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Critical challenges impacting the advancement of slope design reliability

K Moffitt *Equilibrium Mining, Australia*

Abstract

There have been many recent and ongoing advances in the area of slope stability, including tools and processes for slope management, rock mass characterisation, stability assessments, and selection of design acceptance criteria. Despite the many advances and ongoing research in the field, there remain several fundamental unresolved challenges that impact the design and assessment of pit wall stability. In this paper, these have been categorised into six key areas:

- *Assessment and communication of risk: a risk-based approach to slope design has become more common practice, particularly with advances in approaches to calculating a Probability of Failure (PoF). However, the PoF is not quantified in a consistent manner within our industry and can present a false or misleading view of project risk to stakeholders and decision-makers.*
- *Reliance on technology: new and emerging technologies have provided many benefits to our industry but, in some cases, technology has advanced faster than the ability to answer more fundamental and basic questions related to material characterisation and slope behaviour.*
- *Treatment of damage/overbreak zone: the rock mass strength and hydraulic conductivity of the near-surface 'rind' around the pit wall is impacted by damage resulting from blasting and stress relaxation. The depth and extent of damage/disturbance are very difficult to test/evaluate. Although the assumptions may significantly influence predictions of inter-ramp scale Factors of Safety (FoS), there are no consistent approaches or standards for the treatment of this zone in stability analyses.*
- *Integration/communication: within our complex mining environments, disconnects often exist between disciplines but also between the technical teams, management and stakeholders. There are also obstacles to information sharing and collaboration. These can reduce efficiency, design reliability, and the speed of innovation.*
- *Increased demand for minerals: electrification and the demand for resources are arguably greater than they have ever been. With this increase in demand comes additional challenges related to developing deeper mines and steeper pit walls in increasingly remote environments.*
- *Reducing technical workforce: the industry is currently under-resourced. The talent pool is shrinking while mine complexity is increasing. It is critical that the industry take steps in the short term to address this skills shortage.*

This paper is not intended to prescribe or present solutions to these issues. Rather it is intended as a means to engage and challenge the industry to discuss and consider these issues. Based on research along with the author's experience and discussions with industry leaders, this paper explores each of these issues, how they may impact the reliability of slope designs, and ideas for consideration to move the industry along a path to overcoming these challenges.

Keywords: *slope stability, geotechnical risk, technology, slope design reliability*

1 Introduction

There have been many great advances in slope stability in recent years that have improved the ability to deliver reliable slope designs. These include advances in data collection, characterisation, analysis, and development of rationale for the selection of design acceptance criteria (DAC). Despite these advances, and in some cases as a result of them, there remain challenges in the development of reliable slope designs.

Many of the advances in characterisation and slope stability assessments add layers of complexity that are difficult to convey to non-technical stakeholders and decision-makers. The phrase 'the devil is in the details' has never been more true when it comes to geotechnical slope designs. This applies to all stages of geotechnical design from field data collection to slope stability analyses and interpretation of results. For example, characterising the behaviour of fractured rock is not as straightforward as it is for engineered materials like steel or concrete. The inability to test materials at a scale relevant to design requires the development of methods to estimate rock mass strength based on the intact strength and fracture characteristics. This is not an exact science and is open to a range of approaches and theories that produce different results that one can argue are all defensible. The approaches used to estimate the Factor of Safety (FoS) and Probability of Failure (PoF), the key slope design metrics to assess for design acceptance, are also open to individual opinion and selection. This places decision-makers, often not geotechnical experts, in a difficult position of having to rely on their 'trust' in the geotechnical practitioners providing slope design recommendations.

Technology and innovative approaches to implementing technology (e.g. drone photogrammetry, lidar scanning, innovations in monitoring systems, cloud computing etc.), in our industry represent some of the greatest advances to slope management and design reliability. At the same time, these technological advancements often seem to be moving at a pace beyond our ability to answer more fundamental questions related to rock mass characterisation and performance. For example, we now have the computational capability to implement highly sophisticated non-linear constitutive relationships in models, but do we have sufficient confidence in the estimation of the increasingly complex set of parameters that define the stress-strain response?

These challenges, as discussed in this paper, will become more and more pronounced in the future. As demand for minerals increases, design complexity increases, and the forecasted pool of technical resources diminishes, there is a concern of a trend to more reliance on quantification and technology without the appropriate level of experienced engineering judgement. For discussion in this paper, key challenges to delivering reliable slope designs have been categorised as follows: assessment and communication of risk, reliance on technology, treatment of a damage/overbreak zone, communication/integration, increased demand for minerals, and reducing technical workforce.

2 Critical challenges

2.1 Assessment and communication of risk

Design, operation and maintenance of large open pit slopes inherently involves some level of geotechnical risk (financial, social, safety etc.) regardless of the design practices followed. The challenges can be attributed to several factors, including (but not limited to) rock mass uncertainty, spatial variability, geological complexity, data availability etc. Key sources of uncertainty (following from Macciotta et al. 2020) include the geological/geotechnical/hydrogeological models, spatial variability of relevant input properties, applicability of strength criteria, laboratory testing adequacy (scale and bias error), methods of analysis, and human error.

Historically, risk has been managed by adopting the requirement for a higher FoS as the consequence of failure increases, informing the DAC for a particular mining operation. This FoS target can then be reduced as design confidence increases. However, given the uncertainty associated with a single set of inputs in a stability analysis (limit equilibrium [LE], numerical stress modelling or other), stochastic PoF methods are often paired with FoS values as part of the DAC definition. Typical FoS and PoF requirements for open pit slope design are presented in Wesseloo & Read (2009) and reproduced in Table 1.

Table 1 Typical FoS and PoS requirements for open pit slope design (Table 9.9, Wesseloo & Read 2009)

Slope scale	Consequence of failure	Minimum static FoS	Maximum PoF
Bench	Low–high	1.1	25–50%
Inter-ramp	Low	1.15–1.20	25%
	Medium	1.20	20%
	High	1.20–1.30	10%
Overall	Low	1.20–1.30	15–20%
	Medium	1.30	5–10%
	High	1.30–1.50	≤5%

At a bench scale, probabilistic-based design criteria for developing bench face angles, maintaining required catch bench widths, and estimating back-break have been widely documented and implemented in commercial software. At an inter-ramp and overall slope scale, stochastic processes have also been developed (random LE method, point estimate methods, response surface methods etc.) to estimate the PoF associated with a specific failure mechanism or model input assumptions. However, there is no standard procedure for the evaluation of the PoF (or the selection/definition of appropriate inputs for these methods) in the mining industry, leading to inconsistent application and a wide range of PoF possibilities for a single scenario. Specific areas of inconsistency that impact the estimated PoF include the following:

1. PoF analysis is highly dependent on the input distributions of the key parameters considered in the analysis. Without a consistent approach to defining these distributions, or the truncation of inputs, the PoF communicated to stakeholders for standard inter-ramp to overall scale FoS pairs remains a subjective quantity, difficult to benchmark by correlating across projects.

2. Confidence in key parameters impacting FoS does not always improve with as the study level progresses (or not significant enough to impact PoF). Operational confidence improves significantly as pushbacks are successfully executed, but that improved confidence does not directly correlate to critical input variables. Successful operating mines, for example, continue to assess rock mass strengths for critical units impacting stability, but the results can vary significantly based upon biases in the sample selection, lab testing challenges, confinement stress, anisotropy relative to loading direction, sample defect variation etc. (Figure 1), resulting in little to no reduction in the coefficient of variation of strength as additional data is collected. In fact, the coefficient of variation is often a reflection of rock mass variability rather than data uncertainty.

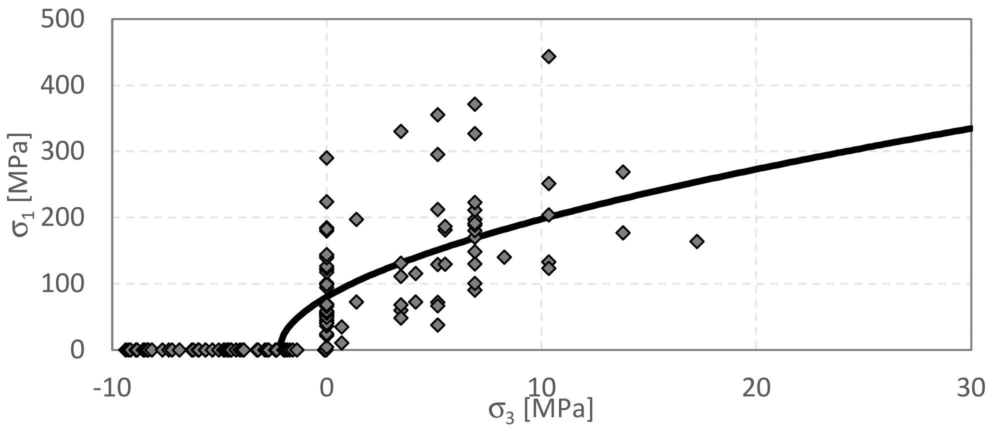

Figure 1 Typical example of intact strength data from laboratory testing exhibiting large variation

3. Most methods of PoF estimation generally identify the critical failure surface for the base case inputs and evaluate the PoF for that specific surface. The impact of varying inputs (i.e. sampling from the probability density function for each parameter) on the geometry of the failure surface is often not considered.

4. The impact of the scale of material variability is often not considered. For example, geotechnical data collected from drillcore will indicate variability on an interval-by-interval basis. Common practice is to develop a distribution for those interval data and present that as the probabilistic distribution for the material, and then apply it uniformly to an entire domain. The coefficient of variation at the scale of interest for inter-ramp or overall wall failures is much less than the drillhole interval data would suggest. This is illustrated conceptually in Figure 2. The figure shows an example scale of variability of downhole rock mass rating (RMR) data along with corresponding histograms of RMR data a) using interval data and b) using the mean of RMR calculated for 200 m lengths of drillcore (the scale of a potential failure surface being evaluated). Note the wider distribution for the RMR taken directly from interval RMR data. The corresponding distributions of FoS calculated clearly illustrates the potential impact of variability scale considerations on the PoF.

5. Input variables are also not equally weighted, or difficult to quantify. Transient or shallow pore pressures, for example, are a key factor influencing slope stability but remain a challenge to estimate even in deterministic studies. When evaluating static pore pressure, definition of upper/lower bounds and distribution types is required – options often include ±5, 10 or 15 m of pressure head, and triangular, uniform, or normal distributions for the latter. The choice of distribution alone can result in up to a 10% variation in computed PoF. In contrast, spatial variation in geotechnical properties is often partially quantified by the development of block models (uniaxial compressive strength, geological strength index, rock quality designation). Input distributions in the PoF assessment should reflect this additional confidence (perhaps limiting the variation in parameters when the block models are informed by nearby drillhole information). Underlying source variables should not be sampled from raw laboratory information when additional spatial improvement in uncertainty is available.

6. The PoF is highly influenced by the number of independent geotechnical domains intersecting the failure surface. If a slope has many geotechnical domains and each is sampled independently, the overall FoS will trend towards the mean and will have a low associated PoF. If the slope is comprised of one unit and that unit is assumed to have a uniform strength, the PoF will tend to be higher.

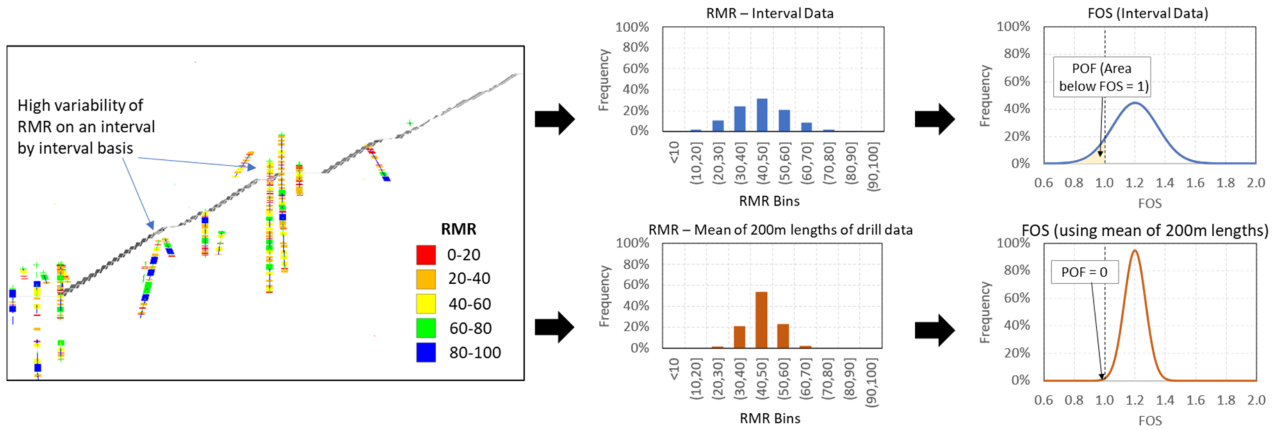

Figure 2 Conceptual illustration of impact of geotechnical scale on the coefficient of variation of data

In many cases, the author has observed that the variation of input parameters is often selected to limit the PoF, which is also considered a valuable exercise, but this does not properly quantify the uncertainty in the underlying input variables (it quantifies the range of acceptable conditions to achieve the selected PoF).

Risk owners and decision-makers also need to be aware that the PoF does not consider the impact of unknown/unidentified structures or even the impact of variability in the location and orientation of identified structures. These geometrical uncertainties of the structural model are often the area of highest uncertainty and have the largest overall impact to the FoS.

To properly evaluate risk, a base set of operating guidelines are required to inform a consistent measure of the PoF. Otherwise, communication of PoF values to management and investment stakeholders can present a misleading view of overall project geotechnical risk.

2.2 Reliance on technology

Over the last few decades, advancements in technology have had a significant impact on improving safety, mining processes, monitoring and design. Remote or autonomous equipment has removed the safety risk of working in confined or inaccessible spaces. Telemetry-enabled radar, GPS, monitoring, and data collection systems are now available and widely utilised at active mines. Optimal use of constrained resources and complex processes are refined through optimisation strategies based on real-time data collection, parameter estimation and machine-learning algorithms.

Slope design, reliability and management have seen improvements as a result of these technological developments. This is largely due to improved data collection and monitoring systems which provide a direct method to quantify the performance of the slope design, but also due to the tools available to the designers. Increased capacity of data storage devices rarely poses a significant challenge to slope design for today's engineers. Wireless, cellular or satellite transfer speeds, even in remote areas, are also sufficient to distribute data globally within minutes. Computing technology has advanced significantly, not only in the form of accelerated computing and graphical processing units (CPUs/GPUs), but also in the accessibility of scalable computing hardware through cloud technology.

As a consequence of these developments, the incorporation of available data into slope design tools has and will continue to increase dramatically, leading to more advanced stability analyses which can be evaluated over a wider range of parameter sensitivities to improve design reliability. However, it has also given engineers the ability to construct very large, complex models with non-linear constitutive relationships where input variables are not well constrained, or the representation of rock mass strength is less understood or subject to debate (such as the case for weak rock or strong, massive, brittle rock).

These complex models commonly incorporate a high degree of refinement, material variability, and non-linear behaviour. As a result, they are more difficult to interpret; the collective influence of the model variability and complex non-linear behaviour is no longer intuitive and requires a deep knowledge of mechanics and numerical modelling. The development of simple graphical user interfaces allows users with limited knowledge of mechanics or modelling to run very complex scenarios that allow them to quantify the FoS and PoF for a given slope design. The increased complexity of models and the wider availability of modelling packages significantly increase the potential for human error and misinterpretation.

Another key area of advance in technology related to rock mass characterisation is the many tools that now allow collection of very detailed information on rock mass structure such as lidar scanning, photogrammetry and borehole geophysics. However, standard approaches have not been widely accepted or adopted to process data in a systematic manner to reduce bias and improve input to stability models. Nor has there been an associated advance in the approaches to assess mechanisms that are at least partly governed by structure. There are widely used and accepted tools, but downstream interpretation and analyses are either very basic conventional kinematics or non-standard approaches used only within pockets of the industry.

Discrete fracture network (DFN) modelling is a natural development given the increasing ability to collect spatial and geometric information on structures. DFN modelling involves developing synthetic realisations of the fracture network in a rock mass – large-scale structures can be input deterministically, and structural fabric input based on the stochastic distributions of fracture length, spacing and orientation. Many realisations of the fracture network can be generated to evaluate the probability of occurrence of a particular outcome. These models have many practical uses; they can be used to design to a specified catch bench width with a given reliability, design an inter-ramp or overall slope to a given PoF, develop heat maps of risk of kinematically controlled failures, identify potential non-daylighting wedges etc. However, our ability to capture the imagery to a high degree of resolution has far outpaced the development of tools and approaches, like DFN modelling, to use this data to improve design reliability. There are many DFN modelling tools available to create synthetic fracture networks, but the only tools available for analysis for pit wall stability have proprietary aspects and do not have the availability, transparency and consistency the industry needs to use as a widespread design tool for pit wall design.

The availability and use of technology should complement the fundamental understanding of slope design gained through validation and observational engineering judgement. In contrast, the adoption of new technologies should not be limited by an unwillingness to embrace change in the industry. The definition, capacity and skill set that embodies mining and geotechnical engineers is rapidly expanding. Advanced data analysis expertise and application of technology are now part of typical graduate and undergraduate programs, providing an opportunity, with proper mentoring, to fuse practical engineering knowledge/judgement with increased data analytics and competence.

2.3 Treatment of a damage/overbreak zone

There is widespread industry acceptance of the concept of a zone or 'rind' around pit walls where blasting and stress relaxation have resulted in rock mass damage and disturbance. This is generally thought to consist of development of micro-cracking and dilation of existing fractures in the rock mass. This results in reduced strength and enhanced hydraulic conductivity over the depth of the disturbed zone. The degree of strength and conductivity variation depends on the degree of disturbance. Assumptions on the degree of disturbance and its depth have a significant impact on rock mass strength and predicted groundwater pressures. Given the fact that a large proportion of actual pit wall failures are within this disturbance zone, it is imperative that we develop an approach to estimate disturbance that is defensible and grounded in pit wall observations and available data.

The Hoek–Brown failure criterion (Hoek et al. 2002; Hoek & Brown 2018) is widely used to represent rock mass strength in pit wall stability assessments. The criterion incorporates a disturbance factor, D, which reduces the rock mass strength from an undisturbed state (D = 0) to a fully disturbed state (D = 1). At D = 1, the rock mass strength can drop below the estimated residual rock mass strength (Lorig et al. 2020). Guidance from Hoek et al. (2002) suggests a D of 1 for blasted pit slopes but offers no specific guidance on how to account for the impact of pre-split blasting nor does it provide guidance on how deep to extend this zone into the wall to account for stress relaxation effects. This is left to the individual practitioner to decide. Pit wall curvature (confinement), initial rock quality, in situ stress, rock strength and rock mass structure are just some of the parameters to consider when deciding on how to implement disturbance in pit wall stability assessments.

There are several concepts for disturbance application in the literature that generally rely on numerical modelling, rather than observed/measured field data, to develop estimates to use in slope stability assessments (i.e. model results informing model inputs). Rose et al. (2018) proposed a system of assigning disturbance based on observations of yielding from several calibrated open pit models. The models suggest a fully disturbed zone (D = 1) that extends anywhere up to 50% of the slope height into the wall depending on a number of factors such as rock strength, rock quality, confinement, groundwater pressure etc. The paper also indicates that this transitions to an undisturbed rock mass at anywhere between 50 and 100% of the slope height. This is a considerable depth of disturbance to implement in comparison to common practice.

Guzman et al. (2015) suggest an application of disturbance based on empirical data and validated using Slope Model (SM), a software development funded by the sponsors of the Large Open Pit (LOP) project. This guideline suggests that disturbance extends a bench-height behind the crest (predominately blast-related damage) and the depth of disturbance resulting from stress relaxation increases with pit depth, as shown in Figure 3.

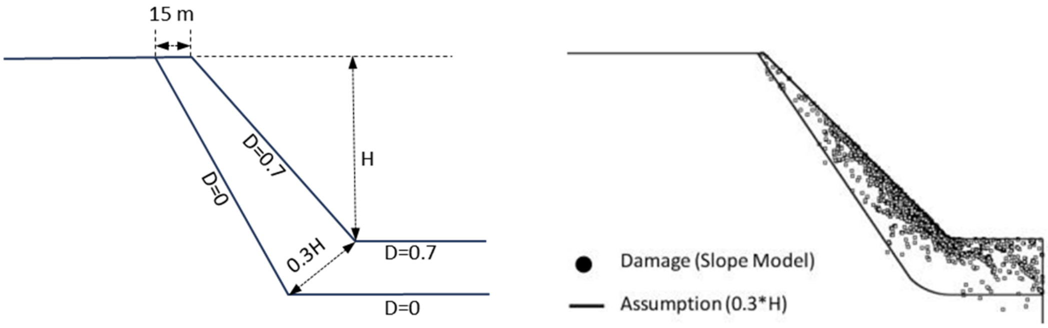

Figure 3 (a) Suggested application of D factor developed empirically and (b) validated based on Slope Model results (after Guzman & Perez 2015)

Back-analysis cases presented in the literature and from the author's personal experience at global mine sites indicate a range of assumptions for disturbance, both in terms of magnitude and extent. Some are applied uniformly, some are graded linearly to an undisturbed state at depth, and some decrease D more rapidly close to surface. Given the impact of D on the rock mass strength in the area of interest for critical failure mechanisms, additional work is imperative in order to develop basic guidelines that can be applied more consistently in the industry.

Increased fracturing and dilation of existing fractures in this disturbed zone also impacts the hydraulic conductivity. This, in turn, impacts predicted pore pressures from numerical groundwater models for input into stability analyses. Again, there are a wide range of assumptions of the impact to hydraulic conductivity and the depth over which to delineate this zone of enhanced permeability. Some cases assume that this zone is depressurised to a depth that can range from 5–20 m behind the pit wall. Some analyses assume several delineated zones based on depth below surface with increasing conductivity with proximity to the pit wall. The impact of these assumptions can be significant to predicted FoS values that rely on pore pressures generated from numerical groundwater models. Considerable rigour is generally placed in developing the conceptual hydrogeological model and in calibrating the groundwater numerical model. However, the pressures in the zone of interest for stability analyses are strongly impacted by somewhat arbitrary and inconsistent assumptions on near-surface hydraulic conductivity.

Given the impact of disturbance on pit wall stability, reliable pit slope designs require a more focused effort to collect field measurements that will allow the development of more consistent guidelines to implement in geotechnical and hydrogeological analyses.

2.4 Integration and communication

Mining is an interdisciplinary industry. A wide range of technical specialists is required to inform and execute designs. At the same time, the technical groups supporting the processes are becoming increasingly more specialised, focusing on narrower portions of the process to make significant (commercial or technical) improvements. This presents communication challenges for the different disciplines within the industry.

The advancement of slope design reliability will require increased collaboration between all stakeholders. Disciplines are often siloed (geotechnical, planning, hydrogeology etc.) in their own discipline teams due to organisational barriers, whether real or perceived. Increased communication between teams is required to improve design reliability. For example, the geotechnical engineer needs to understand the areas of greatest hydrogeological uncertainty and consider these in the design. The hydrogeologist needs to understand the key areas of interest for pit wall groundwater pressures and have a sense of the impact of variations in pressure interpretations on predicted wall stability. The risk to project success is too great if the understanding of assumptions and risk is not properly weighted and evaluated. Alignment of objectives and processes between disciplines can provide a significant improvement in productivity when the level of risk is evaluated, and shared, between discipline teams.

New technology and advancing practices should promote enhanced collaboration, not inhibit it. Less understood proprietary approaches or black-box solutions to engineering challenges do not benefit the mining industry and should be shared for proper evaluation (while acknowledging and protecting commercial rights as necessary). Adoption and validation of new practices are challenging in an established industry such as mining, but they are required to improve reliability and will stimulate interest from the next generation of engineers. Project learnings, whether they be successes, challenges, or failures should be shared within the industry to improve the understanding of operational and engineering options.

Within complex mining environments, challenges to open communication between the technical teams, management and stakeholders should be eliminated along with any obstacle to information sharing/collaboration to the extent possible as they only serve to reduce efficiency, design reliability, and speed of innovation.

2.5 Increasing demand for minerals

The demand for critical minerals is greater than it has ever been. BloombergNEF (2022) predicts that the demand for critical minerals will increase to approximately 17 million tonnes in by 2030, a nearly 10 times increase in demand from 2020 (Figure 4).

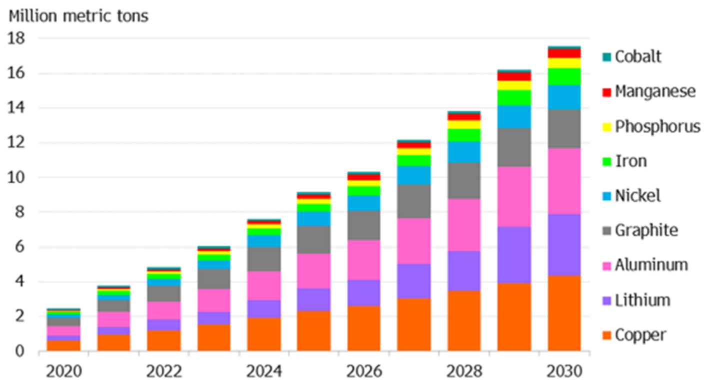

Figure 4 Estimated trend in demand of critical minerals from 2020 to 2030 to support lithium-ion battery manufacturing (BloombergNEF 2022)

This demand is fuelled by aggressive decarbonisation goals and processes; many of which are heavily dependent on these critical resources (Figure 5). As a result, the global green mining market size alone is expected to increase from USD 11 billion in 2022 to USD 18 billion in 2027 (Ahmad 2023). The electrification and increased demand have directed the focus of many in the mining industry to revisit sustainability and

ESG (environmental, social, and governance), together with the availability of these critical resources given 2030 and 2050 environmental pledges from governments worldwide.

While greenfield mining projects and new exploration attempt to add additional supply, the increase in production to support these goals is substantial, requiring companies to revisit the economic viability of extending existing open pit and underground operations. 'Steeper and deeper' is a common phrase used in the mining industry today, where companies look extend the life of existing operations through more rigorous engineering design to evaluate project risk, often while targeting lower grade reserves at an increased operating cost fuelled by increasing commodity prices.

These trends amplify the other challenges to slope design reliability discussed in this paper. The enhanced risk is apparent, both in terms of the increased depth and engineering requirements, and from a financial perspective as major mining companies optimise existing operations. The focus on digitalisation of mining has also increased significantly in the past decade, generating increased demand on expertise, new technology (autonomous/remote mining), and the availability of qualified personnel. Whether the future demand is reasonable or achievable is a common topic of debate, but most parties agree that significant improvements (in technology, collaboration, processes) will be required to succeed.

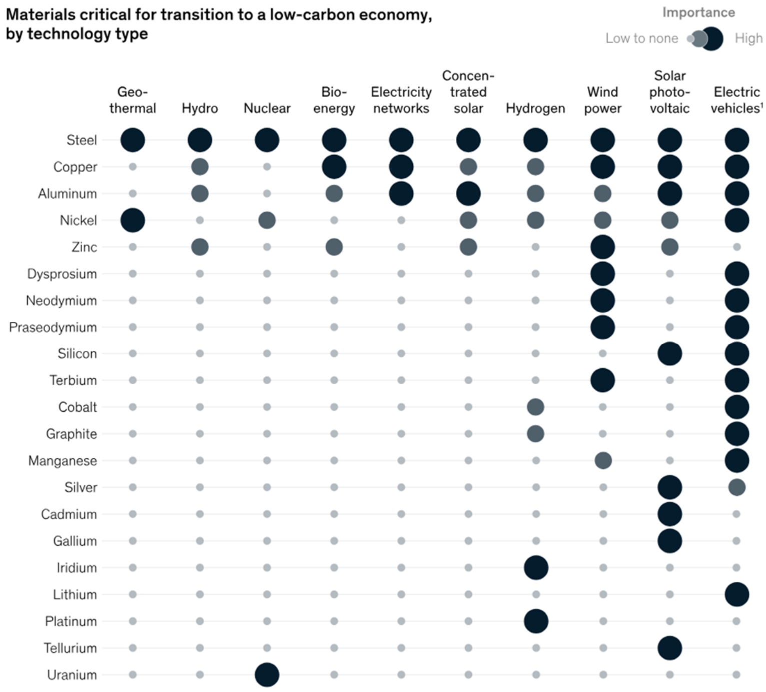

Figure 5 Critical materials for decarbonisation (Azevedo et al. 2022)

2.6 Reducing technical workforce

While demand for minerals increases, partly as a result of the global shift towards renewable energy, there is a decline in the number of graduates in mining engineering and related programs. Data from mining schools across Canada, the USA and Australia show a declining trend since 2016 despite commodity prices holding steady or increasing (Elmo 2023).

As evidenced throughout the industry, this declining trend is not limited to mining engineers but also to other associated technical disciplines that support mine design (e.g. geotechnical engineers, hydrogeologists etc.). There are a number of perceived and real obstacles to increasing the participation of technical specialists in the mining industry that need focused attention in order for mining to deliver on the changes needed to meet future resource requirements. These changes include an increased focus on automation and digitalisation as roles shift to accommodate technology to improve mining efficiency and deliver on ESG targets.

'Mining' does not have a positive reputation in the general population. This reputation has been impacted by environmental events, the destruction of indigenous cultural sites, and reports of workplace safety amongst other issues. A recent survey reported by McKinsey (Abenov et al. 2023) indicates that 70% of respondents aged 15–30 would not consider working in the industry, as shown in Figure 6. Based on reputation alone, the industry has only 30% of the population to target when it comes to recruitment.

Women are also under-represented in the mining industry. Only 15% of the global mining workforce is composed of women (estimated anywhere between 8–17% depending on the source) – a statistic that has not changed dramatically in years. There is a very similar trend for women in engineering, where the global participation of women is approximately 15% and has remained relatively static. If women did not perceive barriers and entered mining (or engineering) at the same rate as men, this would represent a 70% increase in the global talent pool. To date, there has been very slow progress in improving gender equity and gender balance within the industry despite considerable grassroots efforts to highlight and address the issues preventing women from entering the industry or leading them to leave it. Meaningful, lasting change will require more consistent and focused efforts at the board level to hold executive leadership teams accountable for meeting metrics related to gender equity and workplace culture.

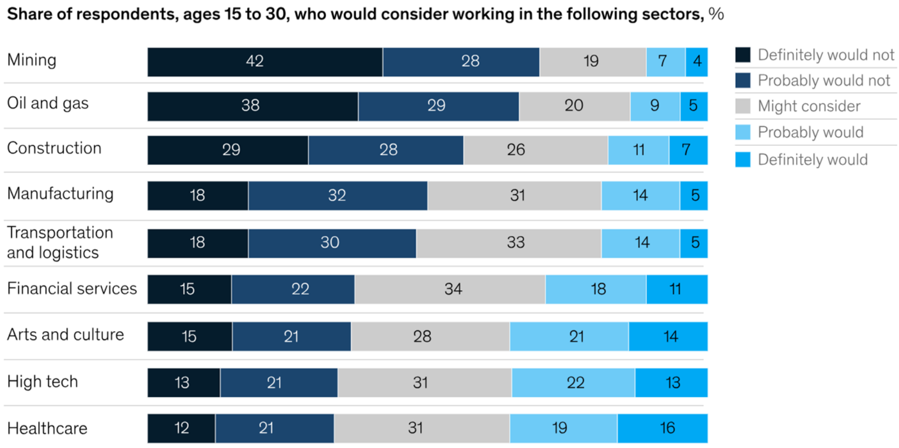

Figure 6 Critical materials for decarbonisation (Abenov et al. 2023)

The industry trends and numbers speak for themselves. There is a declining enrolment in mining programs, poor interest of young people in considering mining careers, and a small proportion of women pursuing careers in mining. This is at the same time as the industry is experiencing (and projecting) trends of increased demand for resources, increased mining complexity, and increased demand for highly skilled workers. It is critical that industry-wide organised efforts be identified and actioned in the short term to address the projected shortfall in the technical workforce.

3 Conclusion

There is no debate that many great areas of research and advancement in slope stability are ongoing within the industry. These are exciting times; technical skills that support pit slope design are in demand and there is an appetite to develop and introduce new technologies to improve design efficiency and reliability. It is critical that we also maintain an awareness that we are working in a field where there are limited codes and standards that dictate how we characterise rock, carry out analyses, or develop design recommendations. As a result, the level of experience and knowledge of those who undertake and interpret analyses must increase as our approaches to design and analyses become increasingly more complex. Communication of outputs to decision-makers should not be limited to single value outputs to meet a DAC, but rather ranges of outputs that cover reasonably expected ranges along with a clear discussion of the limitations inherent in the analyses.

The future presents many challenges for open pit mining but also many great opportunities. Innovative technology is being developed and introduced into the industry at a rapid pace. The development of tools and approaches to improve our design processes is an exciting area of ongoing research, which has the potential to attract more talent if the reputation associated with the mining industry could be swayed to highlight the environmentally and socially conscious sustainable approaches to resource development that are required to support green energy and decarbonisation initiatives. As an industry, it is our responsibility to broadcast this excitement globally so that we attract the required personnel and address the skills shortage dilemma. If only everyone could see mining as I do – full of incredibly rewarding career options, amazing people, and an openness to continuous improvement and innovation.

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