Getting Underground: Design and construction of a portal in a pit with moving walls

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ABSTRACT

Achieving quick underground access after the completion of an open pit mine can be critical to maintaining project value and ensuring regular ore feed to the mill. This paper outlines the design and construction for two portals in an active open pit to commence underground development quickly whilst installing appropriate ground control to maintain long term access in an uncertain setting.

Implementation of the portal designs was complicated by the change in underground design from hangingwall access to footwall access late in the life of the open pit due to preferable ground conditions. The portal locations did not have easy access for ground support installation integrated into the pit design due to the timing of the underground design changes. Practical implementation of the ground support systems subsequently became a key part of the project.

Intact rock strength, rock mass characteristics, gradational weathering / alteration profile and structural information were modelled against pit displacement monitoring as the basis from which the portals were located and ground support schemes designed. Conditions around one of the portals necessitated numerical modelling to estimate the appropriate level of ground control for long term stability. The design was completed whilst the open pit was actively on-going and the portal areas not entirely exposed. The rock mass assessment and analysis for the two portals indicated different ground support scheme capacities would be required. The expected level of control for one of the portals also necessitated the use of monitoring with extensometers and load cells to ensure the rock mass response and ground support scheme performed as planned.

Construction of the portals demonstrates the benefit of a considered design process, a plan which allows practical installation of ground support schemes where access is limited, the benefit of ongoing monitoring to ensure performance remains within design limits and the challenges involved working within an active pit with limited floor space.

INTRODUCTION

An efficient transition from open pit to underground mining aims to minimise the delay in ore feed between completion of the open pit and production from the underground mine. The Bartons Pit to underground transition at Millennium Minerals, Nullagine Gold Operation (NGO) was no different. Three aspects of the Bartons Pit make the underground transition more than a typical challenge:

- the weathering surface had previously been incorrectly defined and was deeper than predicted, particularly on the eastern wall.
- the portal location needed to change from a hangingwall access to footwall access due to conditions in the hangingwall (eastern wall) of the pit
- the prism monitoring showed on-going displacement in the eastern and western wall of the open pit

This paper will explore how these challenges were overcome and the monitoring of the portal and pit that have been used to validate the behaviours.

BACKGROUND

Millennium Minerals NGO is located approximately 10km from the Nullagine township in the East Pilbara region of Western Australia. NGO consists of a 40km strike with multiple open pits across multiple production centres. The primary infrastructure is located around the processing plant located adjacent to the Golden Eagle open pit. NGO has the one operating underground mine at the Middle Creek Mining Centre approximately 20km away from the processing plant.

The Bartons Pit is part of the Middle Creek Mining Centre, it had an open pit mine which had a subsequent cut back commencing in 2017. Both the original pit and the cut back had significant wall failures on the eastern hangingwall side of the deposit and batter scale failures on the west wall. Underground mining commenced in 2018. The sericite enriched orebodies at Bartons strike approximately north to south and dip towards the east at around 65 degrees.

The Bartons underground mine consisted of a relatively conventional Western Australian narrow vein, long hole stoping mine with backfill. The design comprised two portals, the first as the primary access and egress and a secondary portal which would be primarily for ventilation but also form part of the secondary means of egress from the mine. The primary access portal is referred to as the northern portal and the secondary portal is referred to as the southern portal.

Geology

The Middle Creek Mining Centre is hosted in greenschist facies metasedimentary rocks and has a complex structural history of folding, refolding and several generations of shearing (Huston et al, 2001). The overall strike of the deposit is north-northeast, the underground operation is focused on the main ore bearing lode however there are minor splays which are also extracted where viable. The dominant feature of the geology is a strong schistosity to slaty cleavage sub-parallel to the lode.

Geotechnical Data

The key geotechnical features of the Bartons deposit are the structural setting and intensity, and the varying strength conditions (weathering, alteration, original lithological material) within the metasediments across the pit walls.

Four structural sets have been identified from analysis of diamond drilling information, borehole geophysics and photogrammetry data collected from both the east and west walls. Figure 1 shows the dominant geotechnically significant feature in both data sets is the foliation set sub-parallel to the lode. The spacing of the foliation set is typically less than 10cm, in diamond drilling not all foliation structures are open but they are inherently weak. It is noted that the western wall data has a higher concentration of eastern dipping structure whereas the reverse is encountered on the eastern wall. This results in both walls being susceptible to toppling failure. The dominant infill on structure consists of pyrite and sericite, both low friction infill materials.

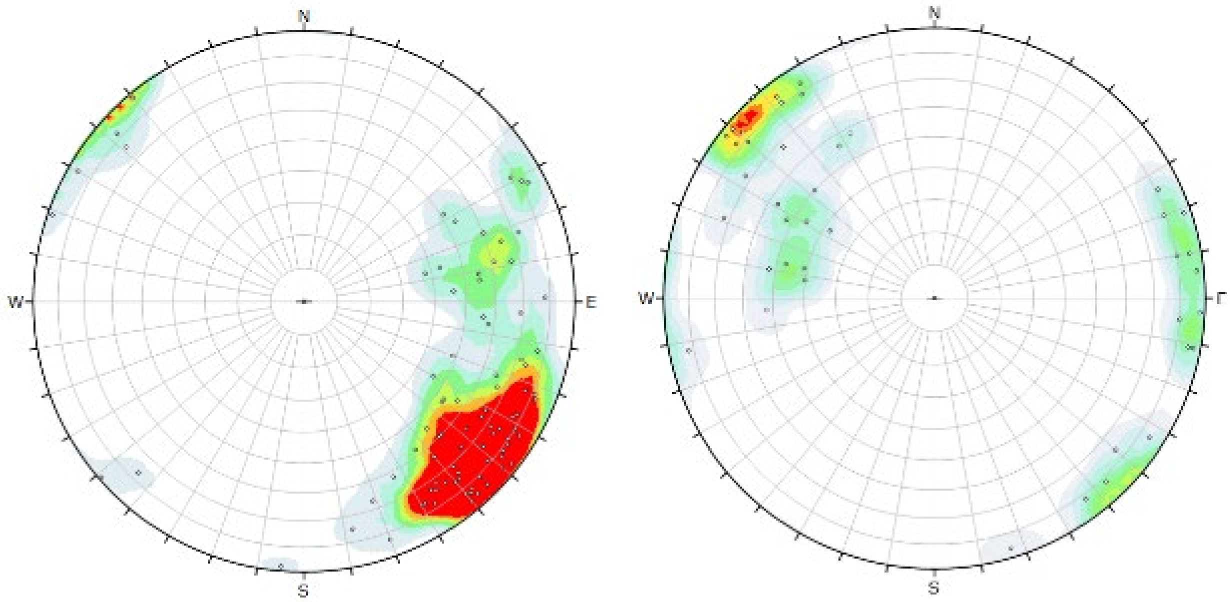

FIG 1 – Structures mapped from photogrammetry on the east (left) and west (right) walls of the Bartons Pit.

Ground conditions were noted to vary across the pit walls, this was observed particularly on the western wall where a sheared zone of softer, weathered metasediments was located between harder sandstones, Figure 2. This area was observed to have significant cracking on berms and ramps as well as elevated velocities in prism movement.

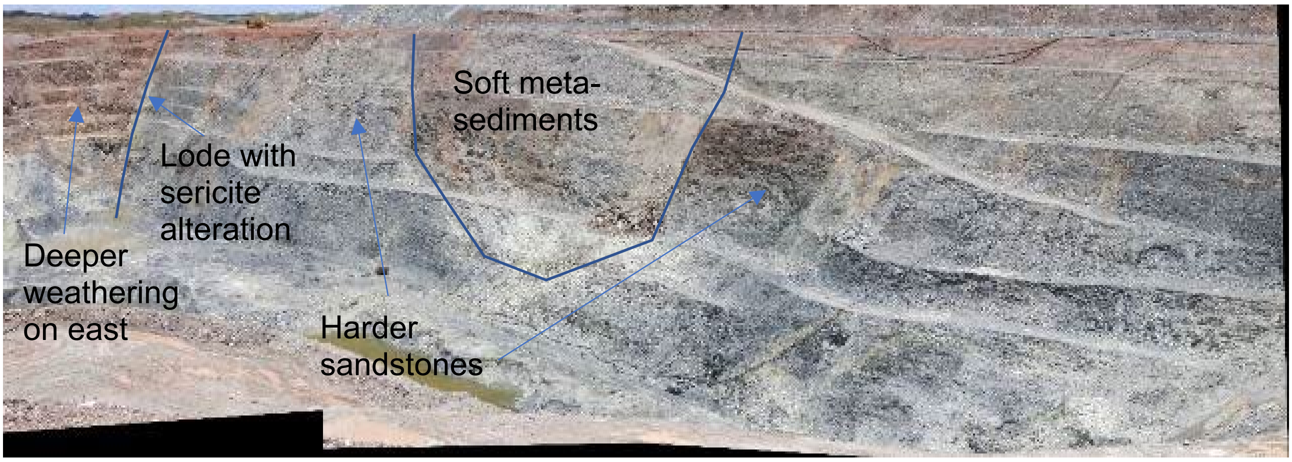

FIG 2 – Geotechnical conditions observed on western wall of the pit

The majority of drilling data comes from RC drilling in the pit area with a number of diamond tails on RC holes for the underground drilling and design. Limited diamond drilling information was available for the pit area but in these holes, it was apparent that the proposed weathering profile was not consistently observed in the core.

Weathering and Rock Mass Performance

The weathering profiles provided from the site team links to the interpretation of weathering in the pit for metallurgical purposes. The metallurgical weathering profile is an assessment of weathering of sulphide minerals and how this will impact recovery. For geotechnical purposes the weathering relates to changes in the lithological units and structural features. When these two weathering conditions are assessed at NGO two different surfaces are present for the bottom of completely oxidised (BOCO) and top of fresh rock (TOFR) surfaces.

The original metallurgical surfaces had the BOCO surface at an average 358 mRL and TOFR at 330 to 325 mRL. The weathering surfaces for the purpose of geotechnical conditions were a further 30 m and in some areas more below the initial surface on the eastern wall. The weathering profile was gradational in the sedimentary host sequence. This is not typical of WA mines that often have a very rapid change from oxide to fresh, where as in this case there is minimal oxide but a very deep transitional.

The original assessment of the weathering surface resulted in the east wall of the pit design transitioning from 10m benches with a batter face angle (BFA) of 50 degrees to 20m benches with a 60 degrees BFA at the bottom of the metallurgically derived TOFR surface on the east wall. The west wall commenced with a BFA of 60 degrees and were designed to transition to 70 degrees approximately 60m below the surface. Toppling failures occurred once 20m benches started being mined and resulted in a number of pit redesigns to manage the ongoing hazards on both the east and west walls. The applied changes slowed the displacement but did not stop the displacement occurring.

Pit Monitoring

Open pit monitoring initially comprised of manually read prisms and visual inspections and surveys of cracking. The rates of movement on the western wall of the pit as well as the ongoing failure on both the east and west wall of the pit resulted in the implementation of a robotic total station (February 2018) taking readings hourly and the implementation of Trigger Action Response Plans (TARPs) to manage the ongoing hazards in the open pit. The TARPS related to prism monitoring data, blasting, rainfall and in the event of a pit failure.

At the time that the portals were being designed prism velocities were commonly in the order of 2 to 6mm per day (see Figure 3). This displacement was typically further affected by blasting and rainfall events. The long-term stability of the pit walls was a concern and the need to strategically locate both portals in areas where life of mine access could be maintained (see Figure 4 below).

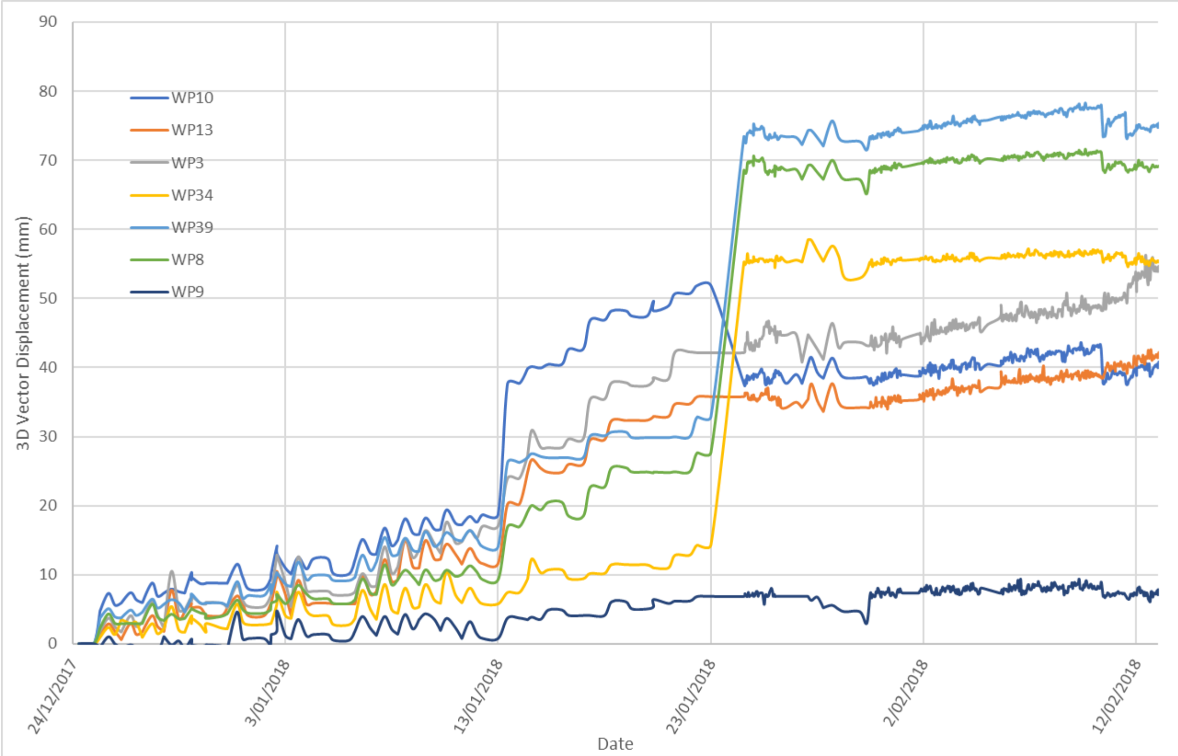

FIG 3 – Prism monitoring data collected from the Bartons Pit whilst the portal design was being conducted

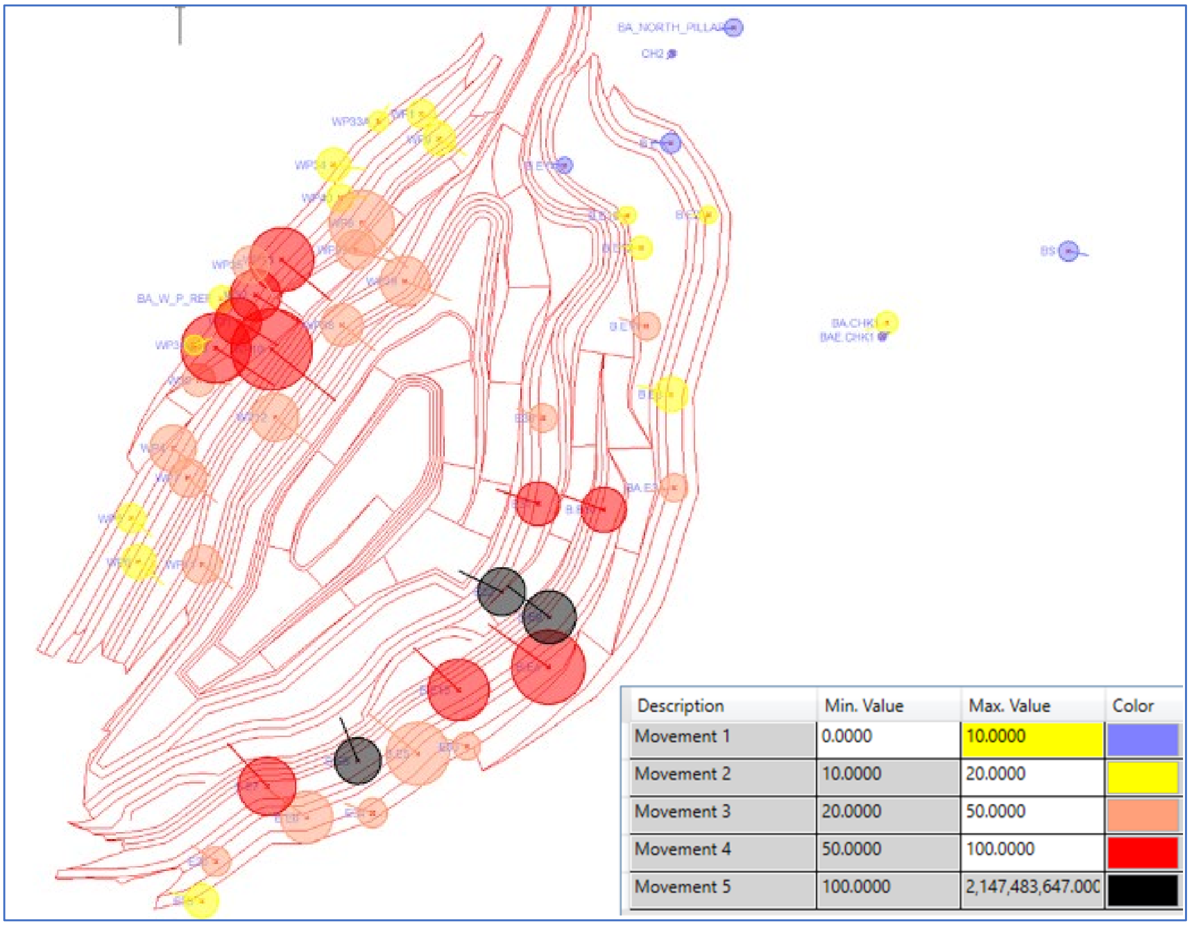

FIG 4 – Prism displacement in the Bartons Pit over a 3-month period highlighting the areas of concern for portal construction.

DESIGN

The weathering profile, rock mass conditions and observed displacement meant that whilst the western wall was not without risk it was deemed preferable to attempting construction on the eastern wall.

The underground design was impacted most significantly by the weathering surface on the eastern wall despite both walls being mobile, having localised failures and potential for large failures. Both the western and eastern wall have challenging rock mass conditions with toppling failures present on both walls.

Due to the on-going prism displacement the portals for the underground deposit required additional design consideration beyond what a conventional in-pit portal may require. The prism monitoring data was used to calibrate the rock mass conditions in a 2D finite element numerical model as limited rock testing data was available.

Due to the known and forecast risks within the Bartons Pit a comprehensive design process was completed to ensure that portals would be adequately supported for the life of the underground operation. The assessment determined that the southern portal could be constructed in a relatively stable area of the west wall of the pit. The northern portal would still be located in an area where considerable prism displacement was recorded and more detailed analysis including modelling would be required.

Modelling

In order to investigate the demands on the proposed support system for the northern portal, a two-dimensional finite-element (FE) model was built in RS2 (Rocscience, 2019). The aims of the modelling were:

- to simulate the recorded deformations on a 2D section coinciding with the portal location
- to determine the loading on the proposed reinforcing systems
- to draw conclusions about the applicability of the proposed ground support scheme

The RS2 model simulated the observed geotechnical domains as shown in Figure 5. One of the challenges of the model was the gradational nature of the weathering profile. Although termed 'fresh' in Figure 5 it should be considered as more transitional as true fresh rock was considerably deeper. The parameters used in the model are as given in Table 1. The model assumed generalised Hoek-Brown with anisotropy for the material model, based on the bedded nature of the host rock mass.

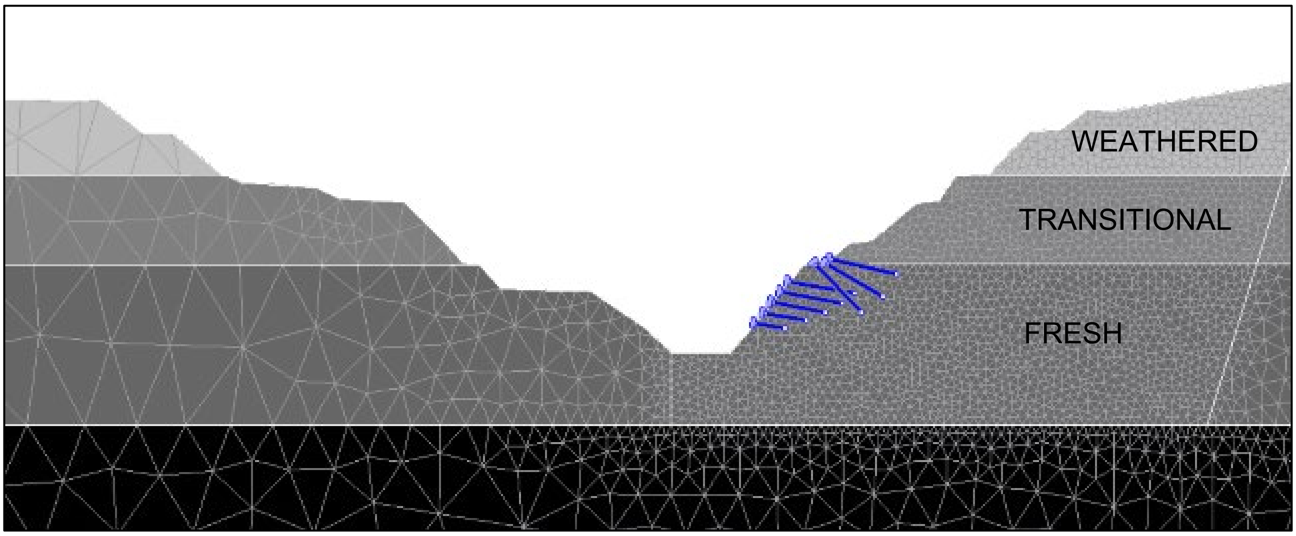

FIG 5 – RS2 FE model representing the observed geotechnical domains at a pit section coinciding with the portal position.

Domain	Density (t/m^3)	Modulus (GPa)	Hoek-Brown UCS (MPa)	Geological Strength Index	Hoek-Brown mi	Barton-Bandis JCS (MPa)	Barton-Bandis JRC	Residual Friction Angle (deg)
Weathered	2.7	0.7	5	15	7	1	5	31
Transitional	2.7	1.6	20	30	10	5	5	31
Fresh	2.7	4.5	40	45	15	10	5	31

TABLE 1 – Material strength parameters assumed in the FE model

A pattern of reinforcement was modelled using the 'Tieback' support element option in RS2 (see Figure 6), with properties as listed in Table 2.

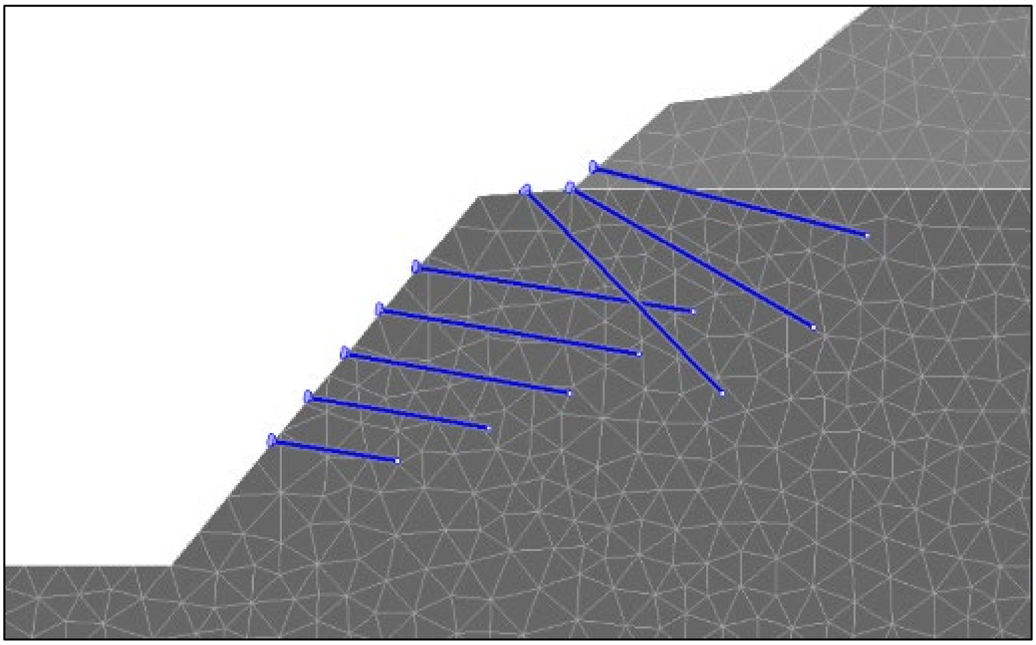

FIG 6 – Reinforcement pattern in the portal area

Bolt Diameter (mm)	36
Bolt Modulus,E (MPa)	200000
Bolt Model	Plastic
Tensile Capacity (MN)	1.07
Residual Tensile Capacity (MN)	0
Out-of-Plane Spacing (m)	3.3
Material Dependent	☐ No
Bond Shear Stiffness (MN/m/m)	10
Bond Strength (MN/m)	1.5
Joint Shear	☐ No
Pre-Tensioning Force (MN)	0
Constant Pre-tensioning Force in Install Stage	☐ No
Face Plates	☑ Yes
Add Pull-Out-Force	☐ No
Use Bond Percentage Length	☑ Yes
Percentage Bond Length (% (of Bolt))	100
Secondary Bond Length	☐ No

TABLE 2 – Reinforcement Inputs to the RS2 model

The model predicted overall slope displacements are as shown in Figure 7, with generally good correlation to measured displacements prior to the conclusion of open pit mining. The model predicted plastic shear strains (shown in Figure 8) indicate a basal shear slip surface defining a zone of flexural toppling instability.

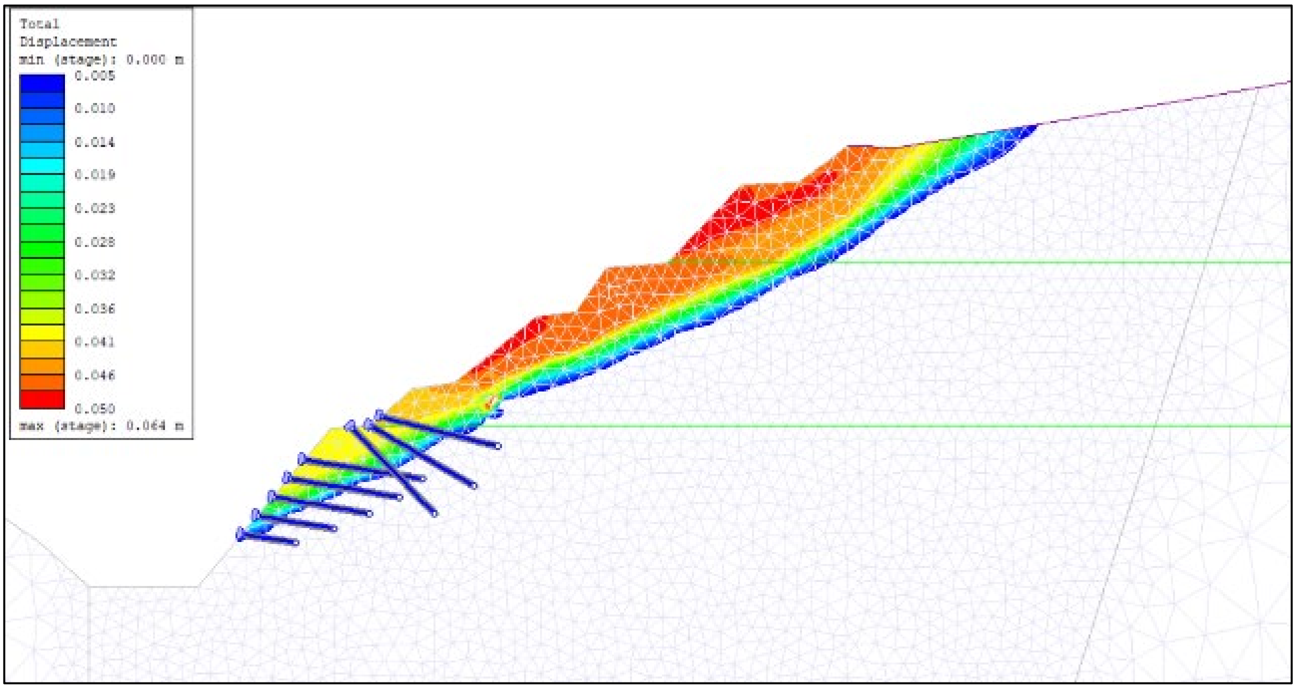

FIG 7 – Model predicted overall slope displacements

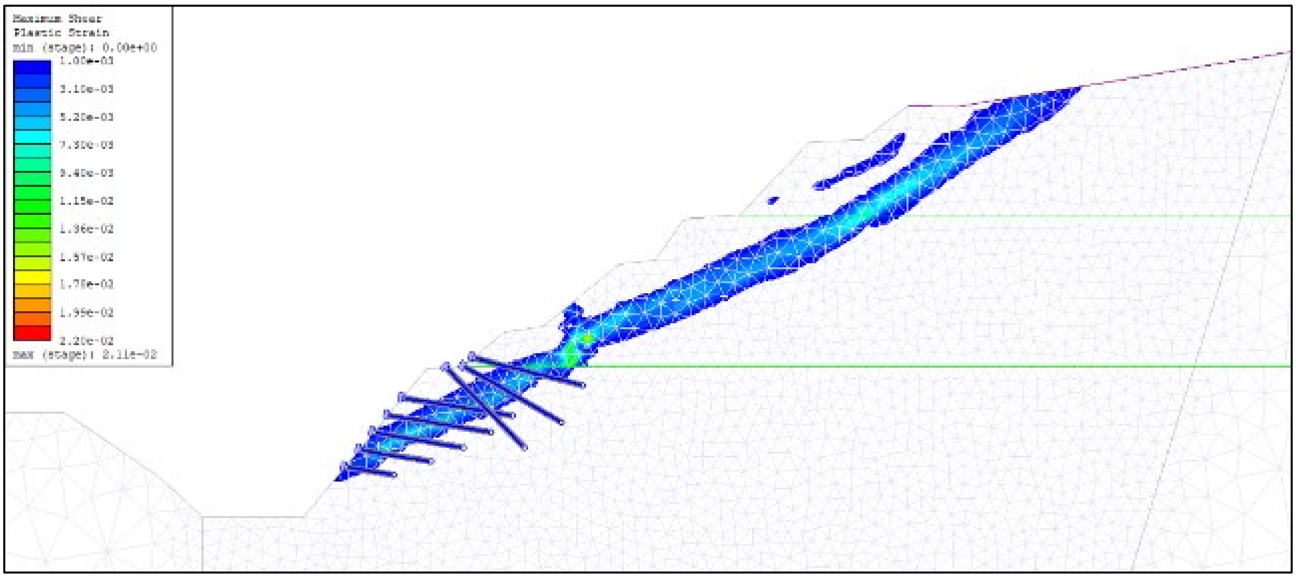

FIG 8 – Model predicted maximum shear strain

The model predicted loads on the installed reinforcement is presented in Figure 9. The maximum load in the pattern is 75 tonnes, or 70% of their capacity, indicating that no yielded reinforcement would be anticipated. Reinforcement length was determined appropriate to the shear strain surface and the modelled axial force on the reinforcement systems.

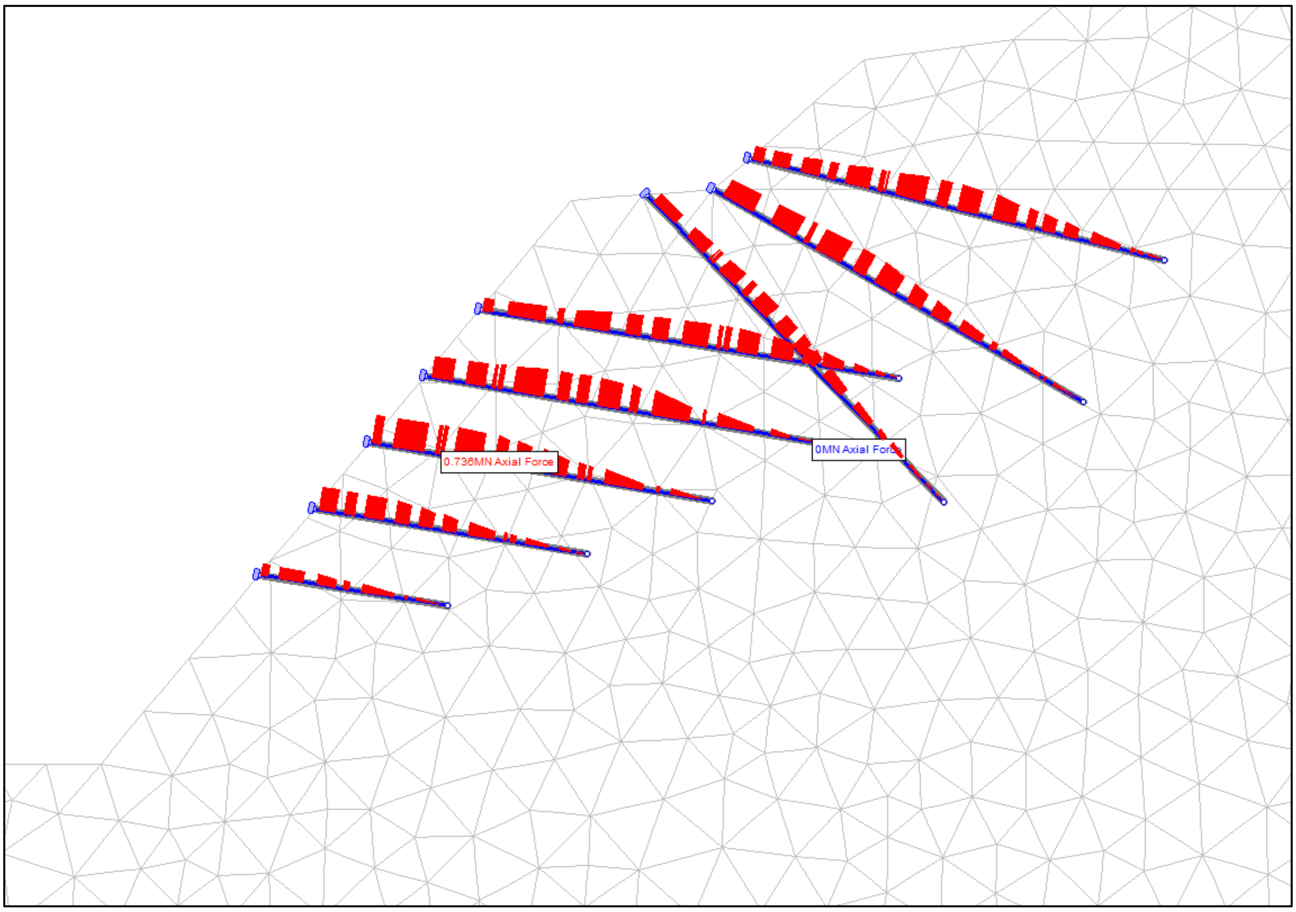

FIG 9 – Reinforcement system axial loads (MN) shown as bars representing the scaled magnitude along each bolt axis

Monitoring Design

Due to pit wall displacement and modelled bolt loads a monitoring system was seen as critical for ground support performance and rock mass displacement monitoring. The system was set up for portal firing and with installed data loggers for the long-term measurement purposes. Ground support scheme performance was established with the use of four hollow load cells to monitor collar load on the deep rock bolt anchors. Rock mass displacement was designed to be monitored with Multi-Point Borehole Extensometers (MPBX) and surface mounted prisms. A cross section of the designed monitoring layout is shown in Figure 10.

Four of the rock bolts which indicated the highest collar load from modelling were selected for monitoring. The load cells have a capacity of 750 kN, which is less than the yield strength of the WR36 rock bolts; however, this was considered adequate for identifying stability issues. The load cells are built with three vibrating wire outputs and a thermistor. Data loggers were selected for the load cells and use 4 channels per load cell with data reduction required to determine the average load on the cell across the three vibrating wires.

Four multi-point extensometers were installed between the berm and the batter face to record the ground movement to establish depth of movement and performance of the ground support scheme in controlling the footwall. The significance of the extensometers is to determine the depth within the slope that the "shear band" is generating and the amount of displacement occurring. Extensometers were linked with data logging capability to ensure that the data is read consistently and regularly.

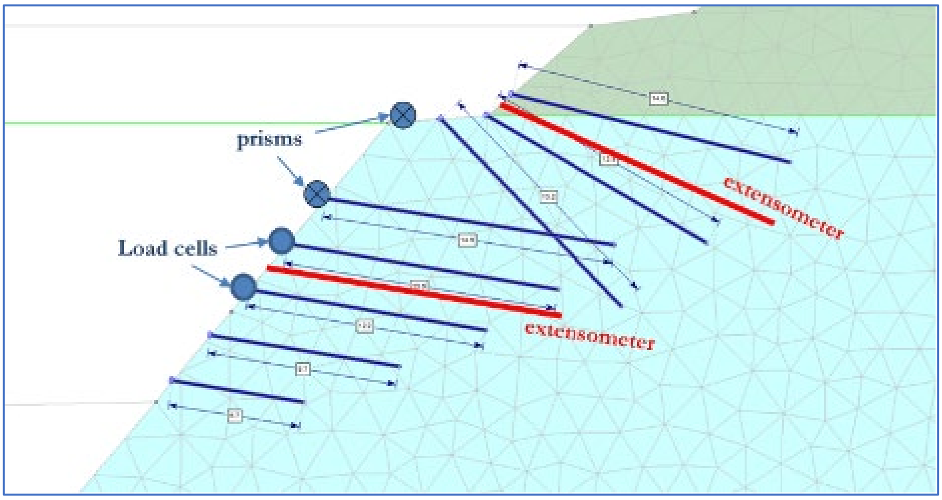

FIG 10 – Cross section of design monitoring layout for extensometers, load cells and prisms.

IMPLEMENTATION

The original pit design was planned with portals on the east wall, the design change meant the pit design did not include access for portal establishment on the west wall, specific issues included:

- No wide berm was located above the portal location
- Access on to the berm above the portal was difficult
- Access to portals required pit design changes and back filling late in the pit life.

Two installation strategies were used for the northern and southern portal. The installation strategy considered the ground support design, access to the work sites and hazards specific to each portal.

The northern portal installation strategy involved backfilling the portal area to allow drilling with existing pit drill rigs, personnel to work at ground level and work to be staged in benches. Long large diameter bolts (36 mm) meant there were significant manual handling benefits to operating in this manner. A final drape mesh was installed using rope access.

The southern portal installation strategy involved the use of rope access from the pit crest to drill, install and grout rebar followed by a drape mesh for scat control. The design for the southern portal with shorter 32 mm diameter grouted rebar was designed as a ventilation and secondary means of egress. The portal was located at the same RL as the main portal however no access was available due to the open pit extraction. A land bridge was constructed from pit waste to re-establish access to the portal bench once mining in the pit had ceased (see Figure 11).

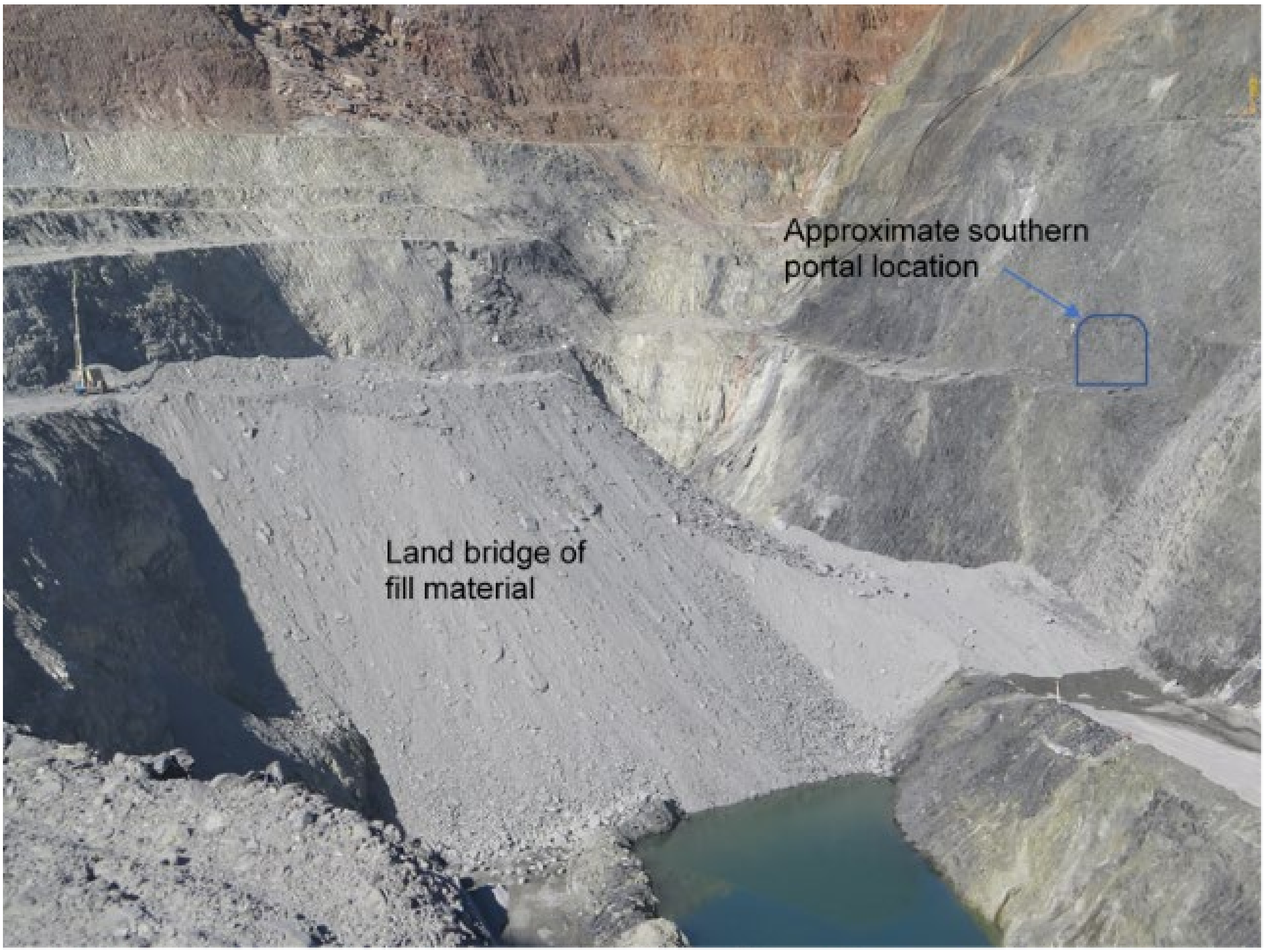

FIG 11 – Construction of land bridge for access to southern portal

Ground Support Scheme Installation

The ground support scheme installation was aligned with the completion of open pit mining in the Bartons Pit. Access to both portals required the use of backfill. In the case of the main portal it was to allow ground support installation to be staged, utilise site equipment and remove the requirement to mobilise a high-reach drill to site. For the secondary portal the backfill was for construction of a land bridge across a narrow section of the pit to provide access to the base of the portal to allow it to be developed.

Bolt lengths selected were a combination of available lengths, manual and mechanical handling capacity, couplers to join shorter lengths together and modelled ground mobility. All bolts were centralised in the hole.

Northern Portal Ground Support Installation

The main portal site was mined to the 305 mRL and then backfilled with waste rock to the 325 mRL to establish a drilling and working platform. Three rings of 15.2 m long bolts were installed to secure the batter face immediately above the 325 mRL and into the 325 mRL berm. Once the bolts were installed the mesh was positioned across the berm in preparation for installation once the fill was removed.

In order to install the first row of bolts into the portal batter face, located approximately 5 m below the crest, approximately 6.5 m of fill was removed. All bolts were completely grouted bottom up prior to removing the next bench of fill being removed and subsequent rows installed.

Subsequent rows of bolts were spaced 3 m apart, see Figure 12, and a decision was made to remove the fill in 3m benches. Whilst it was less efficient to remove only 3 m of fill at the time, the installation cycle meant that holes could be drilled and bolts installed in a single shift whilst fill was removed on night shift. Delays meant that this cycle was not always achieved but repeated cycles later in the installation demonstrated that this cycle was achievable.

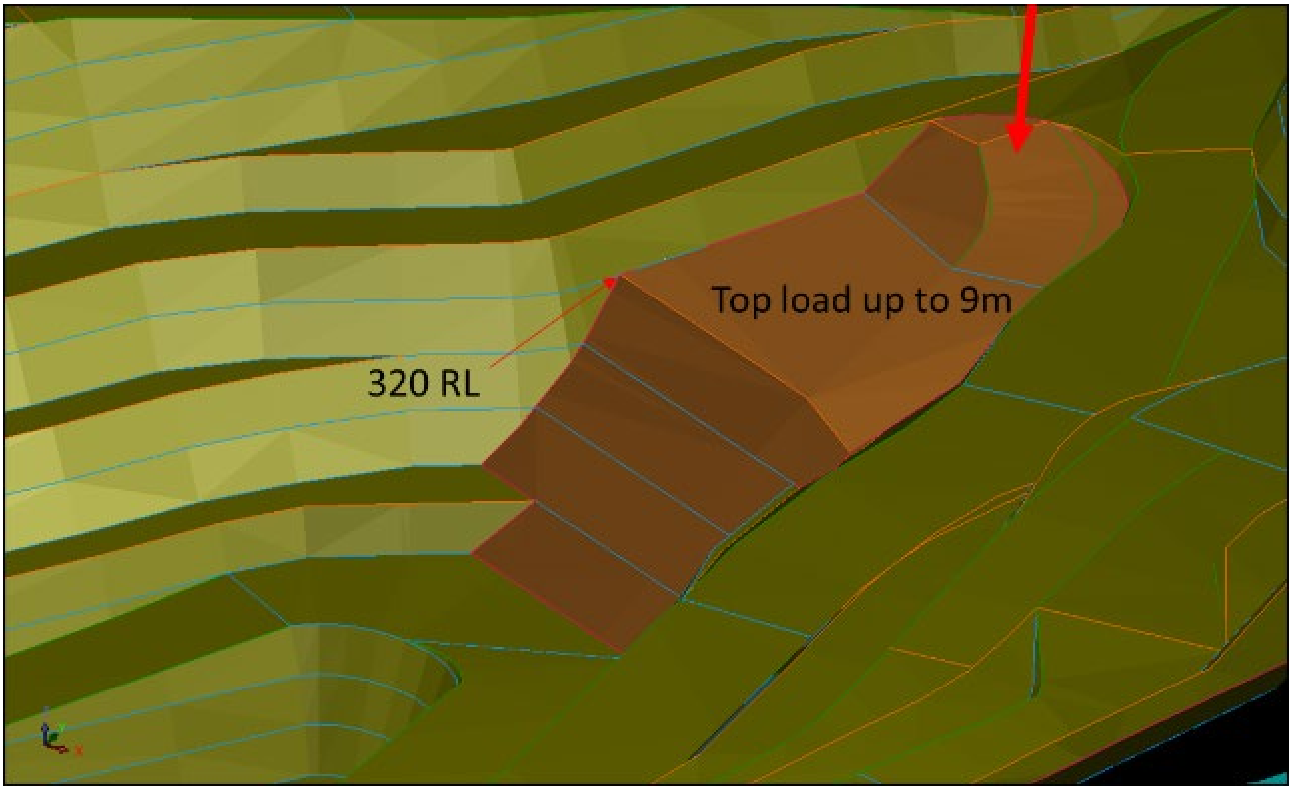

FIG 12 – Graphical representation of the process of backfilling and removing material for installation of ground support for the northern portal

Once all bolts were fully installed the Geobrugg 65/4 mesh was rolled down the batter and positioned off rope access. The mesh was tensioned onto the thread bar using the Geobrugg spike plates to restrain the mesh to the face and distribute load. Instrumentation was installed and a perimeter rope installed to maintain tension around the mesh as shown in Figure 13.

FIG 13 – Mesh tensioned with spike plates and load cells measuring bolt collar load.

Southern Portal Ground Support Installation

Access to the secondary access portal was more complicated however this was offset by the ground support requirement being lower than for the northern portal. To access the bench above the portal rope access was required from the top of the pit. This included lowering air powered drills down the face to facilitate drilling of the anchor bolts and batter face bolts as shown in Figure 14 below. A crane was brought in to lift the materials onto the 325 mRL bench including the mesh and initial anchor bolts. The crane wasn't used to lift the drills into place due to timing of the construction of the land bridge and the installation schedule to commence drilling on the southern portal.

FIG 14 – Drilling of anchors using drills lowered from pit crest.

CONSTRUCTED PORTALS

Both the northern and southern were successfully mined without the use of fibrecrete to assist in confining the laminated walls as shown in Figure 15 and Figure 16 respectively. The drape mesh was integrated into the portal profile which assisted in transitioning the batter face into the portal. Firing the southern portal resulted in less brow loss due to adjustments made in the firing and extraction process.

FIG 15 - Northern portal after mining first 4 cuts.

FIG 16 - Southern portal after blasting the first full cut.

MONITORING

The instrumentation system was commissioned with the firing of the portals in April, 2018. The load cell data has not generated any significant load at the collar of the bolts. This is largely to be expected as the bolts are fully grouted. However, the numerical model was forecasting high plate loads which were not expected due to full column grouting and may have been associated with a greater displacement of the face. The behaviour of the load cells is affected by ambient temperature with increased summer temperatures resulting in extension of the exposed portion of the bolt and a reduction in load. In the 12 months since installation bolt loads have increased up to 5kN (Figure 17).

The four MPBX show a total displacement of approximately 3.5 mm along the total unit in 10 months since their installation in April, 2018 (Figure 18). The majority of displacement occurs close to the batter face, progressively decreasing into the rock mass. The results presented shows no displacement beyond 7.5 m into the borehole. The numerical model predicted between 40 and 45 mm of displacement at the collar to approximately 3 m into the rock mass. Steps in the displacement have occasionally been linked to firing and rainfall events but the majority of these steps have not had a clear correlating event. The prism monitoring of the portal face has measured 10 mm of displacement above the portal.

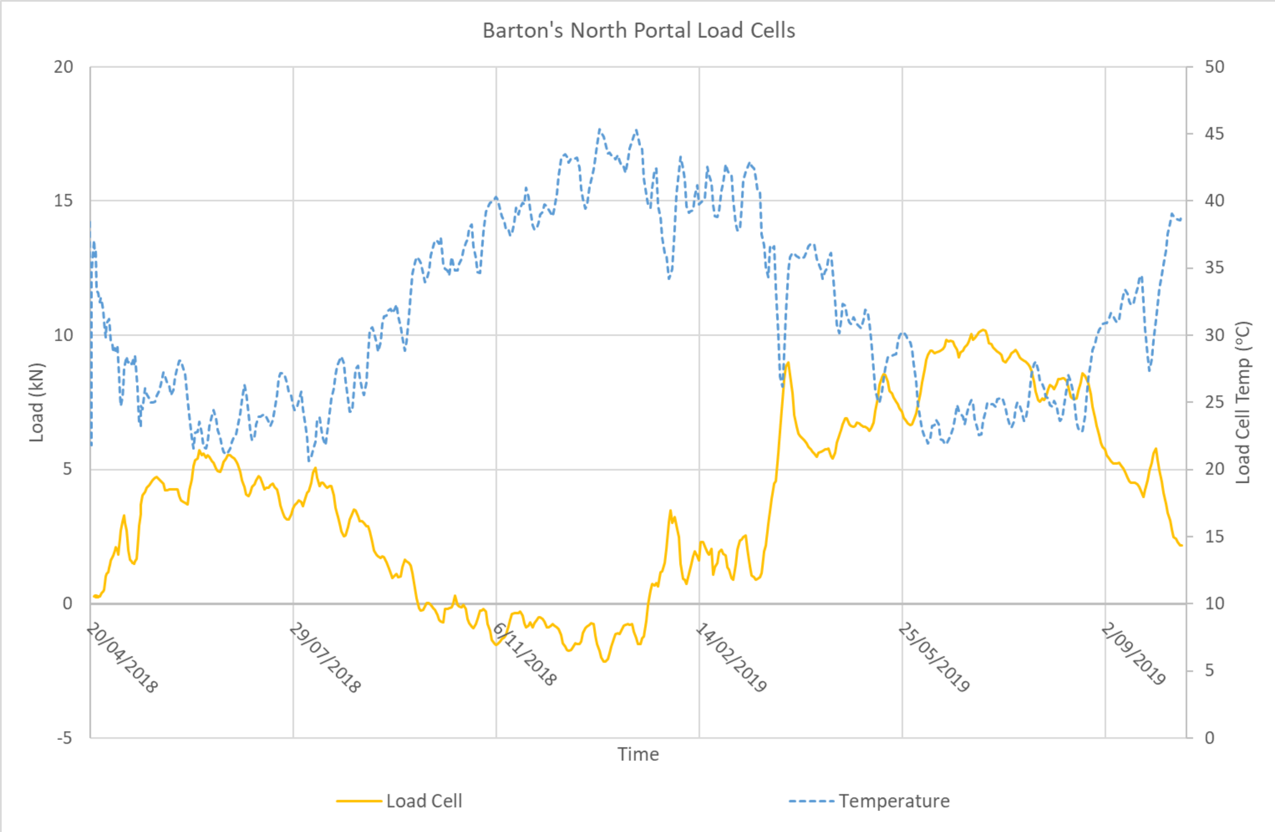

FIG 17 – Load cell monitoring of the Bartons Pit portal face.

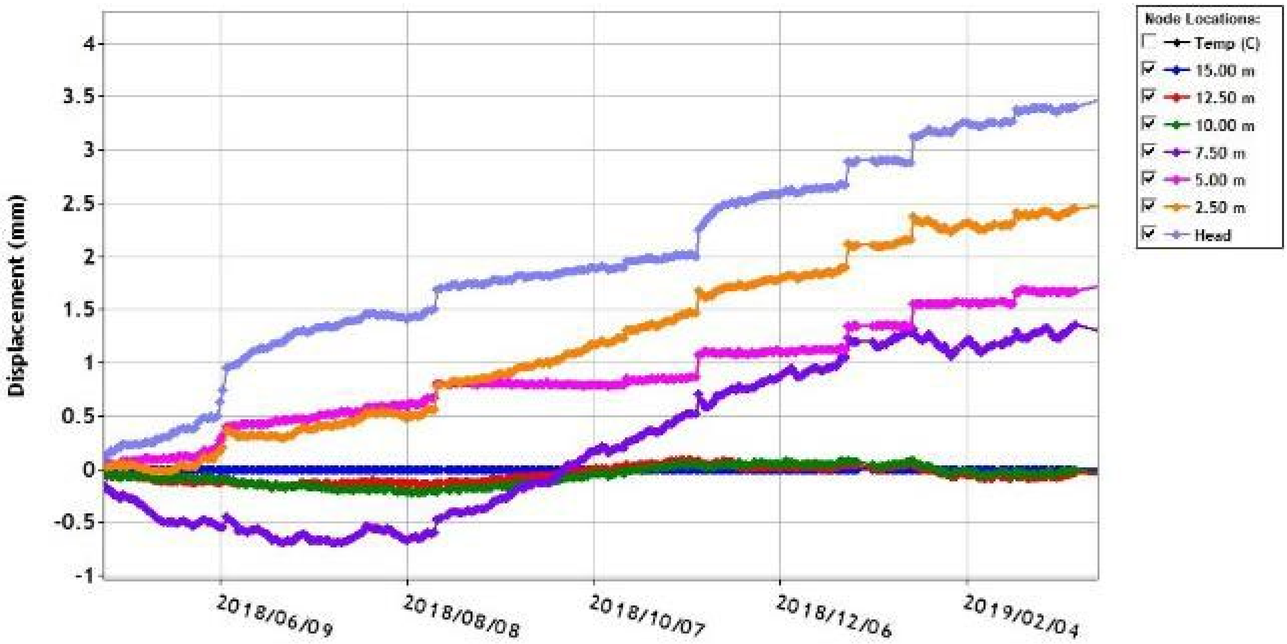

FIG 18 – MPBX in the lower left side of the portal face showing relative displacement between each anchor.

CONCLUSIONS

The portal design for the Bartons Pit was complicated by the pit wall movement observed and recorded with prisms. The increased depth of the weathering profile on the eastern wall meant that to attempt to install the portals on the east wall would be complex and require significant ground reinforcement and stabilisation. A design for two portals on the western wall was implemented using the information available at the time.

The numerical modelling correlated with the prism data indicated the northern portal, which would be the primary mine access, required a heavy ground support scheme. A monitoring system was subsequently developed to validate the ground support scheme once installed.

The implementation of the design required adaptation to suit the available equipment on site where possible. Installation in the pit commenced as soon as mining in the Bartons Pit was ceased. The ground support installation and portal locations necessitated the use of different installation strategies for each portal. Both were successfully completed to a high standard.

Monitoring results may indicate that the ground support design did not need to be as heavy as required. However, as the bolt loads within the reinforcement are not known, the amount of work they are doing in reducing displacement on this wall can not be directly quantified.

In future designs a more rigorous understanding of the design parameters is required prior to determining the portal design. The effect of the deeper and gradational weathering surface caused significant design change and complicated the installation of the portal ground support. Additional information should include further diamond drilling with the provision of rock strength inputs for modelling. The use of a three-dimensional model would be beneficial for the purpose of understanding the effect of confinement provided to the proximity of the end of the pit to the ongoing wall displacement.

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