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Construction method and support design of the mineral transfer system at the Andesita project, El Teniente mine

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Abstract

Within the growth and deepening plans of El Teniente mine, the Andesita project corresponds to an ore production sustaining project located in the northwest part of the deposit, under the old productive level Quebrada Teniente.

The lithologies present in the Andesita project exploitation polygon correspond mainly to the El Teniente Mafic Complex (CMET) and, to a lesser extent, the intrusive dacitic porphyry. Minor bodies of dacitic porphyry igneous breccia, porphyry latite, hydrothermal breccias and quartz dykes are also recognised in the sector.

The project includes the execution of large materials handling infrastructure works such as chutes with a capacity of 1,700 t, located outside the footprint from where, through electro-hydraulic equipment located at the base of the chute, metal trains are loaded to transport the ore through the Teniente 8 level to the surface.

This work corresponds to a consolidation of the geotechnical characterisation, ground support criteria, strategy in the excavation stages, geotechnical monitoring, relevant findings during construction and lessons learned during construction in order to generate the baseline for future chutes. It should be noted that the location of these vertical excavations is outside the area considered to be affected by the abutment stress. This guarantees the useful life and strength productive continuity of the ore transfer system in this sector.

Keywords: *El Teniente, large infrastructure works, geotechnical characterisation, ground support criteria*

1 Introduction

Transfer system 1 of the Andesita project is the first large excavation (of nine to be built) that will make up the ore handling of the mine in its productive stage. It consists of three vertical excavations that will allow the transfer of the ore from the production level (elevation 2010) through a dump point which connects to a square ore bin that finally connects to a chute located at the Teniente 8 level or the haulage level (elevation 1980). The total height of the handling system is approximately 48 m and it has a total design volume of approximately 5,128 m^3. Figure 1 shows the general layout of the transfer system with all of its components.

A relevant advantage of this infrastructure is that it is located outside the abutment stress zone and transition zone ahead of the advance of the subsidence front, ready for when the Andesita project enters production.

Once the design of transfer system 1 was determined, several geotechnical and geomechanical analyses were carried out to evaluate the stability of the three excavations in their construction stages and to establish guidelines for the control of the excavations themselves, as well as for the ground support. This work consolidates the geotechnical characterisation, ground support criteria, strategy in the excavation stages, geotechnical monitoring, relevant findings during construction and lessons learned to generate a baseline for future ore bins.

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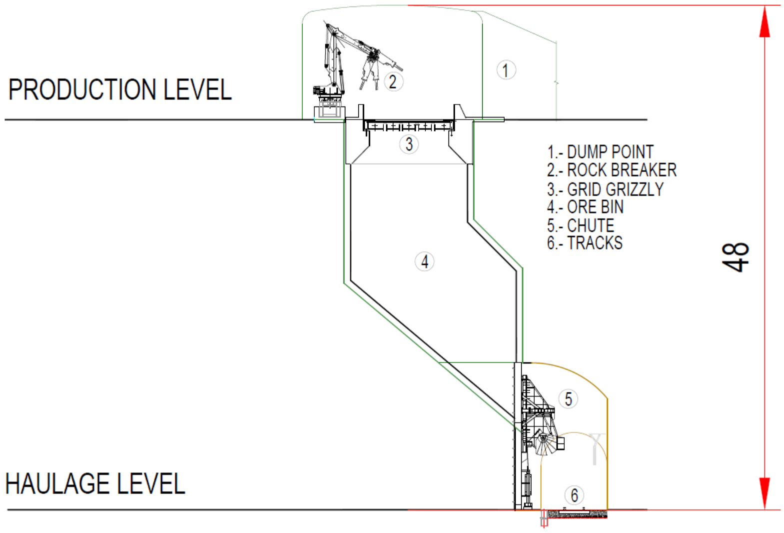
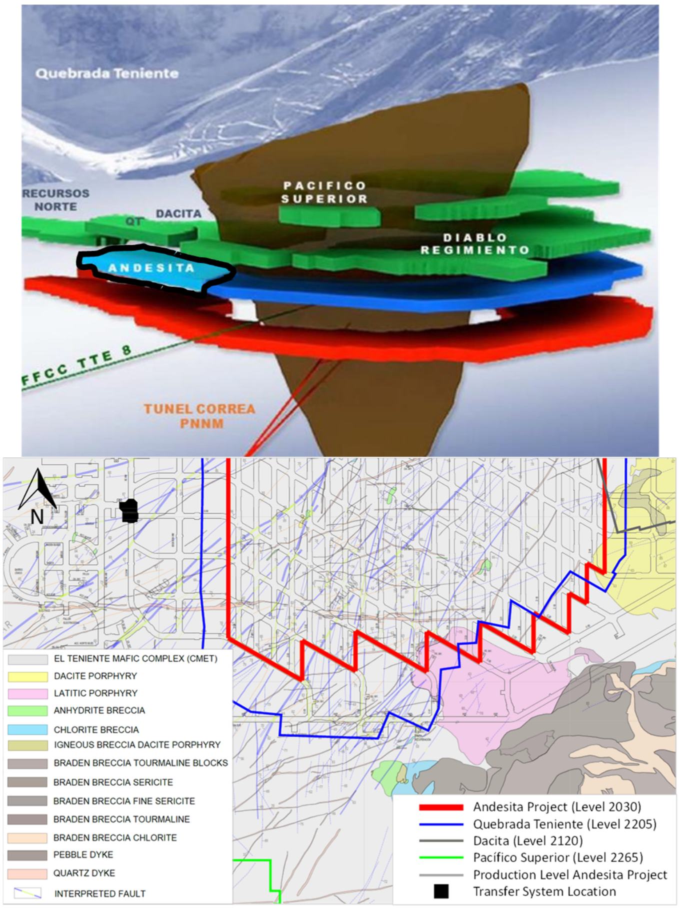


Figure 1 General arrangement of transfer system 1, Andesita project

In Figure 2, transfer system 1 is located to the northwest of the Braden Pipe and is 100% emplaced in El Teniente Mafic Complex (CMET) lithology.



(a) (b)

Figure 2 (a) Isometric view of the Andesita project's location; (b) Plan view of the transfer system

2 Geotechnical characterisation

2.1 Drilling campaign

Near the future location of transfer system 1, about five drill holes were drilled with lengths of 70 and 100 m (with a total of 450 m drilled) to obtain more information for the geological and structural characterisation of the system (Figure 3 and Table 1).

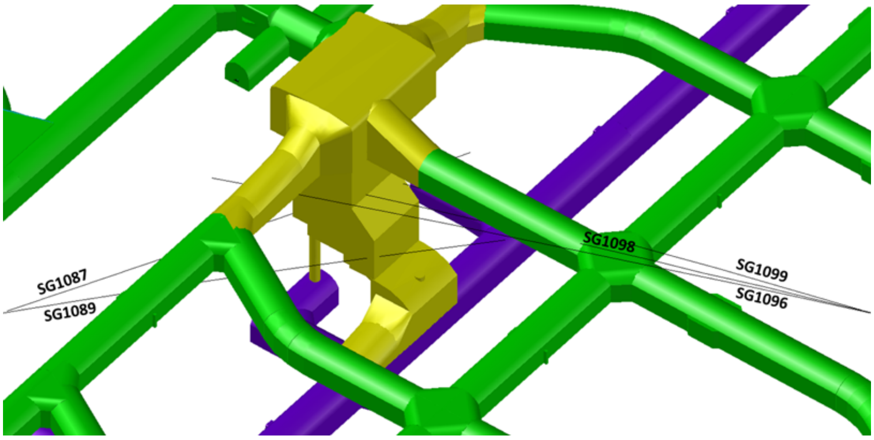


Figure 3 Drilling campaign conducted in the environment of the Andesita project's transfer system 1

Table 1 Detail of the drillings performed

Drill	Metres	Azimuth (°)	Plunge (°)	East (m)	North (m)	Height (m)
SG1087	70	45	6	-55	562	1,992
SG1089	70	28	4	-56	561	1,992
SG1096	110	265	-15	65	599	2,032
SG1098	100	270	-17	65	600	2,032
SG1099	100	275	-18	65	599	2,032

2.2 Geologic and geotechnical condition

As indicated in the previous section, the geological and structural information was provided by the five drill holes and, in addition, geological mapping of the dump point and the chute in advance of the transfer system.

The area where construction of the ore bin is located corresponds to CMET lithology with the presence of quartz dykes. Major faults which have a preferential orientation N45°E were identified, and a series of intermediate faults follow a similar trend to the major faults (see Figure 4 and Table 2). The studied sector is located in a zone of regular-to-good geotechnical quality. It is characterised by an intermediate frequency of soft-filled structures. The dominant mineralogy in this zone is the anhydrite-chalcopyrite association.

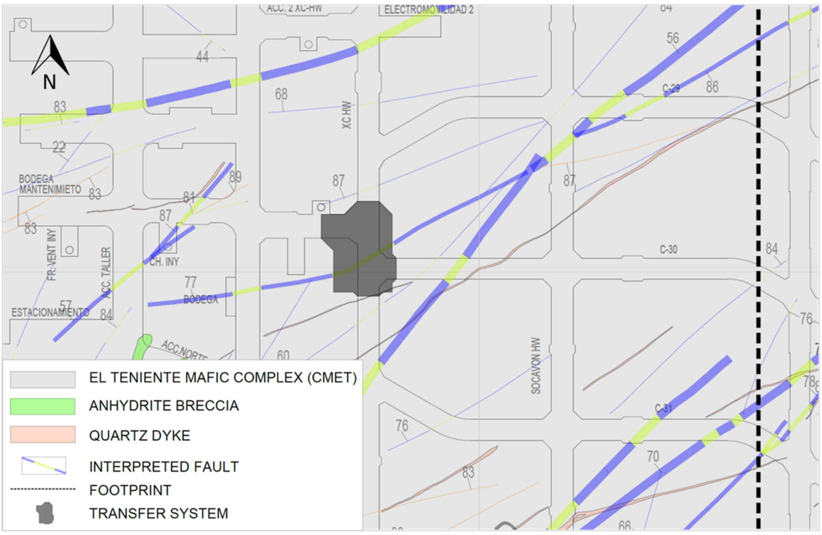


Figure 4 Geological plan view of the production level and the transfer system

Table 2 Geotechnical properties of intact rock (Quezada 2022)

Geotechnical property	Value	Unit
Density	2.8	gr/cm^3
Porosity	0.4	%
UCS	107	MPa
Ti	14	MPa
GSI	80	–
E	51	GPa
v	0.25	–
E/UCS	481	–
Vp	5,135	m/s
Vs	2,831	m/s
σ_{ci}	96	MPa
m_i	5.8	–
UCS/E (Deere & Miller et al. 1996)	B - C	–

2.3 Geological structures

As part of the analysis the main structural domains were determined for transfer system 1. Input comprised geological surveys of horizontal developments (mapping by ADAM photogrammetry) and reconnaissance drilling in the three productive and surrounding levels, considering a circumference of radius 100 m from the centre of the dump point. In this way, eight structural sets are obtained, defining four main and four secondary sets, as shown in Table 3 and Figure 5 (Cifuentes et al. 2022).

Table 3 Summary of main and secondary structural sets

ID SET	Dip (°)	Dip dir (°)	N° data	Type
SET 1	88	333	327	Major
SET 2	90	298	268	Major
SET 3	50	104	304	Major
SET 4	39	73	288	Major
SET 5	57	45	99	Secondary
SET 6	75	36	60	Secondary
SET 7	79	217	43	Secondary
SET 8	37	218	40	Secondary

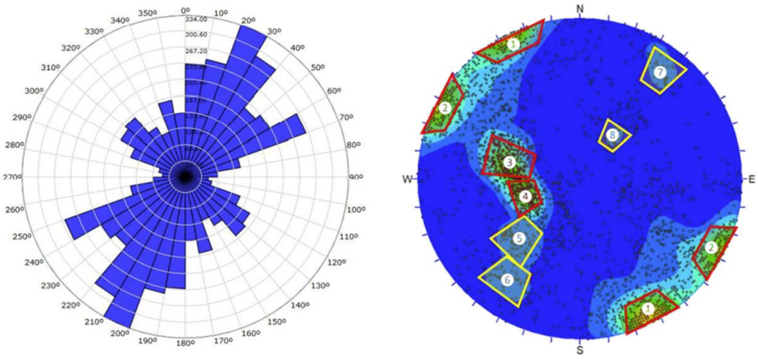


Figure 5 Selection of geological structures with a radius of 50 m, with the centre in the ore bin

The following points are also noted (Jiménez et al. 2023a):

- Most of the faults recognised in the gallery mapping are northeast–southwest oriented.
- Through additional geological mapping collected during the excavation of the dump point and the chute, the lithology is maintained in the CMET.
- At the dump point, two northeast-oriented faults were recognised – (1) N77°E/74°NW and (2) N61°E/76°NW. However, these failures were not identified in the chute.
- A thin quartz dyke was recorded in the chute, which diagonally cuts the access gallery without affecting the overbreak of the sector.
- Based on the drill holes and mapping of the dump point, a structural analysis was carried out for the ore bin, which is shown in Figure 6.

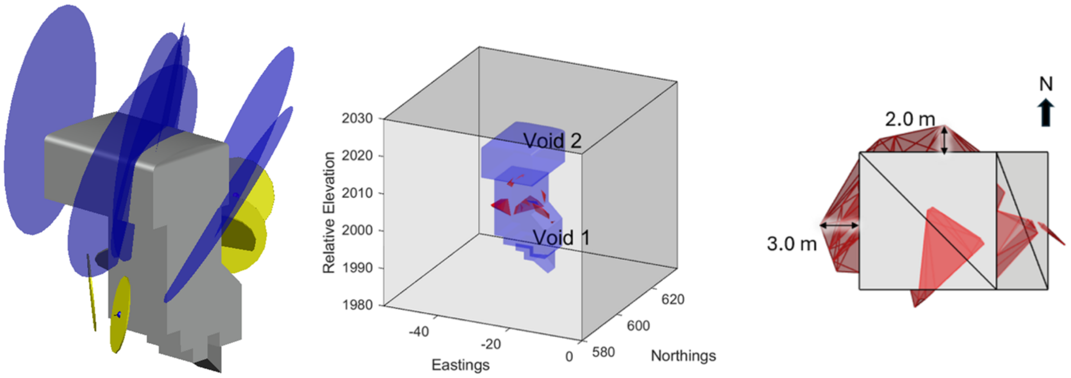


Figure 6 **Structure analysed from drilling and ground control mapping, located in the ore bin (faults and quartz dykes)**

- Blue faults are mapped in galleries and yellow faults are mapped in drill holes.
- In general, no structures subparallel to the walls of the ore bin are observed.
- For this representation of the faults, an influence of 5 m radius and a projected disc of 10 m diameter were considered.
- In a block analysis it could be determined that 90% of the blocks have an approximate volume of less than 13.1 m^3, with an average of 4.4 m^3.
- 90% of the blocks have an approximate size of 4.83 m.
- The maximum possible wedge apex to be formed is 3.0 m in the west face of the ore bin.

2.4 Stress state

To estimate the stress state of the sector, historical stress measurements within a radius of 300 m from the centre of transfer system 1 were considered. Figure 7 shows the spatial location of these measurements while Table 4 shows the principal stress magnitude determined at elevation 2000 from linear regression (Cifuentes et al. 2022).

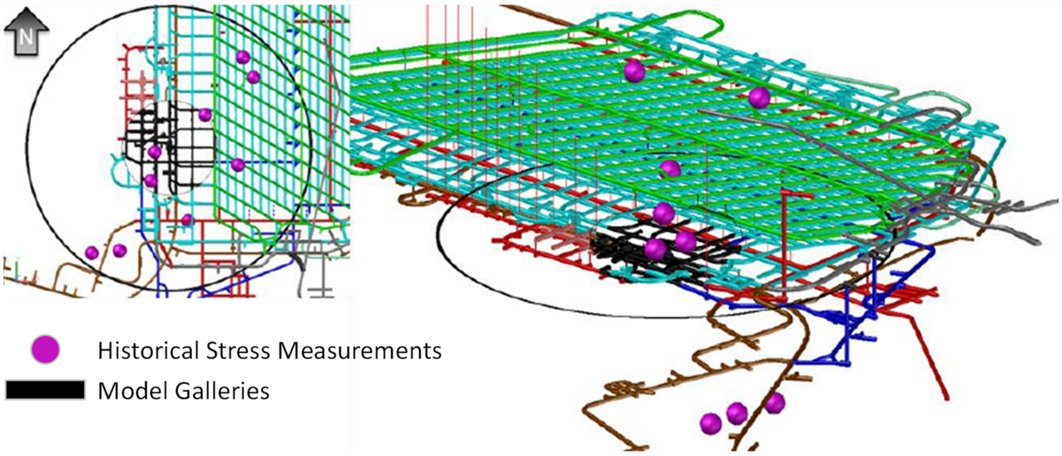


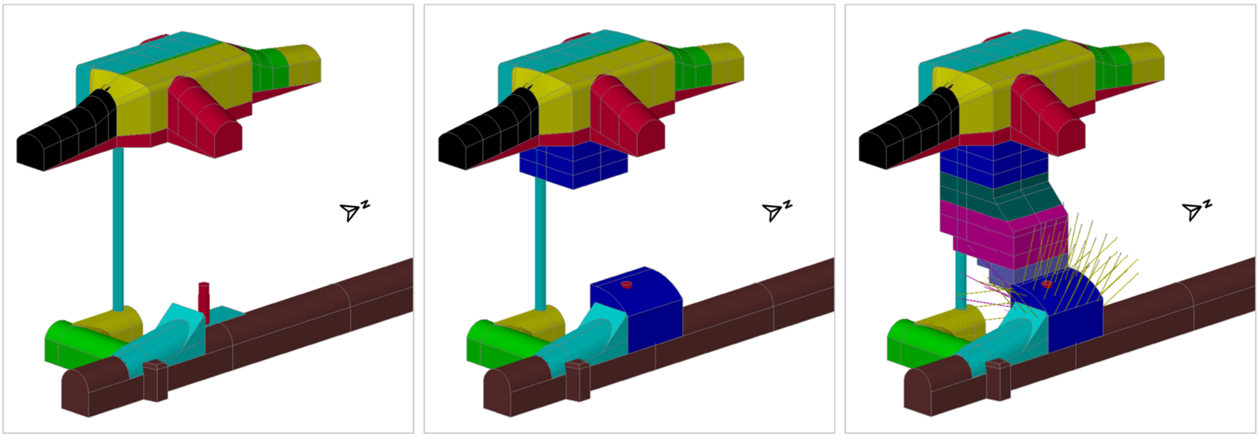
Figure 7 **Spatial location of historical stress measurements within a radius of 300 m with respect to the centre of transfer system 1**

Table 4 Pre-mining stress state in terms of principal stresses

Principal stress	Magnitude (MPa)	Azimuth (°)	Inclination (°)
Major (Sig1)	48	134	–4
Intermediate (Sig2)	33	224	–1
Minor (Sig3)	18	330	–85

3 Construction sequence transfer system 1

For its first excavation, the Andesita project considered the dump point (with a central gallery and controlled blasting in phases) and a blind hole chimney (1.5 m in diameter and 25.4 m long) coming from the haulage level (chimney gallery), which will serve as a free face in the benches to be made in the ore bin and as an emptying point for muck from the lower gallery of the chimney (Figure 9a). These benches will have a maximum height of 2 m. Once they have been started, the lifting of the chute (Figure 9b) will be carried out from the haulage level to connect the ore bin (Figure 9c).



(a) (b) (c)

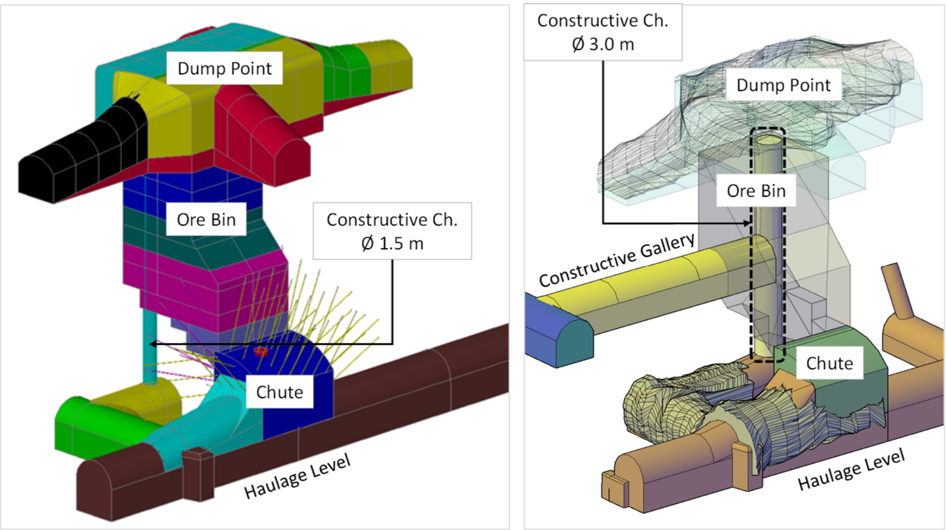
Figure 8 Initial construction sequence of transfer system 1

It should be noted that the strategy for excavating the ore transfer system is characterised by a combination of 'long raising' and 'drop raising' methods, with manual mucking out and controlled blasting from the roof of the shaft to avoid further damage to the shaft visor and overbreak of the ore bin.

In the second stage of analysis, this construction sequence was modified to optimise aspects related to safety, cost and time. The main differences between the optimisation of the construction sequence with respect to the base case are the following (as shown in Figure 9):

- The diameter of the pilot chimney was increased from 1.5 m diameter to 3 m diameter.
- The spatial location of the chimney was adjusted according to the final design wall of the ore bin, being separated 0.50 m from the north and west faces.
- The chimney was developed with a raiseborer, from a lower gallery underneath the ore bin to the dump point.
- The excavation of a constructive gallery was incorporated to receive the sponge muck from the ore bin and to function as a muck retreat for the vertical recesses.
- The new design geometry of the ore bin does consider steps an inclined slope of 50°, and the free face will not be made with an inclined chimney but with blasting in phases.

- For the ore bin, a block of approximately 10 × 10 × 12 m will be blasted in three continuous phases ('slices'). Therefore the ground support will be conducted from a platform supported on the sponge muck resulting from the blasting, which will be removed in a controlled manner from the construction gallery every 2.5 vertical metres.
- It was established that before the blasting of the large block of the ore bin, the excavation and ground support of the chute and the dump point must be completed.



(a) (b)

Figure 9 Constructive sequence base case (a) and optimised sequence (b)

Finally, the following boundary conditions are established, according to this design and the constructive sequence to be executed in the transfer system:

- As an advantage, the Andesita project's transfer system 1 is located outside of the abutment stress zone and transition zone.
- The location of transfer system 1 is favourable to the structural sets.
- There is greater independence of the infrastructure from changes and ore management decisions in the Andesita project footprint sector.
- Spatial location is defined in such a way as to address the growth of the productive area.
- Geomechanical instrumentation (extensometers and load bolts) was considered in the event of a possible deformation of the rock mass, to generate early warnings and ensure its stability during its useful life.
- The constructability of the transfer system allows simultaneous and safe working at the dump point and the ore bin from the upper level, and in the dip of the haulage level.
- Ensuring installation of the designed ground support guarantees the stability of the infrastructure during its useful life.

4 Ground support design and geomechanical guidelines

4.1 Numerical modelling

The purpose of the geomechanical analysis carried out by means of 3D elastic numerical modelling was to calculate and determine the effects of stress redistribution according to the excavations considered in the new sequence. Among the results obtained, the following were identified (Jiménez et al. 2023b):

- Interaction between the construction gallery and the floor at the design level of the pouring station.
- Interaction between the chute and ore bin.

For construction of the model the numerical modelling software Map3D Fault Slip was used. In this model an isotropic, continuous and homogeneous material with linear-elastic behaviour was considered. The model, however, does not consider the major faults; nor does it consider the structural geological conditions present in the sector. The block analysis described in Section 2.3 complements this analysis. Figure 10 illustrates the location of the analysis sector and the geometry used in the model.

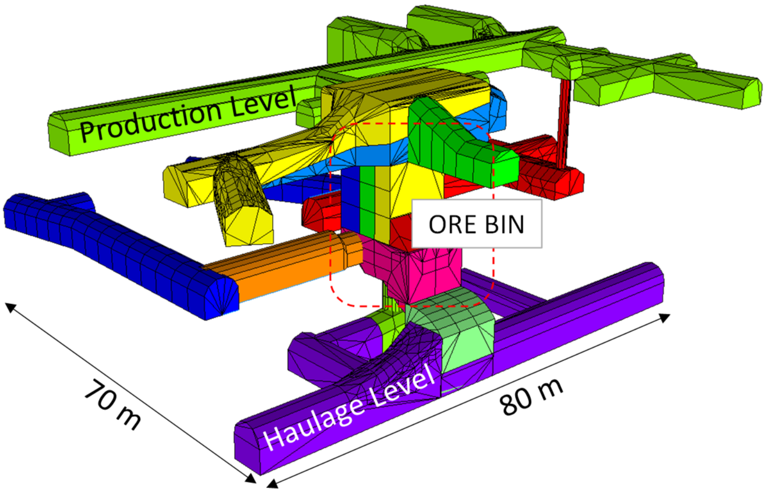


Figure 10 Sector defined for numerical model construction

To validate the stresses used in the model they have been compared with the existing historical stress measurements, revealing an average absolute error of less than 20% for each of the main stresses analysed (Sig1, Sig2, Sig3). In addition, overbreak information taken from the geological mappings data from nearby galleries has been used as a reference point.

4.1.1 Construction gallery

When considering the most conservative and, therefore, the most unfavourable scenario corresponding to the final stage of construction, an abutment stress (stress concentration) of 60 to 70 MPa is evidenced between the production level and the construction gallery at 9.3 m away from the south wall of the ore bin.

Regarding the deconfinement and deviatoric stress, there is a halo of 1.9 and 3.0 m, respectively, in the south wall of the ore bin. The critical zone considered for a Strength Factor (SF) < 1.3 is 4.0 m (average distance) from the ore bin wall, as shown in Figure 11.

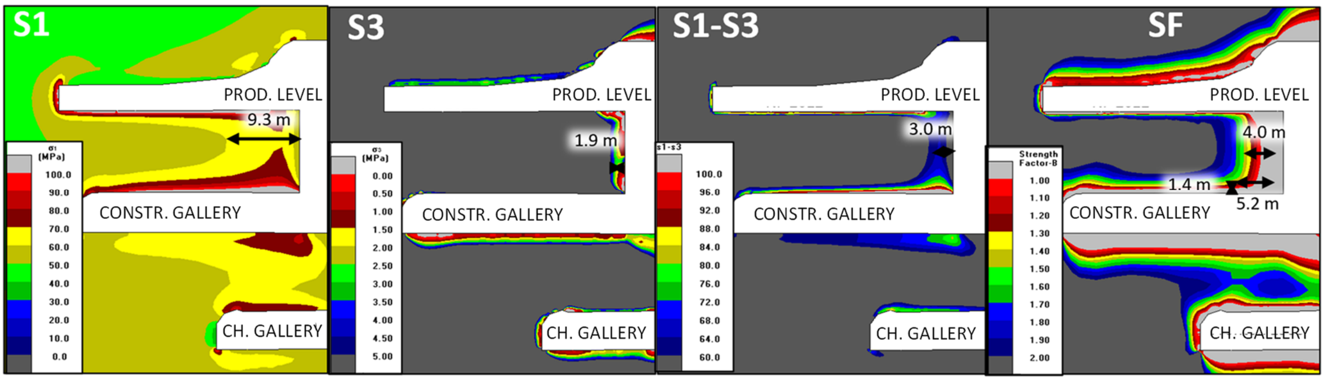


Figure 11 Results' parameters for Sig1, Sig3, Sig1-Sig3 and SF, section north–south

4.1.2 Chute and ore bin

Considering that construction of the dip must be done prior to that for the ore bin, interaction between excavations is generated when there is a distance of 4 m between the roof of the chute and the floor of the ore bin under construction. Figure 12 shows the stages associated with the construction sequence represented by a west–east section profile, and the criterion associated with the deconfinement due to a decrease in the minor principal stress.

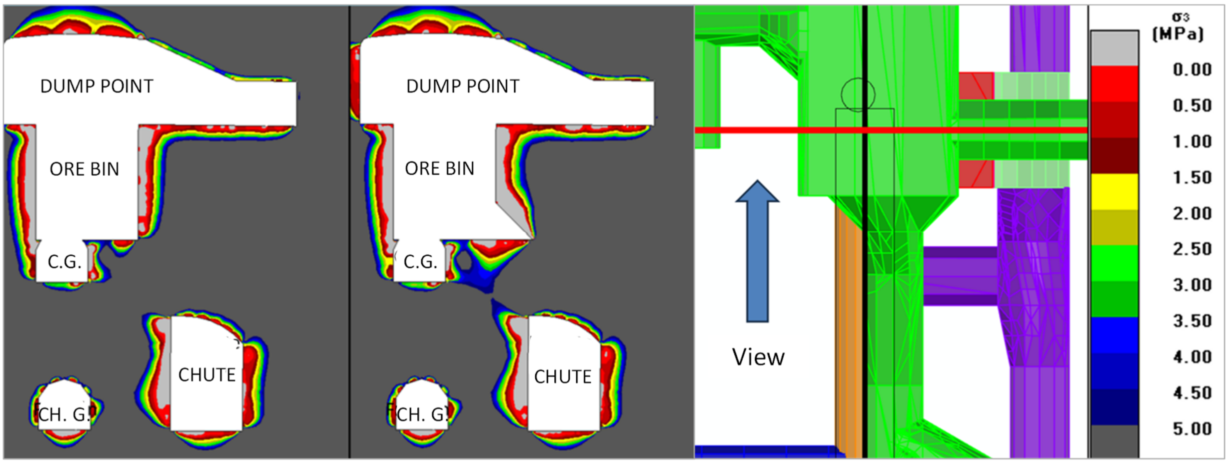


Figure 12 Results of the Sig3 modelling ore bin construction sequence and chute

As the result shows, the interaction explained above can be observed; leaving a vulnerable zone for personnel in charge of the tasks that allow the last steps of the hopper construction.

4.2 Ground support

Based on structural analysis and numerical modelling, the type of fortification for the excavations was defined according to the following criteria (Valdivia et al. 2023):

- useful life (main infrastructure) – working time (15 years), support elements used and tested in the El Teniente division were used
- force balance – reinforcement and retention to disturbed areas (static demand/block). Estimation from numerical models
- damage mitigation – criteria to construction sequence, simultaneous fronts, nearby excavations
- benchmarking – for fortification of large excavations
- numerical tools – to review critical areas (Map3d, OPS).

Based on the above, fortification elements were defined with a time lag between the development and final ground support stage, and were considered both in temporary and long-term designs; as in the case of the dump point, and considering the exposed areas and interaction of the developments. The defined fortification elements to be used are shown in detail in Tables 5 and 6.

Table 5 Ground support considered according to excavation to be developed (green, considered; red, not considered)

Excavation	Bolt	Cable bolt	Mesh	Shotcrete	Steel set
Dump point	🟢	🟢	🟢	🟢	🔴
Ore bin	🟢	🟢	🟢	🔴	🔴
Chute	🟢	🟢	🟢	🟢	🔴
Construction gallery	🟢	🟢	🟢	🟢	🟢
Pilot chimney gallery	🟢	🟢	🟢	🟢	🔴

Table 6 Ground support specifications

Type	Specifications
Bolt	Ø 25 (mm), A280-420 H, L: 3.5 to 4 (m)
Cable bolt	Ø 15.24 (mm), A270k ASTM A416, L: 8 to 9 (m)
Mesh	G80/4, Ø 4 (mm), Ø 80 (mm)
Shotcrete	G25
Steel set	ASTM A36; F_y 248 MPa; F_u 400 MPa

To reinforce the construction gallery that interacts with the south wall of the ore bin, from where the muck is to be removed, 10 m of steel set and cables bolt were considered for installation on the crown. As an example, the following Figure 13 shows the ground support design for the dump point.

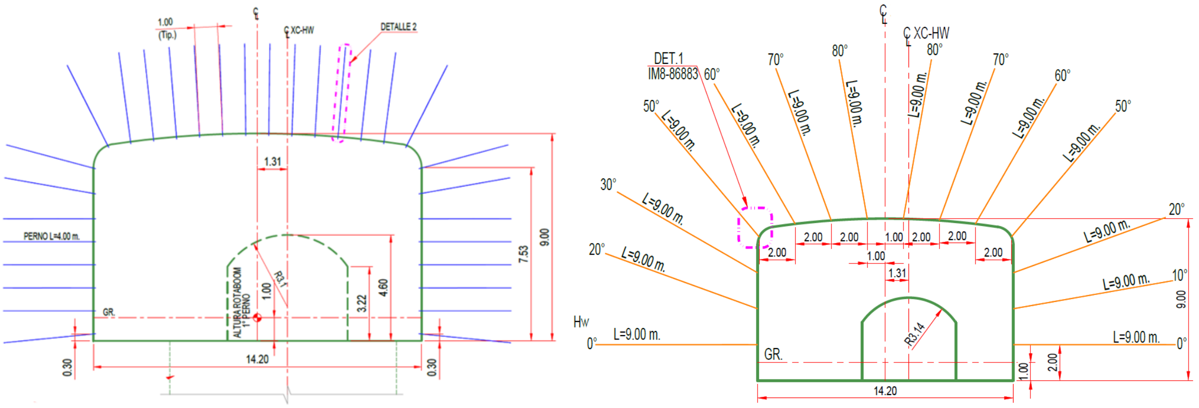


Figure 13 Ground support design for the dump point; bolt (4 m length) and cable bolt (9 m length)

Generally speaking, the design and construction guidelines for the excavations of transfer system 1 defined that all excavations would be developed with a pilot work and subsequent stripping. For example, a pilot gallery was first built at the centre of the dump point excavation, and then the phases were carried out until the final design was reached. Each of these phases was reinforced with the final design's ground support system.

4.3 Geomechanical guidelines applied during the execution of the transfer system

Based on the geomechanical analysis and on this new construction sequence, the following guidelines and considerations were established (Jiménez et al. 2023b):

- Development of the chimney hopper should be carried out by blasting it with the excavation debris. No blasting of nearby developments less than 15 m from the chimney should be carried out.
- Auscultation with a borehole camera in the pilot flue of the constructive chimney should be performed to verify structural sets.
- Excavations of the transfer system must be carried out with electronic delays to mitigate damage to the rock mass. Control and validation of the blasting was done by a specialist company.
- Before excavating the ore bin, installation of the geomechanical instrumentation, which includes load pins and extensometers, must be ensured before development of the ore bin.
- The condition of the shafts must be checked before blasting of the complete block of the ore bin, and the feasibility of blasting must be verified to ensure the quality of the drillings. This analysis must be carried out with a specialist blasting company for validation.
- The construction gallery, as it is adjacent to the south wall of the ore bin and below access to the dump point, must installed with robust fortification consisting of steel frames and cables.
- According to the numerical modelling, cable bolts had to be installed before blasting of the ore bin to ensure stability in the crown of the pilot chimney gallery, which interacts with the ore bin.
- To avoid overbreak and underdraw of the rock mass, the use of emulsion and electronic detonators was recommended.
- Any ground support damaged by additional blasting due to underdraw and/or operational deviation must be replaced according to design.
- Continuous control of the overbreak by means of a topographic survey via scanner of all excavations associated with the transfer system must be maintained.

5 Conclusion

- The execution of transfer system 1 has responded to the boundary conditions defined according to its design, and geomechanical and geostructural vulnerabilities.
- The excavation and construction of transfer system 1 of the Andesita project generates understanding about the execution of the rest of the transfer systems to be built and should become the reference for continuous improvement.
- During its execution, this type of excavation must be carried out with rigorous planning control; otherwise compliance with established deadlines will be jeopardised.
- Topographic control of the excavations was carried out by means of a total station, ADAM photogrammetry and a flight scanner using an ELIOS3 drone. In this way, control of the design is maintained and early decisions on its construction are facilitated.
- Geomechanical ground control is key to ensuring the correct installation of designed support which seeks to guarantee the stability of the excavation.

Acknowledgement

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