Risk Based Geotechnical Slope Reconciliation at Rio Tinto Iron Ore, Pilbara Operations

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Abstract

Geotechnical design is characterised by a relatively large number of uncertainties, even if industry best practice is followed during the design process. Regulatory and corporate standards require appropriate geotechnical design and slope management. Rio Tinto Iron Ore (RTIO) have addressed this challenge by developing a geotechnical reconciliation process carried out during mine implementation. Design assumptions are verified and actual slope performance assessed to close the design cycle. Typically, geotechnical reconciliation includes checking design assumptions and implementation recommendations by mapping pit walls in addition to monitoring actual slope performance. RTIO Western Australia, has over 260 individual open pits at 13 operations across the Pilbara. As such, it is impractical to physically map geotechnical and geological parameters on all slopes. Instead, a risk based approach is taken to focus efforts on high risk slopes whilst still checking lower risk slopes for unforeseen hazards. In order to assess geotechnical risk, RTIO has developed risk assessment tools specifically tailored to support the practical slope management of multiple operations. The geotechnical reconciliation process has been successfully implemented in RTIO pits and is fundamental to effective geotechnical slope management. Improved verification of design assumptions has allowed for reassessment of the pit design and improved hazard management in high risk pits. Two case histories are presented that illustrate the benefits of early identification of changes in actual conditions; one positive (better than expected) and one negative (poorer than expected) both leading to improved outcomes in terms of safety, design reliability and protection of the business plan.

1 Introduction

Effective design and operational management of large open pit mines requires ongoing geotechnical assessment in order to balance the slope instability risk with optimal economic outcomes. In order to do this, geotechnical practitioners must make decisions based on an understanding of the geological materials comprising the pit slopes. Our understanding of the nature of rock and soils in a mining environment may be significantly less detailed or precise than is typical for other engineering endeavours. The volume of material available for direct observation and characterisation (e.g. drill core) is usually orders of magnitude smaller than the construction itself (i.e. the mine slope). This, coupled with the inherent variability of the natural material, can lead to a high degree of uncertainty when estimating input parameters for geotechnical slope design. To some extent, this can be managed using a probabilistic approach with slope monitoring to mitigate risks outside a predicted range of outcomes. However, the economic outcome can still be negative if a slope failure is realised. Examples would include loss of access to ore supply, increased strip ratio due to step out, remediation costs associated with the failure itself and potential pit closure. Geotechnical slope reconciliation can address this issue through early identification of opportunities for pre-emptive changes to the slope design. The aim is to mitigate the hazard itself via an engineering control rather than address the attendant safety or economic scenario. Geotechnical
reconciliation may also identify where conditions are better than anticipated, potentially resulting in improved economic outcomes. Implementation of effective slope reconciliation also addresses both regulatory and corporate standards in demonstrating the suitability/currency of the slope design for the encountered conditions. It is for these reasons that RTIO has embarked on a programme to roll out a geotechnical reconciliation programme across its Pilbara open pit operations.

2 The need for reconciliation

The need for reconciliation is driven by legislative and corporate requirements, safety and economic considerations and best design practice.

2.1 Meeting the requirements of standards and legislation

Regulations and Corporate Standards require that appropriate slope designs are developed and implemented. RTIO’s Pilbara mines are located in Western Australia, where mining is governed by the Mines Safety and Inspection Act (1994) and the Mines Safety and Inspection Regulations (1995). Section 13.8 of the regulations detail the geotechnical requirements. Although the legislation does not specifically refer to reconciliation, it does require that geological conditions are considered in the design:

“Each responsible person at a mine must ensure that the following measures are taken in relation to ground control in the quarry: (a) adequate consideration is given to local geological structure and its influence on wall stability”;

The regulations furthermore specify that:

“(g) appropriate methods of open pit wall monitoring are used over a period of time to determine wall stability conditions”.

Wall monitoring refers not only to displacement monitoring, but also to monitoring of slope performance and behaviour. The guidelines document accompanying the regulations (Department of Minerals and Energy 1999) specifically requires that current geological knowledge should be taken into consideration in the management of geotechnical hazards. The guidelines are more specific regarding slope reconciliation requirements than the regulations and recommend that:

“During operation of the pit, the (newly developed) ground control management plan is used to improve the geotechnical database, and to assess the suitability of the current mine design and the general stability of the mine.”

In early 2011 Rio Tinto introduced a new Safety Standard titled “D3: Management of pit slopes, stockpiles, spoil and waste dumps”, which provides corporate governance on how geotechnical hazards should be managed. The standard covers all geotechnical activities related to open pit mining, from design through implementation and verification. The standard focuses on the safety aspects of geotechnical hazard management. Clause 4.2 of the D3 standard is more specific than the government regulations and requires that:

“Procedures and accountabilities must be in place to verify the conformance of the pit slopes, stockpiles, spoils and waste dumps to design and current conditions.”

The overall objectives for regulators and corporate standards is to ensure a safe working environment, and consequently the slope design must take into account the in situ conditions and planned mining strategy, and demonstrate that geotechnical risks are appropriately managed. It is clear that a process is required to reconcile the as built condition with the design assumptions and parameters. Slope reconciliation provides this process and ensures a systematic approach to verification of design assumptions and recommendations.
2.2 Safety and economic outcomes

The main purpose of the reconciliation process is to verify the design assumptions and recommendations on a routine basis. The design makes certain assumptions with regards to the geomechanical, hydrogeological, and structural and geological properties of the rock mass.

These models are based on data that, in most cases, originates from the logging of drill core. A drill core is a small representation of a large area and often does not present any significant information on the larger scale structures. This, combined with the challenges of the logging process, result in uncertainty of the design data as discussed in detail by Read (2009). The accuracy of the input data can vary and depends on:

- Location and spacing of drill holes with respect to structures and final pit slope location (drilling access). The local changes in structure or rock mass is not always identified or incorporated into a design (Hoek et al. 2001),
- Quality of drilling (e.g. core recovery and drill induced fracture).
- Accuracy of logging and quality of data validation.

The uncertainty in data leads to less reliable design assumptions and lower confidence in the understanding of the expected slope behaviour. In the Pilbara, where instability is largely controlled by bedding orientation, lack of knowledge and understanding of the geological and structural model can lead to unexpected slope behaviour. (Sullivan 2006) identified the ‘failure to appreciate when the overall geological setting carries risk’ as one of the contributing factors for the increasing trend in safety issues in open pit mining.

When a project progresses into the operational stages it provides the opportunity to not only verify the model assumptions, but also to monitor the expected slope behaviour. The exposure of the slope wall allows for large scale data collection by means of mapping, design versus as-built slope reconciliation, and direct displacement monitoring. Feedback of this expanded data set into the design is an important part of the design process.

When the reconciliation process identifies that conditions are worse than expected the likely outcome is a redesign that can result in a reduction of ore recovery and therefore a negative economical impact. However, the reconciliation process can identify better than expected geotechnical or geological conditions. As another example, the monitoring of groundwater levels could indicate better than expected depressurisation results. Either scenario could result in a more aggressive approach – with the accompanied economical benefits.

2.3 Duty of care

Engineers have a professional and legal ‘duty of care’ to design products, processes and systems that are as safe as is reasonably practicable. Safe design is concerned with eliminating hazards at the design stage or controlling risks to health and safety as early as possible in the planning and design of products, process or systems and items that comprise a workplace. Safe design is also good business in that if you can identify and correct design flaws early in the life cycle, it is much less costly than trying to remedy them later, and essentially a more effective product exists for the entire product life cycle (Australian Safety and Compensation Council 2006).

Reliability and operational safety in design is fundamental to engineering endeavours. In recognition of this Professional Codes of Ethics require appropriately high standards of duty and conduct from engineers in discharging their duties to the public, their employers, their clients, their colleagues, their profession and themselves. High technical standards are extremely important given the responsibility assumed by, and integral to, the undertakings of professional engineers (Marston 1996). In the active mining environment, slope reconciliation in closing the design feedback loop is an essential element in achieving demonstrated and documented duty of care.
3 The Pilbara challenge

RTIO’s mining operations span the Pilbara region of Western Australia (Fig. 1), and include 13 mines totalling 260 individual pits. Mining started in Tom Price in 1966, while the 3 newest mines were opened in 2010. In 2009 170 million tonnes were produced from the 100 operating pits, with a target of 333 Mt/pa by 2015. Ore bodies comprise multiple ore pods, resulting in multi pit mines, where a number of pits can be active at one time (depending on product quality requirements).

Figure 1. Locations of Rio Tinto Iron Operations in Pilbara Region of Western Australia

A number of challenges face the RTIO geotechnical team with respect to the implementation of a reconciliation system: 1) large number of active pits; 2) gaps in knowledge and uncertainty of data; 3) legacy pits and legacy data (some mines are more than 40 years old); 4) irregular pit shapes, (resulting in large number of different slope sectors (Fig. 2), which means that pits cannot be treated as a single entity, but has to be divided into several domains to assess compliance to design); 5) limited resources (Australia is experiencing a ‘mining boom’ and skilled labour is a scarce commodity); and 6) significant planned expansions in the near future.

It is therefore clear that a robust, risk based system is required. The reconciliation system has to be designed to allow the teams to cover the areas of geotechnical accountability to make sure changes in conditions and slope behaviour is identified. The system should highlight areas with higher risk and have to cater for a more detailed reconciliation in those areas.
3.1 Slope instability

The dominant instability mechanism in most hard rock Pilbara iron ore operations is structurally controlled sliding on adversely oriented primary bedding surfaces (Fig. 3); often interacting with large scale structures (in the form of faults and/or dykes) providing side release or complex slip surface geometries.

Rock mass strength is strongly anisotropic, with weak shale beds inter-bedded with strong to exceptionally strong Banded Iron Formation (BIF). Individual bedding surfaces within the Hamersley Group iron formation and intercalated shales are highly persistent and well defined across the Pilbara with banding down to cm scale being traceable across hundreds of kilometres (Trendall & Blockley 1970). At the mine scale, the persistence of bedding is essentially infinite, leading to potential structural sliding type instability wherever it dips at unfavourable angles out of the slope. Understanding structural geology is therefore an integral part of Pilbara slope design and reconciliation places a high priority on validation of structural models. Unexpected variations in bedding shear strength or structural model, getting it wrong by a few degrees, can lead to significant instability as illustrated in the examples above.
3.2 A risk based approach

The challenges of designing and operating multiple large open pits in the Pilbara requires a risk based approach to slope design and slope management. This is achieved through identification, communication and mitigation of uncertainty throughout the design and implementation process.

Slope design within a complex structural environment and strongly anisotropic rock masses lends itself toward probabilistic methods to understand and identify the key variables affecting stability. Sensitivity assessments of material properties are useful in this regard, however often the most significant control on slope stability (and arguably the most difficult to include as a routine variable) is the structural geological model. The orientation of fold limbs, axes and other large scale structures in relation to slope orientation and geometry typically controls slope design. Significant effort is expended in modelling and rating the intensity of large and intermediate scale folding of fold limbs (due to the significant impact of these bedding plane undulations on slope stability), as well as in defining the structural geological model confidence.

Effective management of the geotechnical risks across the 100 operational and additional 160 planned pits within the RTIO Pilbara operations portfolio, has required a risk based approach to systematically identify potential hazards, evaluate the business risk (safety, economic, environmental, reputational, etc.) and define appropriate slope management controls. The risk based framework is in alignment with the business risk management strategy, and provides the basis for defining the level of rigour required for slope management, as well as for prioritising deployment of resources.

4 The reconciliation process

In order to achieve the requirements discussed in Section 2, RTIO has developed a geotechnical reconciliation process that is being applied to all existing and future open pit mining operations. This process is documented in an internal guideline document including a detailed description of the associated risk assessment tools. This process is deployed across all sites and is driven by the RTIO Geotechnical Technical Assurance Team that is accountable for internal processes, standards development, and compliance audits. Reconciliation field work is the responsibility of site based geotechnical staff within the Technical Services Group. A ‘Responsible, Accountable, Consult, Inform (RACI) matrix’ tool has been used to clearly identify stakeholders and define their level of involvement in the reconciliation process. This includes technical disciplines and management external to the geotechnical teams.

4.1 Elements of reconciliation

The flow chart illustrated in Figure 4 outlines the important position geotechnical reconciliation holds within the design feedback loop. The level of reconciliation effort and rigour is driven by the risk assessment outcomes. Risk assessment is a central driver of reconciliation work and is undertaken collaboratively involving key design and mine management stakeholders. The results of the risk assessment drive follow up actions aimed at reducing the risk exposure of the operation to geotechnical hazards. Actions would typically include additional operation controls such as slope monitoring or direct modification of the slope design. Accountabilities with regard to the latter are dependent on the scale of change required and its potential impact on the mine planning process.
4.2 Risk assessment tools

To achieve a risk based approach, specific tools have been developed to assess risks specific to geotechnical hazards and to provide outputs that lead into site based risk management planning. A high level project ranking tool is used to provide an initial pit ranking of all current and future operating pits within the portfolio. This was necessary to ensure that the highest risks were addressed as soon as possible. Each pit was ranked according to a variety of criteria including level of geotechnical confidence in the slope design and structural model, pit depth, and contribution to ore production.

Once individual pits were prioritised, risk assessment was applied to the pit slopes using the Geotechnical Risk Register tool. This is a Microsoft Access database that is specifically tailored to address geotechnical hazards. Prior to carrying out the assessment, each pit is subdivided into a set of risk assessment slope sectors (or domains) that broadly align with slope design sectors and operational risk management areas. When defining the risk assessment slope sectors, consideration is given to the following:

- Slope Aspect (wall orientation);
- Geotechnical (geological) domain & associated potential failure mechanism;
- Slope design geometry.

Risk assessments are then carried out for each slope sector. This is a qualitative type risk assessment that utilises a probability versus consequence risk matrix similar to that applied to assess other risks across the mining industry and within RTIO. Notwithstanding this, quantitative aspects of geotechnical risk assessment such as numerical slope stability and rockfall analysis results are considered. This results in a semi-quantitative outcome. A team approach to risk assessment is applied including representatives from the operations, mine planning and technical groups. This blend of knowledge results in consideration of both operational observations of slope performance and design expectations (residual design risks). The Technical Assurance team provides cross-site moderation in order to produce consistent and balanced results across the Pilbara mines.

The Microsoft Access risk register is used to undertake the risk assessments and to provide a repository of the results. Controls applied to address geotechnical risks are driven directly from the geotechnical risk register. This system is being further developed to provide additional outputs (aside from the risk assessment) such as a site monitoring plan and associated Trigger, Action and Response Plans (TARPs). Geotechnical hazards at all scales are addressed by the Geotechnical Risk Register with separate risk assessments generated for overall slope, inter-ramp, multi-batter, single batter and rockfall scale instability. Risk assessments also differentiate between existing risks associated with the as-built slope (current potential risk) and projected risks associated with the
design slope that has not been excavated (future potential risk). The system includes a Microsoft Excel output facility in order to provide tabulated results which are summarised graphically for communication to management.

4.3 Staged reconciliation

It is clearly impractical to carry out detailed reconciliation work such as geotechnical mapping in all areas. In order to focus effort spatially as well as according to risk rank, representative section lines are assigned for each slope sector. Section lines are generally selected to align with slope design section lines where stability assessment has been carried out (e.g. where a stability model has been developed). Reconciliation work is carried out in two levels of rigour. Level 1 is intended to reconcile realised vs. design geotechnical parameters and as such, is essentially a check to ensure that design expectations are realised and that no “surprises” are encountered. This work would typically include the following elements:

- Geotechnical Mapping (window mapping);
- Geometrical reconciliation of as built vs. design batter/berm configuration;
- Slope monitoring (measured slope displacement);
- Hydrogeological monitoring (groundwater status).

Level 1 reconciliation involves high level overview of fundamental design verification parameters which can be achieved with nominal effort acquired to process and report. Level 1 would typically be carried out for slope sectors where the geotechnical risk has been assessed as low to medium. Level 2 reconciliation is carried out where geotechnical risks are assessed to be high or critical and aims to build on the existing geotechnical model by providing additional data. This is generally via scan-line mapping in order to provide a statistically valid data set. Level 2 incorporates the same elements as Level 1 to a greater level of detail and rigour and adds mandatory stability analysis. As an example, following update of the geotechnical model, an existing stability model would be updated and re-run to ensure the risk of instability has not increased. Level 2 reconciliation is generally carried out in areas where a potential issue is known to exist and requires an increased level of management. Increased risk can lead to upgrade of Level 1 sections to Level 2 status.

Section lines identified to focus reconciliation work are assigned Level 1 or 2 status depending on the risks captured in the geotechnical risk register. Figure 2 illustrates an example of a pit subdivided into risk assessment slope sectors with selected section lines identified by stage. Work for both reconciliation stages is scheduled according to mine development. As such, work is only required when new excavation is carried out in the vicinity of reconciliation section lines.

4.4 Reconciliation tools and reporting

The primary tool utilised to carry out reconciliation work is the geotechnical AcQuire database used to capture both window and traverse mapping data. Data can be entered into AcQuire in the field via a Panasonic toughbook or directly onto a paper mapping sheet as an alternative. Improved field data capture tools such as tablet PC’s are also in the trial stages. An excavation compliance indicator (ECI) tool which automates comparison and evaluation of design vs. as-built slope configuration has been developed by Seery & Lapwood (2007). This is being accompanied by the introduction of a laser scanning system to enable site survey teams to precisely map crest and toe position, and provide monthly ECI performance reports. A comprehensive suite of slope monitoring systems are used at RTIO to directly measure slope performance in terms of displacement response to mining. Monitoring system design is also risk based, and incorporates basic visual inspections for low risk areas with a ramp up in sophistication in high risk areas such as near real-time radar scanning for safety critical monitoring. Future developments will include continued integration of alarmed systems into the Perth RTIO Operations Centre where the majority of mine dispatch functionality is now located.

A report is produced for each reconciliation section and this is summarised in a monthly report that incorporates a “traffic light” system to highlight areas of concern. Reporting of results is generally monthly and is passed to Technical Assurance for review and allocation of follow up actions to the appropriate work group.
5 Case study 1

The initial design for this case study pit was prepared in 2007 and subsequent geotechnical assessments highlighted the potential stability problems for the south wall illustrated in Figure 5. The design geometry comprises 195m ultimate depth with 20m high, 65° batters and 8m wide catchment berms (inter-ramp angle of 48°). From 2007-2009 further outcrop mapping and drilling was completed as part of a pit extension feasibility study. A geotechnical review compiled in November 2009 confirmed potential stability issues associated with less favourable (than expected) bedding orientations on the south wall (RTIO 2009). The Footwall Zone (FWZ) was found to dip at angles higher than the shear strength of shales within this unit. This was confirmed by stability analysis carried out in the 2009 review which reported an unacceptable Factor of Safety for the area. The area was consequently highlighted as a potentially high geotechnical risk.

Figure 5. Oblique view of south wall high risk area and reconciliation section with 2009 structural geology.

Following the 2009 work, review of prism monitoring observations revealed a general slow creep response in the area of concern. This result was considered a confirmation of the potential high risk status for the slope.

5.1 Reconciliation application

Level 2 reconciliation was mandated for the high risk area commenced in January 2010. This was the first RTIO Pilbara site to introduce formal geotechnical reconciliation, with intent to verify the structural geological model and rock mass conditions.

In February 2010 initial mapping work carried out on the 630RL berm, confirmed the findings of the 2009 review. A redesign was initiated to remove the haulage ramp from traversing beneath the area (the only pit access). Batters below the 580RL were also reduced from 20m high to 10m to mitigate uncertainty in unfavourable FWZ bedding. Further mapping completed on the 600RL berm in June also identified adverse bedding conditions within the overlying DG2 unit. Bedding within DG2 BIF was found to be more steeply dipping and potentially more adverse for stability than predicted from core logging (RTIO, 2011a).
As part of reconciliation work, re-assessment of the prism data confirmed a constant creep trend since prism installation. The periods of increased displacement rates were correlated with blasting and excavation of trim shots along the south wall. Given the production focus on the mining area, turnaround of benches was occurring faster and hence periods of increased displacement were more pronounced and more frequent. The reconciliation results were then used to re-assess the geotechnical risk for the south wall. This was confirmed to be ‘High’ for both safety and economic implications for overall and multi-batter scales of failure. Given the high risk, further remedial measures and controls would be required.

5.2 Reconciliation outcomes

Following the updated risk assessment, additional staged control measures were recommended as listed below;

1. Further update of the structural geology model;
2. Stability design review using additional data from reconciliation window/traverse mapping;
3. An elevated level of monitoring rigour. Automated prism monitoring required.

The structural model was updated in September 2010. From the window mapping campaign the presence of a local syncline within the south wall was evident and this was included in the model update. A change in bedding dip from shallow (~20°) to moderate (~40°) was identified within the DG2 unit as illustrated in Figure 6.

A stability review of the south wall was completed by October 2010 using new data available from: oriented drill holes, window and traverse mapping, an updated structural geology model and laboratory testing (UCS, direct shear tests). Kinematics, limit equilibrium and finite element analysis methods were carried out as part of the review. Stability models considered the mining schedule and planned bench progression. Slope performance observations from visual inspections and prism displacement data were used to calibrate the stability models. Instability was considered to be due to a combination of unfavourable structural geology and poor rock mass
quality. Stability assessment work concluded that the Factor of Safety for the current slope (above 600RL) did not meet the accepted RTIO design criteria, with the probable failure mechanism involving sliding on DG2 shale bedding with a component of rock mass breakout. It was concluded that a remedial design change would be required to mitigate multiple batter instability in the order of 50-100m high over a 200m extent following mining the next bench to 580RL (RTIO 2011a).

5.3 Remedial options

Three options were provided to mine management for remediation of the south wall:

1. Cutback to unload the upper section of slope. Cutback dimensions; 70-90m high over 200m strike length with a 40m minimum width. Operational Impact: This would have a significant delay on the mining schedule and would require additional waste movement.

2. Step-out at 600RL to provide a large catchment berm to retain material if instability were to occur and to reduce the overall slope angle. The slope area above the 600RL would remain marginally stable and the associated risks managed through improved slope monitoring and increased hazard awareness. A 20m step-out was determined to be the optimal width to contain the potential multi-batter failure volume. Operational Impact: Some ore loss would result, increased monitoring costs.

3. No change to design and manage the risks whilst mining the final 70m. The stability of the slope would remain marginal. In addition, the potential failure volume would increase with each bench exposed, resulting in increased operation risk. This would include increased safety and economic risk with attendant impacts on mine schedule and potential for ore loss. Further controls required would include safety-critical (near-real time) monitoring and hazard awareness would be required to manage the risk. Operational Impact: Highest risk option (safety and economic) in the event of failure. Highest monitoring costs.

Considering the risks associated with the above options, Option 2 was selected by mine management as the best balance of economic impact and geotechnical risk. This was implemented in December 2010. As described above Option 2 requires additional monitoring controls. The slope monitoring controls prior to this were considered inadequate to manage the risk, and improved systems would need to be implemented. The monitoring was upgraded including an automated prism monitoring system and slope Stability Radar to confirm the slope response to mining. Increased hazard awareness education for all mine personnel was completed and a TARP was developed.

The geotechnical risk register was updated following the implementation of the remedial controls described above. The slope is now classified as a ‘Low’ risk for safety and economic impacts. At the time of writing this paper, mining had progressed to the 580RL. Prism movement has slowed and no unexpected response to mining at the toe has been observed. Ongoing geotechnical reconciliation work will be carried out as mining continues to verify the design review assumptions. This case study highlights the benefits of confirming design assumptions in a timely manner. The confirmation of the adverse structural geology conditions ahead of mining allowed for the implementation of effective lead engineering controls to manage the risk associated with mining of the lower slope.

6 Case study 2

The slope presented in this case study is formed primarily within the shale rich MacLeod and Nammuldi units of the Marra Mamba Iron Formation. Bedding follows the regional east-west trending folds with axial surfaces gently inclined toward the north. Several parasitic folds at bench scale reflect the regional structural trend. The initial design analysis was completed in 2007 for this pit with shallow batter angles recommended due to the potential failure mechanism of planar sliding along shale bands (which daylight at 35°). The final design geometry features a 190m high slope with 20m high, 40° batters and 7m wide catch berms (with an inter-ramp angle of 31°). The main haulage ramp switches back beneath this slope. Supplementary drilling campaigns were completed in 2008-2010. Further design review using this data noted potential stability issues associated with
parasitic folding at single and multi-batter scales. Depending on the scale of the parasitic folding, the synclinal trough of the fold could potentially form a ‘ski jump’ undercutting the slope at single or multi-batter scale. Monitoring of this slope consisted of manually read prisms and visual observations.

6.1 Reconciliation application

The Geotechnical Risk Register was first populated for this site in November 2010. The south-west corner was classified as a ‘moderate’ risk for safety outcomes at batter, multi-batter and inter-ramp slope scales, due to the potential instability mechanism of sliding on bedding. In December 2010 a 30m high multi-batter scale slip occurred in south-west wall followed a 2 day rainfall event totalling 12mm. The slip was controlled by adversely oriented bedding in the MacLeod unit. Formalised geotechnical reconciliation was being introduced for this pit at the time of the failure. No geotechnical data collection had been completed since the previous structural model update in early 2010.

Following the slip, Level 2 reconciliation was implemented including a detailed mapping campaign leading to an update of the structural geology model. The instability was previously reported as sliding due to the adversely orientated planar bedding. However after further investigation this was found to be a more complex mechanism associated with bedding plane sliding across a localised synclinal hinge zone with release on a persistent joint set. Back analysis of the failure concluded that the sliding surface occurred along shales within a unit of inter-bedded shale and BIF that was modelled to be approximately 5m thick (RTIO 2010).

6.2 Reconciliation outcomes

The slip area required design changes to be proposed. A step-out on the 560RL was recommended in order to contain an overhang at the western end of the failure. In addition to this, reconciliation mapping data identified that there was potential to steepen the batter from 550RL to 530RL. Double benching (20m high, 60° batters) would be achievable given the shallow dip of the bedding and the better rockmass properties within the underlying Nammuldi Member. This would allow the design toe at 530RL to be achieved despite the step out at 560RL. This in turn would allow the design haulage ramp lower on the slope to be achieved. (Fig. 7).

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Figure 7. Location of moderate risk area on south wall and reconciliation section.
Following the initial slip, the potential for a similar structural mechanism was identified in adjacent areas resulting in the addition of a reconciliation section to the east of the current slip area (Section 2 in Fig. 7). The importance of further structural geology and geotechnical mapping to increase the confidence in the models was communicated and is ongoing. Reconciliation mapping completed for section 2 at the 560RL identified similar parasitic folding and sub-vertical jointing. Limit equilibrium analysis using a 5m thick interbedded shale and BIF band resulted in an unacceptable Factor of Safety. Further instability was considered possible once a further 20m vertical advance had been excavated with a potential failure height of 30-80m (RTIO 2011b). The following controls were recommended for the area to ensure the ongoing risk remains at “moderate” level:

- Ongoing Level 2 reconciliation work to test for adverse bedding conditions (particularly on the 540RL).
- Upgrade of slope monitoring systems, including greater prism coverage and increased frequency of measurement. An automated prism system was specified to ensure an appropriate monitoring frequency.

Two positive outcomes of this case study were realised. Firstly, identifying the opportunity to increase the slope angle beneath the slip to maintain the design toe position and avoid ore loss. Secondly, improved understanding of the structural geological conditions contributing to the failure highlighted other areas of potential instability, allowing for the establishment of proactive control measures.

7 Conclusion

The risk based geotechnical slope reconciliation process has been successfully implemented across the 13 RTIO Pilbara mine operations, and excess of 200 pits, and is fundamental to effective geotechnical slope management. Better characterisation of design assumptions has allowed for re-assessment of the pit designs and improved hazard management in high risk pits. The process reduces the incidence of unexpected slope instability and the improved understanding of rock mass conditions has allowed for improved risk (safety) management and economic optimisation through redesign of slopes. Geotechnical engineers have a professional duty of care through design, implementation, verification and closure; slope reconciliation provides the vital link in closing the design feedback loop and providing documented evidence for improving the reliability of future designs.

8 Acknowledgements

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9 References


