



3D Anchored Retaining Wall Stability Analysis

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Abstract. Anchored retaining walls, widely used around the world, are designed for retain soil masses. They are an efficient alternative to oppose earth-pressures with safety, offering a rigid facing that minimizes displacements. When implementing these retaining structures, the construction sequencing involves descending execution in alternating stability berms, so that the facing structure does not lose support, thus increasing safety during execution. In general, the most critical stages in terms of stability refer to the construction scenarios. This study presents a detailed analysis of the geotechnical stability of an anchored retaining wall, aiming to analyze impacts of construction sequence of excavation in alternating berms, using limit equilibrium method in three dimensions. The wall, approximately 15 meters high, is set on a layer of decomposed mafic rock. The 3D numerical simulations were performed using the Slide3 software, with shear strength parameters obtained from triaxial tests and field geological mapping. Traditionally, two-dimensional (2D) stability analysis are widely used but sometimes do not adequately represents the excavation sequence nor represent the stability berms geometry and spacing, making three-dimensional (3D) analysis indispensable for a more accurate and realistic study. The evaluated scenarios aim to verify the stability during its execution, incorporating the real three-dimensional effects of the berms, ensuring the structure's safety in both temporary scenarios and long term.

Keywords: retaining, tieback, 3D, stability

1 Introduction

The stabilization of deep excavations is one of the great challenges in geotechnical engineering, especially when it involves the combination of elements with different operational mechanisms. Ensure the safety of these structures has driven advances in understanding the behavior of soil and rock masses, making the analysis of containment stability a fundamental discipline in the field.

Among the adopted solutions, the anchored wall stands out for its efficiency and versatility. It consists of a reinforced concrete wall anchored to the ground by pre-tensioned cables, ensuring sufficient rigidity to minimize displacements and ensure the stability of the excavation. The performance of this structure depends directly on the load transfer from the anchors to the soil, a process that occurs through interaction at the soil-bulb interface.

The executive processes of anchored walls are classified as descending, in cuts, and ascending, in fills. Since its execution occurs in stages, the stability analysis should consider not only the final condition of the construction but also each construction phase.

In the descending method, the anchors are executed from top to bottom in successive lines, with each new line executed after the completion of the previous one. The anchors are installed in alternating niches, while the unexcavated niches act as temporary support, ensuring greater safety during construction.

The limit equilibrium method evaluates the stability of the containment considering its condition at the limit of rupture, without taking into account the stress-strain relationship of the soil mass. According to Cheng and Lau (2008), the safety factor is defined as the ratio between the available shear strength and the mobilized shear force along the failure surface.

This study presents a detailed deterministic 3D stability analysis, aiming to evaluate the impact of the executive sequencing of the excavation of an anchored wall, in niches, using the limit equilibrium method in three dimensions.

2 Case Study

The construction of the numerical model was carried out in several stages, the first of which was the definition of the material resistance parameters. The region under study is composed of six lithotypes, whose resistance parameters are presented in Table 1. The analyzed wall, approximately 15 meters high, is seated on a layer of decomposed mafic rock. The failure surfaces traverse this layer of decomposed mafic rock, in addition to pre-existing shear zones, which impact the stability of the mass. Four distinct scenarios were investigated, each with different combinations of berm widths, to evaluate the impact of these variations on the safety factor (SF) during niche excavation. The evaluated scenarios aim to verify stability during the execution of the work, incorporating the real three-dimensional effects of the berms, ensuring the structure's safety in both temporary and long-term scenarios.

Table 1. Shear strength parameters.

Material Name	Color	Unit Weight (kN/m ³)	Strength Type	Cohesion (kPa)	Phi (°)	UCS (intact) (kPa)	GSI	mi	D
Coluvium		17	Mohr-Coulomb	7	30				
Jaspelito		21	Generalized Hoek-Brown			206000	50	18	0.7
Saprolite		18	Mohr-Coulomb	58	30				
Shear zone		20	Generalized Hoek-Brown			100000	30	23	0.7
Decomposed mafic rock		17	Mohr-Coulomb	20	30				
Shear decomposed mafic rock		20	Mohr-Coulomb	7	30				
Concrete Wall		24	Mohr-Coulomb	100	45				

2.1 3D Numerical model

In the 3D model presented in Slide 3, various deterministic stability analyses were conducted using the "spline" search and the G.L.E./Morgenstern-Price limit equilibrium method. This method was chosen for its wide application in limit equilibrium analyses and its relevance in professional practice. Initially, the current scenario with four lines of tiebacks already executed in a 150 m long containment was considered. Subsequently, three distinct scenarios were generated, in which alternating niche excavations with widths of 5.2 m and 10.4 m were simulated, keeping the berms at the same width.

Finally, a last scenario with an open niche 5.2 m wide and an enlarged berm 15.6 m wide was modeled, allowing the evaluation of the structure's behavior under these configurations. Figure 1 shows the current scenario for the anchored wall.



Fig. 1. Current scenario

In the first evaluated scenario, the excavation is carried out alternately, creating interspersed niches. This method aims to ensure the stability of the structure, maintaining berms with a width of 5.2 meters and niches of the same dimension. Figure 2 presents this scenario.

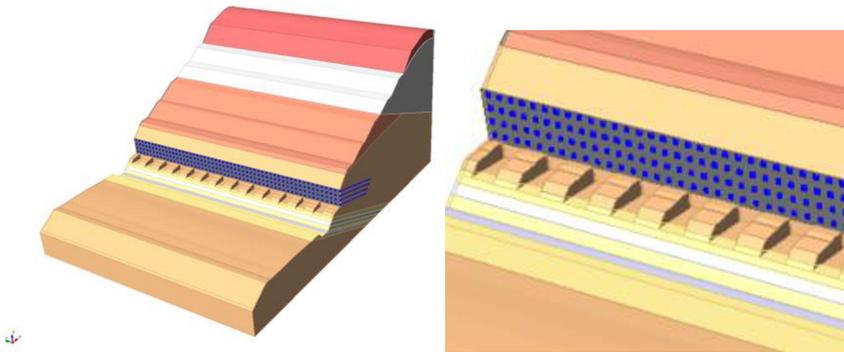


Fig. 2. First scenario – alternate niches

In the second scenario, berms and niches were considered with the same dimensions, 10.4 meters width. This scenario can be observed in Figure 3.

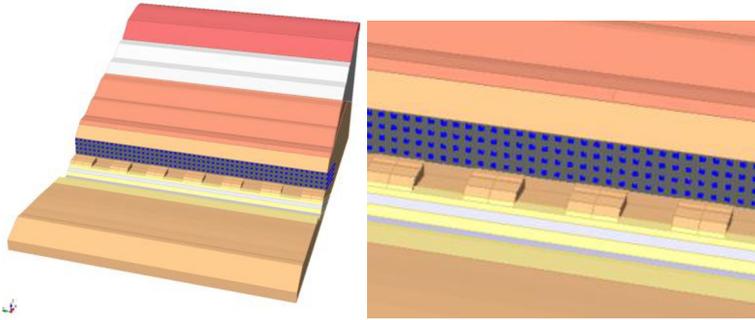


Fig. 3. Second scenario – alternate niches

In the last evaluated scenario, excavated niches of 5.2m and an expanded berm of 15.6m in width were considered. This scenario can be observed in Figure 4.

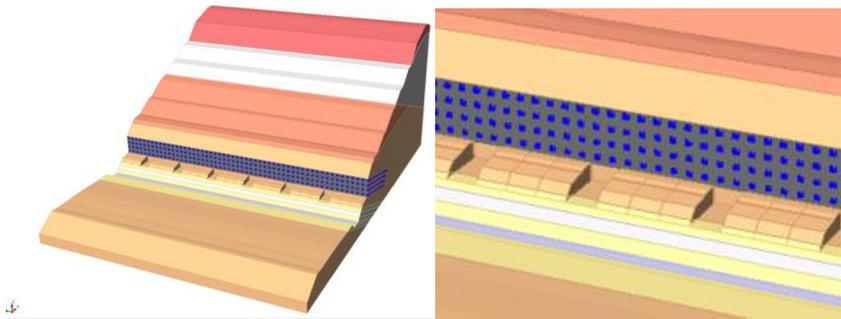


Fig. 4. Third scenario – alternate niches

3 3D Stability Analysis – Limit Equilibrium

The analysis of the results allowed for the identification of distinct safety factors for each scenario, with the highest safety factor obtained in the configuration with four lines of anchors already executed, without excavation for the next line, i.e., in the current scenario. In Figure 5, the stability analysis for the current scenario can be seen, resulting in a safety factor of 1.35.

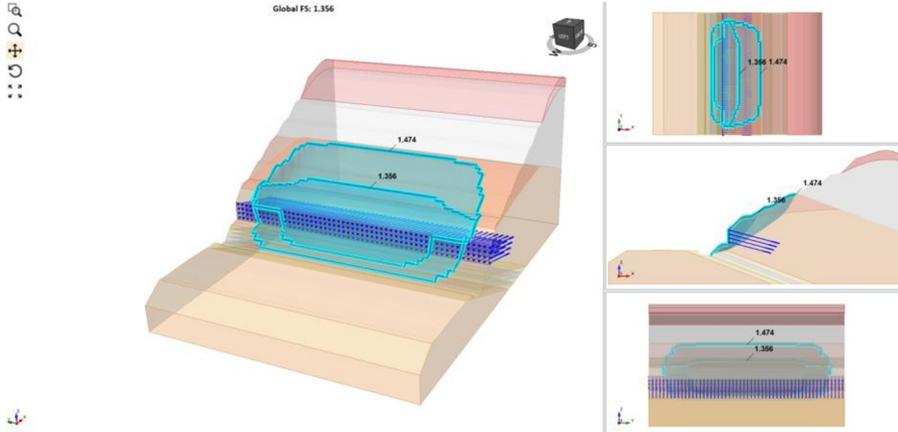


Fig. 5. Current scenario – FS=1.35

Figure 6 refers to the stability analysis of the first scenario, where a safety factor of 1.18 was obtained.

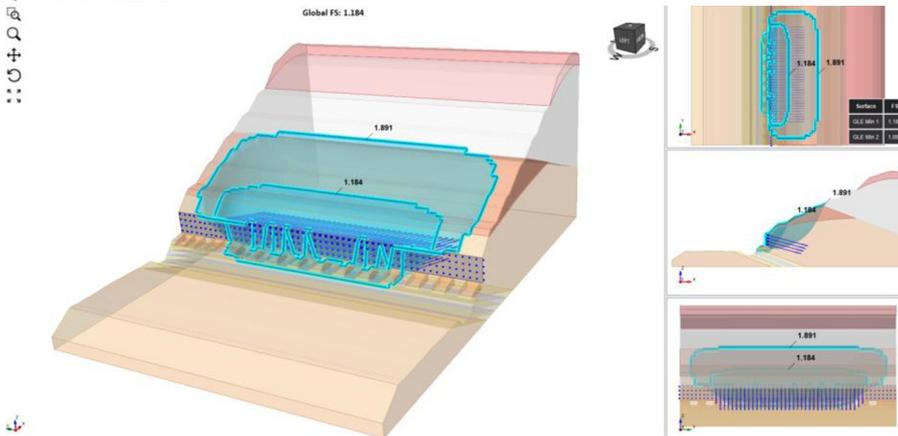


Fig. 6. First scenario – FS=1.18

Figure 7 refers to the stability analysis of the second scenario, where a safety factor of 1.21 was obtained.

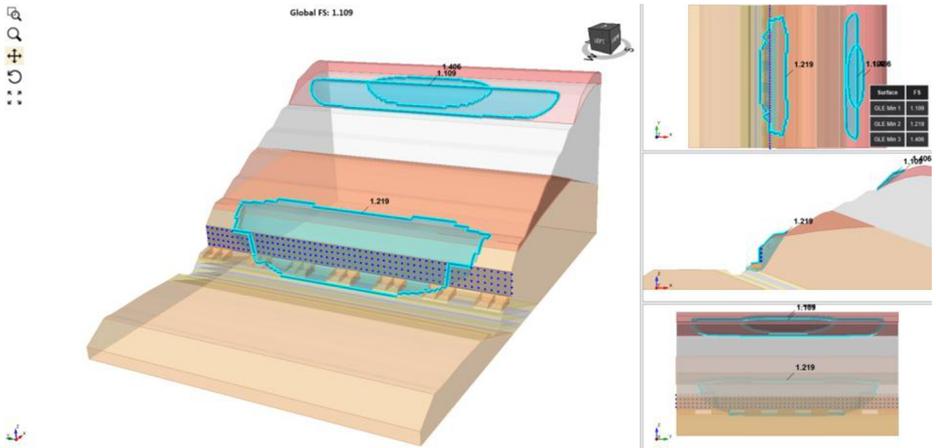


Fig. 7. Second scenario – FS=1.22

Finally, Figure 8 presents the stability analysis of the third scenario, where a safety factor of 1.25 was obtained.

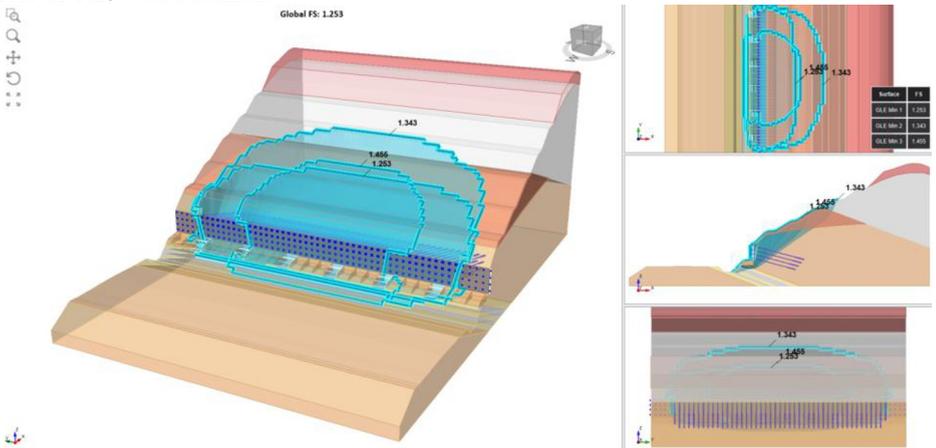


Fig. 8. Third scenario – FS=1.25

In the scenarios where excavation for the installation of the next line of tiebacks would be carried out, it was observed that the first two cases presented safety factors below the recommended minimum ($FS < 1.25$). On the other hand, the third scenario demonstrated a satisfactory safety factor, meeting the required value, indicating greater stability. Thus, it is noted that the increase in berm width directly affected the increase in the safety factor. This behavior highlights the direct influence of geometry on the stability of the containment, demonstrating that larger berms significantly contribute to structural safety.

The stability analysis conducted using a 2D cross-section, taking into account the excavated niche, revealed a safety factor significantly lower than that of the 3D analysis, as expected. This difference, which obviously depends on the niche width (and the

scenario) considered for comparison purposes, reached values of up to 24%, which can be regarded as relevant, as illustrated in Figure 9 below.

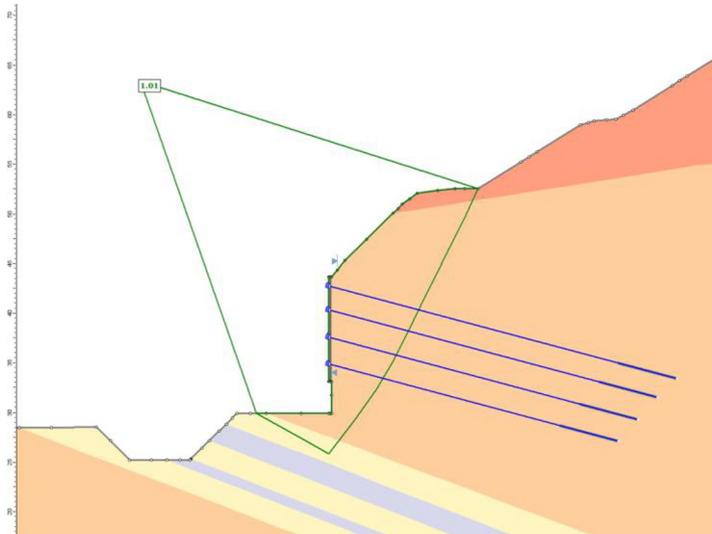


Fig. 9. 2D Limit Equilibrium analysis – FS=1.01

This analysis highlights the importance of utilizing three-dimensional analyses for making more accurate decisions in engineering projects, providing enhanced safety and cost reduction.

4 Conclusions

Given the complexity of the scenario, the technique of alternating niche excavation was recommended as a preventive measure to avoid loss of stability during the excavation process. Traditionally, two-dimensional (2D) analyses are widely used, but they do not adequately translate the excavation sequencing nor represent the geometry and spacing of the berms, making three-dimensional (3D) analysis indispensable for a more precise and realistic study. It was concluded that the executive sequence that presented the best stability results was the third scenario, with smaller excavations and wider berms. These results highlight the importance of three-dimensional analysis for defining the appropriate excavation geometry, taking into account the safety factor and local geotechnical conditions.

Three-dimensional stability analyses were fundamental for evaluating the width of excavation niches, providing consistent and appropriate results as expected. Assessing the width of niches is essential for evaluating safety conditions during the construction stages of the containment, and such assessment is not feasible through conventional 2D analyses.

Certainly, 3D finite element modeling, incorporating construction stages and the respective stress distributions, would lead to results even more interesting than those derived from limit equilibrium. However, for this specific case study, such modeling was not conducted.

The results showed that larger remaining niches lead to higher safety factors for the construction stages, as expected. The indicated critical surfaces refer to global failures of the containment system, extending from the upper region to the bottom of the excavation. From the analyses of this study, it was possible to determine the geometries of the temporary berms in order to proceed with the safest execution of the work.

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