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Mine portal design: considerations, methods and practices

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Abstract

Mine access portals are routinely developed to provide access to underground mines; typically, they are either developed within an existing open pit or in a specially developed box cut. Portals are critical mine access excavations requiring rigorous design and construction practices. In some cases, the portal will serve as a single means of access and egress for a significant period and this requires that design acceptance criteria be commensurate with the acceptable risk being adopted. Failure of a portal can result in both safety and economic consequences. In the authors' view, the rigour around design effort, acceptance criteria and construction quality control are not always at the required level.

Mine access portals can be developed in a range of rock mass conditions including soils, weak weathered rocks such saprolites, to competent good quality rock masses. Portal design requires an understanding and consideration of the geotechnical conditions, likely failure mechanisms, hazards and risk, as well as the intended period that it will serve as the main access to the mine. A range of design methods (empirical, analytical, numerical etc.) can then be used to assess likely loading conditions and the required ground support. Portal designs also need to consider the stability of the slope into which it is developed; in a box cut it is possible to engineer a stable slope whilst in an open pit it is necessary to deal with an already cut slope.

This paper discusses typical hazards and risk associated with mine access portals as well as a range of design methods. A framework for portal design is presented including construction aspects and monitoring. Examples for several portals developed in a range of different rock mass conditions using different design methods and support methods are presented.

Keywords: *portal design, design effort, design acceptance criteria*

1 Introduction

Mine access portals are routinely developed to provide access to underground mines; typically, they are either developed within an existing open pit or in a specially developed box cut. Sometimes, it is possible to take advantage of the topography and develop a portal into a hillside; a cut-and-fill methodology is sometimes employed.

The exposure of personnel and equipment for a portal are high; therefore, the risk tolerance is very low. In addition, collapse of a portal could result in entrapment and loss of access to the underground operation. Mine access portals are critical mine access excavations and are required to remain stable and serviceable for a long time and in many cases for the life of mine.

This implies that a high degree of reliability is required both in the design and implementation stages. To achieve a high degree of design reliability, it is necessary to ensure that sufficient rigour is applied in both the data collection and design stages and that appropriate design acceptance criteria are used.

Unfortunately, this is not always apparent in study reports with the portal support recommendations often based on previous experience without any supporting design analysis and documentation. This paper discusses various considerations in the design of mine access portals.

2 Considerations in portal design

Stephenson & Sandy (2021) provide a good overview of considerations in the design of portals for underground mines. These can broadly be divided into the portal location, geotechnical conditions, likely failure mechanisms and hazards. These are all inter-related and will ultimately dictate the design methodology and design recommendations. Some of the main considerations for portal design are briefly discussed in the following sections.

2.1 Location

Ideally, the portal should be in an area with the least concerns; however, this is not always possible and practical constraints will often dictate where the portal will be located. In mining, it is common to site portals in an existing open pit as this generally gets you underground sooner; other common options are a purpose made box cut or using topography and siting the portal in a hillside. In some cases, a civil engineering cut-and-fill option may be utilised.

2.1.1 In-pit

If the proposed portal is to be developed in-pit the following needs to be considered:

- Inter-ramp slope stability (current and future).
- Bench stability.
- Rockfall hazard.
- Surface water management.
- Water ingress – flow down ramps or pit flooding (i.e. is there sufficient freeboard?).
- Interaction with open pit operations (traffic management).
- In-pit blasting.
- Interaction with future underground operations.

2.1.2 Box cut

In the case of a purpose designed box the following needs to be considered:

- Slope stability.
- Bench stability.
- Erosion.
- Rockfall hazard.
- Surface water management including pumping capacity and siting of sumps.

2.1.3 Natural slopes

In the case of a purpose designed box the following needs to be considered:

- Slope stability.
- Rockfall hazard.
- Erosion.
- Surface water management.

2.2 Geotechnical conditions

Prior to siting a mine portal, it is necessary to have a good understanding of the expected geotechnical, geological and hydrogeological conditions. Initially, a screening assessment needs to be undertaken to identify potential sites; this needs to be followed by a detailed site investigation. The purpose of the site investigation is to describe and characterise the soil/rock mass conditions, structural conditions, geology and groundwater conditions. These aspects form the geotechnical model for the portal location and this should be considered as the foundation of the portal design.

2.2.1 Site investigations

Typically, there would be two levels of site investigation. Initially there would be a screening assessment based primarily on existing information. Although in some cases some additional data would be collected. The purpose of this investigation is to identify preferred portal locations. This would be or should be followed by a detailed site investigation; in some cases, this investigation may indicate that a preferred location is unsuitable and additional investigations at alternative sites are needed.

The purpose of the detailed investigation is to confirm the portal location as well as collect information that will be used to define the design inputs. For an existing open pit there should be existing data and a geotechnical model; however, this is not also ways the case. Existing open pits provide an opportunity to collect mapping data using direct and remote methods. If a hillside is being used it is possible to undertake outcrop mapping and collect structural data using direct and remote methods. When undertaking these investigations, it is critical to also take note of rockfall hazards and likely surface water flow paths.

Investigations for portal will typically include the following:

- Existing geology and structural models.
- Geophysical data that can be used to define the depth of weathering.
- Drillhole data and core photographs.
- Outcrop mapping.
- Geotechnical logging.
- Laboratory testing.
- Open pit as mined pit shell model.

Whilst some of this information may be available from previous studies, it may not be sufficiently close to the proposed portal location (e.g. drillholes some distance away are of less relevance) or there are data gaps (inadequate geotechnical logging or limited laboratory testing). As a mine access portal is a critical long-life excavation it needs to be designed with a higher degree of reliability and this implies that a high level of confidence in the local geotechnical model is needed.

It is necessary to undertake a rigorous gap analysis and objectively assess the confidence of the existing data and models. The outcomes of this assessment should be used to guide the specific investigations needs for the proposed portal location; the investigation program should consider the following:

- Spatial distribution of geological and geotechnical units, the depth of weathering is important.
- Groundwater conditions.
- Drilling and detailed geotechnical logging for characterisation and classification purposes; this may require both soil and rock mass logging.
- Collection of structural data needed for kinematic analysis for the portal and bench face in blocky rock mass conditions.

- Type of drilling needed to collect appropriate data (reverse circulation drilling to define units but diamond core is needed for logging and sampling).
- Appropriate laboratory testing to derive material properties for soils, rocks and discontinuities.
- In many cases, it is necessary to capture data that is needed for the portal design, box cut design or a cut-and-fill design.

2.2.2 Geotechnical model

The data collected by the specific investigation should be used to update the geological and geotechnical models in the vicinity of the planned portal; this needs to consider the depth of weathering, degree of weathering, geological contacts between rock types, faults and intrusives etc.

For the rock mass, geotechnical logging should be undertaken to capture all the parameters needed to derive Q (Barton et al. 1974) and RMR_{89} (Bieniawski 1989) ratings. This should also be done for any scan line or face mapping undertaken. For soils, a system such as the unified soil classification system (USCS, US Army Engineer Waterways Experiment Station 1960) should be used to characterise the soil mass. Joint orientations, spacing and persistence (where possible) should also be collected.

The rock and soil mass characterisation can then be used to classify the soil/rock mass. This data in conjunction with the laboratory testing can then be used to derive material properties for use in design analysis. The locally updated geotechnical model can also be used to assess likely instability mechanisms that could impact the portal, open pit and box cut slopes.

2.3 Loading conditions and potential instability mechanisms

A review of the geotechnical characterisation and geotechnical model will assist in defining loading conditions and identifying potential instability mechanisms. This is a critical part of the design process as it will determine what design methods should be used. It is critical that the investigation and geotechnical model are of sufficient quality and confidence to allow for a confident assessment of these aspects. It is important to understand if the design is dealing with:

- Deadweight situations.
- Soil or rock mass.
- Weak or strong rock both in terms of rock mass classification and intact properties.
- Materials that will deteriorate over time (e.g. high percentage of swelling clay).
- Thickness of a stable beam relative to span.
- Structurally controlled or blocky ground etc.

By understanding the likely instability mechanism, the appropriate design method can be applied and the ultimate ground support solution derived. This assessment also extends to any slopes that have an impact on the portal.

2.4 Hazards and risks

A rigorous design process requires that all hazards and risks are identified so that they can mitigated through the design process or by additional controls. This necessitates that a comprehensive risk assessment be conducted early on in the design process. Stephenson & Sandy (2021) provide a detailed overview of the hazards associated with mine access portals. These can broadly be summarised as follows:

- Inundation through flooding or debris flows.
- Rockfall (existing pits, natural slopes, box cut).

- Ground instability within portal.
- Instability of slopes at various scales (bench, inter-ramp, overall).
- Operational hazards (blasting, flyrock, interactions with open pit production, traffic etc.).

When assessing the risk associated with a portal it is necessary to consider the long-term risk to the operation; for example, the risk profile for a single access portal will be very different to that for a twin portal arrangement.

3 Design acceptance criteria

Given the long life and high people and equipment exposure of a mine portal, a more conservative approach to defining appropriate design acceptance criteria (DAC) should be adopted. Mine portals should be designed to a higher Factor of Safety (FS) with an associated low probability of failure (PF) and a higher design reliability than regular mine excavations. This implies that the design inputs have a level of confidence commensurate with a high level of design reliability.

Uncertainty in the input parameters and design method has a significant impact on the PF; it is possible in the case of high uncertainty (large spread) to have a high PF even when a high FS is used, or a PF that exceeds the PF associated with a lower FS determined from inputs with a lower degree of uncertainty. The aim should be to reduce uncertainty of the inputs to a point where the natural variability is understood. This has previously been discussed by various authors (Hadjigeorgiou & Harrison 2011; Hadjigeorgiou 2012; Fillion & Hadjigeorgiou 2013; Dunn 2013, 2015, 2019).

In addition to the impact of uncertainty on the FS and PF it is also necessary to consider the design effort required for portals. Silva et al. (2008) based on earlier work by Lambe (1985) describe the relationship between level of engineering design input including the underlying investigations and the FS and PF. Whilst their work was predominantly on embankment slopes, the concept is valid for any mining geotechnical/geomechanics design. Four categories of design have been defined:

1. Category I – High failure consequences; facility designed, constructed and operated with a high level of engineering practice (best).
2. Category II – Ordinary facilities designed, constructed and operated with standard engineering practices.
3. Category III – Facilities without site specific design; temporary facilities with low failure consequences.
4. Category IV – Facilities with little or no engineering (poor).

With the design of permanent mine access portals the authors suggest that a Category II design be implemented as a minimum with a Category I being preferred.

Hoek et al. (1995) suggest a FS of 1.3 is suitable for temporary mine openings whilst values of 1.5–2.0 are required for permanent excavations. However, the need to conduct sensitivity studies and understand the impact of input parameter variability is stressed. Hoek (1991) provide further guidance on acceptable rock engineering design criteria.

For the Q-system (Barton et al. 1974) it is suggested that an excavation support ratio (ESR) of 1.6 should be used for permanent mine openings and that ESR = 1.0 can be used for portals. It should be noted that the empirical database on which the this is based is heavily skewed towards civil excavations with larger spans. In effect, ESR acts as an indirect approach to introduce a FS in the design. In practice, mines do not apply different FS between permanent (long-term) and temporary (short-term) tunnels; as workers must access mine tunnels and are exposed to potential rockfalls in both cases (Potvin & Hadjigeorgiou 2015).

Irrespective of what DAC is used, it is necessary to understand what the risks are and the design needs to mitigate the risk to an acceptable level using an appropriate level of investigation and design rigour.

4 Design process, and methods and process

The design of the portal more broadly, needs to consider many aspects such as surface water management, slope instability, vehicle interactions etc. This paper is focused on the design of portal excavations and does not consider slope design aspects required for open pits and box cuts.

4.1 Design process

There are a number of well-documented design schemes (Bieniawski 1992; Stacey 2004, 2008, 2009) and these can be applied to the design of a mine portals. Generally, they all require the following:

- Description of the rock mass and identification of likely failure mechanisms.
- Assessment of support demand (block size, depth of failure, support pressure etc.).
- Assessment of support capacity (element type, technical specifications conditions, density, in situ performance etc.).
- DAC (appropriate FS related to excavation purpose).

A simplified version of Terzaghi's observational approach (design – implement – monitor – verify) can be applied. Typically, this would involve estimating ground support requirements using an empirical method such as the Barton Q-System (Barton et al. 1974), the RMR System (Bieniawski 1976), rules of thumb or analytical methods such as key block methods (Goodman & Shi 1985). The ground support design is then implemented and monitored. Monitoring is usually done by means of observations although, in some cases, instrumentation is used. The ground support design is then modified or optimised based on performance observations; however, in the case of a mine access portal any redesign should be avoided and this tends to drive a slightly more conservative design approach.

Irrespective of the exact approach that is adopted, the important thing is that a rigorous process with supporting documentation is applied. The design approach and level of effort should be matched to the acceptable level of risk.

4.2 Design methods

There is a range of design methods that can be used in the design of portal, some of these are briefly discussed below. The choice of design method depends on the complexity of the site and the identified likely instability mechanism and the proposed solution.

4.2.1 Rock load theory

Terzaghi proposed an empirical classification scheme (Terzaghi 1946) for estimating the loads to be supported in tunnels using steel arches. His classification scheme was based upon experience in numerous rail tunnels throughout the Alps and was comprised of descriptions of various types of ground conditions. This approach has been widely used over several decades in lieu of more advanced methods. Singh et al. (1995) later made modifications to Terzaghi's theory to take into account more advanced tunnelling technology and ground improvement techniques such as tunnel boring machine (TBM) technology and fore-poling/spiling. This method is easy to apply and is a good starting point when designing portals in weaker materials.

4.2.2 Empirical systems

There are several empirical methods that be used to design ground support for portals. The Q-system (Barton et al. 1974; Norwegian Geotechnical Institute (NGI) 2015) is commonly used on mines for the design of portals and this system is well documented. Stephenson & Sandy (2021) present an overview that will not be repeated. The Q-system allows for characterisation and classification of the rock mass and an assessment of the support pressure required to maintain stability. This is linked a design chart the presents a range of options including bolts, shotcrete and arches.

The RMR_{89} (Bieniawski 1989)is approach is similar to the Q-system and presents a range of support options based on the rock mass characterisation. Experienced based recommendations such as those provided in Stephenson & Sandy (2021) which relates different ground support solutions to different rock mass qualities; it also relates weathering and the International Society for Rock Mechanics and Rock Engineering field strength estimates to ground support solutions.

Generally, these methods are easy to use and capture industry experience; however, care must be taken to ensure that the data used for empirical design assessments is representative of the site conditions.

4.2.3 Kinematic methods

In a blocky rock mass, where wedge or block failure will be the dominant instability mechanism, kinematic analysis (e.g. using Unwedge (Rocscience Inc 2023a)) is a useful way to assess stability and ground support requirements. This is often used in conjunction with empirical methods. Easy to use but care must be taken to ensure discontinuity orientation and shear strength inputs are representative of the site conditions. Undertaking sensitivity analysis for key parameters is prudent to evaluate the reliability of the design analysis.

4.2.4 Analytical methods

This can be equations used to determine the deadweight load and required support resistance, beam theory (Beer & Meek 1982) in bedded rocks, design of shotcrete arches (Andrieux & Brummer 2005), and methods to assess the loads and capacity associated with arches and sets. Analytical method can be easy to use and can readily done a spreadsheet, which allows sensitives to be run with minimal effort. Understanding the inputs and reliability of those inputs is important when using analytical methods.

4.2.5 Numerical modelling methods

A range of numerical models could be used in the design process and this can include simple two-dimensional models like RS2 (Rocscience Inc 2023b) to evaluate zones of instability around the portal to more complex three-dimensional models such as RS3 (Rocscience Inc 2023c), FLAC3D (Itasca 2023), Abaqus (Dassault Systèmes 2023) etc. Depending on the complexity of the site, it is possible to explicitly include ground support into numerical models. There are also specific modelling packages such as Microstran (Bentley 2023) that can be used to model steel arches etc.

There are a range of numerical modelling solutions that can be used in the design of mine portals and these range from relatively simple to highly complex. Irrespective of what solution is used, it is important that a rigorous process is followed, the modelling solution matches the complexity of the problem and is able to capture the expected or likely failure mechanism, and that the modelling inputs are representative of the site conditions and have the required design confidence level and reliability. Sensitivity analysis is a useful tool to evaluate the model and the impact of variations in critical inputs on the design.

5 Case studies

Graaf & Parrott (2013) present two very good case studies that demonstrate how portal design should be approached in fresh and weathered rock. Stephenson & Sandy (2021) present some good examples of portal designs and practices. Additional case studies are included for different conditions and ground support approaches.

5.1 Case A

Case A is a gold mine in Western Australia. Open pit mining operations were being undertaken but previously underground mining had been done. The original portal had been mined through with an open pit cut back. Subsequently, it was discovered that there was additional underground mining potential. A decision was made to establish a new in-pit portal that would be developed to intersect the existing decline which would then be rehabilitated.

The portal was sited close to the contact between the fresh and weathered rock. This location choice was driven by practical needs and site availability. The rock mass was a foliated, relatively weak (R3) ultramafic rock mass; three joint sets were present, and the Q values were in the 0.5–1.0 (very poor) range, although these increased within the fresh rock mass (Figure 1). No specific investigation drilling was undertaken but it was possible to map the bench face and use existing geotechnical information. There was mapping available from the existing decline ≈50 m behind the portal face position – this mapping indicated a reasonably competent blocky rock mass.

(a) (b)

Figure 1 **(a) Bench face conditions; (b) Bench mined back with fibrecrete applied to face and spiling bars installed**

The following hazards were identified:

- Rockfall hazard.
- Bench instability (planar failure due to foliation undercutting and wedges).
- Portal instability – wedges and unravelling of the weak blocky rock mass.
- Middling above portal back.

To eliminate the hazard of the low middling (≈3 m) between the portal back and next bench, the face was mined back locally. The bench face above the portal was meshed to prevent rockfalls.

The following ground support was installed for the portal face area and bench face above the portal to reduce the likelihood of bench instability and the rockfall hazard:

- 100 mm of 32 MPa fibrecrete. 8 m on either side of the portal and up to the bench crest.
- Three rows of cablebolts into the bench between 1,280 mRL and the ramp, with the first row installed approximately 1.5 m below the crest. The cablebolts were twin strand 12 m bulbed cablebolts (15.2 mm diameter) installed into a 89 mm diameter hole, plated and pre-tensioned to 10 t/strand with 4 m of embedment installed at a 5° incline on a 2.5 × 2.5 m staggered pattern.
- 2.4 m long (20 mm diameter) grouted Gewi bars installed on a 2.5 × 2. 5 m staggered pattern.

For the portal ground support, fibrecrete arches were used in conjunction with fibrecrete and bolts. The design of fibrecrete arches is based on analytical solutions for concrete arches and is described by Andrieux & Brummer (2005). In addition, Terzaghi's rock load theory (later modified by Singh et al. 1995) and support pressure (Barton et al. 1974) have been used to estimate possible loads. The NGI Q-system (NGI 2015) also makes provision for the use of fibrecrete arches in poor ground conditions. The following ground support and installation process was used:

- Primary ground support to be installed prior to installation of the fibrecrete arches.
- Ground support and reinforcements for development within the portal are to include:
    - 12 m spiling bars installed around the perimeter of the arched profile at 0.5 m centres for the first 12 m.
    - Stiff Split Sets 2.4 m long in walls and 3.0 m long in backs and shoulders on 1.5 m spacing, 100 mm 32 MPa fibrecrete applied floor-to-floor.
- All ground support and reinforcement must be galvanised.
- Fibrecrete arches (300 × 300 mm in cross-section) were installed in the following sequence:
    - First two fibrecrete arches installed once the face has advanced ≈4 m; arch spacing of 1.5 m centre-to-centre.
    - Fibrecrete arches should not be installed closer than 2 m from the advancing face to avoid blast damage. Fibrecrete arches can then be installed as the face advances.
    - A detailed job safety analysis (JSA) is required for fibrecrete arch installation.
- The remaining ≈30 m of the portal to be supported with 100 mm of fibrecrete and 2.4 m long Stiff Split Sets (or alternative) on a 1.5 m spacing.

The first few metres of the portal were developed using road header to limit blast disturbance (Figure 2); the initial ground supported was then installed and then the fibrecrete arches were constructed. This approach worked well and was far more efficient and flexible compared to steel sets that were initially being considered. In hindsight, the design was likely conservative as the arch spacing could have been decreased and a 50 mm thickness of fibrecrete would have been sufficient.

(a) (b)

Figure 2 (a) Road header cutting face; (b) Fibrecrete arches being installed

5.2 Case B

This portal is located in between Kambalda and Norseman, in the Goldfields region of Western Australia. The underground gold mine was planned to be accessed via a ≈53 m deep box cut, followed by decline development to access the orebody (Figure 3). The depth of the box cut in this case was chosen for two reasons – firstly, to recover shallow gold-bearing ore, and to also gain access as close as possible to the fresh rock horizon for establishing the portal.

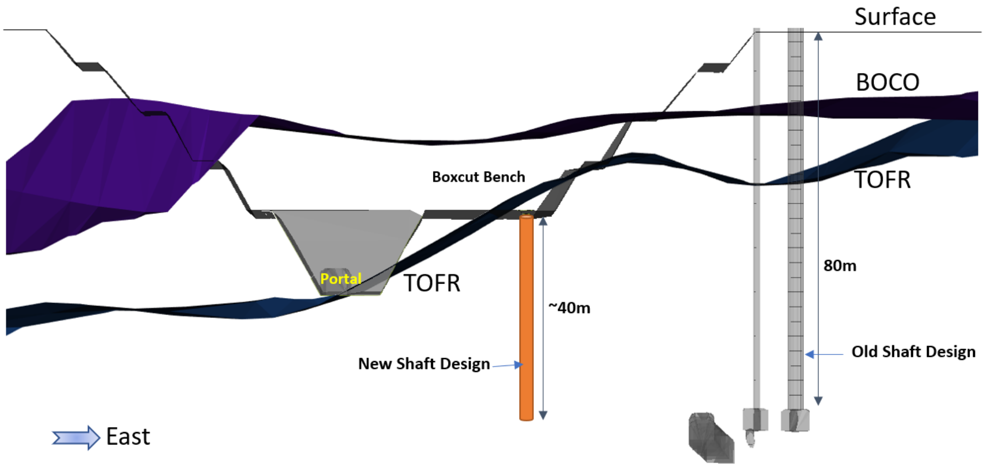

Figure 3 Cross-section at the portal face location showing box cut geometry and depth of weathering

The investigation of the box cut position consisted of a single geotechnical diamond drillhole to the depth of the proposed box cut, drilled down approximately in the location where the portal face was to be established.

The bedrock geology comprises of a complex tectonographic assemblage of mafic, ultramafic and sedimentary-dominated units metamorphosed under amphibolite to greenschist facies condition. The box cut face conditions consisted of moderately to strongly weathered material in the upper portion, with the lower portion of the face located in moderately to slightly weathered rock.

The design approach used empirical, numerical and first-principles design methodologies. The box cut analysis utilised the slope stability program Slide2 (Rocscience Inc 2023d) to analyse the box cut face, and to determine the load demand requirements (in terms of driving force of potential sliding failure) for input into surface and reinforcement design. This was chosen due to the nature of the material in the face consisting largely of highly weathered mafic materials.

Establishment of the initial portion of the portal or tunnel utilised Terzaghi's rock load theory, Singh's modified Terzaghi, first principles and support pressure determined from Barton's Q-tunnelling index. Singh's modified approach appears to give the most realistic load demand requirements.

The box cut face included sprayed fibrecrete to a thickness of ≈100 mm, mesh embedded within the fibrecrete, a pattern of grouted 3.0 m long rebar and grouted 9 m long twin strand bulbed cable bolts (Figure 4). The portal face height was ≈20 m, and the perimeter of the portal was spiled with 32 mm rebar to a depth of 12 m, and 0.5 m spacings for the crown (Figure 5).

Significant issues were experienced during the mining of the box cut. These included bench to multi-bench scale instabilities requiring rehabilitation due to unforeseen, unfavourable and highly weathered shear zones, as well as blasting in hard rock without due care.

The initial ≈15 m of development was heavily modified to ensure a successful outcome for construction. The advances were limited to 2 m length per round, with the inner core of the face blasted, and the outer ≈1 m scaled to the desired design profile. The ground support consisted of 50 mm fibrecrete, followed by bolts and mesh to the floor, a second layer of ≈50 mm shotcrete, in-cycle cable bolting and steel-reinforced shotcrete arches. The level of ground support was gradually reduced in response to improving rock mass conditions.

Figure 4 Portal face during excavation of the box cut with progressive installation of surface support and reinforcement

Figure 5 Portal development commenced and ≈20 m long

5.3 Case C

This particular mine is located in the central Goldfields of Western Australia, and is yet to be constructed at the time of writing this paper. Two portal locations were required, with one being located totally in fresh rock and the other within transitional (slightly weathered) rock (Figure 6). Both portals were established from within an existing pit where open pit mining operations were complete.

The investigation for these two locations principally involved a pit inspection and pit wall mapping of the proposed locations. Drillhole data from an existing database was used to characterise the rock mass for the declines further from the portal locations. Furthermore, high-resolution photogrammetry modelling was undertaken in order to digitise structure locally and at a multi-batter scale. No rock properties test work was undertaken for this particular project; however, existing data was available.

The mine is located within the Greenstone Belt in the Eastern Greenfields Province of the Archaean Yilgarn Craton. Both portals are proposed to be located within a felsic rock mass, which is situated within the footwall of the orebody (Figure 7).

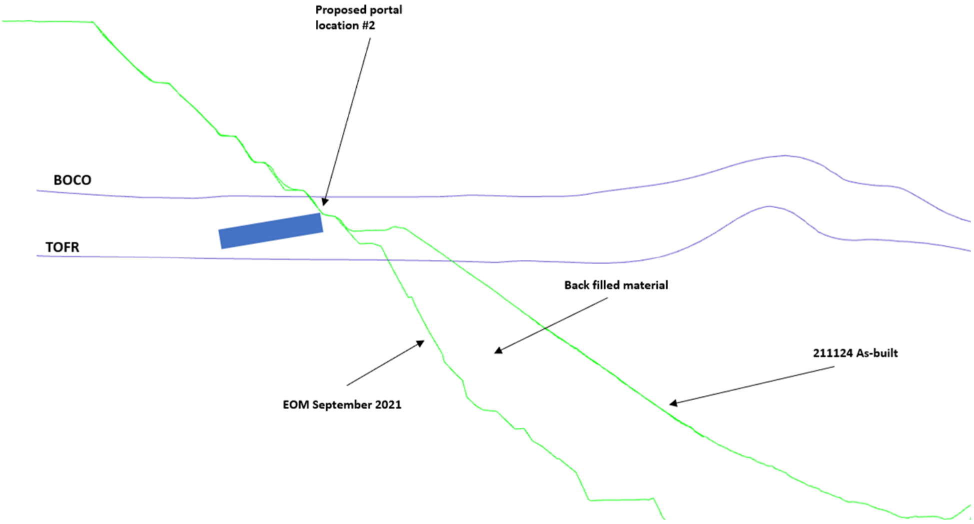

Figure 6 Cross-section looking east through a proposed portal location

The design approach used empirical, numerical and first-principles design methodologies. In order to determine adequate portal face surface support and reinforcement requirements, a kinematic analysis utilising the software package Swedge (Rocscience Inc 2023e) was used. Data collected from the photogrammetric techniques was used as input for the major structures, as well as for scaling the trace length of the structures. Swedge (Rocscience Inc 2023e) allows for the application of reinforcement support into the slope geometry; however, it cannot be applied as a pattern across the face. This is a limitation of the software, and single reinforcement element is installed 'equivalent' to the total number of elements needed within a given face.

In both the fresh and the slightly weathered locations, a single layer of fibrecrete was recommended to a thickness of ≈100 mm for the full bench face height to the bench above, and ≈10 m either side of the portal. Furthermore, a draped mesh either side and beyond the fibrecrete was recommended for rockfall protection.

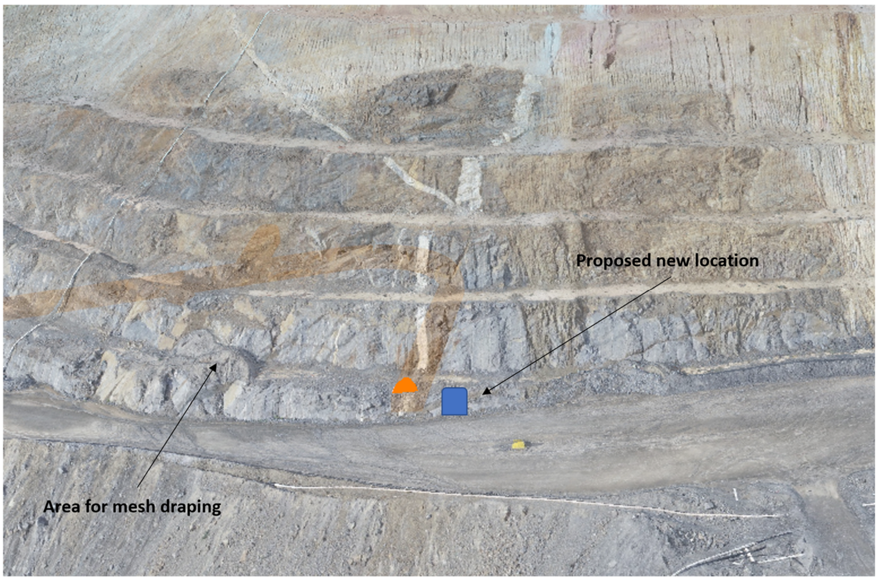

Figure 7 Proposed location of portal within existing pit and within transitional material

In both the fresh and the slightly weathered locations, a single layer of ≈100 mm thickness fibrecrete was recommended for the full bench face height to the bench above, and ≈10 m either side of the portal. Furthermore, a draped mesh either side and beyond the fibrecrete was recommended for rockfall protection.

Reinforcement of the portal face included the proposed use of grouted, 3 m × 20 mm threadbar bolts and 9 m long twin strand bulbed cable bolts (Figure 8). Spiling of the portal profile was kept as an optional extra for the portal located within the transitional material, which included the drilling and installation of 12 m long, 32 mm rebar spaced 0.5 m within the row, and 0.5 m from the portal crown and shoulder.

The initial ≈10–15 m of development of the portal itself utilised Terzaghi's rock load theory, Singh's modified Terzaghi, first principles and kinematic analysis using Unwedge (Rocscience Inc 2023a). Singh's modified approach appears to give the most realistic load demand requirements when considering empirical approaches; however, the kinematic analysis provides a more realistic assessment of potential wedges that may form. Consideration must be given to the fact that the development is occurring from within an open pit, which has been subjected to blasting-induced damage to the rock mass, loss of confinement due to the large pit excavation and geometry. Therefore, an appropriate level of conservatism must be incorporated into the design and development philosophy.

Development for the initial ≈10–15 m includes short development rounds of 2 m in length, tight perimeter control for drilling and blasting, and the application of in-cycle fibrecrete, meshing and bolting with resin rebar of 3 m in length, and twin strand bulbed and grouted 6 m long cable bolts installed in-cycle (Figure 9).

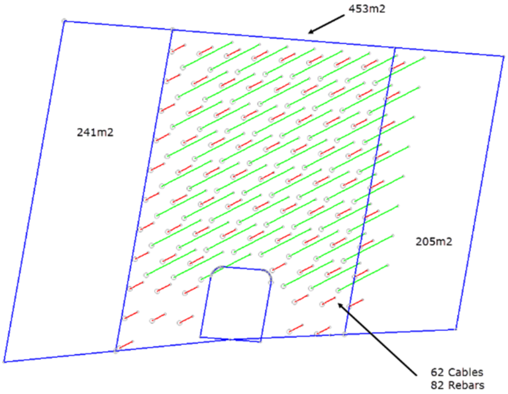

Figure 8 Reinforcement design for a portal located in fresh rock within a pit

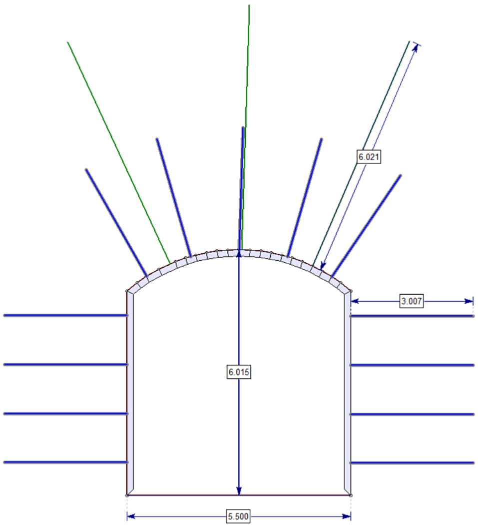

Figure 9 Ground support profile for portal development for the initial ≈10–15 m

5.4 Case D

The mine is a mature open pit in New South Wales and significant underground potential had been identified by exploration drilling. However, due to the location adjacent to a large lake and environmental considerations, further drilling of the orebody from surface was not feasible. A decision was made to develop an exploration access so that drilling of the steeply dipping orebody could be done more efficiently from underground. This necessitated an in-pit portal. As this was a busy operating pit, the access development had to ensure limited impact on mining operations – this limited portal locations.

A saprolite profile is present with a depth of 20–50 m and this is overlain by a transported lacustrine clay giving an overburden of ≈100 m. Locally, the saprolite is referred to as softer oxide (SOX) and this is underlain by a transitional zone called the hard oxide (HOX). The fresh rock is diorite and various volcaniclastics. The site selected for the portal was based on practical pit traffic considerations and was, unfortunately, close to the HOX and fresh eastern volcaniclastics (EVc) contact as shown in Figure 10. Originally, the bench face angle was 45°, but this was mined back to 70° to provide more space and create a better profile for the portal breakaway.

Figure 10 Proposed portal location

The site has good geological, structural and geotechnical models based on an extensive drillhole database and face mapping, as well as an extensive laboratory testing database. No specific investigation holes were drilled for the portal; however, the closest drillhole was 17 m away. The area was structurally mapped using photogrammetry techniques; field mapping was done to confirm the structures, and window mapping to assess the of the rock mass quality was undertaken.

An RMR_{89} design value of 42 (poor) was determined and a Q value of 0.15 (Very Poor); although, it should be noted that a conservative value of RQD was used (25th percentile). The field strength for the HOX was R1–R3 and R4–R5 for the fresh rock. There was some uncertainty around the HOX–fresh rock contact as it dips and rolls and is undulating.

Stability analysis for the bench was done using Dips (Rocscience Inc 2023f) and Swedge (Rocscience Inc 2023e). For the portal, Unwedge (Rocscience Inc 2023a) analysis was done and this was accompanied by empirical analysis using the RMR_{89} and Q systems, and the guidelines developed by Rogers & Haycocks (1988, 1989).

For the bench face, the following recommendations were made (Figure 11):

- Fibrecrete 100 mm thick be applied to the pit wall face to the bench above and to 8 m either side of the portal walls.
- Two rows of twin strand bulbed cable bolts 10 m in length to be installed +10° from horizontal above the portal backs, 1.5 × 1.5 m spacing (staggered), to 5 m either side of the portal. Use a thick grout or breather tubes to ensure full encapsulation. Cable bolts to be plated and tensioned before development commences.

- Install two rows of fully grouted solid bar bolts 2.4 m long into the face from 6 m above the portal backs, 2 × 2 m spacing.
- Install a round of 6 m long 32 mm diameter, fully grouted spiling bars 0.5 m outside the decline profile and spaced 0.3–0.4 m apart, across the backs. Spiles should be maintained and replaced after every 4 m of development advance, until the ground improves. The purpose of the spiles is to maintain short-term stability to control the profile and between blasting and ground support installation.

Figure 12 shows the bench face and portal mark-up prior to the commencement of blasting.

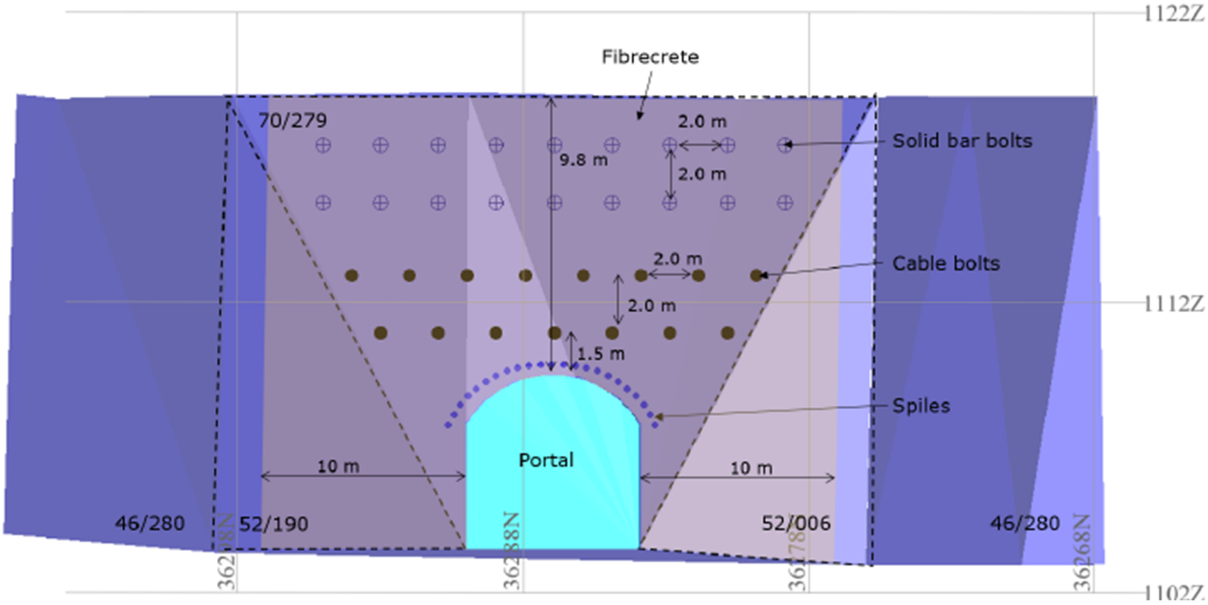

Figure 11 Bench face support

Figure 12 Bench face and portal mark-up prior to the commencement of blasting

For the first 16 m of the portal, the following was recommended (Figure 13):

- Blasting rounds of 2 m length in the first 10 m of development. Smooth-wall blasting for at least the first 10 m of development and recommended on an ongoing basis.
- Fibrecrete 75 mm thick applied to the development walls, floor-to-floor.
- Fully encapsulated resin bolts 2.4 m long installed with 1.2 × 1.2 m spacing in the backs and walls, to 2 m from the floor for the initial 16 m of development.

- Twin strand bulbed cable bolts 8 m long installed in-cycle with 2 × 2 m spacing in the backs in the first 16 m of development. The first two rows should be inclined forwards at 20° from vertical. Cable bolts should be installed and tensioned after each cut is taken.
- Cable bolt positions should be adjusted, if necessary, to avoid drilling through the cable bolts installed from the pit wall face.
- Two extensometers be installed in the portal backs for long-term monitoring.

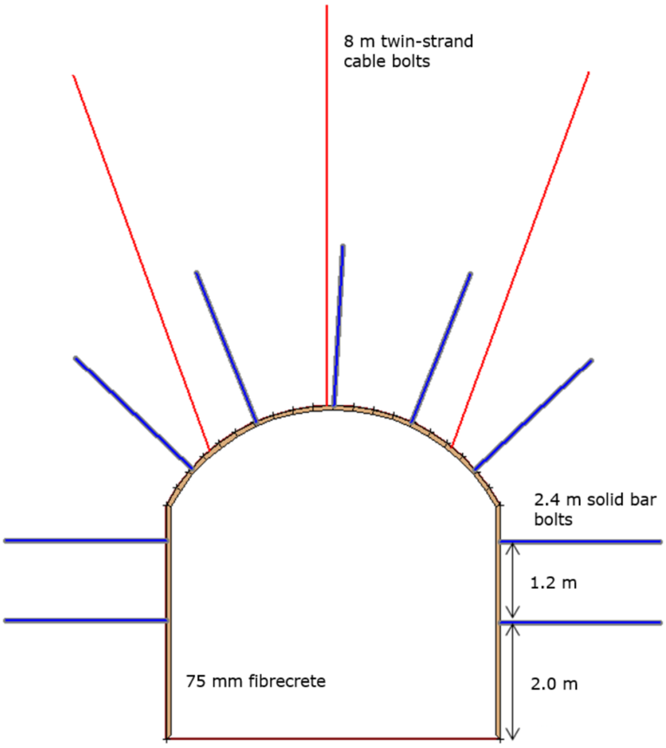

Figure 13 Portal ground support

This design was successfully implemented; there was some minor movement on the bench associated with structures, but this seemed to stabilise and did not propagate once the fibrecrete and cable bolts had been implemented.

6 Implementation and monitoring

Whilst a robust, good quality design commensurate with the accepted risk profile is important, the level of implementation needs to be commensurate with the mine portal design level of effort. This requires the following:

- The design is implemented as intended by the designer and all recommendations are implemented; if there are unavoidable changes, a detailed (documented) change management process must be followed to confirm the design changes are acceptable.
- Ground conditions are verified during implementation to confirm design assumptions and inputs.
- Quality control is needed for all ground support and must extend excavation practices such as drill-and-blast.
- Detailed construction records should be maintained.

An appropriate monitoring program is needed. The objectives are early warning of any potential instability and to confirm and verify the performance of the design.

7 Discussion and conclusion

Mine access portals are important long-life excavations with high personnel and equipment exposure; therefore, they should be designed to have a high level of reliability. This implies that they are designed to an appropriate FS and PF that is commensurate with the acceptable risk. This requires that a high level of design effort and rigour is applied. This encompasses all aspects of design including field investigations, choice of DAC and design analysis, and use of appropriate methods.

The design of a portal can be complex and often needs to consider the stability of slopes in open pits, box cuts and natural slopes. Surface water management and rockfalls are often issues requiring attention. It is not uncommon for the portal to be located in a less than optimal position because of operational constraints and this require additional measures to manage additional hazards.

The design of a mine access portal requires that all hazards and risks are identified and that the likely instability mechanisms are identified. The correct identification of the instability mechanisms requires that the geotechnical model is fit for purposes and has acceptable uncertainty. Only once there is a thorough understanding of the risks, mechanisms and geotechnical conditions, can the DAC and design process be defined. In cases where there are data gaps that cannot be addressed, a more conservative design approach should be adopted.

There is a range of design methods and ground support solutions available for the safe development of long-life mine access portals and some examples are provided in this paper. The design methods available range from simple empirical systems which have industry experience built in to very complex numerical modelling solutions. The most important aspect for successful portal design is to follow a systematic and rigorous design process.

Irrespective of what design method is used, it is important that it is matched to the complexity of the problem and is able to capture the expected or likely failure mechanisms. Design inputs must be representative of the site conditions and have a confidence level and reliability commensurate with the accepted risk profile.

Sensitivity analysis is a useful tool to evaluate the design sensitivity and response to uncertainty (or variability) in key input parameters – especially if the level of confidence for these inputs is lower than what is ideally required. This can also be dealt with by using more conservative DAC where there is a high uncertainty in the key design inputs.

As a minimum, a Category II level of design effort should be used. Ideally, a Category I level of design effort should be used for mine access portals as they are important long-term and high-exposure access excavations. Effective and good quality implementation, combined with an effective monitoring program, are needed to close out the design of mine access portals and manage any risks.

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