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Automated reinforcement of orepasses in the Andes Norte project

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Abstract

After 118 years of operation, the emblematic worksite El Teniente, from Codelco, aims to expand its lifespan another 50 years via site exploitation through the Nuevo Nivel Mina project. The initial stage, the Andes Norte project (PAN), amounts to 2,020 million tonnes of reserves with average grades of 0.86% copper and 0.022% molybdenum. This will translate to more than 17 million tonnes of fine copper over the 50-year operation (which commenced in 2018). The configuration of the project comprises exploitation by the panel caving system, with an orepass system through orepasses inside the footprint streets and a level scheme typical of the El Teniente mine site: sinking, production, ventilation, transporting and crushing, and panel caving.

This article describes the construction methodology and mechanised shielding of the orepasses developed for the PAN. Based on excavation of the 1OP-X3AS shaft, which was unsuccessful due to the collapse of the orepass in the reaming stage of the final section, they were designed to improve the construction method. The reinforcement process started with shotcrete spraying using remote-controlled remote equipment. Then the sequence of mechanised shielding of the shaft (BMP) began and ended with concreting of the annular space between the shield and the walls of the shaft. The use of micropiles prior to the drilling of the pilot shot in some of the constructed pouring points was also analysed. Lessons learned and some particularities solved during their application in order to start the ore transfer system, written by the team of construction engineers who led its development, are included.

Keywords: *orepass, mechanised shielding, automation*

1 Introduction

The Andes Norte project (PAN) is the first stage of the El Teniente Division deepening process below the level of transportation (Teniente 8 Railway). Subsequently, the next stages of Nuevo Nivel Mina project (NNMP) can be developed; namely Andes Sur, Pacífico Norte, Pacífico Central and Pacífico Sur.

Ore movement from the mine site to the plant starts with transportation via the production level (mine elevation 1862) using load–haul–dump (LHD) equipment that discharges the ore into pass shafts connected to the intermediate transportation level. Here load trucks transport ore to the hoppers that feed the primary crusher.

As part of the transfer system, the PAN requires 13 orepasses (OP) completely enabled in the level of transportation along three partial works (Figure 1). Thus, it is considered to develop 16 orepasses for the development of these discharge points.

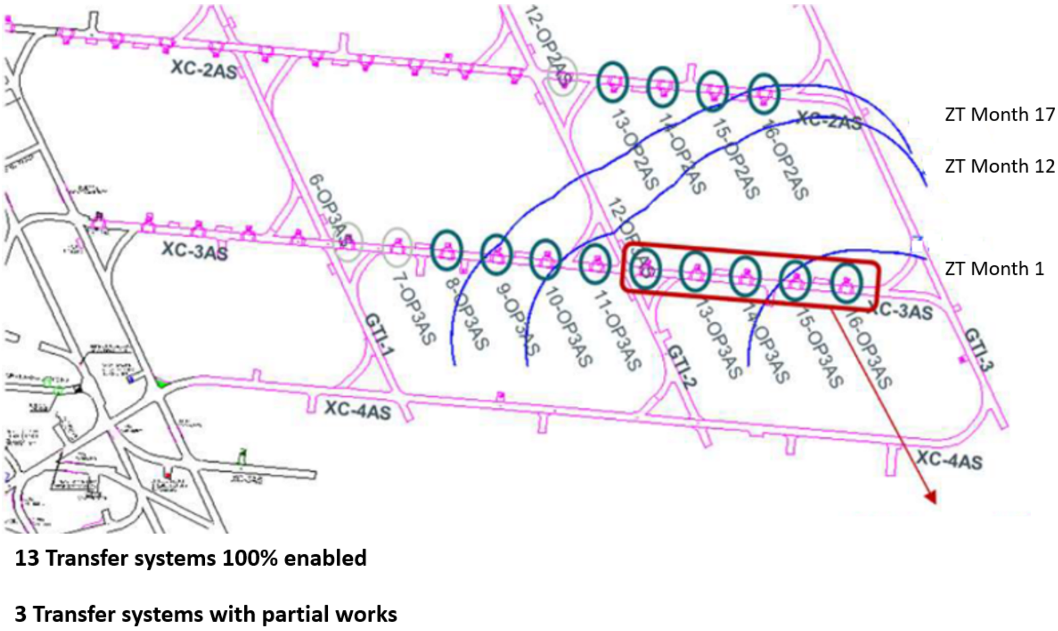

Figure 1 Orepass system to be developed in the NNMP — Andes Norte (Codelco 2017). ZT = zone transition, XC = crusader, AS = Andes south

The material management system defined for the PAN involves the construction of OPs from the production level (level production [NP] elevation 1862) to the intermediate transport level (intermediate level transport [NTI], elevation 1808). These vertical works will be carried out initially with the construction of a 30 cm-diameter pilot shaft (Ø: 12 1/4”, 31.1 cm). Later, total excavation will be undertaken using raise boring methodology with a 4 m diameter (in the final section). Once the excavation is completed, it was reinforced by the mechanised installation of armour-type support elements using a mechanised shaft armouring machine (BMP) designed by the PAN engineering team, which can be seen in Figure 2 (Landeros et al. 2019).

The total height of the orepass is 50 m, level production is 1862 and level transporting is 1808.

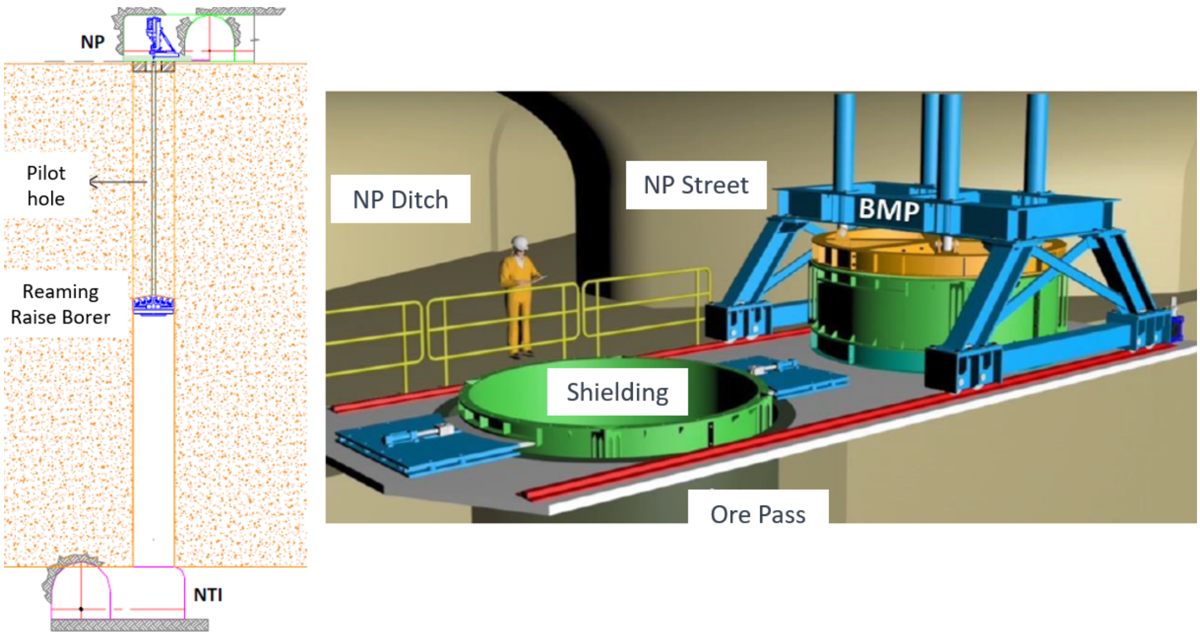

Figure 2 Representation of constructive methodology orepass at AN-NNM (Codelco 2017)

2 Geotechnical data

2.1 Lithology

The AN mining zone is characterised by the presence of mostly El Teniente mafic complex rocks (CMET) which, in its central part, are intruded by felsic bodies plus hydrothermal and igneous breccias.

- CMET corresponds to a rock of dark aspect constituted by diverse lithological types. In the sector of interest, the main subtype is gabbro in a fine phaneritic texture that is equigranular and shows the presence of plagioclase phenocrysts.
- Dioritic porphyry (PDI) is a white to greenish-white rock with a porphyry texture formed by plagioclase phenocrysts and, in a subordinate manner, biotite books (rectangles). It is located towards the central part of the beginning of production.
- Anhydrite-quartz hydrothermal breccia (BXANH-QZ) is preferentially developed in the contacts of the dioritic porphyries that form the CMET, incorporating fragments of mafic and felsic rocks. These have been subdivided according to their cement content in anhydrite-quartz hydrothermal breccia.
- Igneous breccia of PDI (BXPDI) is preferentially located in the contact between the rocks of the CMET and the PDI that instructs it, developing lengths from a few centimetres to tens of metres. They usually occur as fragments of CMET in a matrix of dioritic porphyry.

2.2 Structure

The types of geological structures recognised in the primary rock in AN are faults, stockwork veins and fractures. All of these, except the fractures, have different mineralogical associations as fillers. In the construction area of the 9OP and 12OP transfer drifts, north–west–south–east oriented faults with 77–80° to southwest dip are observed; in 9OP, northeast–southwest oriented faults with 80–85° to southeast dip are observed; and in 16OP, northwest–southeast oriented faults with 60° to northeast dip are observed (Figure 3).

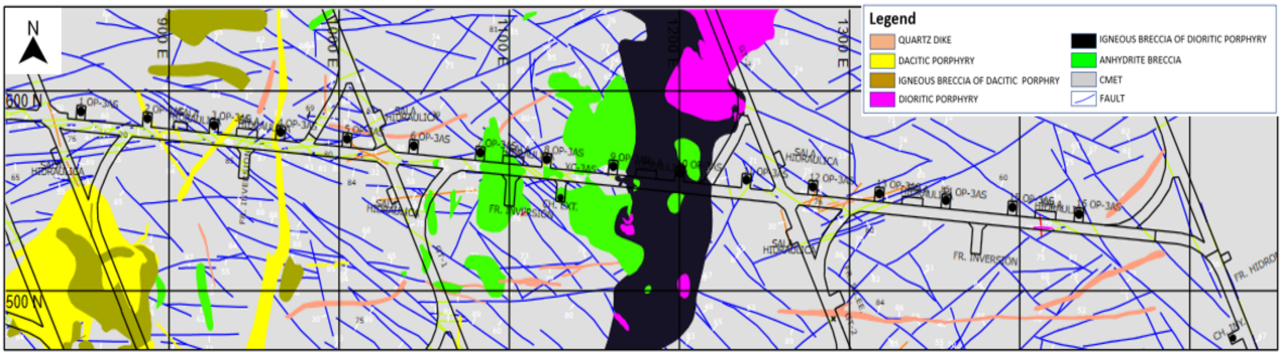

Figure 3 Lithological PAN — Intermediate transportation level (Codelco 2023)

3 Construction methodology

3.1 Methodology test onset on 1OP

Due to the high importance of orepass at the NNM — and with the purpose of constructing one using raise borer methodology as the first objective, followed by testing of the BMP mechanised armour methodology as the second objective — the construction of the 1 OP 3 AS trespass pit was initiated in November 2018 in the AN-NNM footprint.

In this excavation project, no preconditioning of the massif was carried out in the excavation environment. While the 10P is located on the hanging wall side, focus was instead on the footwall side of the developments due to construction considerations.

At El Teniente, manual installation of the armour rings has traditionally been employed. However, this change in construction methodology is based on avoiding exposure of the people inside the vertical excavation during the entire process (see Figure 4).

> *'According to the proposed methodology, the raise borer does not consider connecting in its totality to the upper level and, according to operational definitions, a 4 m rock bridge (Chiflón) must be left, which must be excavated with explosive to definitively connect the NTI with the NP. According to the problems recorded in the execution of the 1OP3AS pit, the singularities begin to manifest (mostly) at the moment when the reaming is being completed, that is, before reaching approximately 4 m below the level of the NP'* (Landeros et al. 2019).

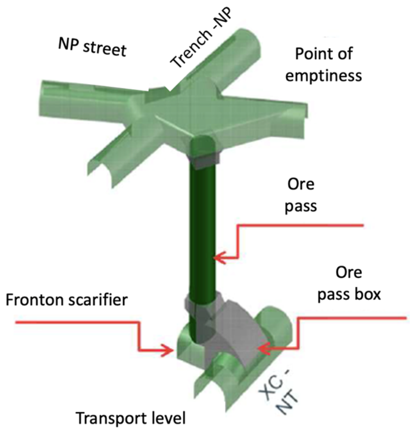

Figure 4 Transfer system AN-NNM (Codelco 2017)

> *'In November 2018, the construction methodology test of the Andes Norte project – Nuevo Nivel Mina (AN-NNM) transfer system shafts was started. The test consisted of initially performing a pilot shot of diameter 12.25, subsequently the excavation of shaft 1 OP-3AS with raise borer equipment to full section and finally the mechanised shielding of the shaft from the production level to the transport level through the use of equipment devised and designed for this purpose. The purpose of the test was to obtain operational information on the construction of the shaft and the implementation of the mechanised armouring equipment. During the excavation of this shaft there was an increase in the seismic response in its surroundings, which triggered the activation of geological structures (preferably sub-vertical) generating the detachment of large rocks, evidenced in the transport level (Figure 5), which caused the over-excavation of the shaft, modifying its design geometry. In addition, cracking of the shotcrete was evidenced at the pouring point at the production level.'* (Landeros et al. 2019)

Figure 5 Rockfall in pique, fall at transportation level

3.2 Construction methodology of orepasses

It was determined that prior to the orepass (pilot hole) construction, a geo-structural characterisation sheet must be prepared (which is fed back during the pilot shot process) in order to develop a full section reaming plan that considers geological structures identified during the construction of developments adjacent to the shaft.

> *'The selected construction methodology considers to previously perform hydrofracturing and then proceed with the drilling of the pilot shot and the reaming of the pit to a final section of Ø 4.0 [m] diameter keeping the pit confined with the detritus of the same reaming in order to avoid a larger open area inside the excavation, at a maximum distance of 2.60 [m] between the level of the detritus and the reaming head. The above must be rigorously controlled to avoid, on the one hand, over-excavation and, on the other hand, jamming of the reaming head, which will be removed by the production level.'* (Tobar 2020)

The ground support installation process starts with shotcrete spraying (with remote-controlled equipment) carried out by means of mechanised shotcrete spraying equipment. This procedure is performed in a sequential and descending way together with the systematic repelling of the detritus that remains confined in the pit. Once the previous process is finished, the installation of the mechanised rockfill shielding (BMP) equipment is carried out. This performs the shielding of the rockfill in a mechanised and descending way, finishing the process with the concreting of the annular space between the shield and the rockfill walls (Figures 6 and 7).

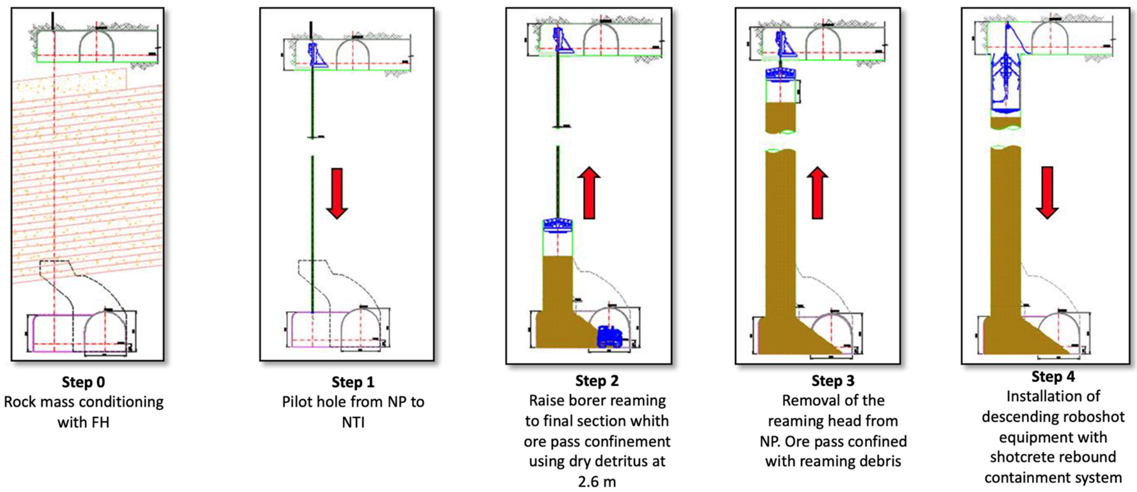

Figure 6 Construction method orepass 5 OP XC3AS (Landeros et al. 2019)

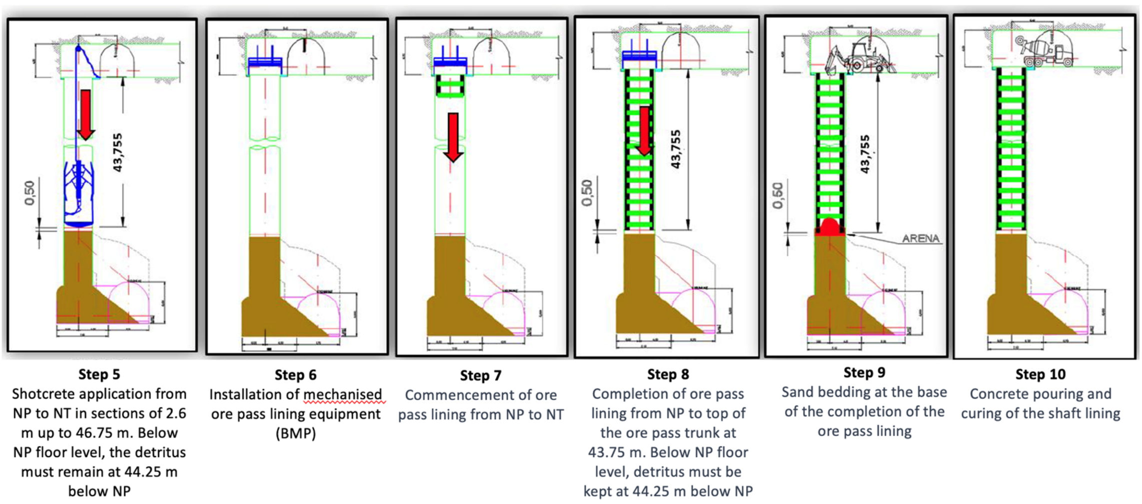

Figure 7 Construction method orepass 5 OP XC3AS (Landeros et al. 2019)

4 Industrial tests, 5 OP-3AS construction

Based on the study and recommendations provided by professionals from the AN-NNM project and El Teniente division in Chile, a methodology was defined to enable the construction of the mineral transfer systems required for the AN-NNM project. This methodology was developed based on the experience gained from the excavation of orepass 1 OP-3AS, which was not successful due to the collapse of the shaft during the final reaming stage. As a result, a planned operational test will involve implementation of the definitive construction methodology to ensure efficiency and safety in the project's construction.

4.1 Description of test stages

4.1.1 Step 0: hydraulic fracturing

With the aim of covering a larger volume of the hydro-fractured area, the drilling of two boreholes with a descending HQ diameter of 96 mm is carried out from the sinking level. The fractures are made every 3.0 m, from 5.0 m below the production level to 5.0 m above the roof of the front of orepass 5 OP located at the transport level (approximately 17 fractures per borehole).

4.1.2 Step 1: guide hole drilling 51.15 m length and 4.1 m

The drilling is carried out normally and the raise borer equipment is installed at the upper level (production level) to execute the drilling of the guide hole in a descending manner. Rigorous control is exercised during the connection, with topographic support both at the start and in the verification of the initial metres.

4.1.3 Step 2: reaming to the final 4.1 m diameter section

Prior to the start of the activity, an update of the technical data sheet (Figure 8) incorporating the information obtained from the monitoring conducted on the guide hole is carried out. In this stage, the defined methodology is based mainly on the geo-structural conditions identified in the area and consideration of the experience of orepass 1 OP-3AS. The following maximum progress conditions must be strictly adhered to as edge limits:

- Maximum reaming advance per shift: 1.8 m.
- Maximum reaming advance per day: 3.8 m.
- Maximum distance of detritus at 2.6 m from the reaming.
- Dry reaming (without the use of industrial water).

	Level	Description	Speed (m/h)	RPM	Thrust pressure (T/Cutter)	Metres per day	Detritus extraction (tonnes)	Observations
	1862		0.2	4.4 - 5	3	3.6	73.89676	Pillar breakage
	1857		0.5	8 - 10	16	3.6	73.89676	
		1856-1852	0.3	4.4 - 5	6	3.6	73.89676	Faul Zone
	1852		0.5	8 - 10	16	3.6	73.89676	
	1847		0.5	8 - 10	16	3.6	73.89676	
	1842	1844-1841	0.3	4.4 - 5	6	3.6	73.89676	Faul Zone
Zone FH	1837		0.5	8 - 10	116	3.6	73.89676	
	1832		0.5	8 - 10	16	3.6	73.89676	
	1827		0.5	8 - 10	1	3.6	73.89676	
	1822		0.5	8 - 10	16	3.6	73.89676	
	1817	1819-1816	0.3	4.4 - 5	6	3.6	73.89676	Faul Zone
	1812		0.5	8 - 10	16	3.6	73.89676	
	1807		0.2	4.4 - 5	3	3.6	73.89676	Dead heat

Note: Advance 3.6 m per day
and Total Ore Pass 50 m

Figure 8 Scaling plan elaborated for 5 OP-3AS (Tobar 2020)

4.1.4 Step 3: breaking the reaming to the production level floor and removal of reaming head

The breaking of the orepass took place on 20 December 2019, and marked a significant milestone in the methodology, the history of El Teniente Division and the project. It is the first time this methodology was used as previously it had always been performed from the lower level. However, there was a need to maximise the confined time with detritus during the excavation of the shaft and to avoid using explosives for breaking the connection to the upper floor (NP).

4.1.5 Steps 4 and 5: projection of shotcrete (5 cm thick) onto the walls of the shaft using robotic equipment

The equipment used, which belongs to the company Master Drilling (MD), involves a system of hoisting with a pneumatic winch and pulley to raise and lower the structure. The shotcrete projection stage was not possible to implement, however, as the proposed robotic equipment encountered problems with the components of the shotcrete preparation mixture due to the dimensions of the shaft, making projection difficult. Due to Codelco's interest in conducting this test, the equipment was obtained from MD and a new attempt was made, achieving a volume of only 1.5 m^2. Given the difficulties illustrated by MD, the decision was made to abandon this activity and assume the risk of not projecting shotcrete, in order to continue with the test. The MD team remained on site for a total of 22 days.

4.1.6 Steps 6 to 8: mechanised shaft lining (BMP)

The equipment consists of a system of metal structures and a central hydraulic unit which provides the power required to execute the shaft lining work, specifically the raising and lowering of lining rings, with a translation system to move the rings for installation and opening and closing of the jaws (Figure 9).

The structural assembly of the BMP equipment, despite its size and weight (approximately 12.5 t), caused no issues during transport or assembly. However, the installation and calibration of the different electrical/hydraulic and control systems proved complex. This was attributed by the vendor (Küpfer) to it being a prototype with no 'real load' testing having been conducted: as it was the first installation, it required more calibrations and adjustments that subsequent installations with the same scope would need.

The installation of the lining proceeded without problems until ring No. 12. From ring No. 12 onwards, the shaft began to experience wall disassembly activity, with falls of rocks impacting the installed lining and resulting in high friction between the ring column and the shaft's walls. Due to the extra effort, the BMP equipment experienced mechanical failure of the engine, which had to be replaced and led to a three-day stoppage. Nevertheless, as more rings were installed, the weight helped to stabilise the column, thus reducing these difficulties. From ring No. 31 onwards the conditions improved, enabling three to four rings to be installed per shift until the installation of the final ring, no. 44. A crucial operation in this step is the removal of detritus to install the lining. During this process it is essential to leave approximately 2.0 m between the reaming head and the rock waste inside the shaft to avoid deconfinement of the shaft.

The equipment is composed of a metallic structure system and a hydraulic oil centre, which generate the required power to carry out the shaft shielding works. Specifically, this equipment is responsible for the rise and fall of shielding rings, with a translation system to move the rings to be installed, and to control the opening and closing of grips (Figure 9).

1. Lift cylinder
2. Upper platform
3. Portal
4. Bogie driven
5. Clamp
6. Clamp cylinder
7. Rail
8. Centre oleo hydraulic
9. Motorised bogie
10. Lateral structure crossbar

Figure 9 BMP metal structure components (Tobar 2020)

4.1.7 Steps 9 and 10: lining concrete of the orepass

Upon completing the installation of the last ring (here, No. 44), the annular space of the orepass is filled with concrete. This activity was carried out without any issues.

> *'The main challenge that could have arisen in achieving the plug seal in the first lower ring turned out to be quite successful with the applied methodology. Lowering the debris level approximately 1.0 m below the lower elevation of the lining and then creating a seal with sand reaching about 0.5 m above the lining elevation proved to be very effective. This approach allowed the plug to be formed with the first 8.0 m³ of concrete, leaving approximately 5.0 hours for curing before continuing uninterrupted with the concrete filling of the entire required lining length (40.5 m).'* (Tobar 2020)

4.2 Problems encountered during the construction of the transfer orepass

- Damage to the slab of the production level, built for the assembly of the raise borer equipment and subsequent installation of the mechanised shaft lining (BMP).
- Prolonged halt (48 days) in the productive sequence of the shaft after completing the reaming to the final section (4.1 m diameter).

- Detachment of slabs from the shaft walls, hindering the shaft lining installation activities and the placement of the lining backfill concrete.
- Delays and extended waiting times for the shaft's skips due to the lack of nearby storage areas and timely availability of LHD equipment.

5 Results

The analysis of results obtained from the new methodology implemented in the PAN for the construction of mechanised OP was based on the progress per shift in the lining of the five main OP that had be completed in order to start ore hoisting. The results of the construction cycle for the transfer orepass are presented in terms of effective days.

Effective days refer to the actual days in which the execution of a task or project took place, excluding days dedicated to movements, equipment installation, or any other type of interferences or activities that did not directly contribute to the progress of the main task. In summary, effective days represent the real and productive time in which the specific activity was carried out.

The constructability planning of the orepass was guided by the project's geomechanics, which indicated unfavourable geomechanical conditions on the east side of the mine.

The chronological order of construction for the transfer shafts was as follows:

1. 16 OP.
2. 15 OP.
3. 14 OP.
4. 12 OP.
5. 13 OP.

5.1 Effective days, orepasses constructive method cycle

The difference between the effective drilling times of 16 OP and 13 OP varies by seven days because of operational problems with the concrete slab.

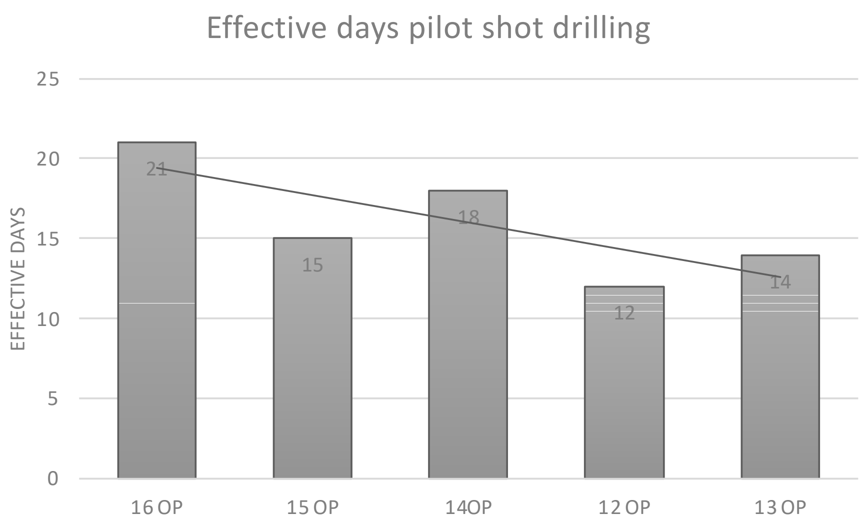

Figure 10 Effective days for pilot blasthole drilling (Codelco 2023)

The scaling time of 16 OP had several operational problems that greatly extended the number of days required for the operation.

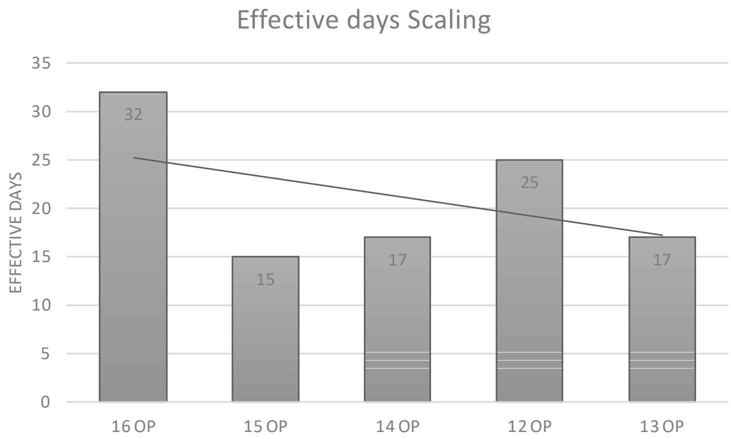

Figure 11 Shaft scaling effective time (Codelco 2023)

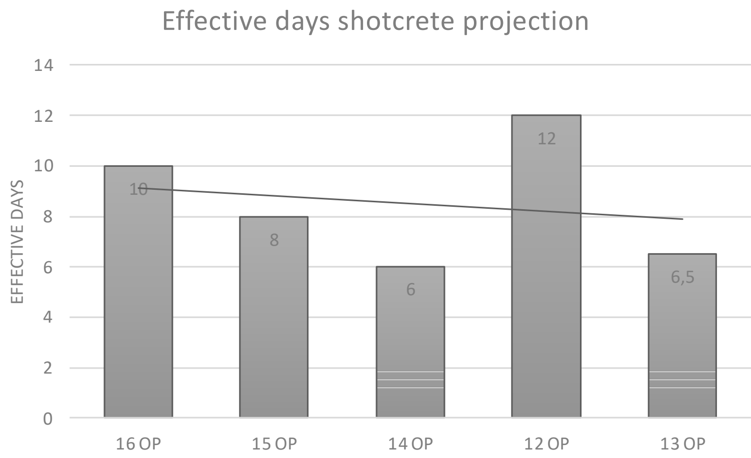

Figure 12 Shotcrete projection effective time (Codelco 2023)

Regarding the shotcrete projection on the walls of the orepass, longer times were observed in OP 12. This was due to issues with the workability of the shotcrete resulting from changes in additives supplied by the provider. It is important to note that in OP 16, after rock detachment occurred during the installation of ring No. 22, the decision was made to apply shotcrete to the remaining section of the shaft (which had not been lined yet).

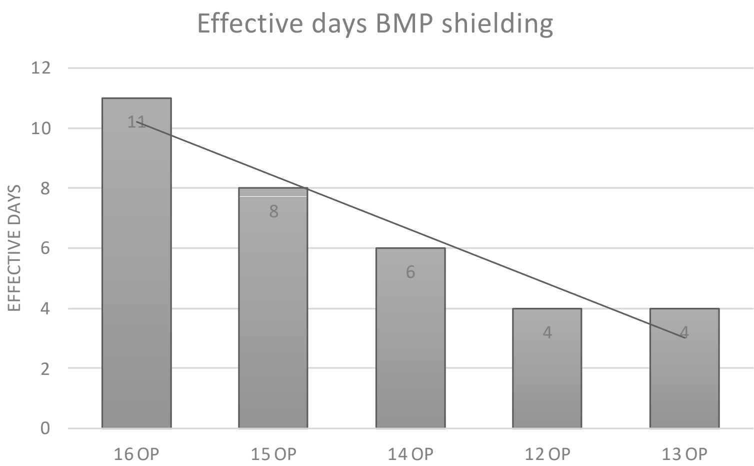

Figure 13 Mechanised shielding effective time (Codelco 2023)

The effective lining times are shown in Figure 4, where a higher effective time is observed during the installation of rings in 16 OP. This was due to material falling from the southern orepass box when installing ring No. 15, which required moving the ring before continuing. Subsequently, when installing ring No. 22, a new rock detachment occurred in the northern Fw shaft box, trapping the ring column up to ring No. 21.

Spraying of shotcrete on the walls before starting the lining was not considered in the construction of 16 OP, which could have contributed to the detachments. When unable to continue lowering rings, the decision was made to concrete the 21 rings already installed and opt for smaller diameter rings 3.0 m in size. This measure was taken to avoid future issues and ensure the stability of the shaft during construction.

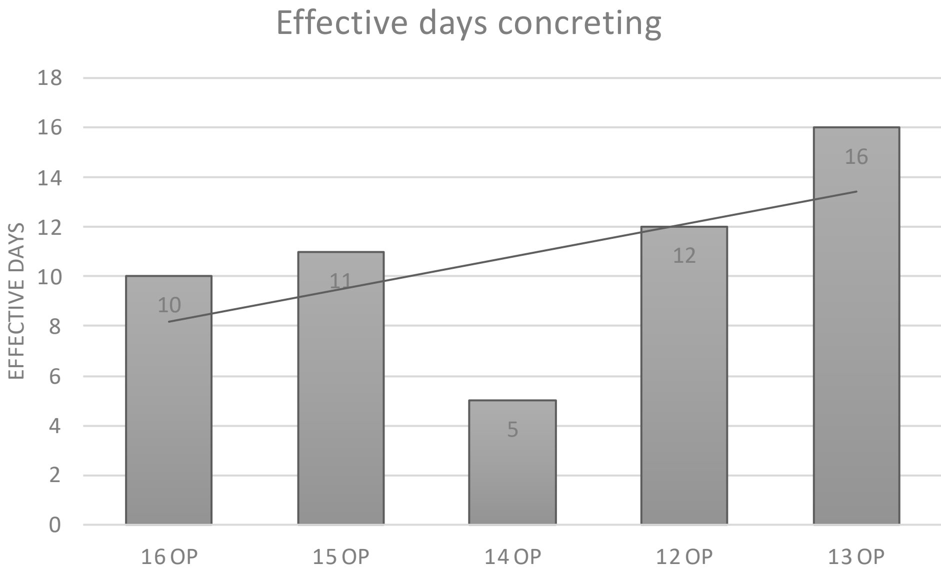

Figure 14 Annular space concreting effective time (Codelco 2023)

Regarding the concreting process, longer times were observed in 13 OP. During the construction process of reaming, the reamer bar was cut. Once the reaming head was retrieved, and due to the production level, a micropile ring was installed around 13 OP to prevent unconfined ground conditions. Due to this failure it was estimated that there would be over-excavation in the walls of the orepass, which increased the amount of concrete needed to fill the annular space between the shaft wall and the lining.

6 Conclusion

In summary, this document highlights the successful development of the implementation of a mechanised method for shaft construction using the mechanised orepass protection (BMP) equipment in the Andes Norte NNM project. Some significant conclusions are as follows:

- The PAN-NNM design includes a transfer orepass within the footprint, which prevents the continuation of the traditional methodology used in the El Teniente mine (support installation with personnel inside the orepass). The implementation of this new methodology redefines the way future transfer systems will be built in subsequent projects.
- During the execution and implementation of this mechanised methodology, various specific operational problems arose in each orepass, such as guide bore deviation, over-excavation, difficulties in shotcrete dosing, lack of equipment for continuous support and issues with the robot's projection line.
- The success of the mechanised assembly's ramp-up is noteworthy, with an initial learning period of 13 days which was later reduced to just four days for the assembly of 44 rings, demonstrating efficiency and improvement in the process.
- The successful implementation of this new construction methodology was made possible thanks to the collaborative work between different cross-functional areas and shaft development operation teams.

Overall, the adoption of this mechanised methodology has proven to be a significant advancement in the way geotechnical challenges are addressed and construction is carried out in the Andes Norte NNM project. It represents an important milestone for future projects at the mine.

Acknowledgement

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