Optimised Gotechnical Design of Iron Ore Slopes, Pilbara Region, Western Australia

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Abstract: Increasing resources demand and operational cost focus has become a catalyst for optimised mining practices in the Pilbara Iron Ore Industry in Western Australia. A reliable geotechnical data base is required for pit slope model development and consequent derivation of slope design parameters. A dominant feature of Banded Iron Formations in Pilbara is regular stratigraphic banding and frequent weak shale beds of infinite persistence at mine scales. Therefore, Pilbara geotechnical designs must be accompanied by robust structural models. As a result, anisotropic properties of rock play crucial role in defining rock shear strength. Limit Equilibrium Techniques are typically used to assess stability. Besides, all mining activities need to respect traditional land owners cultural and heritage rights and therefore protect heritage sites when mining occurs. This paper presents the solution adopted to meet this requirement and maximise mining objectives.

1 INTRODUCTION

Increasing global resources demand has become a catalyst for a mining boom in the last decade. This growth has been cyclic one where the market experienced periods of high demand resulted from industrial needs of China, Japan, Korea, India etc. as well as lows which caused by global financial crisis (e.g. the GFC and recent pressure on iron ore prices). An increased focus on cost has resulted in a renewed need for optimised mining practices in an environment where high and low grade resources are mined in large volumes. This has made present day open pits much larger and deeper than in previous decades. Maintaining the stability of the associated large slopes is crucial for safe and economically efficient pit designs supporting Iron Ore operations in the Pilbara Region of Western Australia. Requirements to reduce operational costs has resulted in a focus on the development of optimised slope designs aimed at reducing waste strip and maximising ore recovery whilst maintaining the interests of other stakeholders such as traditional landowners. In some mining areas there are places of historical importance to traditional land owners. Therefore, there is a need to minimise mining impacts on these sites of historical value from mining activities. This can include blasting and any slope instabilities which might affect heritage areas. This paper describes the geotechnical design sequence adopted to minimise waste strip and protecting a heritage area in the Pilbara which accomplishes both cost optimisation and community expectation outcomes.

2 PILBARA GEOLOGY

Pilbara iron ore deposits occur within banded iron formations (BIF) of the Hamersley Group which comprises Archaean to Proterozoic marine sedimentary and volcanic rocks. Many Hamersley province geologists recognize the significance geological structures play on the location, geometry and preservation of high grade iron ore bodies, and therefore a large number of studies regarding the structural evolution of the Hamersley province have taken place (e.g. Dalstra 2005; Martin and Morris, 2010). There is a general consensus that the western Hamersley province is dominated by normal faulting and thick-skinned tectonics whereas the eastern Province is dominated by more intense folding, minor thrust faulting and possible thin skinned tectonics. The stratigraphic units of most economic interest consist of Banded Iron Formation (BIF) with interbedded carbonates and shales. BIF canvary in thickness due to differing amounts of carbonate dissolution & silica replacement during iron ore enrichment formation (Harmsworth et al., 1990) and typically contain thick interbedded shale bands. Certain shale bands make excellent stratigraphic marker horizons in the mining areas as they are remarkably persistent throughout the entire Hamersley Province. These also form the major potential sliding planes that can cause instability.

High resolution structural models are derived from borehole logging and geophysical data combined with surface and pit-wall mapping. Boreholes target areas of geotechnical concern such as weak shale zones and bedding orientations at depth utilising geophysical methods such as natural gamma and televiewer. Once all data has been validated, the structural geologist typically models the deposit using Vulcan^{TM} software with structures and stratigraphic horizons as 3D triangulations.

In this area considering the significance of the design review and impact on mining, a special program of surface mapping was initiated to improve the resolution and confidence of the structural model. Face mapping structural halos together with existing structural model was used to refine the structural setting of the south wall to facilitate geotechnical modelling.

3 GEOTECHNICAL IMPLICATIONSOF PILBARA GEOLOGY

Anisotropic material properties of BIF and intercalated shales and carbonatestend to control the stability of Pilbara pit slopes. Anisotropic parameters that differentiate rock mass and defect shear strengths must be developed as inputs into stability analysis. Therefore, in Pilbara mining environments,both appropriate rock mass characterisation combined with robust structural geological models are required to effectively design pit slopes. It is important to identify the spatial distribution of relevant modes of instability ahead of committing to numerical analysis given the geometrically specific nature of structural and slope aspect interactions. As an example, relatively small variations in overall dip angle of bedding may have significant implications for large scale slope design.

Land ownership of Pilbara mining areas is held by traditional aboriginal people under native title arrangements. These lands host many artefacts of historical and cultural value such as rock shelters (caves), stone arrangements, religious sites etc. Therefore, mining activities need to comply with heritage protection protocols and agreements into which mining companies have entered with traditional land owners.

Mining near heritage sites may have adverse impacts on their existence leading to community and reputational impacts on the business. These impacts could be as follows:

- Slope failures triggered by geotechnical instability of the pit crest
- Damage of the site due to ground vibrations caused by Trim and Production Blasting

Any potential impacts and inability to manage mining risks on places of heritage significance may warrant implementation of special mining practices having significant negative impacts on mining.

4. DESIGN REVIEW SYNOPSIS

4.1 Requirement

A heritage cave (historic habitation shelter) was identified not far from the crest of a high grade iron ore pit in Pilbara. The pit has been designed with a focus on ore recovery with minimised, strip ratio. However, review of the design with heritage considerations in mind was required. Management of mining risks associated with heritage caves can be addressed by the following:

- Heritage clearance of the cave to eliminate need for special mining practices (safety management during excavation of items of historical value).
- Revision of pit slope design to maximise crest stand-off to reduce the likelihood of damage from blast vibrations and/or slope instability (in the event clearance of the site is not approved)

4.2 Assessment

For the area concerned it was decided to conduct a revised geotechnical assessment of the pit slope to increase buffer distance to prevent any damage to the cave referred to later in this paper from blast damage and potential slope failures.

Initially, 3 design sections were selected to conduct stability analysis for a revised design (Fig. 1).In addition to existing material properties developed from geotechnical diamond core drilling data, new information from face mapping and window mapping were also used to review the design (Fig. 2).

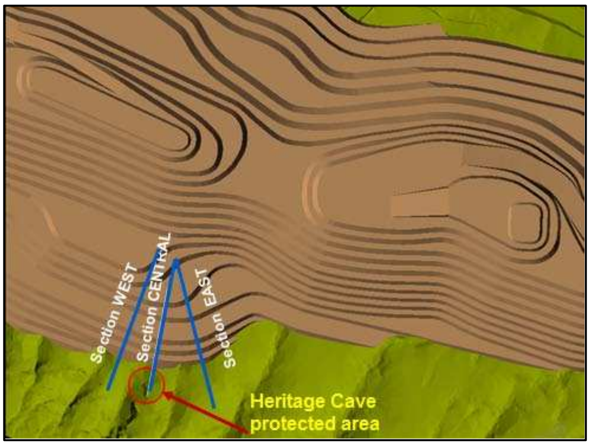
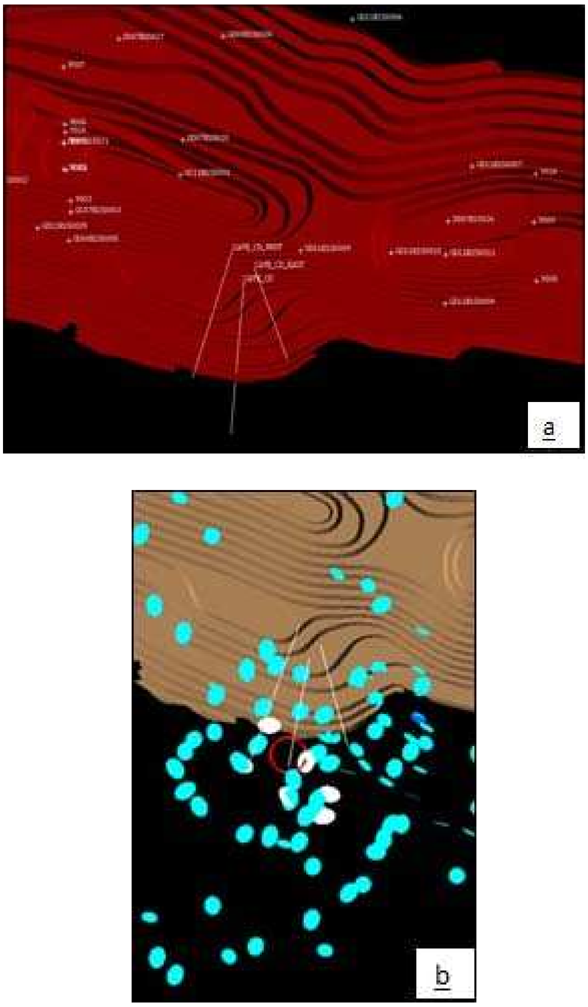


Fig. 1 Heritage cave location with reference to pit crest and analysis sections



.Fig. 2(a) Geotechnical drilling and (b) face mapping structural orientation halos

In the case presented, following additional data capture, a revised structural model was developed specifically for the project area. Material parameters were also revisited (e.g. RQD, UCS, GSI for rock mass strength and JRC, JCS and basic friction angle for defect shear strength). Statistical distributions were also carefully reviewed to characterise statistical ranges and select appropriate inputs for developing design shear strengths. Rock mass shear strength was estimated using Generalized Hoek Brown criterion as described in Generalized Hoek-Dietrich's (2006) method and defect shear strength estimated with Barton-Bandis strength criterion (Barton & Bandis, 1990).

Typically, Pilbara pit design practice is to define mean and lower bound values (generally 25th percentile) in order to develop Mohr-Coulomb properties (M-C properties) for a scale referenced normal stress range. These material properties are used in Limit Equilibrium analyses as applied to stability assessment.

M-C properties were developed for both batter and inter ramp scales with respective stress ranges as given below:

a) Inter ramp scale: 100-1100 kPa normal stress range
b) Batter scale: 10-150 kPa normal stress range.

Industry standard Limit Equilibrium Techniques typical of those used by geotechnical practitioners were used in this study. The anisotropic linear strength model in SLIDE^{TM} v6.0 was used in the analyses. For this strength model, A and B parameters are used to define the strength transition from defect to rock mass shear strength. A and B are dip angles where bedding and rock mass strength defines failure mechanisms respectively.

Lower bound rock mass Mohr-Coulomb properties were developed for the lithological unit Nammuldi given this is the dominant lithology on the south wall of the pit where the heritage site was located. Lower bound parameters were used to test sensitivity of the slope to reduced material strengths.

Stabilityanalysis has been carried out iteratively increasing stand-off distance from heritage site to the pit crest whilst maintaining the slope toe location. This has the added benefit of reducing waste stripping whilst not affecting high grade ore recovery. The critical section selected for LE analysis was taken forward 59m from the original crest position. This was possible due to the more favourable structural geological model update made in the area than the previous model used for the design. A revised design with a 59m step-in meets RTIO Geotechnical Design

Acceptance Criteria for overall, inter-ramp and batter scale slope performance. Further optimisation is limited by RTIO recommended batter berm configuration and ore distribution constraints.

4.3 Outcome

Implementation of the new revised design increases the crest standoff from the heritage area. This will reduce requirements for specialist blast practices needed to reduce vibration at the cave site (and incurred cost). In addition, the design has reduced waste stripping as well as requirements to carry out inefficient contour mining.

Furthermore, it was also decided to investigate extension of the design review further along the slope beyond the heritage area using the same material properties and an extended structural model update exploring opportunities to reduce stripping and contour mining. This was successfully carried out north and south of the heritage focus area where crest has been stepped-in approximately by 80m and 27m respectively (Figs. 3 and 4). This was a positive outcome to the business where significant reduction in stripping has been achieved without affecting high grade recovery.

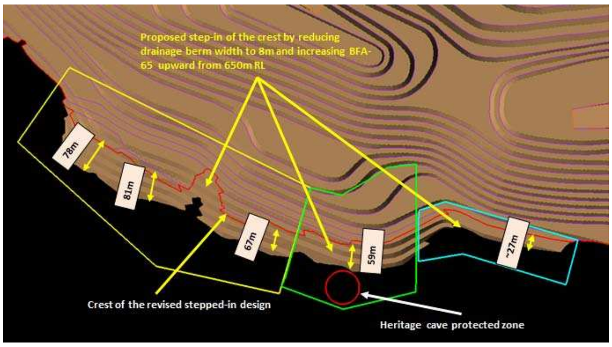


Fig. 3 South wall Geotechnical Design Sectors showing design step-in distances

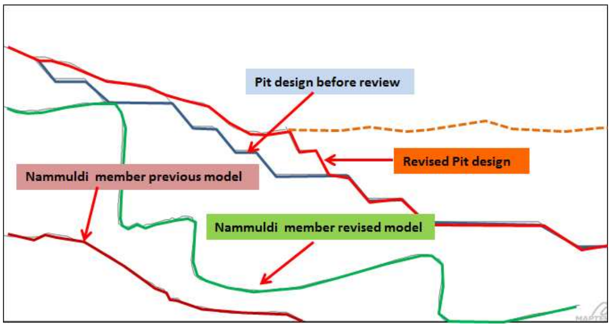


Fig. 4 Revised and current structural models

5 CONCLUSIONS

This work has paved the way to steepen the upper south wall, meeting heritage protection requirements as well as improving economic outcomes for the business. Over 1Mt of waste stripping has removed without affecting high grade ore recovery. Use of lower bound rock mass and defect properties as a sensitivity is considered to be a reasonable approach where full probabilistic methods are impractical or unsupported by a limited data set.

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Rio Tinto Iron Ore Geotechnical Design Acceptance Criteria (RTIO-HSE-0221884)