On the Use of Dips and RocFall for Designing Structures in Highly Fractured Igneous Rocks in the Chilean Patagonia

Néstor René Espinoza Guillén[1](✉), Jorge Andrés Arriagada Triana[2], and Lorna Andrea González Martínez[1]

[1] School of Civil Engineering, University of Valparaíso, Valparaíso, Chile
rene.espinoza@uv.cl
[2] Soil and Rock Mechanics Laboratory, School of Civil Engineering, University of Valparaíso, Valparaíso, Chile

Abstract. The Carretera Austral, today Route 7 of Chile, is one of the most important roads in the Chilean Patagonia. The road is in a mountainous area with very steep slopes. Due to the challenges presented by the zone a geotechnical assessment is necessary to make improvements to the road. During the opening of the penetration path, the rock mass was damaged in some areas by the poor application of explosives. This type of project requires that the geotechnical engineer have a deep knowledge of structural geology and behavior of the igneous rock (granodiorite) in the area, before, during and after construction. To meet the geotechnical demands and infrastructure needs of the project, a survey of the dis-continuities was conducted, and several boreholes were drilled to better under-stand the structure of the Patagonian Batholith. Using Dips and RocFall software, we gained insights into the data that allowed for a more comprehensive geotechnical engineering analysis. We also classified the rock mass and designed protection systems for the road using steel wire mesh and special drill bits. We used geometric design, orthophotos, and low drone flights to inspect inaccessible areas, such as the crest of the slopes, to identify zones where tensile cracks may have formed. As a result, we were able to determine the best placement of structures for the widening of the new road without causing greater damage to the igneous rock mass.

Keywords: Rock Slope Engineering · Structural Geology · Patagonian Batholith

1 Introduction

The Carretera Austral, today Route 7 of Chile (Fig. 1) is one of the most important roads in the country because it links territories far away from the most developed centers in the south. This road was opened in the mid-1970s by Chilean Army engineers and converted from a penetration path to a narrow road. To widen this roadbed to a width compatible with current traffic, it will be necessary to make rock cuts in some cases and stabilize the existing cuts in others so that the traffic is safe and pleasant for users, whose number is increasing from year to year. This improvement will require several engineering works

R. E. Hammah et al. (Eds.): RIC 2023, AHE 19, pp. 820–826, 2023.
https://doi.org/10.2991/978-94-6463-258-3_76

that will be accompanied by cutting and securing slopes of varying heights from a few meters to more than 70 m in some sectors (Fig. 2) in a mass of very fractured igneous rock that tends to form blocks of different geometries and with different types of failure possibilities.

For this purpose, the authors of this work took a sample of some slopes of the section between the towns of Puerto Puyuhuapi and Puerto Cisnes, and developed an evaluation technique that enabled us to identify not only the potential types of rock (block) failure, but also the approximate size of the rock. Using the methods of structural geology to

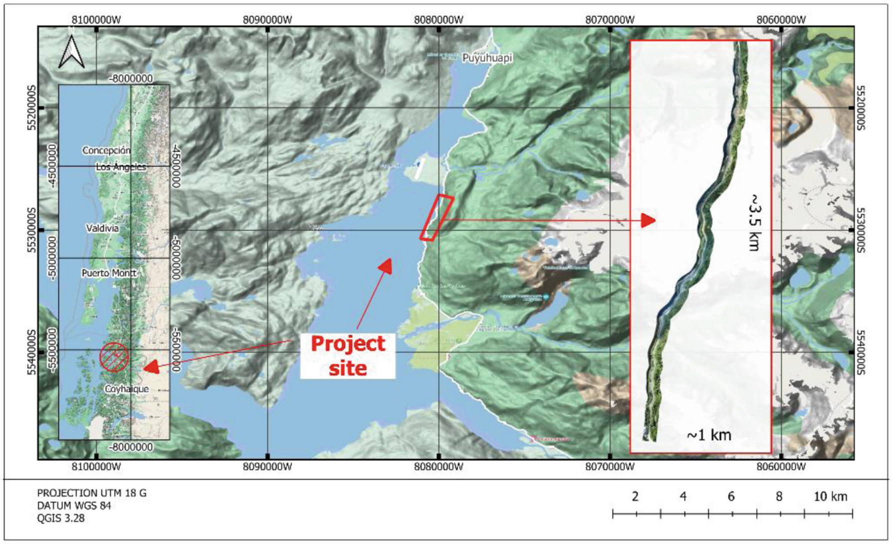


Fig. 1. Location of the study area as part of Route 7 or Carretera Austral de Chile

Fig. 2. Images from the low drone flight during the fieldwork at Route 7. August, 2022

estimate the possibility of flat, wedge or toppling failure, the authors proposed a way to make the cuts that would ensure traffic a safe and comfortable circulation. While the slope itself was safe (SF > 3.50), the authors designed a method to stabilize the potentially unstable blocks with the help of the programs Dips and RocFall [5, 6].

2 Fieldwork

To develop the study, the authors planned fieldwork in seven different sectors where the rock mass presented the highest degree of fracturing, to determine the characteristics of the rock mass. The high degree of fracturing is mostly due to an improper use of explosives, since the blasting damaged the rock mass even more than tectonic factors, generating very low RQD values in some cases and opening discontinuities beyond 2 mm in others, reaching more than 50 mm in some sectors (Fig. 3).

Following Palmström's recommendations, more than 100 measurements were made in areas of no less than 100 m^2 (at least 2 areas per section) of the typical separations of the discontinuities, with which it was determined that the rock mass reached a maximum RQD of 70% and a minimum of 40%. The rock mass was classified according to Bieniawski and Romana as Type III and Type IV, that is, a medium rock with a tendency to a poor rock. With the values of the separation of the discontinuities and the number of discontinuities per meter, the approximate volume of the largest block that could be formed was determined, which reached 0.3 m^3.

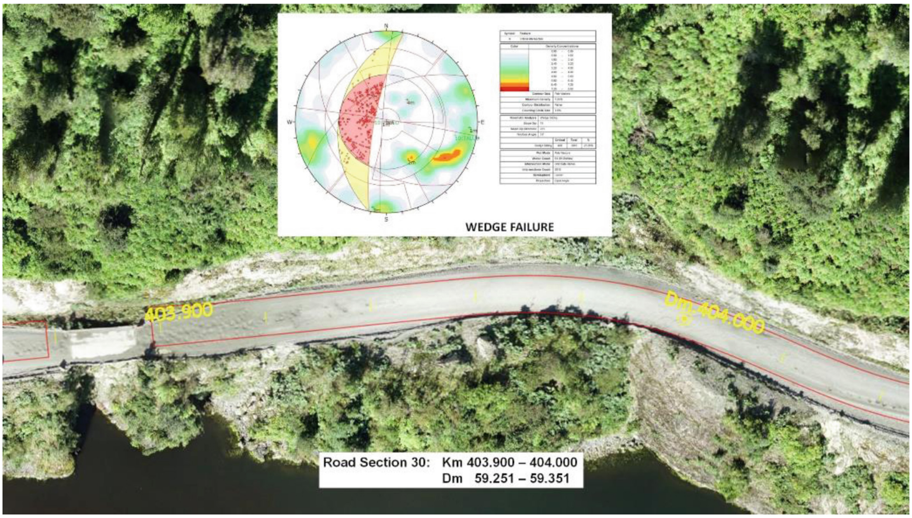


Fig. 3. Kinematic analysis – Wedge failure – In this section of the road it will be necessary to create very steep slopes up to 90 m in height

3 Laboratory Work and Interpretation of Results

For the interpretation work, all the data obtained in the field were duly organized and processed with the Rocscience programs. The diagrams of equal area were obtained with Dips, and RocFall was used to visualize the rock paths along the slopes. Subsequently, the kinematic analysis of each case was carried out, considering the following cases: Flat failure; Wedge failure and Toppling. The most common shape of the blocks that were found on-site had a polyhedral structure (see Fig. 4).

The results obtained gave us the chance to determine the possibility of failure of each case, the cases analyzed by the combination of the possible values of the strike and mean dip of the discontinuities, and the approximate size of the intact rock block. As an example, the results of the section 4 are shown in the following figures.

The results of the analysis of a planar or flat type failure indicate that, in general, only 5 out of 52 cases are critical, giving a 9.62% probability of failure in the sector, which is associated with the most probable size of the blocks (approximately 0.30 m^3 maximum). This type of failure therefore does not represent an important potential risk for the section.

In the case of a wedge failure, the following results are obtained for this same section. According to the analysis, this is the case with the highest probability of failure in the section. Out of 1,325 possible intersections 330 are potentially risky with a 24.91% probability of occurrence, a value that is associated with the maximum size of the blocks and makes this case a controllable problem using very simple procedures.

The case of direct overturning presents several possibilities according to the origin of the overturning process of the intact rock block itself. Thus, out of 1325 possible cases of an overturning over an intersection, 65 cases of direct overturning can occur, showing a 4.91% probability of occurrence, while for an oblique overturning over an intersection, there are 186 possible cases with a probability of occurrence of 14.04%. Now, if a direct

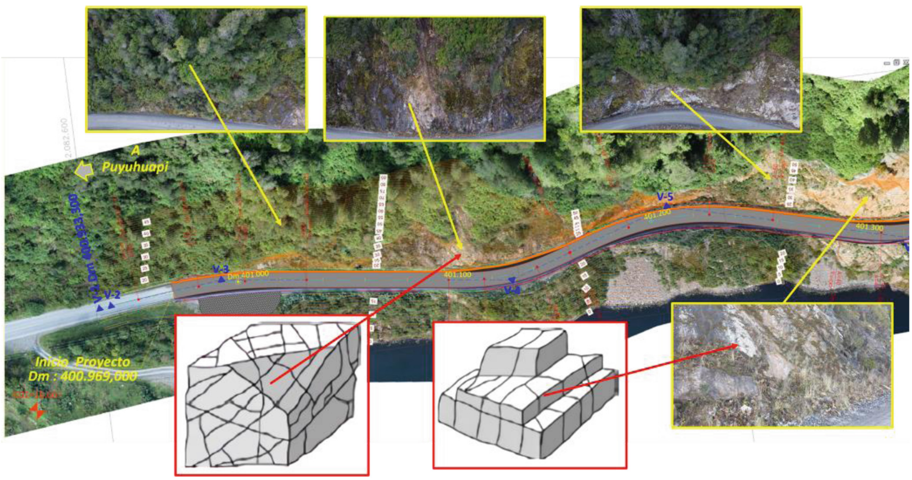


Fig. 4. Method proposed by Palmström to estimate the value of RQD and the type of structure (Polyhedral) of the rock blocks [4]

overturning on a flat base is considered, the situation changes since in general there are 5 critical cases out of a total of 52 with a probability of occurrence of only 9.62% and 5 critical cases if the family of discontinuities 3 is considered for 16 possible cases with 31.25%. For the case of flexural overturning, there is only one critical case out of 52 possibilities, leaving a probability of occurrence of only 1.92% (Fig. 5).

The information collected in the field makes it possible, with the support of the results obtained in the Dips and RocFall programs, to determine that the possibility of a massive fall of rock blocks (more than 10 blocks) of a size greater than 0.30 m^3 is very low. This leads to the conclusion that the protection of slopes where there is a possibility of falling blocks can only be done with steel mesh placed with a cable fastening system and passive anchors arranged in two directions, forming a mesh of approximately 2.50 × 2.50 m^2. This system not only provides security to users but also facilitates the cleaning of debris after each rainy season.

Once the safety of the road from a possible fall of rock blocks was determined, a model was created using the RS2 program. The model included the three most important families of discontinuities in the rock mass properties with the objective to determine the possibility of a failure due to a general cut in the slope, before and after the intervention to widen the road. Said intervention will consist of cutting works using explosives that will create slopes reaching up to 90 m in height in some sectors. Due to past experience of damage to the rock mass, it was therefore recommended to proceed with blasting, considering the use of precut or controlled blasting techniques (Fig. 6).

The previous figure presents the analyses carried out to determine the safety factor for a failure due to generalized shearing throughout the slope and the potential stability of the slope based on the slope stability method provided by the RS2 program. With the slope

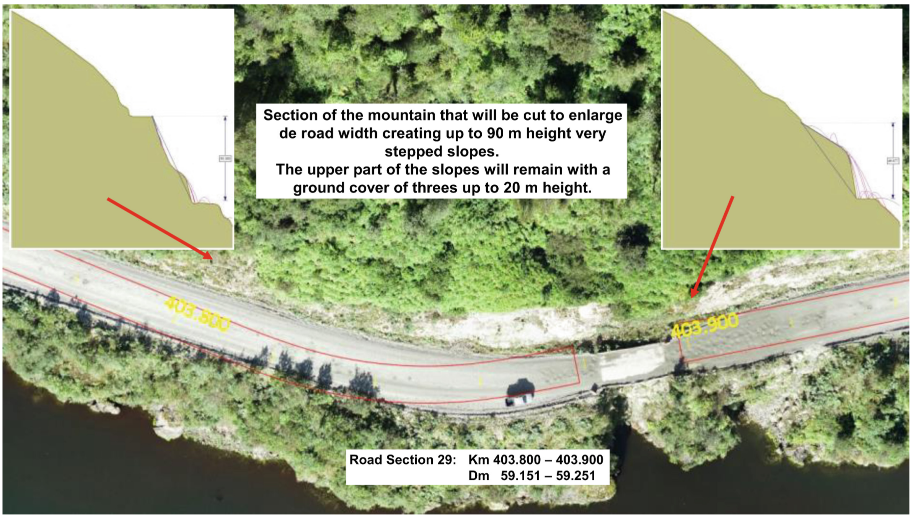
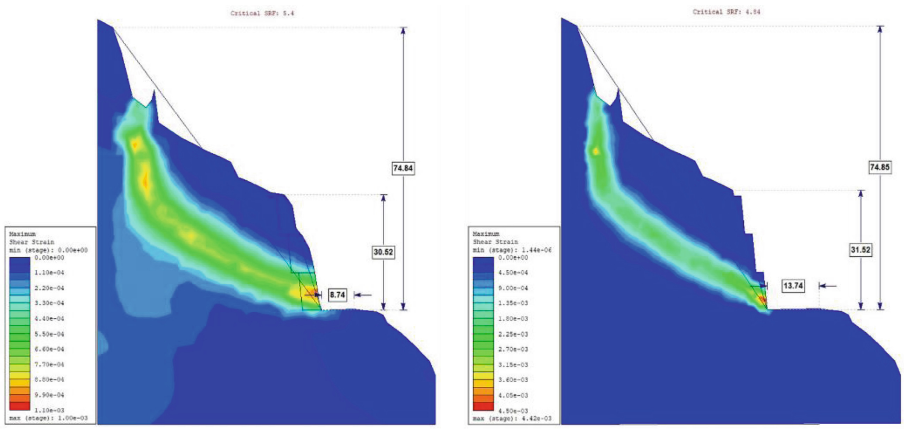


Fig. 5. Possibility of a generalized shear failure of the fractured rock slope, both before the planned blasting works, and after those works, considering the use of presplitting in the blasting plan



Road section: Dm 403,880
Initial state before the intervention SRF: 5.4

Road section: Dm 403,880
Final state after the intervention SRF: 4.8

Fig. 6. Possibility of a wedge failure of a block of intact rock over the intersection of two discontinuities of section 4

stability and finite element method provided by this program it is possible to estimate the stability of the massif. The results indicate that the massif is stable despite the damage caused by blasting from previous works where excavation methods did not consider the protection of the rock mass behind the work face. For example, in this sector of the highway, users will be protected by the use of mesh throughout the excavated slope, since the analyses carried out indicate the possibility of block formation that can be detached as wedges or by direct toppling.

4 Comments and Conclusions

As can be seen, the use of the programs Dips and RocFall combined with simplified methods to determine the volume of intact rock blocks proposed in the literature [1–4] and verified in several cases including the present one, leads to a relatively simple solution in this sector of the Carretera Austral. The solution consists of using kinematic analysis to locate the sectors where wedge failure or plane failure presents the highest probability of occurrence. Also, due to the maximum probable dimensions of the potentially unstable intact rock blocks, the movement of the blocks can be restricted or almost completely restrained by a steel wire mesh that can dampen the kinematic energy developed by the moving blocks. Such a mesh does not allow the blocks to reach a significant fall velocity and forces them to slide between the massif and the mesh, reducing their potential damage to only a deformation of the mesh at the base of the slope or the shoulder, which can be repaired and permits cleaning the accumulated debris.

In conclusion, engineering knowledge combined with the use of geotechnical software tools (Dips, RocFall, RS2 and RSData) enabled the authors to reach a simple and economic solution for the stabilization of slopes in the very fractured diorite and granodiorite rock of the Patagonian Batholith.

References

1. Palmström, A.: The volumetric joint count—A useful and simple measure of the degree of jointing. IVth International Congress IAEG. 221–228. New Delhi, India (1982).
2. Palmström, A.: Application of the volumetric joint count as a measure of rock mass jointing. In: Proceedings of the International Symposium on Fundamentals of Rock Joints, pp. 103–110. Bjorkliden, Sweden. (1985).
3. Palmström, A.: RMi—A system for characterizing rock mass strength for use in rock engineering. Journal of Rock Mechanics and Tunnelling Technology 1(2), 69–108 (1996).
4. Palmström, A.: Measurements of and correlations between block size and rock quality designation (RQD). Tunnelling and Underground Space Technology, 20, 362–377 (2005).
5. Dips v8.021 Manual. Rocscience Inc., Toronto, Canada, 2022.
6. RocFall v8.020 Manual. Rocscience Inc., Toronto, Canada, 2022.