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October 2016 – COMREC Paper 3.4

Memorandum

Question 1.

Factors influencing the stability of rock slopes:

1. Geology – natural given condition, out of the engineer's control 1
2. Geological structure. – as above. 1
3. Rock mass properties. – as above. 1
4. Groundwater – natural given condition, but slope can be depressurised. 1
5. Blasting – entirely within the engineer's control. 1

Approach regarding ~~&~~ instability considering these factors:

1. Geology – the base of all slope engineering. Unknown geological conditions ~~as~~ such as ~~changes~~ variability in the dip / dip dir of a contact or bedding may result in instability in a slope. 1 Therefore, geological drilling, mapping, interpretation, modelling and reconciliation should form an integral and ongoing process in any mining operation. The higher the confidence in the geological data, the less likely it will be to encounter unexpected geological conditions. 1

2. Geological structure – the main controlling factor in the stability of hardrock and even often saprolite slopes. 1 ~~Struct~~ Good quality structural data is required to provide confidence in the slope stability analysis and slope design. Structural data should be collected for:

   a) Major structures – faults, shears and folds, as well as dyke contacts, etc. for 1st order structures.

   b) Intermediate structures – 2nd and 3rd, etc. order faults shears, etc.

   c) Minor structures – Joints, foliation, bedding, veining etc. making up the rock mass fabric.

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This data guides the kinematic analysis to determine the likely failure mechanisms and together with geology and rock mass data is used to define the geotechnical domains for slope design and data gathering purposes. 1

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~~A3 to~~ On the basis of these factors, a slope showing signs of instability can be improved as follows:

(1) Geology – improve data confidence to improve design confidence and reduce the likelihood of encountering unknown geological factors.

– change the slope design, i.e. geometry and orientation of the slope.

(2) Structure – improve the level of confidence in the structural model to avoid unknown structural interactions.

– establish the influence of major to minor structures on the slope from improved data confidence.

– consider remedial measures, such as rock mass support.

– change the slope design, i.e. geometry ~~of the slope~~ and orientation of the slope.

(3) Rock mass – improve data confidence to improve design confidence by better definition of geotechnical domains and rock mass strengths vs. failure mechanisms and slope geometry.

– establish influence of intact rock relative to structure to improve the application of rock strengths in the design.

– consider remedial measures, ie. rock mass support, material improvement/replacement strategies, rock fall protection measures, etc.

(4) Groundwater – determine the influence of water pressure on the slope stability.

– implement slope depressurisation programmes such as horizontal drain holes or dewatering wells to lower the water table and reduce water pressure in the slope.

– implement judicious surface water management, such as surface and in-pit drainage programmes.

(5) Blasting – implement blast monitor via high speed videography and seismometers/geophones to measure PPV.

– implement cushion blasting techniques such as pre-splitting, buffer and trim blasting and delay timing and initiation as well as limit blasting design to protection of the highwall.

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Question 3

The components of a geotechnical model are:

1. Geology model.
2. Structural model.
3. Rock mass model.
4. Hydrogeology model.

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The collation of these 4 models forms the geotechnical model. 1
Each of the 4 individual models affects an open pit slope design in terms of the data confidence for input to the design analysis.

1. Geology model – determines the main lithological contacts and weathering profile, 1 with each defined unit having it's own mineralogical and physical (strength) characteristics. The geology model defines the first step in interpreting geotechnical domains 1 for design purposes and data acquisition programmes, and gives a first interpretation of areas/zones that may be problematic due to poor ground conditions, eg: an excessively deep weathering profile and ~~present~~ presence of clay rich saprolitic material requires specific sampling and materials testing procedures, and is often associated with slope instability due to the variable and weak nature of the saprolitic material. 1

2. Structural model – can be split into major and ~~inter~~ intermediate, and minor structures. 1 The orientation and continuity of ~~major~~ structures in relation to the pit slope geometry 1 along with the rock mass strength, ~~determines the~~ are ~~stability of the slope~~. amongst the main controlling factors in slope stability, 1 especially in hardrock slopes. The structural model should identify the potential for anisotropy 1 in the rock mass and provide an interpretation of the major and minor structures present, such as:

- faults – what type and what is their relationship to each other and the ~~rock~~ lithology.
- shears – their extent and relation to other structures and the tectonic environment.
- folds – ~~to~~ what is the type and scale of folding and what interaction is there with faulting and shearing.
- shear/faulted contacts, etc.

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Question 4

a.) Blast damage results from the energy wave generated by the explosion back into the remaining rock mass. Similar to natural seismicity, this results in P, S, and R-waves propagating through the rock mass and dissipating radially with distance from the blast. This in turn results in graded vibration that disrupts and damages the rock mass, causing a loss of integrity in the rock fabric and ~~the~~ potential displacement along structures. Around the blasthole, the rock is broken in compression as the energy pulse passes through it with the P-wave. The arrival of the S-wave signifies rock breakage in shear rather than compression, ~~resulting in tensile failure~~ while the R-wave results in surface disturbance. Additionally high pressure gasses in the blasthole are forced into any available void space in the rock mass, propagating preferentially along structural planes and effectively "loosening" the rock mass. Water contained along structural planes is often dissipated, adding to the high pressure gasses, or forced away from the blast, resulting in a pore pressure increase and then sudden dissipitation.

b) Controlled blasting techniques include: pre-splitting, post-splitting, buffer/cushion blasting and trim blasting.

~~Pre-splitting~~ Post-splitting results in a clean, well-cut rock face, ~~by slicing~~ but does not protect the rock face from the energy propagated during production blasting. Therefore, pre-splitting is commonly practiced, whereby a continuous tension crack is induced in the rock mass along the mining limit line. This then dissipates the energy wave from adjacent blasting. However, due to the large amount of energy involved in production blasting, the pre-split itself is protected by reducing the explosive charge in directly adjacent blasthole rows (buffer blasting). Finally the direction of the blast energy can be controlled by trim blasting, whereby the blast initiation and timing ensures that the blast energy is directed mainly away from the remaining highwall.

Continued overleaf.

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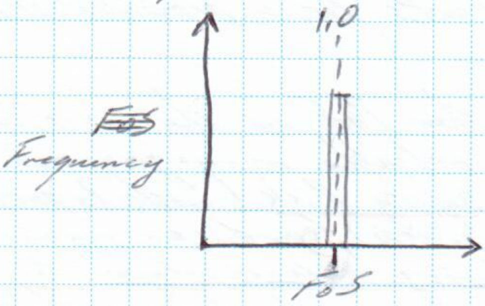
Question 5

Risk based open pit ~~design from~~ slope design involves determination of the likelihood or probability that the slope will fail, resulting in a risk to personnel and/or a risk to achieving the design and committed mine planning requirements. Therefore, a probabilistic design approach is required.

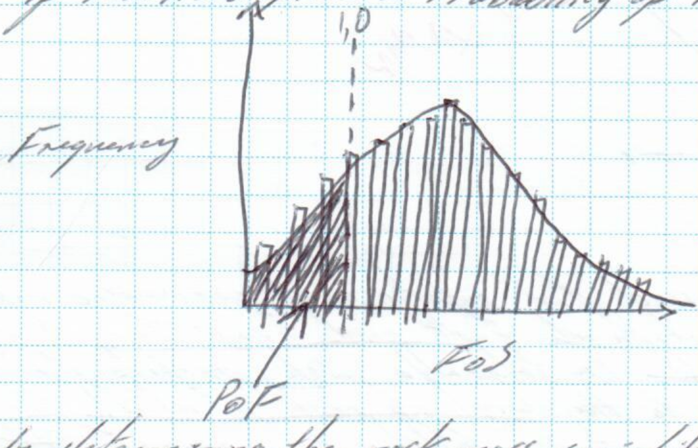
Deterministic slope design involves the calculation of a Factor of Safety (FoS), from:

FoS = Resisting forces / Driving forces.

This results in a discrete number that is convenient for engineering design calculations, but does not consider the inherent variability present in rock mass. The resultant FoS can be expressed as:



A probabilistic design considers variability in the input parameters for the stability analysis to define a range of analysis outcomes in accordance with the inherent variability of the rock mass analysed. This ~~can be expressed as~~ range of results defines a Probability of Failure (PoF), and is expressed as:



In determining the rock mass variability as input to the PoF analysis, a large number of data points are needed for all analysis input parameters, such as:

- UCS
- Friction
- Cohesion

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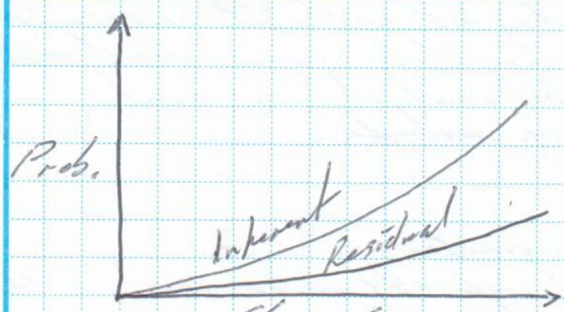
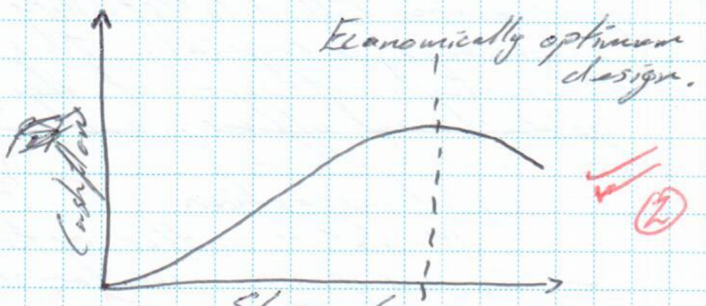


Slope ∠.
Safety risk.



Slope ∠.
Economic Risk.

The economic risk is usually expressed as cashflow/NPV/etc. per slope angle evaluated, with the cost of slope failure mitigation calculated into the risk ①. This results in an expected risk to value profile that indicates an economically optimum slope design. This must then be assessed against the safety risk profile to determine the final risk based slope design.

In evaluating these risk profiles, risk mitigation and controls are assessed, these may include:

- Slope depressurisation
- Limit blasting and wall control methodologies ②
- Slope stability monitoring and warning.
- Emergency operational procedures.
- Geotechnical resourcing.
- Rockfall mitigation.
- Slope support.

These mitigations determine the eventual residual risk profile, and it is crucial that they be included in all project and operational planning and remain in place for as long as what the ~~path~~ associated design is mined. Failing/altering this alters the safety and economic risk profile of the pit and may lead to disastrous consequences.

① These may include economic mitigations such as the establishment of strategic stockpiles, multiple ore exposures, multi-pit mining, etc.

② Blasting requirements may include pre-splitting, buffer and trim blasting to accomplish the required wall control standards for the mining of aggressive slopes.

→ Geotechnical data requirements for good limit blasting include on-going mapping and borehole core correlation to provide rock mass characteristics for detailed blast design.