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SLOPE PROTECTION ON THE ISLAND OF VIS

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ABSTRACT

Slope protection in modern engineering represents a common task faced by geotechnical engineers. The selection of a slope protection system is primarily determined by the material in which the excavation is made, specifically its mechanical properties. The slope protection on the island of Vis was carried out for the construction of a supermarket. The location of the supermarket is on a natural slope, where a cutting was made with a maximum height of 22 meters. The excavation was executed in four levels, with each level having a maximum height of 6 meters. Prior to the project, geotechnical investigative work was carried out, including geophysical methods of shallow seismic refraction. Following the investigative work, geostatic analyses of global stability were conducted using limit equilibrium methods. Based on the calculations, the protection system was designed using self-drilling geotechnical anchors with lengths of 9.0, 6.0, and 3.0 meters. The slope is protected with mesh to prevent rockfalls, with one type of higher tensile strength being placed at the upper part of the excavation, while a lower tensile strength mesh is placed in the lower section. Due to the significant height of the excavation, which will house a supermarket with a parking lot and experience high human traffic, a polypropylene anti-erosion mesh is installed across the entire surface to prevent the fall of small rock fragments. After each excavation stage, engineering geological mapping of the rock mass was conducted, followed by control analyses of global stability and block stability to verify the designed solution.

Keywords: slope protection, slope stability, rock anchors, rock mass.

INTRODUCTION

The construction of new buildings increasingly necessitates the deep excavations, presenting new challenges for geotechnical engineers.

For the construction of a supermarket on the island of Vis, slope with a maximum elevation difference of 22 m was constructed. The total area of the construction pit is approximately 10,000 m². In addition to accommodating the supermarket building, the construction pit includes a parking area for customers and designated handling zones for supply trucks.

To facilitate the safe excavation of such a deep excavations and to ensure the long-term stability of the supermarket and its surroundings, the slope protection project was developed. Prior to the design of the protection measures, a comprehensive geotechnical investigation was conducted. This investigation provided critical data regarding the stratification of the soil and rock layers and enabled the determination of their mechanical properties.

The slope protection system comprises several stabilization measures, including the installation of rock anchors, the application of a polypropylene anti-erosion mesh, and the application of a high-strength rockfall protection mesh. Furthermore, excavation was carried out in levels with a

maximum height of 6 m to ensure stability. After the excavation of each level, engineering geological mapping was performed, followed by localized stability control analyses.

These analyses served to validate the design solution and allowed for necessary adjustments based on actual ground conditions. The implemented measures ensured the stability of the excavation and minimized the risk of slope failure, thereby safeguarding both the construction process and the future operation of the supermarket.

GEOTECHNICAL INVESTIGATION WORKS

The refraction method is based on the refraction of an elastic wave at the boundary between two media, where the velocities satisfy the condition $V_2 > V_1$ (V_1 representing the velocity in the upper medium and V_2 representing the velocity in the lower medium). An elastic wave is generated at the surface and initially propagates at the velocity of the upper medium. Figure 1 shows the illustration of seismic refraction method.

For this method, the most significant wave is the one that reaches the boundary between the media at the critical angle, also known as the angle of total reflection.

This wave subsequently propagates along the boundary at the velocity of the lower medium (V_2)

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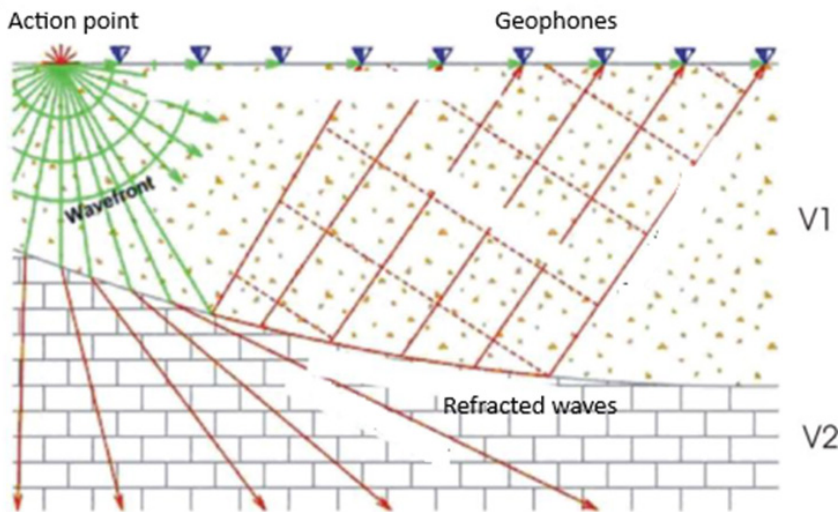


Figure 1 Illustration of seismic refraction

and then returns to the surface, in accordance with Huygens' principle, where its arrival is detected by geophones.

Based on the geometry of the geophone arrangement and the ignition points on the terrain surface, along with the recorded times of the first arrivals of the elastic wave, s-t diagrams (where s represents distance and t represents time), known as dromochrones, are constructed. By applying both direct methods and inverse modeling techniques, the depths and spatial distributions of elastic discontinuities are determined from the dromochrones.

The fundamental assumption of this method is that the velocity gradient within each individual layer remains constant (Gibson et al., 1979). The propagation path of the seismic ray over a distance Δ from the source (ignition point) to the receiver is represented by circular segments within each layer.

For a simplified model consisting of a horizontal layer of thickness h, where both the source and the receiver are positioned at the surface, and the corresponding seismic ray trajectory is tangent to the bottom of the layer, the following equations hold (Gebrande et al., 1985):

$$\Delta = \frac{2\sqrt{1-p^2b^2}}{p\gamma} \quad (1)$$

$$t = \frac{2}{\gamma} \log \left(1 + \frac{2\sqrt{1-p^2b^2}}{pb} \right) \quad (2)$$

$$\beta = b + \gamma h \quad (3)$$

$$p = \frac{1}{\beta} \quad (4)$$

where:

- t is travel time of the ray from the ignition point to the receiver
- p is ray parameter
- γ is gradient of velocity in the layer
- b is velocity on the top of the layer
- β is velocity on the bottom of the layer.

From the previous equations, thickness of each layer was calculated as follows:

$$h = \frac{\beta - b}{\gamma} \quad (5)$$

Using the seismic refraction method, three distinct layers within the geotechnical profile were identified based on variations in seismic wave velocity. The uppermost layer, extending to a depth of approximately 1 meter, represents the surface wear layer, composed of clay and fill material, with seismic wave velocities below 1000 m/s.

Between depths of 1 and 5 meters, the subsurface consists of the upper wear layer, characterized by a highly fractured to fractured rock mass, where seismic wave velocities range from 1000 to 1800 m/s.

The third layer, found at depths greater than 5 meters, corresponds to the bedrock, exhibiting seismic wave velocities exceeding 1800 m/s. Figure 2 presents the predicted geotechnical profile derived from seismic refraction analysis.

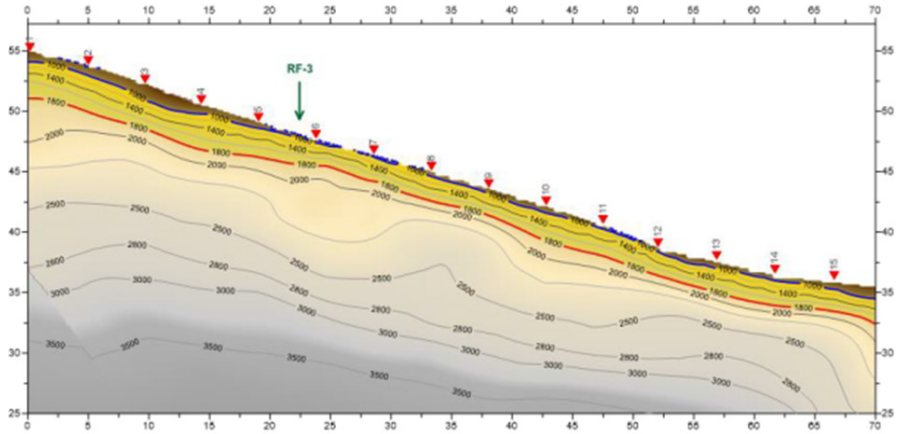


Figure 2 Seismic refraction profile

The mechanical properties of the layers within the geotechnical profile were determined through engineering geological investigations of exposed rock mass sections. This involved sampling intact rock specimens and utilizing empirical data for subsequent analysis. Rock mass samples were collected from a slope located in close proximity to the subject slope, and were used for the determination of uniaxial compressive strength.

GLOBAL STABILITY ANALYSIS

The calculations were performed on critical cross-sections in accordance with Design Approach 3 (DA3) as specified by Eurocode 7 (HRN EN 1997-1, 2012). Material and load parameters were incorporated following Design Approach 3. The analysis assessed the global stability of the rock slope after excavation, considering both scenarios: with and without the application of stability assurance measures.

Table 1 presents the mechanical properties of the geotechnical layers used in the global stability calculation.

Table 1 Mechanical properties of the layers

Layer	γ (kN/m ³)	σ_{ci} (MPa)	GSI (-)	D (-)	m_i
GS1	26	5	5	0,7	9
GS2	26	50	20	0,7	9
GS3	26	100	50	0,7	9

The generalized Hoek - Brown strength criterion was used, described by the following equation (Hoek et al., 2007):

$$\sigma'_1 = \sigma'_3 + \sigma_{ci} \left(m_b \frac{\sigma'_3}{\sigma_{ci}} + s \right)^a \quad (6)$$

The Hoek-Brown failure criterion is particularly effective in representing the mechanical behavior

of rock masses characterized by a high degree of discontinuities, such as joints, fractures, and bedding planes. Although primarily developed for characterizing rock masses, the Hoek-Brown criterion can also be applied to intact rock, particularly when supported by laboratory-derived strength parameters of the intact material.

The calculation performed for the excavation at the most critical cross-section with a total height of 22 m resulted in a safety factor of $F_s=0.85$. Given the above, an additional calculation was performed with applied rock anchors (Popescu, 2001; Cruden et al., 1996). The rock anchors were placed in 6 rows, at the distance of 3 m in the vertical direction. The calculation performed with applied rock anchors results in a safety factor of $F_s=1.25$. Figure 3 shows the critical sliding surface.

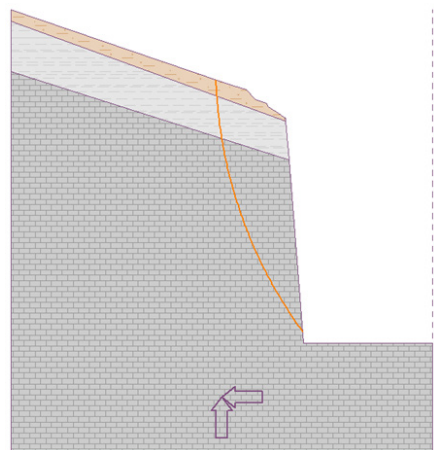


Figure 3 Critical sliding surface, GEO 5 software

The global stability was calculated using the limit equilibrium method, employing several analytical approaches, where the Spencer method gives the lowest safety factor values. In the global stability analysis, the rock mass was modeled as a continuum. Additionally, local stability analyses of individual blocks were conducted following the excavation of each 6 m high level. These analyses were performed after the excavation of each level to ensure stability throughout the process.

PROTECTION SYSTEM

The slope stability was ensured by the following measures:

- - excavation in the levels with the height of 6 m
- - installation of self-drilling anchors with a diameter of $\varnothing 38/21$ mm, lengths of 3.0, 6.0 and 9.0 m
- - installation of edge anchors with a diameter of $\varnothing 25$ mm, lengths of 1.5 m
- - installation of high tensile mesh for rockfall protection and anti-erosion polypropylene mesh.

Self-drilling anchors are installed across the entire surface of the slope. The anchors are arranged on a grid with horizontal and vertical spacing of 3.0-3.0 m, with each successive row offset by 1.5 m compared to the previous one, ensuring that the anchors in adjacent rows are placed diagonally. Self-drilling anchors with lengths of 3.0 m, 6.0 m, and 9.0 m are installed along the slope surface.



Figure 4 Finished part of the protected slope

On the most critical part of the slope, a rockfall protection mesh with a longitudinal tensile strength of 150 kN/m^2 is installed, while on the lower part of the slope, a mesh with a tensile strength of 100 kN/m^2 is installed. A polypropylene anti-erosion mesh is planned for the first 5 m of height, measured from the existing terrain surface. The function of the anti-erosion mesh is to prevent the washing out of the clay parts of the slope and to inhibit the fallout of smaller fragments of the rock mass. The high-strength mesh, in combination with the self-drilling anchors, ensures the global stability of the slope and prevents the fallout of larger blocks. Figure 5 presents a cross-section of the slope with the protection measures indicated.

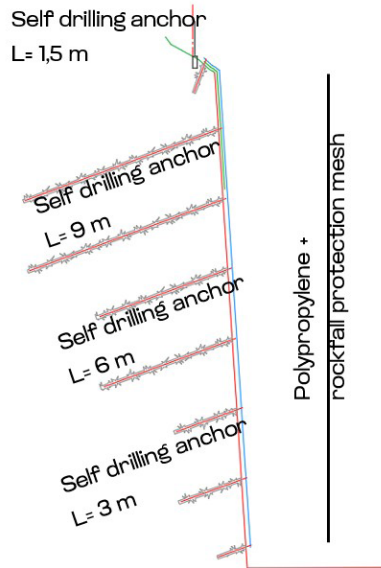


Figure 5 Cross section with applied protection measures

EXCAVATION MONITORING

After the excavation of the each level with a height of 6 m, engineering-geological mapping of the excavation face was conducted. Based on the results of this mapping, control analyses of the stability of the blocks were performed, and the design solution was optimized and adjusted to reflect the actual conditions on site. The proposed design includes the installation of self-drilling anchors: 9 m in length for the first two rows, 6 m in length for the subsequent two rows, and 3 m in length for the final two rows. Control calculations identified three blocks where 9 m anchors were installed in the second two rows.

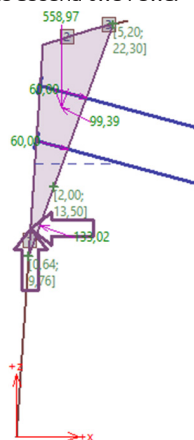


Figure 6 Control of block stability, GEO 5 software

The protection with polypropylene mesh, as initially proposed in the project, was extended to cover the entire slope zone due to the presence of smaller fragments of rock mass.

CONCLUSION

The slope protection project on the island of Vis, carried out in preparation for the construction of a supermarket, serves as an example of effective collaboration between engineering geologists and civil engineers in the development of geotechnical works.

Monitoring of the excavation allowed for the additional stabilization of potentially unstable blocks, which were reinforced with longer self-drilling anchors and the installation of polypropylene mesh across the entire surface.

During engineering geological mapping of each level, unstable rock blocks were identified in the area designated for the installation of 6 meter long anchors. Stability control calculations demonstrated that the proposed anchor length of 6 meters is insufficient in these zones. Consequently, the anchor length must be extended to 9 meters within the unstable block area to ensure adequate stabilization. Additionally, occurrences of soil pockets within the GS3 layer, as well as smaller rock fragments, were observed. As a result, it was decided to extend the polypropylene mesh across the entire slope surface.

The project also highlighted the critical importance of investigative work and the preparation of geotechnical studies prior to the design phase of the slope protection and other geotechnical structures.

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