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Comments: Code of Practise: Ground Control in Open Pit Mines

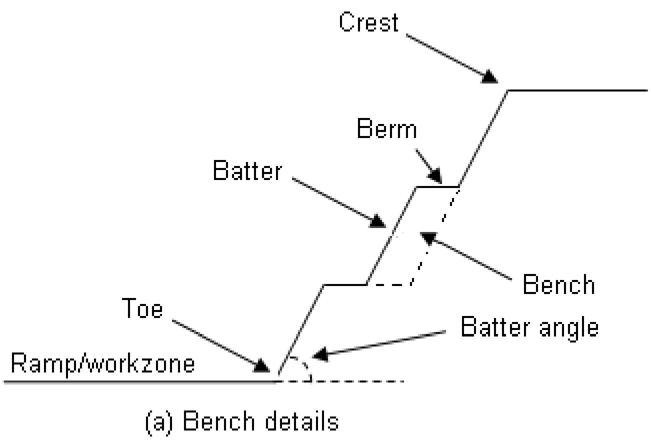
2 GROUND CONTROL IN OPEN PIT MINES

2.1 Terminology of open pit mine slopes

Page 7 Para. 1

Open pit slopes are generally designed as a series of benches separated by berms, which are provided at predefined vertical height intervals of the slope (Figure 1). The principal functions of berms are to catch and retain any material falling from the batters and crests and to improve overall slope stability. Access to a pit is usually via a ramp that may spiral around the pit and/or be located on one side of the pit with switchbacks at each end. A succession of batters between two access ramp sections (or between a ramp section and the pit floor or pit crest) is defined as the inter-ramp slope. The inter-ramp slope angle is always flatter than the batter angle in that slope. The full height of a pit slope, from the toe to the crest, comprising several benches separated by berms (and access ramp sections if the ramp is on that slope) is the overall slope. Figure 1 illustrates the terminology used.

(note changes in labelling in Figure 1)



Note Figure (b) is OK

Figure 1 Pit slope terminology

2.3 Mine Planning

Page 10 paragraph 3.

No space left between Para. 3 and Para. 4.

Page 10 paragraph 7.

In general, geotechnical inputs to the MPD process start with a high level of assumptions

2.4 Geotechnical Design of Pit Slopes

Formulation of a geotechnical model

Page 12 Para 3.

The availability of a comprehensive geotechnical model is the fundamental basis for all slope designs and (delete "is comprised") comprises four component models:

The structural model

Page 13 Para 2.

The purpose of the structural model is to describe the orientation and spatial distribution of the structural discontinuities (defects) that are likely to influence the stability of pit slopes. The discontinuities include faults, folds, foliation and bedding planes, joints, cleavage etc, and can be divided into two groups:

(a) large structural features such as folds and faults that are widely spaced and continuous along strike and dip across the entire mine site (major structures), and

(b) closely spaced joints, cleavage and faults etc that typically do not extend for more than two or three benches.

Rock mass model

Page 13 Para. 6

This model represents the engineering properties of the rock mass, which comprises various material types and structural discontinuities

Page 14 Para. 4 dot point 2

- Properties of structural discontinuities: surface roughness, waviness, infilling materials, aperture size, wall strength, spacing and persistence as well as shear strength (friction angle and cohesion), and normal and shear stiffness, if distinct element numerical modelling of slope stability is envisaged.

Page 14 Para. 7

Nevertheless, the laboratory tests are useful to determine the basic friction angle (ϕ_b) of a saw cut discontinuity. This angle is a function of the residual friction angle (ϕ_r) of the discontinuity. More reliable values of discontinuity shear strength parameters

Hydrogeological model

Page 15 para. 3

High water pressures also reduce the shear strength of discontinuities in an unweathered strong rock, leading to structurally controlled instability.

Geotechnical domains and design sectors

Page 16 para. 6

For a different slope orientation in the same geotechnical domain, the potential for structurally controlled instability will not be the same.

Geotechnical slope design and stability analysis

Page 17 Para. 4

In stronger rocks, structure is likely to control stability. The typical structurally controlled modes of instability include planar sliding, wedge sliding and toppling, and are common in stronger rocks, especially at bench scale. Large scale structurally controlled failures are also possible at inter-ramp and overall slope scale, if adversely oriented through-going structures are present. In general, structurally controlled sliding occurs when adversely oriented discontinuities undercut or daylight in the slope. However, this is not always the case. In some rock masses with medium to low strength, rock wedges and slabs that do not daylight could become unstable due to crushing and/or shearing through the rock mass/material at the toe. Moreover, depending on the number of discontinuity sets present and their orientation the structurally controlled failure modes could have several variations to those mentioned above. The variations include step-path, step-wedge, active-passive blocks etc (see Call, 1992; and Sjorberg, 2000). In each case instability may be further aggravated when high water pressures are present in the pit slope. These must all be recognised by diligent analysis of the discontinuity orientation data in each geotechnical domain.

Page 17 Para. 5

When the orientation of discontinuities is such that the formation of rock slabs, wedges or any other modes mentioned above is not possible, instability could still occur due to the movement along discontinuities and failure through the intact rock material.

Design acceptance

Page 18 Para. 2 and 3

No space left between paragraphs 2 and 3.

Page 18 Para. 3

The text suggests that designing a slope in rock on the basis of no other criteria other than achieving a specified FoS (e.g. 1.2 ≤ FOS ≤ 2.0) may be acceptable. This practise MAY be acceptable for homogenous, continuous, isotropic materials (e.g. some soils). It is NOT acceptable for heterogenous, discontinuous, anisotropic materials like rock. This argument has been well known and discussed ad-nauseum since the 1980s. Slopes in rock must be designed to achieve a specified maximum POF and a specified mean FOS. This paragraph should be rewritten to reflect this requirement.

Page 18 Para. 6

As with FOS, there are no strict criteria that specify the acceptable POF. The literature shows that different guidelines are proposed by different authors. The acceptable values of FOS and POF proposed by Priest and Brown (1983) are presented in Table 1.

Please note the following discussion by Stephen Priest emailed to the author of this document on 4 Aug. 2011.

> *Thank you for drawing my attention to the draft code for Ground Control in Open Pit Mines. I don't believe it is appropriate for this Code to present Table 4 from Priest and Brown (1983) for the following reasons:*

- *The acceptable values of mean F, P(F<1.0) and P(F<1.5) were developed and adopted for the slope design exercise described in the paper, which relates to the Cerro de Pasco open pit mine, high in the Peruvian Andes.*
- *Our research is now nearly 30 years old, and has been superseded by other work.*
- *The authors of the Code have not reproduced our Table 4 either completely or correctly. Specifically, the acceptable values of P(F<1.0) and P(F<1.5) are both maxima.*

> *If the authors of the Code wish to cite my and Ted's [Brown] paper, I suggest it should be along the following lines: "Priest and Brown (1983) were among the first to apply probabilistic methods to the design of slopes for open pit mines. In their paper they proposed acceptable values of mean F, P(F<1.0) and P(F<1.5) for application to the Cerro de Pasco open pit mine, in the Peruvian Andes. Although their recommendations provide general guidance, they should be applied with caution on other mine sites, where mining techniques, geological conditions and climatic factors are likely to be different." The authors of the Code should then go on to discuss more recent work.*

A good summary of acceptance criteria are in

- *Read, J and Stacey, P. (2009) Guidelines for Open Pit Slope Design, Chap. 9, pp.221-235. Pub. CSIRO Publishing.*

Table 9.9 Page 235 in Read and Stacey would be a reasonable replacement for Table 1 in the Code of Practice.

Stability Analysis

Page 19 Para. 4

- Kinematic analysis of structurally controlled failures: this is the analysis of removability of rock blocks from the slope without referring to the forces that cause them to move, and is based on stereographic projection methods (Hoek and Bray, 1981; Goodman, 1989; Priest, 1985, 1993; and Wyllie and Mah, 2004) and Block Theory (Goodman and Shi, 1985; and Goodman, 1989). This analysis is mainly applied for batter angle designs, but may also be used for inter-ramp angle and overall slope angle slope design, if anticipated failure is controlled by structures.
- Limit state equilibrium analysis: Two dimensional methods of analysis are widely used for the computation of FOS and POF against rotational shear failure in soil slopes. The methods can also be used to assess the FOS and POF against failure through rock material or rock mass at bench, inter-ramp and overall slope scales. Three dimensional limit state equilibrium methods of analysis can be applied to assess the FOS and POF of structurally controlled "kinematically unstable" rock blocks and wedges at bench and inter-ramp scales. The major limitation of limit state equilibrium analysis is that it assumes the unstable mass can be represented by solid blocks and it cannot represent deformation and/or displacement of the failing rock mass.
- Numerical analysis: This is based on numerical modelling tools such as finite element and distinct element methods. Some two-dimensional and three dimensional methods can overcome some of the limitations in the limit equilibrium analysis in that they can model complex rock masses and the deformation of a failing mass. These analyses can be useful for stability assessments at bench, inter-ramp and overall slope scales.

Page 19 Para. 5

The author considers that there is no place for empirical (i.e. rock mass classification) approaches to the design of slope angles in rock. As such this paragraph should be removed.

(The only necessity to apply an empirical classification process when designing slopes in rock is when estimating the shear strength of the rock mass (e.g. GSI method used to obtain parameters for describing rock mass shear strength in terms of cohesion c_m and friction angle ϕ_m)

Bench design (rather than batter and berm design)

P20

As mentioned previously, open pit slopes are generally designed as a series of benches separated by berms, which are provided at predefined vertical height intervals of the slope. The principal function of the berms is to provide a safe environment for personnel and equipment that must work near the slope face.

In most open pit mines, bench heights typically range from 10 to 20 m. In large open pit mines bench heights up to 30 m are not uncommon providing that the rock mass is strong and massive. From a safety point of view the final decision on the maximum bench height should be based on:

a) the reliability of the batter slope, i.e. stability under the potential failure modes, and

b) the availability of equipment for adequate scaling the batters to remove loose pieces of rock that may fall creating potential safety hazards for personnel working below the slope.

For reliability of the bench design all possible failure modes should be identified and their stability assessed by appropriate methods.

The berms must be wide enough to arrest potentially hazardous rockfalls and contain any spillage from the batters above. They should also allow long-term access for berm cleanups and to access instrumentation for slope movement monitoring and groundwater monitoring. The decision on the berm width should also take into account the likelihood of achieving the design width. This depends on the geological structure as well as the level of blasting and excavation control. As a rule of thumb, berms on a production slope should have a minimum width equivalent to 2/3^{rds} the height of the adjacent bench. On a final slope, berms should have a minimum width equivalent to 1/3^{rds} the height of the adjacent bench.

P21 Para 3

As there is no role for empirical approaches to the design of slope angles in rock, this paragraph should be removed.

Design of ground support and reinforcement

P21 Para. 4 and 5

It is well known that the currently available rockfall control (e.g. mesh, rock fall protection barriers etc.), ground support (e.g. shotcrete, fibrecrete, etc.) and reinforcement (e.g. rockbolts, cable bolts, dowels, shear pins etc.) systems are not capable of preventing inter-ramp and overall scale instability in large open pit mines. Nevertheless, they may still be used for rockfall control and stabilisation of bench scale failures.

If any form of control, support or reinforcement system is considered its design must be based on a thorough understanding of the rock mass properties, the properties of the system, the potential failure modes, the operating life of the pit slope and the required mean FOS and maximum POF.

2.5 Implementation of the slope design

Page 22 Para. 3

In any open pit mining operation, prior to the commencement of mining, the design will usually be changed or modified with time, as detailed information is gathered by site investigation programs. After the commencement of mining the design may continue to be.....

Minimising blast damage

Page 22. Para 5

Industry experience clearly shows that inappropriate blasting practices can result in substantial damage to the rock mass in the interim and final pit slopes. Examples of the outcome of poor blasting practices near open pit slopes include:

- *Remove the first dot point as loose rock on batters is inevitable and will be dealt with by effective scaling.*
- Over-break in the slope face leading to over-steepening of the slope which in turn could lead to further instability depending on the level of stability allowed in the original design.
- Sub-grade damage of berms leading to a reduction in their effectiveness as a means of retaining loose rock and supporting equipment.
- Undercutting toes of benches resulting in potential bench scale instability due to failure of the respective batter.
- A cumulative reduction in the strength of the rock mass. In particular, by reducing the shear strengths of the discontinuities.

Page 22 Para. 8 Dot point 1

- Geotechnical characteristics of the rock mass: dynamic compressive and tensile strength and elastic properties of rock material, discontinuity properties

Page 23 Para. 1 Dot point 1

- The presence of groundwater in the rock mass: water saturated rock masses transmit shock energy more efficiently than dry rock masses. The vibration and pressure levels do not attenuate quickly as in dry rock mass and the damage envelope is likely to be greater. Thus there is greater susceptibility to slope damage.

Excavation control and Scaling

Rewrite paragraph as follows

Adequate excavation of batters and selection of the mining equipment to be used to achieve the desired standards are critical elements for achieving safe slopes in open pit mines. Effective scaling is the single most important factor for reducing the risk to personnel from rockfall. (end paragraph)

In soils and weak and weathered rock, batters can be excavated by free digging using hydraulic excavators. A critical factor in batter excavation in soils and weak rock is that the slope must not be under-cut such that the as-built slope is steeper than the as-designed. This could result in instability leading to safety implications. The berms separating the batters must be provided with adequate surface runoff control measures to minimise water infiltration and slope erosion. In these materials experienced machine operators can construct slopes with smooth surface so that scaling is not generally required.

In hard rocks, batter scaling is begun as soon as loading equipment reaches the muckpile of blasted rock. It continues while the equipment operator waits for trucks. There can however be issues associated with the use of the loading equipment for scaling:

- *The equipment is generally fitted with a large bucket that can be ineffective for thoroughly removing small rocks without damaging the batter.*
- *Loose rock at the crest represents a particular hazard, particularly if it is overhanging, and it must be removed. However, the reach of the loading equipment's boom may be insufficient to reach the crest unless a ramp of broken rock, upon which the equipment can stand, has been built up.*
- *Scaling can be time consuming if it is done properly and can prevent the loading equipment from being used elsewhere.*

For these reasons scaling should occur in two stages; primary and secondary. Primary scaling involves the operator of the loading equipment removing all larger loose rock from between the toe and the crest of a batter aiming to achieve a straight, consistent and clean batter. Care needs to be taken to ensure that doing so preserves crests and hence berm widths as much as possible. An overhang, comprising a secure massive protruding boulder, may be less of a concern than is one comprising a mass of smaller rocks. If, by removing any boulder, a crest will be damaged or a potentially unstable caverns created it is often better to leave the boulder in place as long as it is reasonably secure.

Secondary scaling is carried out after the muckpile has been removed and before the final cleanup of the berm. It requires fitting a small bucket to the loading equipment or a ripper tyne to the end of its boom. It may involve the use of dedicated scaling equipment thereby freeing up the loading equipment. At the end of secondary scaling there should be no loose rock remaining on the batter.

Groundwater and surface water control

Page 24 Para 2

Open pit mines excavated below the ground water table are likely to need some form of dewatering and depressurisation .. The most significant groundwater related problem is the effect that water pressure has on the stability of the pit slopes. Water pressures in discontinuities and pore spaces in intact rock material reduce the effective stress with a consequent reduction in shear strength.

Performance monitoring

Page 25 Para 4

- geological and geotechnical mapping of exposed pit slopes, particularly batters
- supplementary drilling, logging, testing and installation of instrumentation for the confirmation of geotechnical and hydrogeological characteristics of the deeper areas of the pit
- performance monitoring of near wall blasting (i.e. the depth of bench damage and back-break of bench crests) and ground movements
- reconciliation of as-mined batters and berm widths
- assessment of the effectiveness of dewatering and depressurisation measures, and

- assessment of the effectiveness of mine planning and sequencing in achieving the designed slope configurations.

Page 25 Para 7

All work zones should be inspected daily prior to work beginning to detect evidence of pending instability. At least once every week the entire pit should be inspected for the same reason.

Numerous techniques are available for pit slope monitoring including various survey monitoring techniques; 3D-photogrammetry, surface and borehole extensometers; and radar monitoring systems. The selection of the most appropriate monitoring technique is dependent on site-specific conditions such as modes of failure.

3. GROUND CONTROL MANAGEMENT PLAN

PAGE 27 Para 2.

Ground control in an open pit mine is an integral part of any well managed mining operation. The aim of an open pit ground control program is to design and excavate pit walls so that the required levels of workforce safety and economic extraction of ore are achieved. A successful ground control program is not necessarily one that has had no rock mass failures. Success is measured by the level of awareness developed before any bench or multi-bench scale failure occurs, how geotechnical learning opportunities are incorporated into the pit design process over time, and how the safety and economic risks are managed. The stability analyses discussed in the previous sections may form the basis of a risk assessment that incorporates mitigating factors to achieve acceptable levels of risk in terms of safety.

To comply with the WHS Act and regulations a mine operator needs to demonstrate "sound practice" in the field of geotechnical engineering as applied to open pit mining ground control. The use of sound practice assumes that operational and design practices will evolve and improve continually. The ground control management plan (GCMP) is an essential component of the site PHMP. The GCMP demonstrates that sound practice and continuous improvement is integral within the mining process.

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APPENDIX A – MEANING OF KEY TERMS

Abutment	The areas of unmined rock at the edges of mining excavations that may carry elevated loads resulting from redistributions of stress.
Batter	The planar surface between catch berms within pit walls - excavated to a specific angle from the horizontal.
Bedding planes	Planes of weakness in the rock that usually occur at the interface of parallel beds or laminae of material within the rockmass.
Bench	A parallelepiped shaped mass of rock bounded by a batter, an underlying berm and either an overlying berm or the ground surface. The bench height is the vertical distance between the latter surfaces.
Bund	A continuous mound of loose material, of appropriate height, placed out from the toe of a slope to act as a barricade to limit the horizontal movement of falling rocks thereby preventing them from entering workzones.

	Bunds are also placed behind the uppermost crest of a slope to prevent personnel/equipment from falling down pit walls and to redirect overland flows of surface water.
Buttress	A body of material either left unmined or placed against a section of the pit wall to prevent continued movement or propagation of wall failure.
Cable bolts	One or more steel reinforcing strands placed in a hole drilled in rock, with cement or other grout pumped into the hole over the full length of the cable. A steel face plate, in contact with the excavation perimeter, would usually be attached to the cable by a barrel and wedge anchor. The cable(s) may be tensioned or untensioned. The steel rope may be plain strand or modified in a way to achieve the appropriate load transfer from the grout and the steel strand to the rock mass
Catch berm	The width of lateral ground separating successive batters. The purpose of the catch berm is to both reduce the overall angle of the pit walls and to retain any loose material or bench scale rock mass failures, thus reducing the risk of injury to the workforce below.

Windrow	A continuous mound of loose material, of appropriate height, placed adjacent to the crest of a berm to act as a barricade to falling rock and to prevent personnel/equipment from falling down pit walls.

Yours sincerely,

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