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Geotechnical challenges during excavation of Crusher Chamber 1, Andes Norte project, El Teniente mine

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Abstract

The Andes Norte project is an expansion of the El Teniente mine and is planned to be the deepest project to enter production beneath the Esmeralda and Pilar Norte operating sectors. The material handling system involves transferring material from the productive sector via ore passes and loops with trucks, which move to a crusher inside the mine. Finally, the material is connected to a 9 km-long conveyor belt tunnel to the surface.

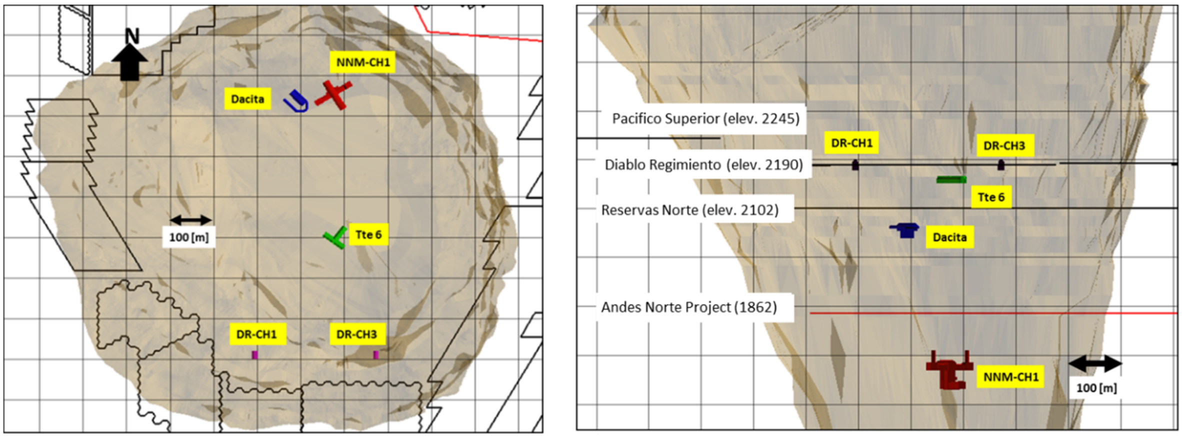
The Andes Norte project Crusher Chamber 1 is the deepest cavern at the El Teniente mine, located 250 m below the current operative chambers. It is also the largest, with a total design volume of 74,000 m^3. The entire design is a complex of several caverns excavated in phases, which are finally coupled. Geomechanical guidelines were defined and implemented with a risk-based operational strategy, complemented by a geotechnical ground control plan and instrumentation monitoring system that would allow early identification of variations. The focus was on the long-term and overall stability of the excavations.

This paper describes the designs as well as considerations for geotechnical ground control and construction. Additionally, the main challenges faced during the excavation stages are summarised, along with additional actions that have supported the stability of this excavation. This project is of vital importance for the future of the El Teniente mine production, and the actions taken to ensure its stability will play a critical role in maintaining this production.

Keywords: *El Teniente mine, crusher chamber, cavern, ground control, geomechanics*

1 Introduction

Crushing Chamber 1 is an essential component of the future material handling system for the Andes Norte project and future projects. It is spatially located below the haulage level, and its geological environment is fully considered within the Braden breccias complex, a non-mineralised body in the middle of the El Teniente mine. This crushing chamber is considered to be the deepest cavern at the El Teniente mine, located 250 m below the current operative chambers. It is also the largest, with a total design volume of 74,000 m^3 (Figure 1).



(a) (b)

Figure 1 (a) Plan view and (b) cross-section of Braden Breccias Complex, showing the different crusher chambers of El Teniente mine (Valdivia 2015)

After the design stage was completed, several geotechnical considerations were established in order to address important aspects during the construction phase. The excavation process started in April 2019 and has already been completed, and this document describes the main challenges encountered during construction and highlights lessons learned.

2 Geotechnical and geomechanical characterisation

2.1 Drilling campaigns

Between 2008 and 2017, four drilling campaigns were carried out in the area of the future location of the crushing chamber, resulting in a total of 5,951 m drilled. Additionally, data from previous campaigns were utilised, resulting in a total of 11,892 m of drilling for the geological and geotechnical characterisation stage (Figure 2 and Table 1).

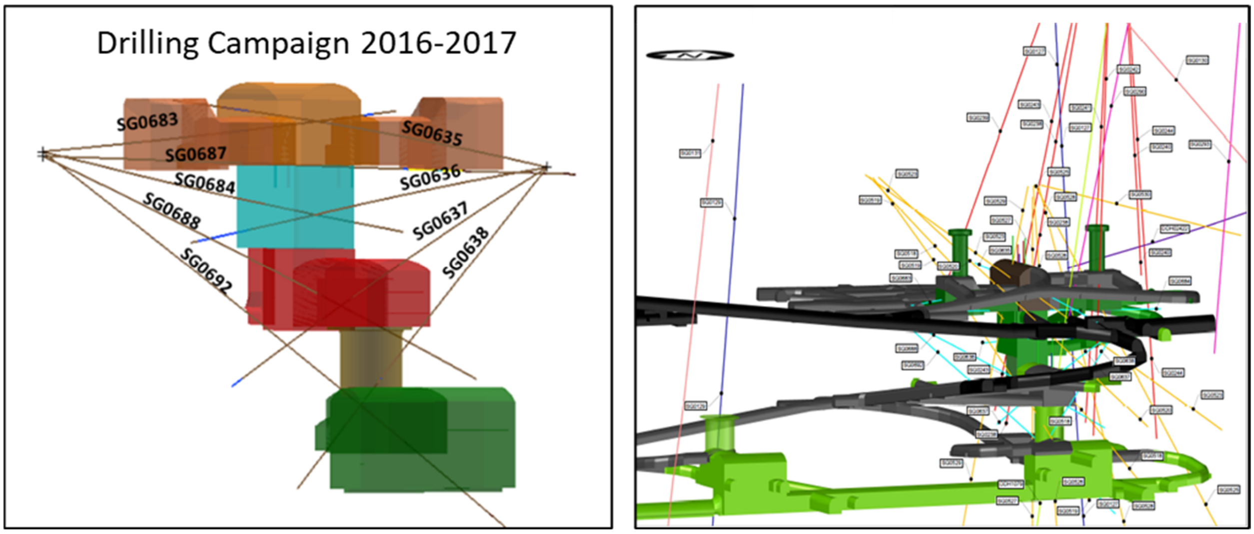


Figure 2 Drilling campaigns in comparison to accesses and cavern design (Pereira et al. 2017)

Table 1 Drilling campaign details (Pereira et al. 2017)

Year	Metres
2007–2009	1,800
2009–2010	600
2012–2013	2,202
2016–2017	1,349
Total	5,951

2.2 Geological and geotechnical conditions

During the design stage, the lithological model considered all the lithological information collected from both the drilling campaigns and the mapping of galleries in the upper levels. In this way, the main recognised units were as follows (see Figure 3):

- Braden sericite breccia (BBS).
- Braden chlorite breccia (BCB).
- Braden tourmaline breccia (BTB).
- Subordinate dacitic porphyry (SDP).

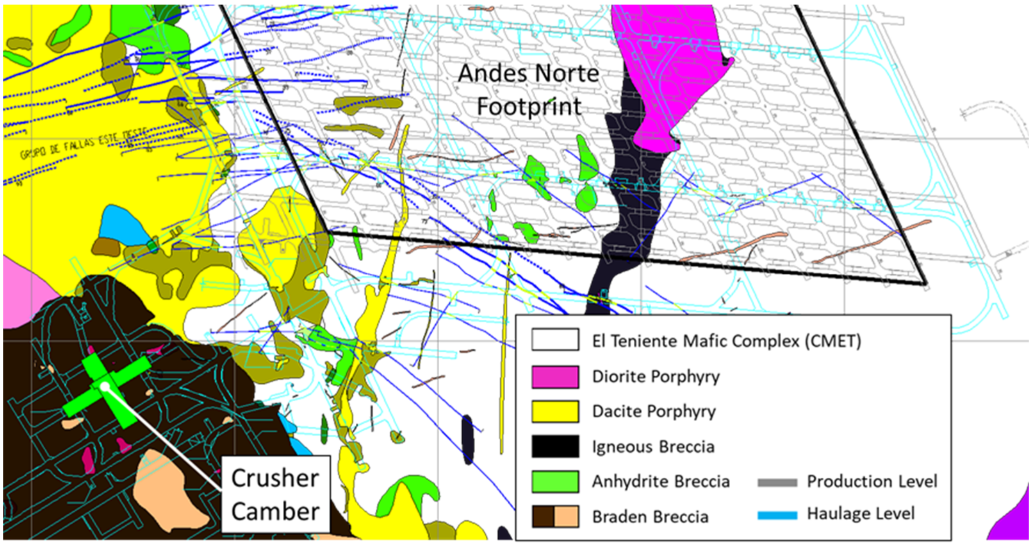


Figure 3 Lithological map, elevation 1808 and production and haulage levels layouts

The contact observed between BTB and BBS and/or BCB is well-defined at the edges. However, the contact between the varieties of BCB and BSB is gradational. The degrees of alteration in both the matrix and clasts do not allow for a clear distinction between the two lithologies at first glance.

According to the geotechnical properties of strength and deformation in intact rock, obtained prior to excavation, the following conclusions were reached:

- The BSB and BCB units have similar properties and are considered as a single geotechnical unit, UG1.
- The BTB unit is identified as another geotechnical unit, designated as UG2.

One noteworthy aspect was the identification of a 19% increase in the deformation modulus (Young's modulus) compared to the same lithological type in the upper levels (Pereira et al. 2017).

2.3 Geological structures

During the design stage, the structural geological model considered information from drilling campaigns and the experience gained from excavations in the upper areas. A schematic perspective is presented in Figure 4. As will be discussed later, the lithological and structural recognition was considered a fundamental element for geotechnical ground control during construction, mainly due to the scale of work (excavation size) and the fact that the excavations are deeper. The main aspects of the structural characterisation were as follows:

- The recognised preferential orientation is northeast (NE) with a sub-vertical disposition.
- Relevant structures exhibit a continuity range of 12–30 m. Low evidence of structural controlled hazard stability was estimated.

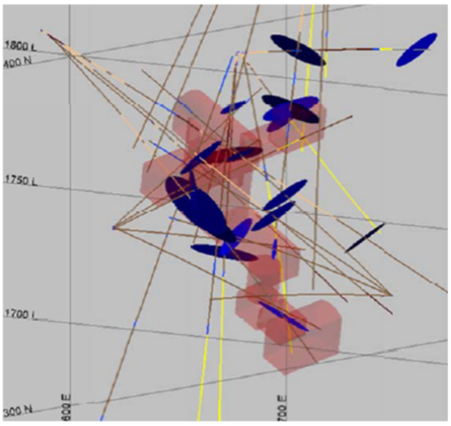


Figure 4 3D structural model around crushing chamber, viewed from the southwest (Pereira et al. 2017)

2.4 In situ stress state

The pre-mining stress state was estimated based on stress measurements using hollow inclusion and acoustic emission techniques (Moraga & Guajardo 2013; Moraga et al. 2017). Additionally, information from drillhole breakouts and the mine-scale model of El Teniente were used to enhance the reliability of the estimates in terms of the orientation of the principal stresses. Table 2 provides the pre-mining stress estimation for the zone of interest.

Table 2 Pre-mining stress state in terms of principal stresses

Principal stress	Magnitude (MPa)	Azimuth (°)	Plunge (°)
Major (Sig1)	54 ± 3	182 ± 10	14 ± 10
Intermediate (Sig2)	27 ± 4	90 ± 10	10 ± 10
Minor (Sig3)	20 ± 2	338 ± 20	75 ± 10

3 Excavation and rock support designs

The definitive support system corresponds to the design to be installed for the overall stability of the excavation. In this regard, it must be kept in mind that a cavern of these dimensions is necessarily excavated in stages following a construction sequence that allows for progress while maintaining the necessary conditions for equipment operation and ensuring the quality of the installation. An important aspect is the minimisation of impacts from repairs caused by blasting and/or equipment. Therefore, several criteria were defined to provide flexibility, integrated with the ground control monitoring plan and geotechnical instrumentation. The main aspects considered were as follows:

- As a general criterion, all excavations are initially carried out in the upper part, creating operational conditions for the installation of the definitive support system.

- In terms of geological and geotechnical considerations, rock support schemes were defined according to excavating sequences and long-term stability, then, the definitive system considers installation in layers. A criterion was established for the time lag between advance support (first layer) and definitive support (remaining layers). In the latter case, a critical area for the installation of the definitive system was defined.
- A support system was defined for temporary excavations, such as the side walls when deepening excavations.

In Figure 5, an example of the rock support system applied to the maintenance cavern (upper chamber of the whole design) is shown.

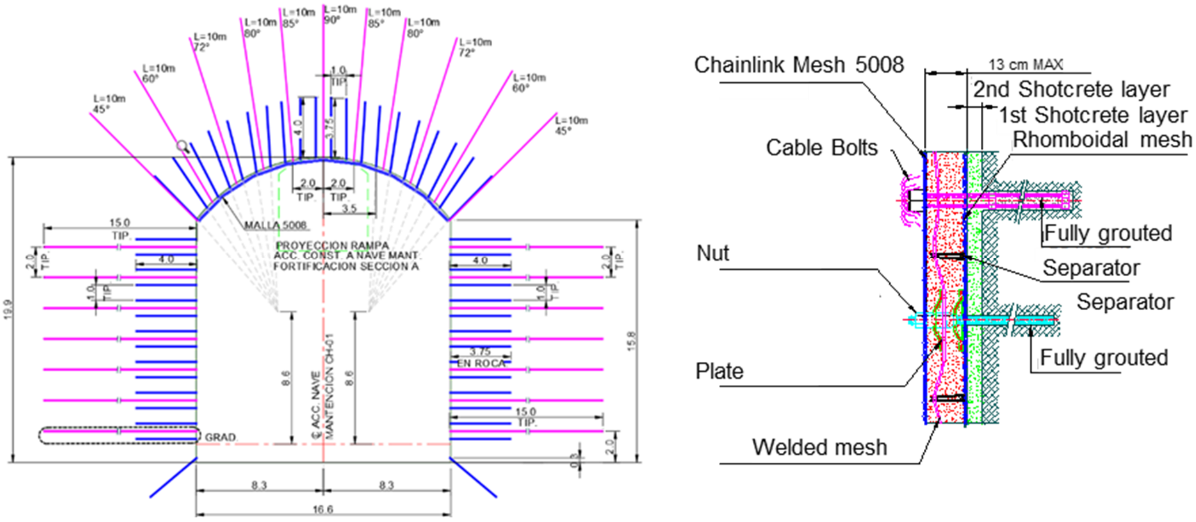


Figure 5 Rock support system of the maintenance cavern (Muñoz et al. 2018)

4 Excavating sequences and geomechanical guidelines

The design and construction guidelines for the crushing system excavations defined that all caverns are developed with a pilot heading and subsequent benching to reach the final section, always starting from the roof and then excavating downward. In the case of benching, the depth should not exceed 7 m in order to minimise the effect of wall convergence. For the planning of the works, a 15 m distance between fronts was maintained to mitigate potential interaction between them. Furthermore, the complete design consists of a set of caverns, which are initially excavated independently and then connected to achieve the final geometry. Excavations sequences were simulated with 2D and 3D numerical modelling in order to identify vulnerabilities during construction (Pardo et al. 2017; Van Sint Jan & García 2018).

As an example, the excavation of the upper cavern was carried out in four phases. It started with entry from a central gallery of the upper level (Phase 1), followed by a sequence of benching to expand the geometry until reaching the final shape of the roof and corners. Then, a descending ramp to the north was constructed (Phase 2), connecting with perpendicular excavations (apron feeder). The next phase (Phase 3) allowed for further descent. Finally, it connected with construction galleries and levelled off to the base of the final design. An illustration is provided in Figure 6.

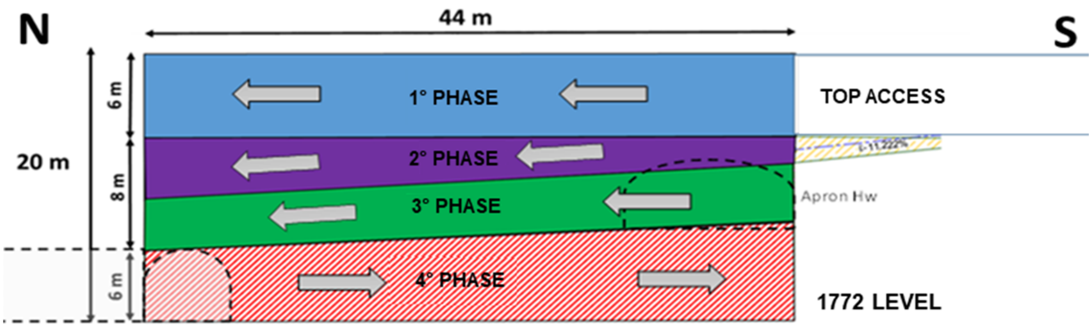


Figure 6 Example of excavation sequence scheme (Valdivia et al. 2017)

5 Geotechnical ground control during construction

Geological and geomechanical ground control was carried out both through onsite inspections and the use of additional information capture tools such as stereophotogrammetry, topographic techniques, and geotechnical instrumentation, with an emphasis on controlling the final geometry and monitoring deformations compared to design estimates, as shown in Figure 7. The methodology includes weekly reports on the status of the instrumentation, and its operational continuity is overseen by the construction management for replacement actions when necessary.

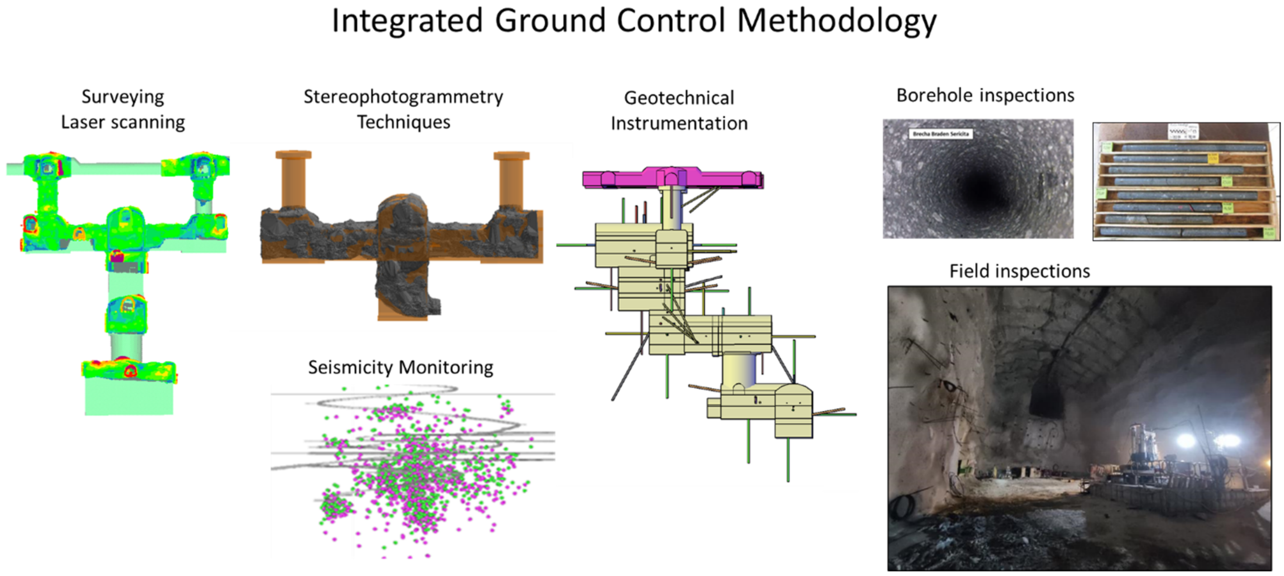


Figure 7 Integrated ground control methodology applied during crusher chamber construction (Landeros et al. 2019)

6 Main challenges during construction.

The main challenges faced during the construction process of the cavern are related to the following aspects:

- Assurance and control of construction quality, in terms of excavation geometries and installation of rock support systems (QA/QC process).
- Early capture of ground control information and effective communication of geotechnical findings.
- Operability of instrumentation systems and operational decision-making based on the response of the rock mass to excavation advances.

- The crusher chamber is a complex of different smaller caverns which are initially excavated separately and then they were joined together (joining of main excavations and monitoring of the geomechanical behaviour of geometrical singularities, such as the intersections of vertical walls and roofs).
- Deformation processes of the excavation contour and installation of additional rock support if required.

6.1 Geometries and rock support systems installation.

As mentioned before, the control of excavation geometry was carried out through the capture of topographic information using laser scanning systems (LiDAR). This information allowed for detailed monitoring as the excavations progressed. On the other hand, the monitoring of rock support system installation is part of the previously defined operational and ground control procedures, which also include stages of quality control and certification of the elements used. The identification of quality and geomechanical findings is interconnected and required daily reporting for operational teams and weekly reporting for project management oversight. Figure 8 illustrates the integration between topographic ground information and onsite inspections.

Figure 8 **Ground control inspections during intermediate construction stage for different caverns and large excavations (Valdivia & Parada 2020)**

6.2 Operability of geotechnical monitoring instruments

Based on the experience from similar excavations at El Teniente mine, the observed behaviour during excavation stages, and the relevant geotechnical findings during construction, the design of applicable instrumentation for both the construction and operation phases defined the installation of extensometers, load cells, inclinometers, and monitoring holes in walls, floors, roof, as well as rock support elements. This system allowed for monitoring of loading and deformation processes in response to construction sequences, improving the capture of information in developments and the final considerations for coupling between large-scale excavations such as caverns and hoppers.

It is worth noting that the location of the instrumentation was adapted based on ground conditions, aiming to achieve the best operational strategy and ensure long-term operability. Figure 9 illustrates the general arrangement of the installed instruments along with an example of designed protections for construction phases as a measure against potential operational damage.

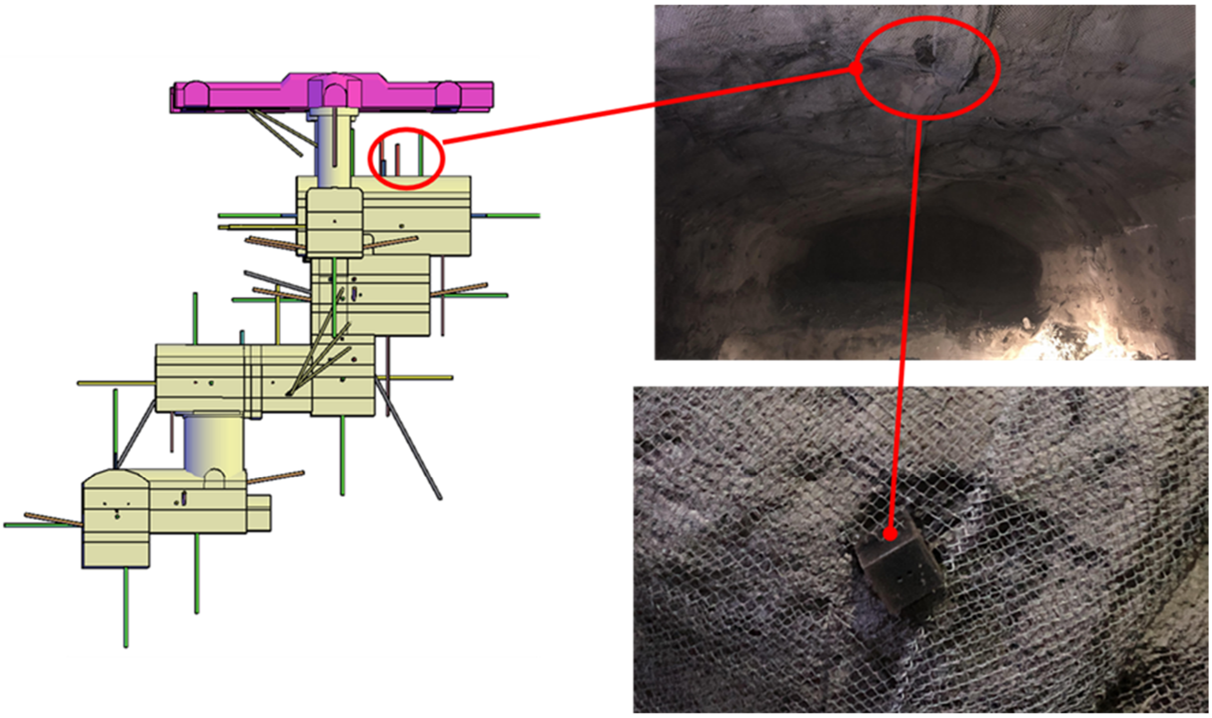


Figure 9 Overall instruments locations and an example of collar protection against operational damage

6.3 Complementary rock support installation due to deformation processes

In June 2020, during the construction of the final phase (Phase 4) of the maintenance cavern, the extensometer installed on the south wall alerted an increase in deformation rate, which was expected due to mining and the established sequence. However, after completing the excavation stages, the extensometer continued showing a constant deformation rate without reaching equilibrium, reaching a cumulative deformation of 27 mm at the anchorage of the contour by 8 September 2020 (see Figure 10).

This process was accompanied by the identification of cracks in the shotcrete on the floor of the upper access gallery lookout. The formed cracks were parallel to the main wall and at a distance of 2 to 4 m apart. With this process underway, the remaining capacity of the support system was estimated, and it was decided to install additional rock support systems to initially stabilise the wall and increase the system's capacity for long-term stability (see Figure 11).

This finding was considered significant, and immediate actions were initiated to reinforce the wall. A summary of the actions and recommendations made based on this condition are as follows (Cifuentes et al. 2020):

- Increase the capacity of the support system by installing cables from the crushing room.
- Update the lithological and structural model of the site by conducting 10 diamond drilling surveys, with the purpose of confirming the influence of geological structures.
- Implement operational measures, such as reducing excavated volumes and reviewing excavation sequence details, minimising the temporary exposure of unconfined final walls.

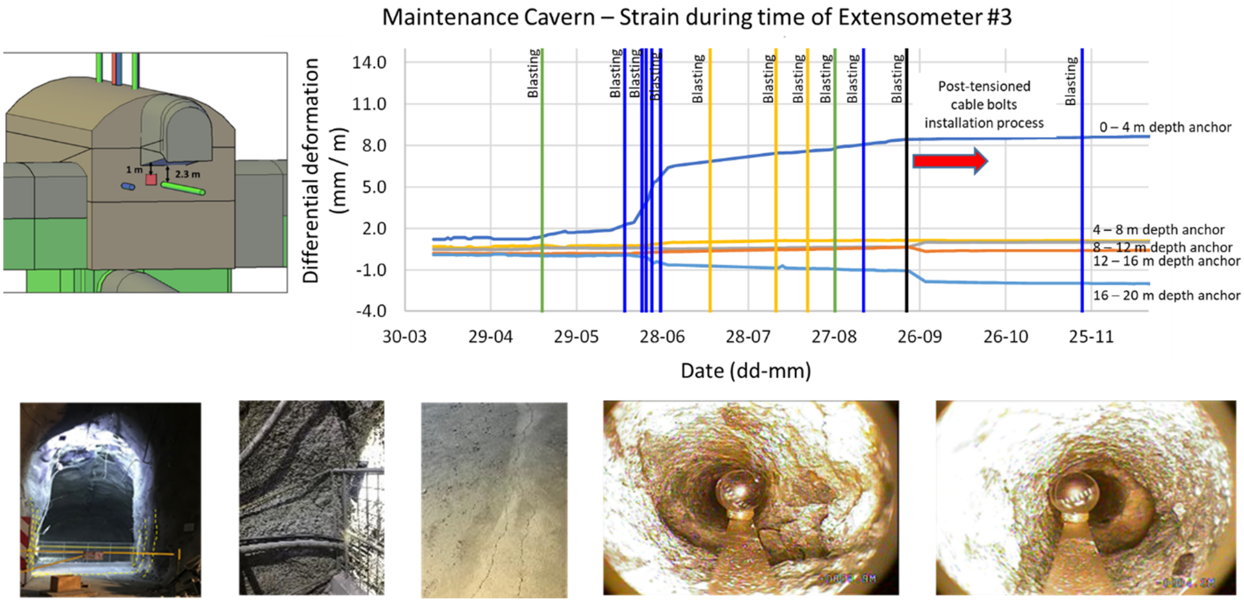


Figure 10 **Deformation process and cross-information between instruments, measurements and field inspections, which required the installation of complementary rock support elements**

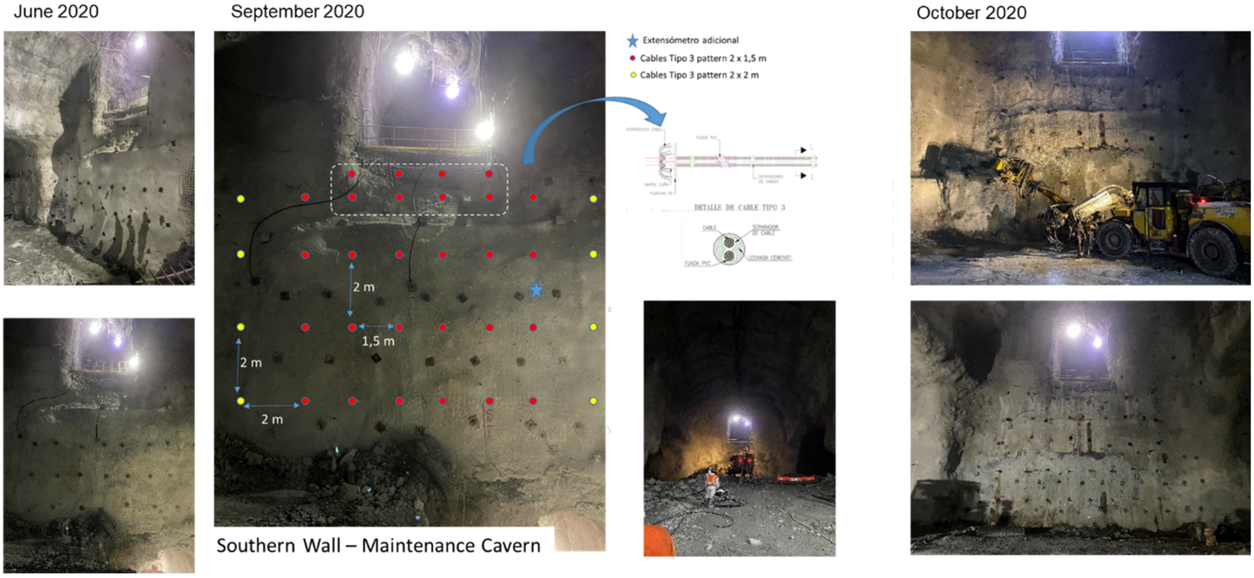


Figure 11 **Complementary rock support installation process**

7 Conclusion and final comments

The excavation of Crusher Chamber 1 in the Andes Norte project is a key component of the future mineral handling system. The design of excavations and rock support systems, along with geomechanical considerations during construction, were aimed to prioritise overall stability. The main challenges faced during the construction process of the cavern were related to the following aspects:

- Assurance and control of construction quality, in terms of excavation geometries and installation of rock support systems (QA/QC process).
- Early capture of ground control information and effective communication of geotechnical findings.
- Operability of instrumentation systems and operational decision-making based on the response of the rock mass to excavation advances.

- Joining of main excavations and monitoring of the geomechanical behaviour of geometric singularities, such as intersections between vertical walls and horizontal roofs.
- Deformation processes of the excavation contour and installation of additional rock support, if required.

To achieve these main challenges, a practical methodology for monitoring and controlling the construction site was proposed, incorporating various elements that facilitated early identification of findings and decision-making when necessary. Additionally, different reporting instances and frequencies were adapted, considering the scope and interests of each multidisciplinary working group.

The methodology considered the following aspects:

- Field inspections performed by geologists and geomechanics engineers.
- The use of additional information capture tools such as:
  - Stereophotogrammetry. This element required some adaptations to achieve the proper data collecting of large excavations.
  - Topographic techniques such laser scanning (LiDAR) to control geometries and excavated volumes.
  - Geotechnical instrumentation, with an emphasis on monitoring deformations. For this purpose, several estimations were performed during design stage, in order to have reference values that could trigger operational actions, like the example described in this document. One important challenge was related to keep all the instruments available during the construction and not only focused on the long-term stability.

Acknowledgement

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