results found for the ultimate tensile strength and the axial stiffness are, respectively, 65 kN/m and 500 kN/m.

According to the authors, this was classified as a clay soil due to certain plasticity found in it. The value of the internal friction angle estimated through the consolidated undrained triaxial test for the compacted soil was 22º, with cohesion of 30 kPa. This expressive cohesion value represents an apparently cohesion considering the compacted soil as partially saturated.

The backfill soil parameters used in these analyses were internal friction angle of 25º, specific unit weight to $19 kN/m^3$ and the cohesion was disregarded, as recommended by the authors.

The simulation that was made on this work included the piezometric surface in the stability analyses, due to the local road with presence of water and admitted a load distributed on the highway of 40 kPa.

The safety factors of the reinforcement used in the analyses were 0.5 in the soil-reinforcement interaction, 1.302 against the rupture and 1.0 against pull-out.

3.2 *Case 2: "Lessons learned from a segmental retaining wall failure", COLLIN (2001)*

According to Collin (2001), in 1998, New England, a wall of segmental blocks was built aiming to optimize the available space in a commercial development area. The maximum height was 8.5 m with a length of 120 m.

The project used a system that consisted of segmental concrete blocks in the wall face and two kinds of reinforcement in the soil:

- Primary Reinforcement: Steel mesh with a length of 5.4 m and,
- Secondary Reinforcement: Polyester Geogrid with a length of 1.2 m.

The reinforced layers were displayed interchanging two kinds of reinforcements. According to the project, the connection with the segmental blocks was done only through the secondary reinforcement.

The soil where the structure was built was a typical sandy soil containing these parameters obtained through the tests: $\phi=32^{o}$, c'=0, $\gamma=18.9$ kN/m^3.

In the end of May, 1999, however, the first collapse of this wall occurred during a hard storm. The wall face (segmental blocks and secondary reinforcement) fell down and was detached from the mass of the reinforced soil. According to the author's analyses, the collapse was confined to this part without affecting the rest of the wall (primary reinforcement and reinforced soil mass).

A second collapse occurred in September 1999, during a hurricane. This fact was apparently similar to the first one where only the wall face was affected.

According to the author, the presence of water triggered the failures, but this cannot be considered as the main agent. The cause of these collapses is related to the low safety factor between the connection of the blocks and the secondary reinforcement. According to COLLIN (2001), the average safety factor for the connection was approximately 0.5 which is lower than the one recommended in the literature.

To represent this case in the program, the selected section had a maximum height with 8.5 meters. All characteristics described above were taken into account, but not considering the water table inside the reinforced zone.

As this soil is sandier than the other one, the interaction factor of reinforcement/soil was 0.65 against rupture of 1.302 and against pull-out of 1.0.

4 RESULTS - ANALYSIS AND DISCUSSION

4.1 *Case 1: "Lessons learned from a failure of geosynthetics-reinforced segmental retaining wall", YOO et al. (2004)*

This wall was built with two kinds of spacing by using the same geosynthetics as reinforcement. Thus, it was necessary to divide the reinforcement zone in two blocks with separation of 0.4 and 0.6 meters.

4.1.1 *Internal Stability Analysis*

To analyze the internal stability, Block 1 was considered as it was the most critical. A total of 200 failure surfaces for analyses with an interval of 12 to 16 meters were considered. The length of lamellas was 1 meter. The result obtained is illustrated in Figure 1.

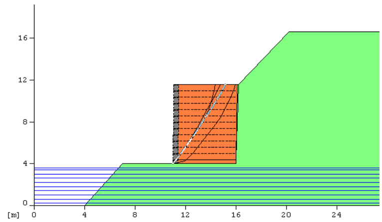

Figure 01 –Internal Stability Analysis – Block 1.

The safety factor found on the internal stability of this wall was 1.61 higher than the minimum commonly used, offering stability in the structure.

4.1.2 *Global Stability Analysis*

Global stability analyses were performed considering 108 surfaces of rupture with 9 starting points and 1 meter-length of lamellas. The interval suggested for these curves was initially with 4 to 8 meters and 15 to 28 meters in the end (figure 02).

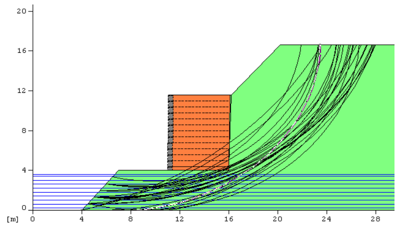

Figure 02 – Global Stability Analysis.

The result of this analysis confirms the global instability of the structure. The safety factor obtained was 0.62 under the minimum recommended. The analysis carried out by Yoo et al. (2004) using the software SLOPE/W, resulted in a critical surface (figure 03) with a safety factor of 0.7.

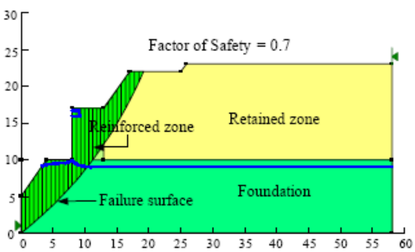

Figure 03 – Global Stability Analysis performed by YOO et al. Source: YOO et al (2004).

This result shows similarity between both analyses performed.

The location of the rupture surface coincided with both studies and it is in accordance with the rupture surface observed in the field.

4.2 *Case 2: "Lessons learned from a segmental retaining wall failure", COLLIN (2001)*

The simulation of this wall considered that only the secondary reinforcement was tied to the segmental block. To represent this connection, different frictioned angles were adopted between the block and the reinforcement for each geosynthetic used: the Geogrid Polyester at 30º (connection) and PVC Steel Mesh at 1º (no connection).

4.2.1 *Internal Stability Analysis*

This analysis covered 100 surfaces with an interval of 13 to 18 meters and 1 meter-length lamella. The third block was chosen for this analysis because the two first were more solid due to the existence of a berm acting as a passive reinforcement. The figure 04 shows the result attained.

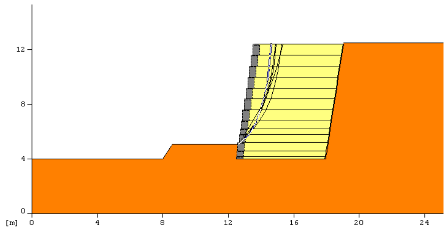

Figure 04 – Internal Stability Analysis.

The safety factor calculated by the program was 0.41, which is insignificant for a reinforcement work.

With reference to the reported case, the rupture surface was located at the end of the secondary reinforcement; that is, 1.2 meters of the wall face. This result confirms the critical region on this wall explaining the reason for the collapse.

4.2.2 *Global Stability Analysis*

For this case, 250 surfaces were analyzed with 25 starting points and 1 meter-length lamella (figure 05). The interval suggested for these curves were initially from 6 to 10 meters and 26 to 30 meters at the end.

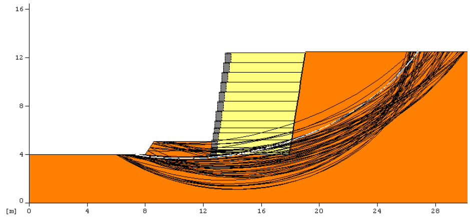

Figure 05 – Analysis of global stability.

The safety factor was 1.59, higher than the commonly value used, offering global stability in the structure.

5 FINAL CONSIDERATIONS

According to the results presented, it can be concluded that there is compatibility between the program used and those mentioned by the authors, where the critical failure surfaces were in the same region and the safety factors were lower or equal to 1. The success of any analyses using a different tool is related directly to the correct choice of intervals of the surface rupture analyses and the way to select the properties of the soil. To obtain parameters similar to the ones in the field, laboratory tests are recommended.

To learn more about the geotechnical profile in the interested region, it is necessary to perform a site investigation. These profiles will avoid unexpected problems as the influence of the freatic line in the reinforced zone.

6 REFERENCES

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