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# A risk-based approach to pit slope design and slope management approval, and geotechnical assurance

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## Abstract

*Pit slope designs and slope management processes need approval and commonly this is accompanied by some form of assurance or independent review. To be most effective, the process for approval and assurance needs to be commensurate with the level of complexity and the perceived consequence of failure. Often in large open pits, especially those that exhibit a broad range of geotechnical risk, only a fixed level of independent review is applied across this spectrum, with the potential that limited expert resources are misused or technical risk is overlooked. A transparent, pragmatic, risk-based slope design approval and geotechnical assurance process developed for Rio Tinto's copper open pits is outlined in this paper. The criteria used to establish the different categories of slope design risk are defined and the corresponding types of independent review required are described. The approach also defines levels of approval and assurance for other key elements of the slope management process and are again based on risk. The primary benefits of the approach are design approval targeted to the appropriate level of leadership and a better alignment of the intensity of assurance to the level of economic risk inherent in slope design decision-making.*

**Keywords:** *design, pit slope management, uncertainty, risk, assurance, approval*

## 1 Introduction

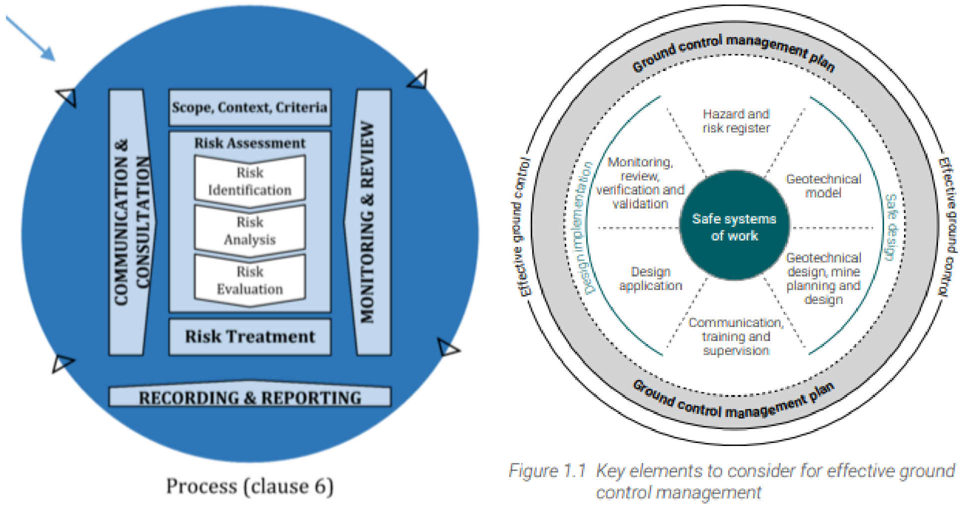
Open pit slope designs and slope management processes need approval and are increasingly subject to some form of assurance or formal review. At a study or mine investment approval stage, a review provides management and potential financiers with increased confidence in the viability of a mining project. At an operating stage, a review of the slope design and slope management processes gives management an independent assessment and additional confidence in the designs and implementation procedures. Mining companies operating open pit mines often manage geotechnical risk by establishing and implementing a geotechnical or ground control management plan (GCMP) that is specific to each mine and its level of risk. The GCMP is typically consistent with a risk management framework in accordance with ISO 31000 (International Organization for Standardization [ISO] 2009), as seen in Figure 1a. Monitoring and reviewing of progress and the effectiveness of all steps in the risk management process are critical to ensure continuous improvement and that the risk management plan is implemented effectively and remains relevant.

Most mining companies develop their GCMP based on their corporate risk management policies, standards and procedures. While these documents provide good guidance on the slope management processes to be used to manage the geotechnical risk, there is often a one-size-fits-all review process or limited detail on how to achieve appropriate levels and types of approval and review geotechnical risk.

This paper provides some examples of current open pit review systems, and presents a pragmatic risk-based approach to pit slope design and slope management approval, and geotechnical assurance developed by Rio Tinto (RT) copper for its international copper mining assets.

## 2 Examples of current open pit review systems

From a regulatory perspective, the Department of Mines, Industry Regulation and Safety (DMIRS 2019) provides a guideline with the key elements to consider for effective ground control management for mining in Western Australia (Figure 1b). The practical guideline recognises the need for independent review to be part of the broader monitoring, review, verification and validation steps, and that it should focus on the geotechnical model, mine planning and design processes, and general operational issues.




(a) (b)

**Figure 1 Examples of (a) Risk management framework, ISO 31000:2009 and (b) Ground control management plan**

Graaf & Wessels (2016) described a geotechnical management system and a risk-based approach (GRAHAMS) for its multiple Rio Tinto Iron Ore (RTIO) operations in Western Australia. They included a high-level framework for geotechnical review based on risk, but with little further detail on the types of independent or peer review (Table 1).

**Table 1 RTIO risk-based geotechnical review framework (Graaf & Wessels 2016)**

| Geotechnical risk (GRAHAMS) | RTIO geotechnical reviews | | |
|---|---|---|---|
| | Mine operations | | Design |
| Critical | Two yearly external (independent) reviews (including operational designs) | Slope dump management plans reviewed and signed off by geotechnical 'qualified individual' and nominated D3 managers | Independent technical Review board – typically external |
| High | | | Independent technical peer review |
| Moderate | | | Technical peer review |
| Low | | | Technical peer review |

RT's Safety Standard for the Management of Slope Geotechnical Hazards (D3 Standard) requires that designs and slope management processes for engineered slopes as well as geotechnical hazard management processes for natural slopes must be reviewed by an independent reviewer and/or expert panel at least every two years, or more frequently as determined by risk assessment, monitoring outcomes or a significant geotechnical event. The D3 Standard and its associated group procedure provide guidance on different types of independent review based on risk (Table 2).

**Table 2 Types of independent review (from Rio Tinto D3 Group Procedure Figure 1)**

| Risk | Type | Purpose | Application | Typical composition | Required for compliance |
|---|---|---|---|---|---|
| Critical | Independent technical review board (ITRB) | Detailed independent review of geotechnical design and/or slope hazard management processes and general approach to geotechnical risk management | Studies or operations with complex geotechnical conditions representing Critical business risk | Minimum of 3 recognised multidisciplinary specialists in their respective geotechnical field | It is mandatory to undertake a risk assessment to determine the requirement for an ITRB |
| High | Independent technical reviewer | | Routine review of design and/or hazard management approach. Reporting to Project Management for situations with a high business risk | | Yes |
| Moderate | Technical review | To ensure changes to design, planning, implementation, operations or monitoring elements that are not assessed as high risk are checked | Planning and/or operations | Technical peer with at least equivalent skill and experience to the person whose work is being reviewed | Yes |
| Low | | | | | Yes |

The different levels of independent review shown in Table 2 are a good framework and starting point as RT operates open pit mines across the full spectrum of pit size, geotechnical complexity and risk. At the lower end of the spectrum RT mines bauxite at its Weipa operations with open pits that are laterally very extensive but seldomly exceed 10 m in depth. At the upper end of the spectrum is the Bingham Canyon Mine (BCM) in Utah, USA. BCM is the world's deepest open pit mine, with current slopes just over 1,000 m deep and planned final pit slopes of approximately 1,200 m depth. The orebody and country rocks are geologically and geotechnically complex, presenting great challenges for managing the risk of slope failures. RT Copper also operates the Oyu Tolgoi mine (OTM) in Mongolia, which is currently 540 m deep, and is a joint venture partner with BHP in the Escondida mine in Chile: 3,900 m long, 2,700 m wide and with pit slopes in excess of 600 m in depth.

Although not targeted towards open pit slopes, the recently published Global Industry Standards on Tailings Management (GISTM) provide a more explicit definition of the requirement for independent review than DMIRS (2019). GISTM (2020) describes two key types of independent review: an independent tailings review board (ITRB) and a senior independent technical reviewer (SITR), which is inline with the RT D3 Standard and is most applicable to the very large and challenging open pit mines where geotechnical risks are rated high and critical, Figure 2. An ITRB provides independent technical review of the design, construction, operation, closure and management of tailings facilities. The expertise of the ITRB members reflects the range of issues relevant to the facility and its context, and the complexity of these issues. An SITR is an independent professional with in-depth knowledge and at least 15 years' experience in the specific area of the review requirements, e.g. tailings design, operations and closure, environmental and social aspects or any other specific topic of concern. Some company tailings management standards go further and provide expectations on the independent design review of detailed stage designs and independent operational reviews (IORs). If warranted by the level of risk, each detailed design stage and final closure must be reviewed by an independent tailings specialist or ITRB prior to the start of construction. Separate to the ITRB requirement, IORs must be completed through the facility lifecycle, including closure and post-closure phases, to identify physical hazards (as opposed to chemical/geochemical hazards) associated with the geotechnical, hydrological, hydrogeological and operational performance of the facility.

In summary, current industry standards, guidelines and regulations provide only high-level guidance regarding the level and type of geotechnical independent review required to manage different levels of geotechnical risk across open pit studies and operations. A search of technical literature reveals little practical guidance and detail on the level of approval or sign-off required for pit slope designs and for operational reviews.

A risk-based approach to pit slope design and slope management approval, and geotechnical assurance developed for use in RT Copper open pit mines is described below.

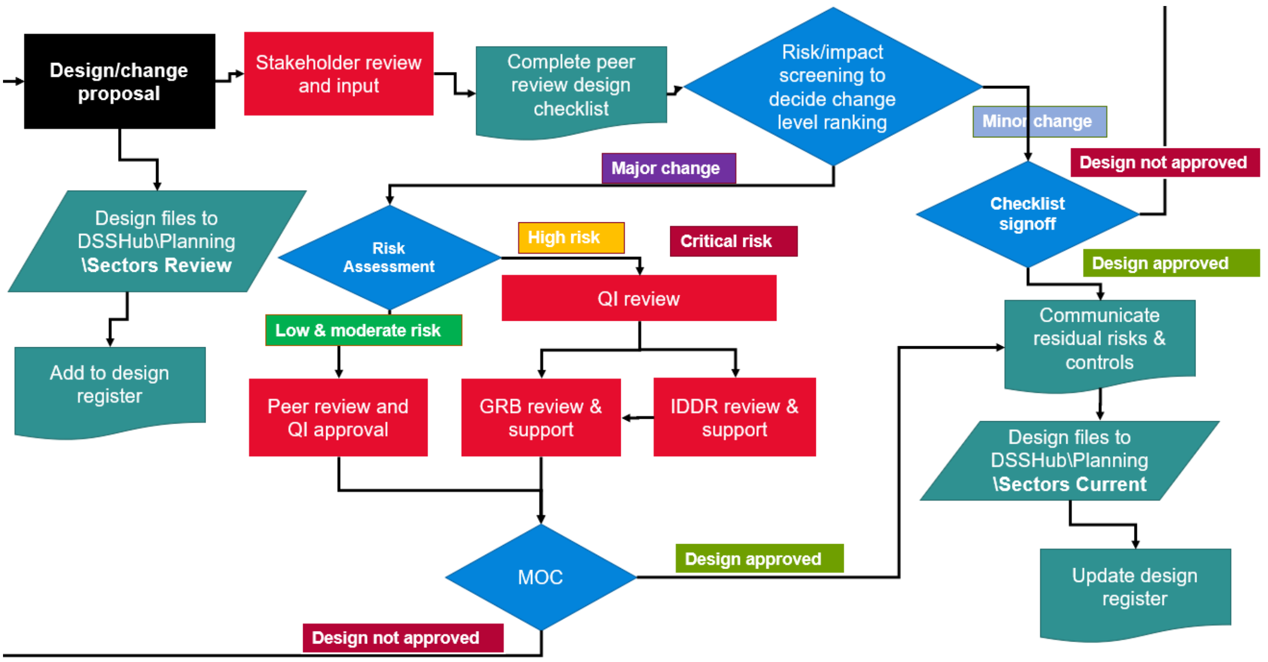



**Figure 2 Rio Tinto design approval and independent review flow chart**

# 3 RT Copper pit slope design and slope management approval, and geotechnical assurance process

A risk-based matrix that defines the minimum requirements for pit slope design approval and assurance of slope designs and slope management processes is shown in Table 3. The upper part of the matrix (Table 3a) covers slope design, which is essentially considering economic risk. The lower part of the matrix (Table 3b) captures the key slope management processes and predominantly considers safety risk. The matrix is colour-coded by risk level, with the highest risk in red and the lowest in green. A higher level of authority is required for approvals for higher levels of risk, as is a greater level of detail for assurance.

| Risk rating | | Site<br>Geotechnical team and leadership | | | | Offsite and external | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | First line assurance | | | |
| Design change level/item | Residual risk ranking | Responsible | Reviewer(s) | Accountable (approval) | Inform | Support | Accountable (approval) | Inform | Independent review board | Independent detailed design review |
| Major | Critical | Supt geotech – design | Qualified individual | General manager | Director | Principal 1 | Principal 2, General manager | Director | Yes | Yes |
| Major | High | Supt geotech – design | Qualified individual | Manager technical services | General manager and director | Principal 1 | Principal 2 | General manager and director | Yes | No |
| Major | Low and Moderate | Snr engineer (geotech design) | Qualified individual and supt geotech – design | Qualified individual | Manager technical services | Principal | – | – | No | No |
| Minor | – | Engineer (geotech) | Snr engineer (geotech design) | Snr engineer (geotech) | Supt geotech – design | – | – | – | No | No |
| **(a) Slope design** | | | | | | | | | | |
| Risk assessment | Class III and IV risks | Supt geotech – design | Qualified individual and D3 nominated manager | General managers | Director | Principal 1 | Principal 2 | General manager and director | Yes | No |
| Observational mining decision | | Supt geotech, supt planning, supt operations | qualified individual, manager technical services, manager mine operations | General managers | Director | Principal 1 | Principal 2, general manager | Director | Yes | No |
| D3 incident investigations | SI and PFI | Supt geotech – operations | – | As per HSE requirements | As per HSE requirements | – | Principal | General manager | No | No |
| TARPs and exclusion zones | – | Supt geotech – operations | Supt geotech – operations | D3 nominated manager | General manager | Principal 1 | Principal 2 | – | No | No |
| Slope monitoring /performance reporting | – | Snr geotech – operations | Supt geotech – operations | D3 nominated manager | Qualified individual | Principal | – | – | No | No |
| SDMP update | – | Supt geotech – design | Qualified individual | D3 nominated manager | General manager | – | Principal | – | No | No |
| Slope risk registers | – | Supt geotech – design | Qualified individual | D3 nominated manager | – | – | Principal | – | No | No |
| Assurance actions formulation | – | Supt geotech – design | Qualified individual | Qualified individual | D3 nominated manager | Principal | – | – | No | No |
| **(b) Slope management processes and risk** | | | | | | | | | | |

**Table 3 Key components of the pit slope design and assurance matrix. (a) Slope design; (b) Slope management processes and risk**

The matrix is a variation of a responsible, accountable, consulted and informed chart. The roles shown in the matrix relate to the RT Copper organisation, and are typical of large- and medium-scale companies that have both an onsite geotechnical team and an offsite corporate geotechnical team. The D3 nominated manager is accountable for the implementation of, and conformance to, the intent of the D3 Standard and group procedure. In many instances this role is filled by the site manager technical services, to whom the site geotechnical team reports. The qualified individual (QI) is accountable for all engineered slope designs and natural slope geotechnical hazard management. The QI requires: an appropriate tertiary education majoring in engineering or a related earth science; a minimum of 10 years' postgraduate relevant experience in slope geotechnical investigation, design and implementation; and an appropriate professional registration. The QI is often the superintendent geotechnical responsible for slope design as part of the site geotechnical team.

The two key aspects of Table 2 are described in more detail in the following section.

## 3.1 Slope design

The slope design component of the pit slope design and assurance matrix is shown in the upper part of Table 3. There are two levels of risk classification for slope design:

1. Design change level (major/minor).
2. Residual risk rating for the major design change level.

These are discussed in Section 3.1.1.

### *3.1.1 Design change level*

The design change level (column 1 of Table 2), with the two categories of minor and major change, was drawn from existing site pit design approval and management of change (MoC) protocols relating to the scale of impact of the design change, is shown in Table 4.

**Table 4 Pit slope design change level**

| Design type | Minor change | Major change |
|---|---|---|
| Phase (pit) design | Total material movement (TMM) change <500 kt<br>Cu metal loss <0.5 kt<br>Au metal loss <2 koz<br>Inter-ramp angle does not change<br>Change impacts more than one bench | TMM change >500 kt<br>Cu metal loss >0.5 kt<br>Au metal loss >2 koz<br>Inter-ramp angle changes<br>High/critical risk design changes should be considered a major change regardless of scale or design change level |
| Waste dump design | Final dump capacity changes by <1 Mt | Design changes final dump footprint<br>Changes to final landform<br>Changes to net acid producing/potential acid forming material boundaries |
| Stockpile design | Changes to cutoff policy<br>Stockpile capacity changes by <0.1 Mt | Design changes final stockpile footprint<br>Changes to final landform<br>Changes to lift design<br>Changes to construction sequence |
| Road design | All road alignment changes are considered as a major change | |

### 3.1.2 Major design change level

The major design change level (column 2 of Table 2) is further classified based on geotechnical (economic) risk using the following criteria (refer to Table 4 for definition of risk class):

- Critical – Factor of Safety (FoS) < design acceptance criteria (DAC) or where risk exceeds normal 'base case' expectations.
- High – FoS exceeds DAC but with little contingency, and some Class III and IV risks are identified in some design sectors.
- Low/Moderate risk – FoS exceeds DAC and no Class III and IV risks are identified.

Typically the high and low/moderate risk levels are identified as part of the slope design process, where the basic requirement is that the data adequacy requirements are met and that the design exceeds the DAC threshold. The design and those identified risks are approved and assured prior to commencement of mining that particular cutback.

The critical risk level is recognised only after mining has already commenced, when:

- Slope performance monitoring indicates an area is deforming in excess of design estimates and therefore has a lower FoS or stability margin than estimated by the slope design, and hence is now lower than DAC.
- Back-analysis after a failure or deformation shows future designs through the same area are no longer able to meet DAC with new back-analysed properties.

### 3.1.3 Risk assessment process

The author suggests that the classic 5 by 5 of the Health, Safety, Environment and Communities risk matrix be used to assess risk (Table 5). The fundamental rule is to define the consequence first, in terms of maximum reasonable consequence, and then assess the likelihood of that particular consequence occurring.

**Table 5 Health, Safety, Environment and Communities risk matrix**

| | Most serious consequence | | | | |
|---|---|---|---|---|---|
| **Likelihood** | **Very low** | **Low** | **Moderate** | **High** | **Very high** |
| Almost certain | Class II | Class III | Class IV | Class IV | Class IV |
| Likely | Class II | Class III | Class III | Class IV | Class IV |
| Possible | Class I | Class II | Class III | Class IV | Class IV |
| Unlikely | Class I | Class I | Class II | Class III | Class IV |
| Rare | Class I | Class I | Class II | Class III | Class III |

Class III and IV risks require additional controls and levels of proactive pit slope management to manage the higher level of risk. This would typically take the form of more intensive slope monitoring (more elements installed targeting the specific failure mechanism and increased frequency of measurement) and developing an area-specific trigger action response plan (TARP). It would also include additional elements such as depressurisation or reducing blast energy. In the case where a critical risk level is identified, one option for managing that increased risk is to adopt a further increase in operational control with a process called observational mining (OM). OM is a continuous, managed and integrated risk management process of design, implementation, monitoring, review and adjustment to enable safe and progressive mining with well-defined production stage-gates. It aims to arrest any progressive slope deformation responses and avoid or defer the significant expense of a large cutback or step-in as a preventative control against catastrophic slope failure. Three key co-commitments of implementing OM are: business acceptance of the higher level of risk; excellent slope monitoring systems; and the development of contingency mine planning and design options that, in the worst case, cater for post-failure remediation or a large cutback or step-in.

The risk assessment process assesses the maximum reasonable consequence and the likelihood of that consequence occurring. The maximum reasonable consequence is the largest realistic or credible consequence from a geotechnical event. Managing safety risk is of foremost concern to a mining operation, and this is handled by other mechanisms such as slope monitoring and TARPs for slope failures, and other different controls to manage small rockfalls. The pit slope design approval and assurance process deals with economic risk.

The likely cause of a material economic consequence is a slope failure generally greater than two benches high. Economic consequence is best described in terms of total free cash flow (FCF) impact, rather than attempting to break out revenue impacts and capital loss etc. The total FCF impact is calculated as the sum of lost and delayed revenue and extra opex/capex. Lost revenue would typically be a loss or deferral of ore tonnes, or from impaired access to active mining cuts. Extra opex or capex captures the costs to remediate a slope failure, i.e. the cost of a new cutback or to re-establish access across a ramp covered with slope failure debris, or to replace/repair any damaged infrastructure. The benefits of using FCF is that it is more simply derived, and is clearer when comparing different slope design options. An example of the FCF categories used for economic risk assessment at a particular RT Copper asset are shown in Table 6.

**Table 6 Rio Tinto categories of economic consequence free cash flow**

| | Very low | Low | Moderate | High | Very high | Extremely high |
|---|---|---|---|---|---|---|
| Free cash flow (USD millions) | 5–10 | 10–25 | 25–50 | 50–100 | 100–250 | >250 |

The descriptions for the RT categories of likelihood shown in Table 7 align to industry standards.

**Table 7 Rio Tinto categories of likelihood**

| Category | Description | Frequency | Frequency (%) |
|---|---|---|---|
| Almost certain | Recurring event during the lifetime of an operation/project | Occurs more than twice per year | >75 |
| Likely | Event that may occur frequently during the lifetime of an operation/project | Typically occurs once or twice per year | 50–75 |
| Possible | Event that may occur during the lifetime of an operation/project | Typically occurs once in 1–10 years | 20–50 |
| Unlikely | Event that is unlikely to occur during the lifetime of an operation/project | Typically occurs once in 10–100 years | 5–20 |
| Rare | Event that is very unlikely to occur during the lifetime of an operation/project | Occurrence greater than 100-year event | <5 |

Figure 2 shows the flow chart for the design approval and independent review process. The key step of the process is the risk/impact screening to decide the change level ranking, which then drives the level of design approval and independent review required. Major changes requires full documentation as part of the MoC process. Minor changes do not require MoC and key details are captured in the online design register.

### 3.2 Slope management processes and geotechnical risk

The lower part of the RT design approval and assurance matrix contains the key slope management processes, some of which provide more of a focus on safety risk, Table 3b. The primary accountability for slope management processes and managing geotechnical risk sits with the site geotechnical team, but the risk acceptance goes higher in the organisation. The offsite corporate geotechnical team provides varying levels of support and assurance, depending on the level of risk and being guided by the matrix.

The risk assessment process and OM are described in the earlier section on slope design residual risk rating. Due to the elevated risk associated with OM it is important that the independent review board is comfortable that the technical work characterising and back-analysing the area of increased deformation is appropriate and that the elevation in controls managing the area is reasonable.

The D3 Standard provides a definition for a geotechnical incident and these are reported in the RT safety management system. When a geotechnical incident is classified as a significant incident (SI) – i.e. it has an actual serious, major or catastrophic consequence (Table 3b) or a critical or high MRC, or is a potentially fatal incident (PFI) – the offsite corporate geotechnical team is informed and is involved in the investigation process as well as sign-off on the investigation report. All other geotechnical events are entered into the site fall of ground and slope failure database.

TARPs, including the setting of deformation threshold levels and the specification of appropriately sized exclusion zones, are critical controls for managing safety and economic risk. As such, they require assurance from the RTC technical team. The slope monitoring systems that underpin the TARPs are critical enablers and are very much the focus of the site geotechnical operations teams. The RTC technical team provides support in their development and an overview of the deformation trends reported by the monitoring.

The benefits of involving the offsite corporate geotechnical team in the support and assurance of these slope management processes is the increased levels of experience across multiple operations of its members and their independence from day-to-day operations.

## 4 Types of Rio Tinto Copper independent review

Figure 3 shows the three types of independent review utilised for the different levels of geotechnical risk at RT Copper's open pit mines, and are those referred to in the risk-based pit slope design approval and assurance matrix, Table 3a. The three types of independent review are derived from Table 2, and provide further guidance for situations where the risk is classified as high or critical. Every effort has been made to be pragmatic with the level and application of the independent review and how it best fits with the fast-paced and dynamic mining environment. The use of the independent review board (IRB) is the most typical form of independent review at RT Copper's surface mines. The key improvement is the introduction of independent detailed design review (IDDR) for critical risk situations.

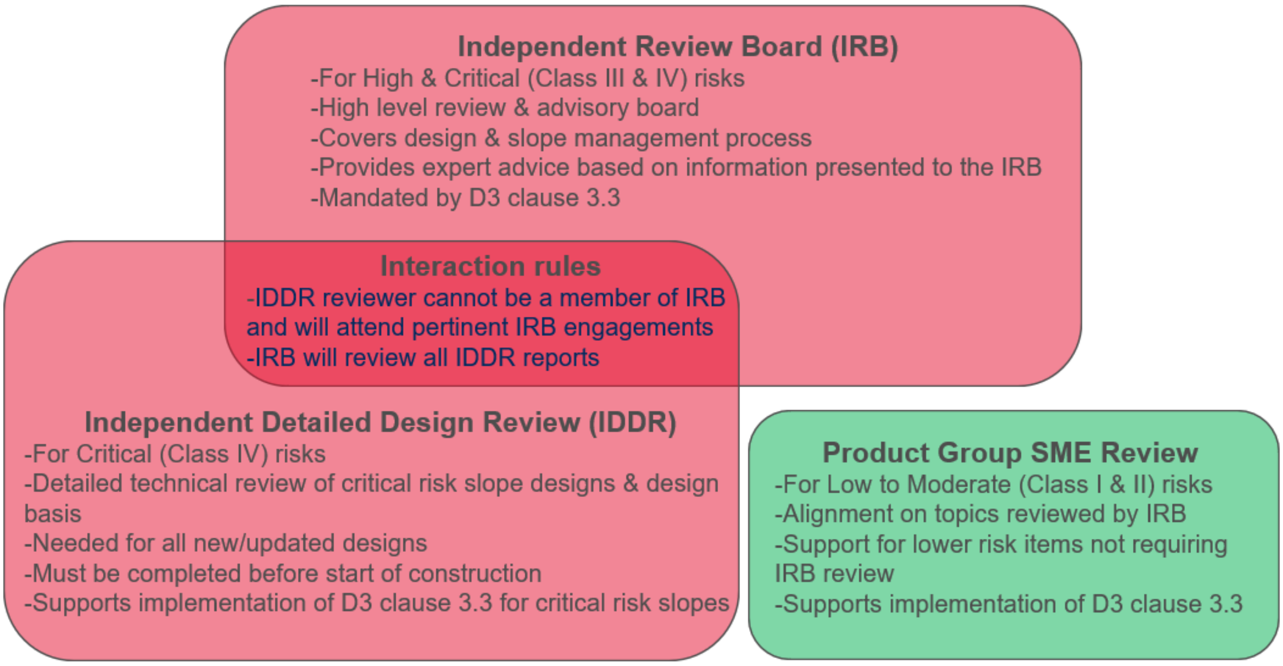



**Figure 3 Types of Rio Tinto Copper independent review. 'SME' is subject matter expert**

Members of an IRB or IDDR are issued a written scope of work which indicates that they do not approve slope designs nor make risk decisions on behalf of RT, but rather they provide high-level advice and guidance directly to the most senior level of management at the operating asset. The RT Copper site general manager accountable for D3, the D3 nominated manager, the QI and the offsite corporate geotechnical team are also informed of the IRB and IDDR findings, and any actions derived are tracked in the RT risk management system.

The three types of RT Copper independent review are described more fully below, and examples of their use provided.

## 4.1 Independent detailed design review

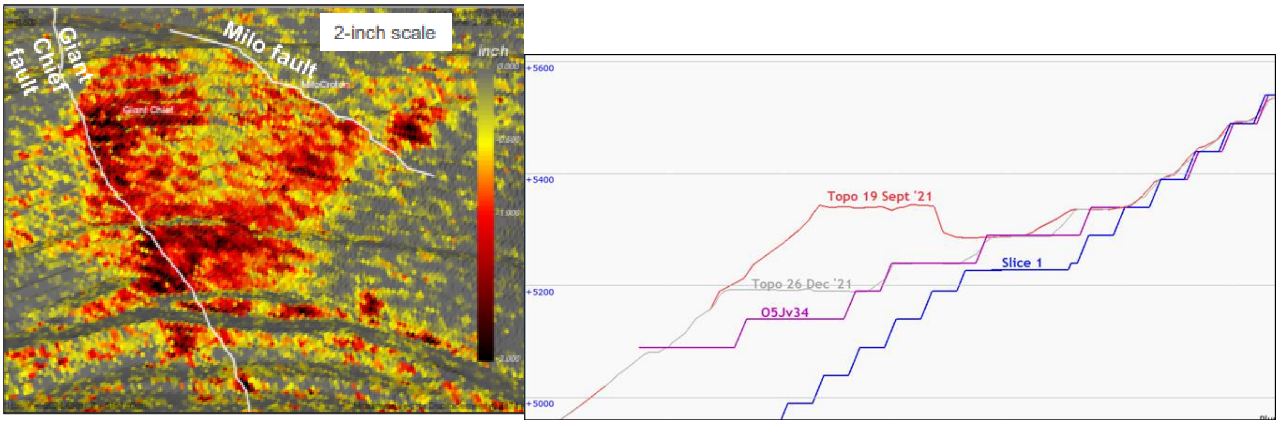
IDDR is the most comprehensive, time-consuming and detailed of all the types of independent review. The IDDR focuses solely on slope design and where the risk has been classified as critical. The overarching objective of this level of review is to assure that the right technical work been done as part of the slope design process to adequately assess and manage the risk associated with the recommended slope design.

IDDR is to be conducted by a single, very experienced subject matter expert (SME) with the same level of experience as a member of the IRB. The IDDR requires a detailed review of slope design documents and data that is demonstrably more detailed than slope design reviews performed by the IRB. This type of review equates with the highest level of review: the Level 3 'audit' described by Read & Stacey (2009).

IDDR should ideally be completed prior to field implementation of design change. However, schedules are typically very tight and IDDR will often be on non-final iterations of any design assessment, with final analysis reports unlikely to be available. Analysis should be well underway (i.e. past the halfway mark) in order to provide meaningful review. For the sake of the project schedule this is acceptable as it is expected that the IDDR would reveal any major flaws associated with the interim iterations and any recommended changes could be accommodated after the start of field implementation.

### *4.1.1 Examples of independent detailed design review implementation at Rio Tinto Copper*

The first IDDR conducted for RT Copper was at the BCM in January 2022, for a design change to manage the Phoenix dilation zone located in the south wall of the BCM (Figure 4a). This quasi-stable area encompassing some 270 m of slope height is located directly above the haul road at 5340 elevation. In March 2021, mining reached an existing designed extra-wide bench on the 5600 elevation, which totalled 30 m. However, this design step-out failed to arrest movement but did maintain the current quasi-stable wall condition. The Phoenix dilation zone, which in the case of failure would sever the haul road that is the only access to the base of the mine, was assessed as a class IV risk and rated as a critical risk per Table 2a. A design change was required to maintain stability and was critical to the continuing of short to mid-range ore extraction from the BCM (Figure 4b).




(a) (b)

**Figure 4 Phoenix instability. (a) Deformation; (b) Design change and mining status as of December 2021**

The January 2022 IDDR reviewer was a former member of the site's IRB. The IDDR comprised: a site visit to the location in October 2021; review of PowerPoint presentations of detailed work for this area developed between October and December 2021; and discussions with the site geotechnical team conducting that work. The technical work focused on recent slope performance and conformance; detailed local geological and geotechnical characterisation, the construction of an RS3 (Rocscience 2023a) stress/strain model to undertake a back-analysis; and investigation of design and depressurisation options. The short IDDR report issued in January 2022 supported the proposed design change, and made several useful observations and recommendations that enabled the mine geotechnical team and mining to move forward with increased confidence.

Review of the IDDR process by the RT Copper offsite corporate geotechnical team identified some improvement opportunities to better meet the desired intent of the IDDR; primarily that it needs to demonstrably include more detail than an IRB-type review. As a result, a more detailed scope of work was created for future IDDRs that should include the following elements:

- A field visit as necessary where feasible.
- Detailed review of slope monitoring performance, conformance and reconciliation information.
- Scrutiny of design geometry and a planned excavation sequence.
- Review of the conceptualisation of possible slope failure mechanisms (including review of geotechnical risk assessment and structural geology).
- Review of model inputs, build and results, and any consultant's design reports, including:
  - Whether the model is capable of realising the likely failure mechanisms, and identified mechanisms are plausible and supported.
  - Review of rock mass and discontinuity strengths for suitability.
  - Assumptions for predictive cases consistent with back-analysed properties are appropriate.
  - Whether plausible sensitivity scenarios have been tested.
  - Whether the recommended slope design criteria (slope angles) are appropriate.

- The IDDR is deliverable as a technical memorandum detailing the materials reviewed and findings. It should contain commentary on the overarching questions:
  - Is the design-analysis scope suitable for the known conditions, and executed correctly?
  - Has the right technical work been done to adequately assess the risk of the design?
  - Are the residual design risks clearly identified for the site to manage?

The second IDDR at the BCM was conducted in February 2023 to review the east wall extension area. This area has a history of several small one- to three-bench scale failures between 2011 and 2022, and ground support was proposed as an integral part of the slope design. Successful management of potential bench scale failures is a key control for preventing a much larger inter-ramp scale failure that is rated as a class IV risk. This IDDR focused primarily on the ground support program and comprised:

- Three site visits to the location over a 12-month period up to February 2023 to observe the geotechnical domains and current slope performance.
- Review of the design consultant's technical work and reports that focused on:
  - Back-analysis of the historical bench scale failures.
  - Probabilistic modelling of slope stability with ground support using SWedge (Rocscience 2023b) and FracMan (WSP 2023) discrete fracture network (DFN) methods.
  - Probability of failure analysis of DFN models to consider joint and rock mass strengths, and pore pressure, and to assess ground support requirements.
- Discussions with the site geotechnical team conducting that work.

The IDDR report issued in May 2023 was complimentary of the modelling work conducted and supported the ground support design and implementation plan. The progressive site visits during ground support implementation enabled review and practical advice to be provided based on field evidence, and increased the confidence of the mine geotechnical team that the design was appropriate. It further recommended the need to review and adjust the bolt spacing on each bench down the wall, and improvement of the bolt QA/QC program by adding short encapsulation pull tests to check on bond strengths achieved in the various rock mass areas. To date, no bench scale failures have occurred in supported ground and no indications of slope instability have been observed from slope monitoring. A secondary benefit of the IDDR site visits was the mentoring provided to all the site geotechnical team members in terms of ground support design and implementation. The IDDR findings were presented to the BCM IRB during its May 2023 remote engagement.

## 4.2 Independent review boards

IRB reviews cover both slope design and slope management processes and are primarily focused on high and critical risks. The IRB is a panel or board of typically three but sometimes four people who are SMEs covering geotechnical and hydrogeology. This is the most typical of all the independent review types in RT Copper as most of the operating assets are porphyry copper orebodies with large open pits in excess of 500 m deep. Gerritsen et al. (2023) provides a very useful overview of how to successfully work with an ITRB and describes the purpose and responsibilities of an ITRB; assembling an ITRB; and interaction of the mine owner and design engineers with an ITRB. This guidance for an ITRB is directly applicable to pit slopes and transferrable to IRBs described in this paper.

### *4.2.1 Examples of independent review boards implementation*

The geotechnical team at the BCM has been supported by an IRB since 2013. Since then, membership and the cadence of IRB engagements has evolved. Membership currently comprises four specialists (three geotechnical, with one of these a specialist in natural slopes and slope hazard assessment, and another a hydrogeologist). Previously the membership was even bigger and included some mining specialists. The BCM currently has a bimonthly cadence of remote IRB engagements (reduced from monthly in early 2023) and two IRB site visits per year, commensurate with its higher level of risk. The OTM has operated with an IRB since 2014 and, like the BCM, has a risk rating of critical (Figure 3). However, this risk rating is at the lower end of that rating bracket and as such its IRB has three members (two geotechnical and one hydrogeologist), and conducts two site visits and one or two more ad hoc remote engagements per year.

An example of an IRB for slope design is given for the BCM that is conducting a feasibility study (FS) for a new cutback, with the plan of IRB engagements shown in Table 8. The overall rationale for the approach is to get progressive IRB support throughout the slope design process. Key milestones include geotechnical characterisation; model build and calibration; DAC and predictive results; risk assessment of design cases; and recommended slope design criteria.

**Table 8 Independent review board engagement schedule for a new cutback feasibility study**

| Dec 2022 | Jan 2023 | Feb 2023 | Mar 2023 | Jun 2023 | Sep 2023 | Oct 2023 | Jan 2024 |
|---|---|---|---|---|---|---|---|
| 2D and 3D data review and model build | Intact and discontinuity strengths update | Geotechnical block model update | Inter-ramp model build and bench scale calibration | DAC definition | 2D and 3D predictive stability runs and sensitivities | 3D drainage gallery assessment | Slope design criteria recommendations |
| – | 2D data review and model build IRB response | – | – | 2D and 3D predictive stability runs and sensitivities | – | Risk assessment | Project gating review |
| – | – | – | – | Inter-ramp slope sector recommendations | – | – | – |

For each engagement, the site geotechnical team will prepare a comprehensive information pack summarising all the work done for that stage of the design process. This is sent out ahead of the IRB engagement as pre-read material. In the IRB engagement meeting the site geotechnical study lead, often supported by the external consultant who has completed the technical work, will present the key messages from the pre-read material and the IRB will ask clarifying questions and challenge the work. The technical material presented includes some high-level focusing questions: for example, 'Does the IRB support the inter-ramp analysis methodology employed for FS study?' and 'Does the IRB support the rationale used to define the DAC?'. The IRB formalises its response to each engagement with a report in which members provide their feedback and recommendations, and their response to any focusing questions. The IRB does not review any of the design consultant reports. This type of review equates with the intermediate Level 2 'review' level, described by Read & Stacey (2009).

With the introduction of IDDR at BCM in 2022, rules of engagement were established to manage interactions between the IRB and IDDR (see Figure 4). These include:

- The IDDR cannot be a member of the IRB.
- The IRB will review all relevant IDDR reports for that site.
- The IDDR reviewer will attend pertinent IRB engagements.

At the OTM in May 2022, the IRB was asked the high-level focusing question: 'Does the IRB support the slope management processes to manage geotechnical and hydrogeological risk?' During the IRB's three-day site visit, members were given presentations on:

- Slope monitoring strategy and current pit slope performance.
- Reconciliation and slope conformance (geometry checks and final wall assessments).

- Structural model updating and the fault register.
- Dumps and stockpile slopes.
- Hydro update (surface water management plan, hydro drilling and depressurisation).
- Drill and blast (trim blast design, blast assessments and vibration monitoring).
- Risk and hazard management (TARPs, hazard map and 2022 risk assessment).
- Geotechnical team resourcing.

Various pit visits enabled the OTM's IRB to validate the status reported by the site geotechnical team with actual conditions in the pit. Each topic presented to the IRB had its own focusing question, such as: 'Does the IRB support the slope monitoring and strategy plan?' and 'Does the IRB support the limits that blasting and vibration monitoring practices used?'. The assurance process worked well and feedback in the IRB report was positive. This type of review of slope management processes equates with the highest level of review: the Level 3 'audit' level described by Read & Stacey (2009).

## 4.3 Product group subject matter expert review

This level of assurance by a single SME covers both slope design and slope management processes, and is primarily focused on low and moderate risks that do not require IDDR or IRB review. Most commonly this lower level of assurance is provided by someone from the site geotechnical team who has not been directly involved in the particular item of work requiring review. On occasions this is supplemented by someone from the RT Copper offsite corporate geotechnical team.

Several three- to four-bench-high inter-ramp scale failures occurred in the slice 2 east wall of the BCM in 2022 and early 2023, with no impact on safety (Figure 5).

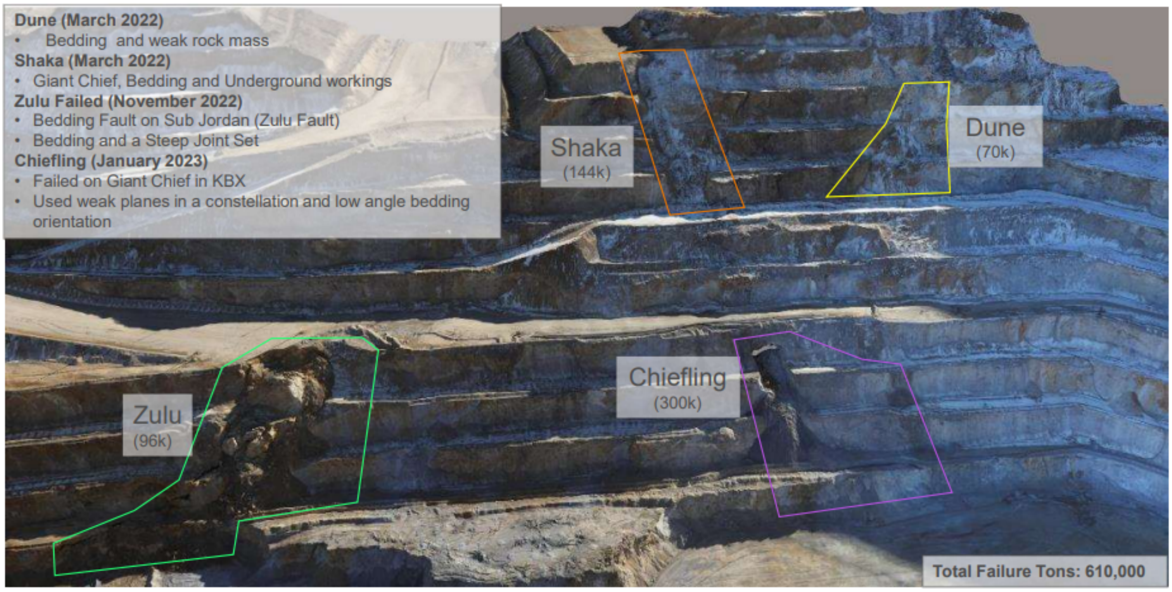



**Figure 5 Slice 2 east wall inter-ramp slope failures (March 2023)**

The location of the slope failures and size in kt are shown in Figure 6. The surface area of the failures constituted less than 8% of the surface area of each design sector mined up to March 2023, hence the actual slope performance met its DAC.

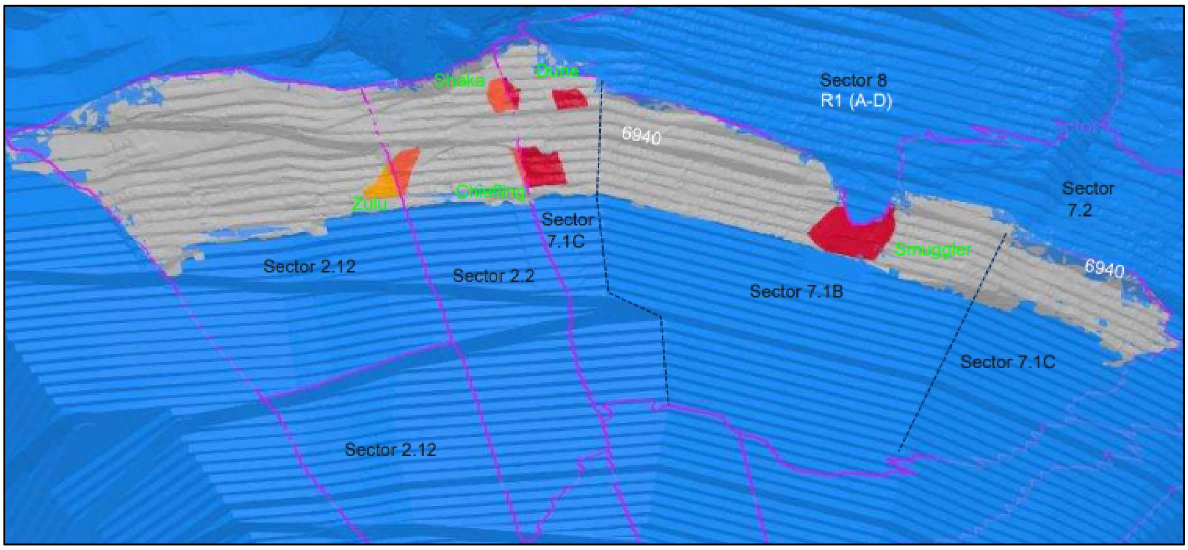



**Figure 6 Location and size of slice 2 east wall inter-ramp slope failures (March 2023)**

Notwithstanding the relatively small scale, the failures negatively impacted mine production, requiring unplanned local step-ins, shallowing of inter-ramp angles, and required the site geotechnical design team to investigate the root causes and define appropriate remediation options. The scale of the required design changes were classified as major with a low to moderate risk rating, Table 2a. A product group SME review was conducted in March 2023 by the leader of the site geotechnical operations team who was not involved in the design process, supported by the RT Copper offsite corporate geotechnical team. The scope of the review looked at the original design reports and more recent information on design methodology, design sector generation, input parameters, calibration methodology, existing slope performance and verification review. The review objectives were to determine why these instabilities were not adequately accounted for in the design process and models, and what findings can be applied to the design methodology for future pushbacks.

This review worked well as the lead has a strong background in geotechnical design as well as geotechnical operations management. Several useful process enhancements for future design were identified, including:

- Developing an engineering geological model to conceptualise potential failure mechanisms before starting any numerical modelling.
- Collecting and fully utilising slope reconciliation data from previous pushbacks in future design.
- Ensuring geology, structural and geotechnical model resolution and design sector size are sufficiently granular to capture the variability causing these three- to four-bench-high inter-ramp scale failures.
- Critical challenging of geotechnical strength parameter selection and differentiation of 'characteristic' values for large design sectors versus those more 'representative' and more suited to design in poorly performing smaller subdomains.
- Improving how these smaller-scale potential instabilities, identified as part of the design process, are communicated in the slope design handover from the design team to the operations team.

# 5 Conclusion

Based on the experiences of the author and the discussions presented above, the key conclusions are:

- The increased use of assurance and independent review is an important step towards minimising slope failures or instabilities that could cause a fatality or material interruption to mine production.

- Current standards, guidelines, regulations and industry practices provide only high-level guidance on the level and type of geotechnical independent review and slope design approval based on risk.
- Many GCMPs provide good guidance on the slope management processes to be used to manage the geotechnical risk, but often have a one-size-fits-all review process or limited detail on how to achieve appropriate levels and types of approval and the review of geotechnical risk.
- The more detailed risk-based approach to pit slope design approval and assurance put in place for RT Copper operations caters for its broad spectrum of risk and also includes the most important elements of pit slope management.
- The uppermost review level, IDDR, was more recently introduced to better suit critical risk slope design reviews where a more detailed 'audit' level approach is required.
- The primary benefits of the RT Copper risk-based approach to pit slope design approval and assurance are:
  - Better alignment of the intensity of assurance, and the skilled resources required, to the level of economic risk inherent in slope design decision-making.
  - It ensures the right level of management is aware and signing off on slope designs and geotechnical decisions that could have a material impact on the business.
  - Sufficient adaptability to cater for learnings derived from early cases of the adoption of IDDR, enabling it to remain practical in the fast-paced and dynamic mining environment.

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## References

Department of Mines, Industry Regulation and Safety 2019, *Ground Control Management in Western Australian Mining Operations*, Government of Western Australia, Perth.

Global Tailings Review.org, Global Industry Standard on Tailings Management, 2020, https://globaltailingsreview.org/global-industry-standard/

Gerritsen, T, Johndrow, T, Ridlen, PW, Winckler, C, Yenne, L 2023, 'Leveraging knowledge and experience of a well-formed independent tailings review board to enhance tailings facility safety', *Proceedings of the Management for Safe Dams Symposium,* Swedish National Committee of ICOLD, Gothenburg.

Graaf, PJH & Wessels, SDN 2016, 'A framework for managing geotechnical risk across multiple operations', *Journal of The Southern African Institute of Mining and Metallurgy*, vol. 116, no. 5, pp. 367–377.

International Organization for Standardization 2009, *ISO 31000 (2009) Risk Management - Guidelines*, International Organization for Standardization, Geneva.

Read, J & Stacey, P 2009, *Guidelines for Open Pit Slope Design,* CSIRO Publishing, Melbourne.

Rocscience 2023a, *RS3*, computer software, Rocscience, Toronto, https://www.rocscience.com/software/rs3

Roscience 2023b, *SWedge*, computer software, Rocscience, Toronto, https://www.rocscience.com/software/swedge

WSP 2023, *FracMan*, computer software, WSP, Montreal, https://www.wsp.com/en-gl/services/fracman