RISK MANAGEMENT IN OPEN PIT SLOPE DESIGN

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THE TOPIC

Risk Management in Open Pit Slope Design

"The application of risk management concepts and process to the geotechnical risks associated with each stage of the slope design process"

Order of Discussion

- Essential Definitions
- Perception and Acceptance of Risk
- Risk Analysis Concepts & Process
- Data Uncertainty
- Reporting Data Uncertainty (Geotechnical Reporting Code)
- Acceptance Criteria
- Risk Evaluation
- Risk Management Process
- Risk Mitigation Process

NOTE: Text & example figures courtesy of the LOP Project Sponsors & contributors to Chapters 8, 9 & 13 of the LOP Project *Slope Design Guidelines* publication currently in preparation

LOP Project Sponsors

Anglo American plc, Barrick, BHP Billiton, Codelco, Collahuasi, DeBeers, Debswana, Newcrest, Newmont, RioTinto, Xstrata, Vale

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Essential Definitions (1/2)

***Consequence* – the outcome or impact of an event**

***Hazard* – a source of potential harm; a potential occurrence or condition that could lead to injury, damage to the environment, delay or economic loss (eg, slope failure)**

***Risk* – the likelihood of something happening (eg, slope failure) that will have an impact on the objective (the consequence)**

***Likelihood* – the probability of an event, described in qualitative or quantitative terms**

***Risk analysis* – a systematic process to understand the nature of and to deduce the level of risk**

***Risk assessment* – the overall process of risk identification, risk analysis and risk evaluation.**

Essential Definitions (2/2)

Risk criteria **– the terms of reference by which the significance of risk is assessed**

Risk evaluation **– the process of comparing the level of risk against risk criteria**

Risk identification **– the process of determining what, where, when, why and how something could happen**

Risk management **– the culture, processes and structures that are directed towards realizing potential opportunities whilst managing adverse effects**

Risk treatment **– the process of selection and implementation of measures to modify risk**

Perception & Acceptance of Risk

Risk is inherent in most human activity

- **Domestic (kitchen, bathroom & bedroom)**
- **Industrial (civil, mining & marine)**
- **Traffic (road, air, sea)**
- **Natural hazards (earthquake, cyclone & fire)**

Involuntary risks **- risks to which the average person is exposed without choice (dread diseases, general accidents)**

Voluntary risks **- only the select few that choose to take part in certain activities are exposed (extreme sports, dangerous employment, cigarette smoking, alcohol or drug abuse)**

Voluntary or involuntary? **- social risk acceptance studies have shown that people will accept risk if they perceive the benefit to outweigh the risk. It has been suggested that industrial risk can be regarded as voluntary if and only if the employee has been empowered to consciously accept the risks in order to obtain the reward.**

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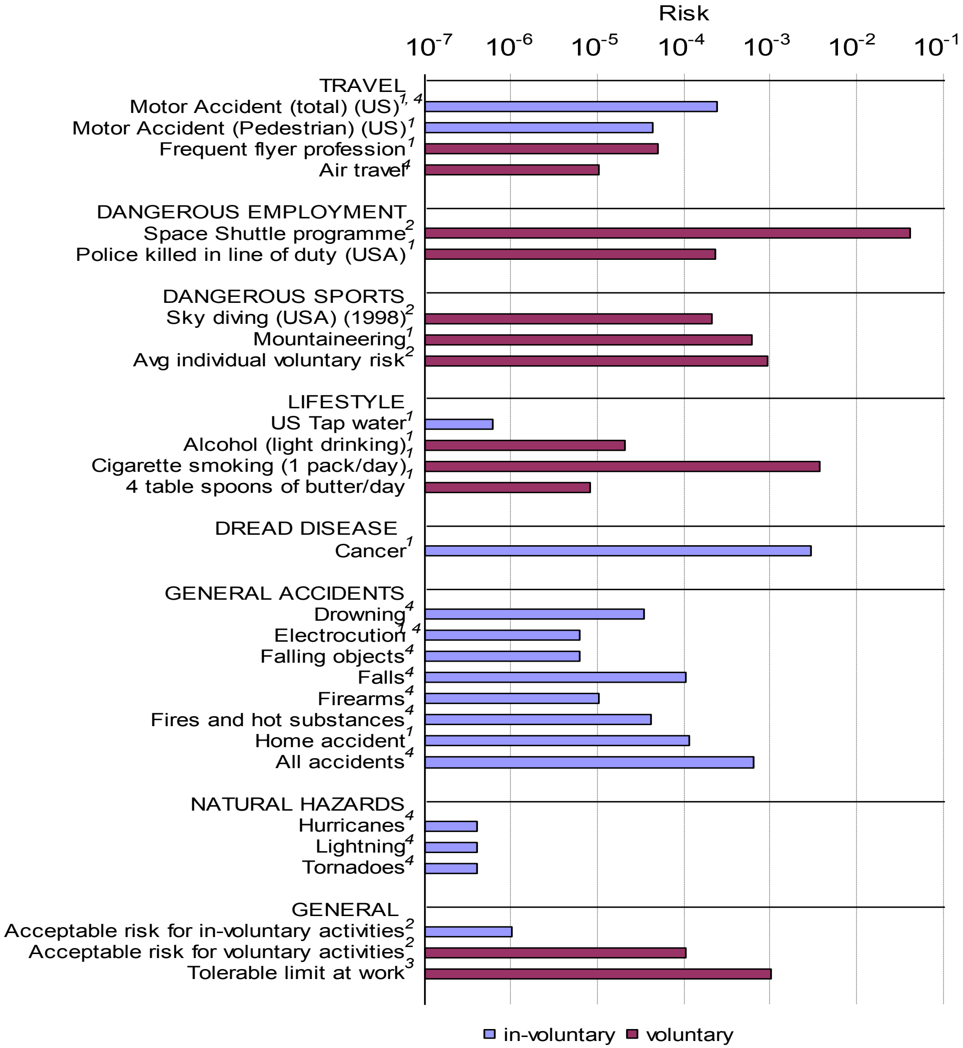

Comparative Fatality Statistics

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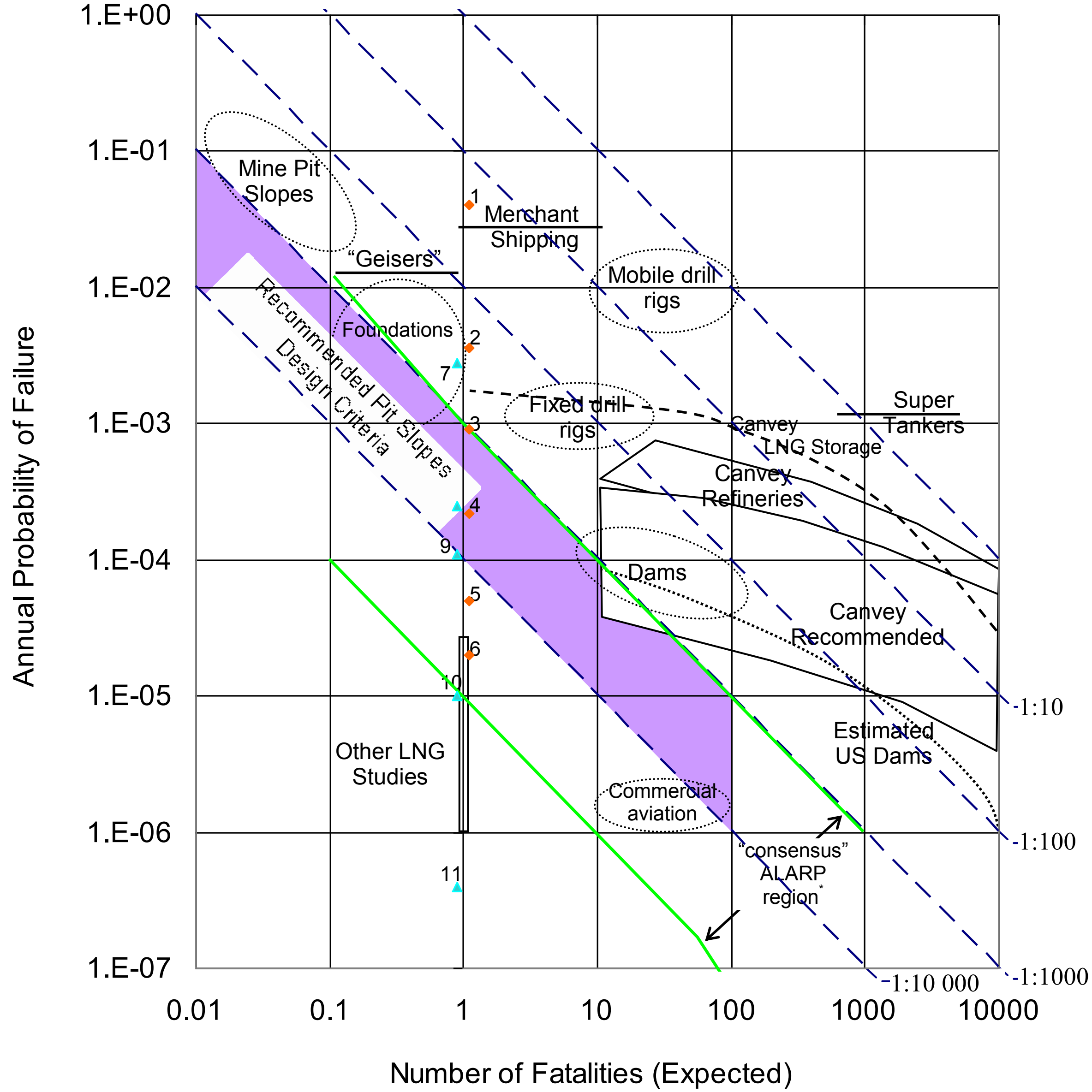

1. Space shuttle
2. 1 pack/day
3. Sports
4. Police killed
5. Prof. Freq. Flyer
6. Light drinking
7. Cancer
8. Motor Vehicle
9. At home
10. Air travel
11. Cyclone/lightning

ALARP = As Low As Reasonably Possible

Concepts & Process

Slope Design Process

- Data collection consistent with level of project development
- Assessment of the level of confidence in the data
- Application of the data to slope design
- Assessment of design risks against acceptance criteria

Slope Performance & Management Process

•Risk evaluation as mining proceeds

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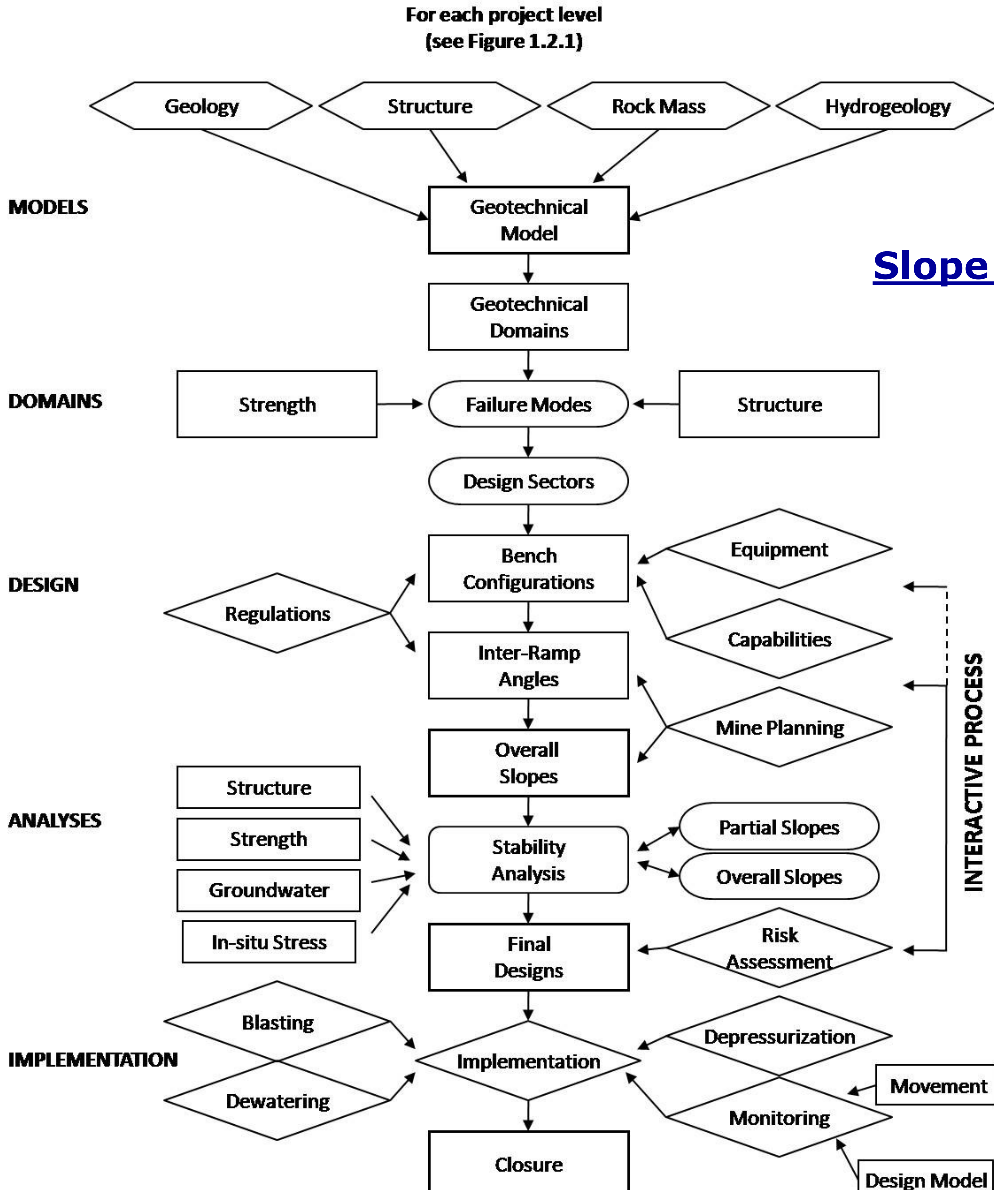
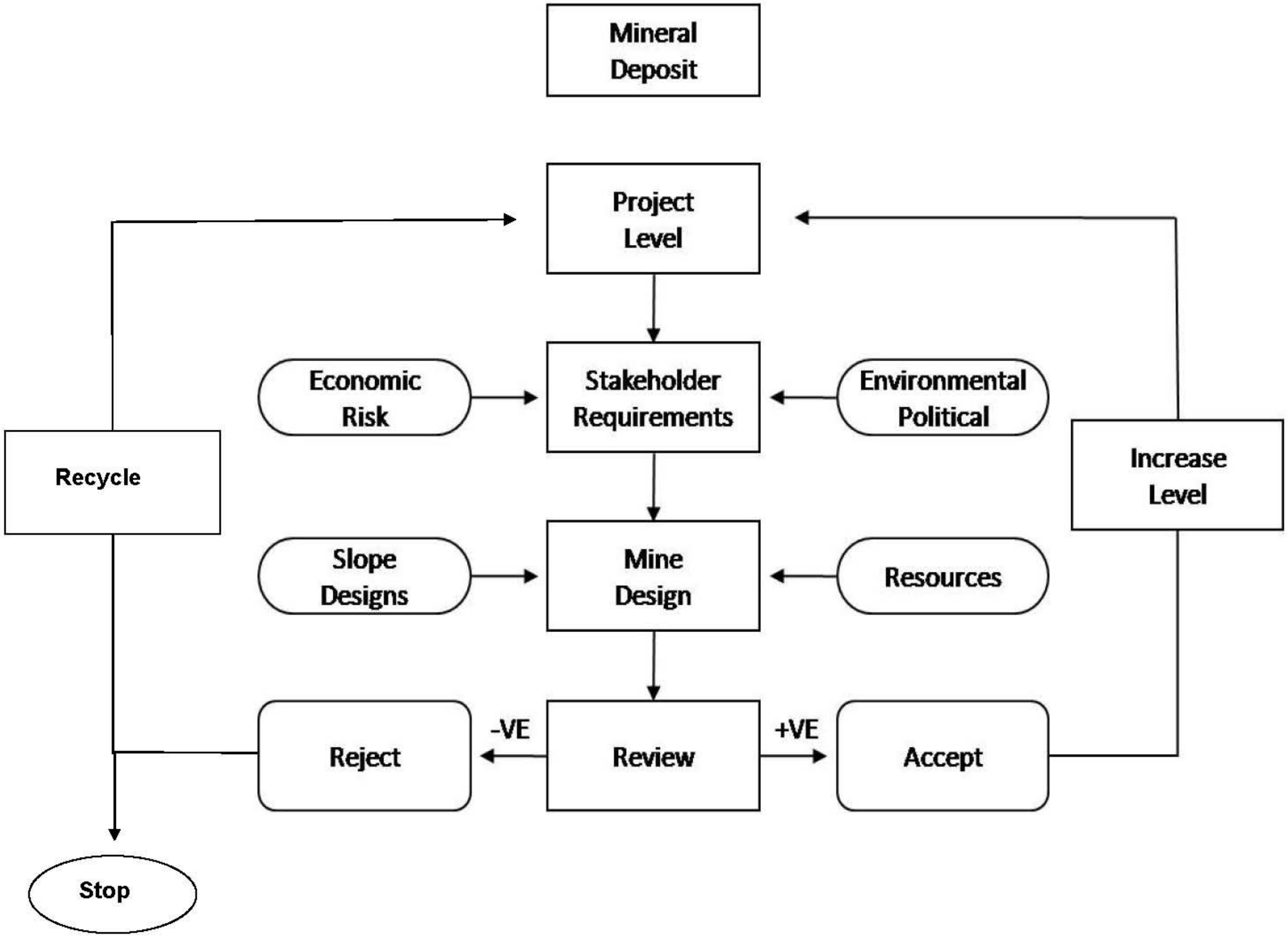
Slope Design Process





Project Development Flow Chart

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Project Levels & Geotechnical Data Gathering Effort

Level 1 = Conceptual

Existing reports, pertinent regional information & geotechnical assessment of advanced exploration data

Level 2 = Pre-feasibility

Assessment & compilation of initial mine-scale geotechnical data; preparation of initial geotechnical database & 3D model

Level 3 = Feasibility

Ongoing assessment & compilation of all new mine scale geotechnical data; enhancement of geotechnical database & 3D model

Level 4 =Design & Construction

Refinement of geotechnical database & 3D model

Level 5 = Operations

Ongoing maintenance of geotechnical database & 3D model

Data Uncertainty

- **In open pit mining data uncertainty stems from the recurrent inability of mining engineers, geologists and geotechnical engineers to correctly predict the properties and characteristics of the natural materials and phenomena they deal with**
- **From the perspective of open pit mining the relevant types of uncertainty can be placed into three groups: geological uncertainty; parameter uncertainty; and model uncertainty**
  - **Geological uncertainty = the uncertainties arising from features such as incorrectly delineated lithological boundaries, major faults, and unforseen geological conditions**
  - **Parameter uncertainty = the uncertainties associated with the values that are adopted for geotechnical parameters such as the friction angle, cohesion, dilation angle, and deformation modulus**
  - **Model uncertainty = the uncertainties surrounding the selection process and the different types of analyses that are used to formulise the slope design and estimate the reliability of the pit walls.**
- **In the geotechnical model we are concerned with geological and parameter uncertainty as they lead directly to unreliability and poor performance of the pit slopes**

Quantifying Data Uncertainty

- **In our daily lives we cope with uncertainty intuitively by using our own previous experience to rank and guide our choice.**
- **In open pit mining, we evaluate and update the uncertainties in the geological, structural, rock mass and hydrogeological parameters within each geotechnical domain and design sector using *relative frequency concepts* and probability distributions aided, if necessary, by subjective assessments of how the data was collected.**
- **The boundaries between the geotechnical domains and design sectors however, are positional, which makes it difficult if not impracticable to derive probability distributions from measured values. The alternative is to gather boundary data using *subjective assessments* prepared by competent geologists, engineering geologists and geotechnical engineers, acting either individually or as members of a review panel.**

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Subjective Assessment (1/2)

- Although they have not been widely used in the mining industry, subjective assessment methods have often been used to help overcome these challenges and disagreements in formal assessments of the reliability of underground nuclear waste storage facilities. The most well known methods probably are:
  - Bayesian probability. Provides an organised system for using new information to update prior knowledge, indicating how opinions held before an experiment should be modified by the results of the outcome. It is a good approach when the fundamental mechanism is understood and the data comprises a representative sample of the value being assessed. Geostatistical estimation of ore reserves is one example
  - Calibrated assessment. Adjusts individual assessments to reflect the assessor's known biases. Thus, two sets of assessment are required: assessments of the values in question; and an assessment of the assessors. The assessors can be assessed by their peers or through a set of questionnaires that quantify their biases with respect to known conditions

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Subjective Assessment (2/2)

- **Assessment methods (cont):**
  - **Delphi panels. Individuals in a defined group of experts are each provided with the same set of background information and requested to perform assessments in writing. These assessments are then provided anonymously to each of the other experts, who are encouraged to adjust their assessments in light of their peer's assessments. The iterations are continued until the results stabilise. In situations where consensus cannot be achieved, the group average may be used.**
  - **Probability encoding. Similar to the calibrated assessment approach except that an encoding analyst works with each expert to obtain a more accurate assessment instead of simply correcting the expert's assessments based on pre-determined calibration factors. The method tacitly assumes that the expert is incompetent in quantitatively assessing his own uncertainty and uses the encoding analyst to bridge the gap. The limitations of the method are that it depends on the credibility of the analysts and there is no mechanism for achieving consensus.**

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Relative Frequency Concepts & Probability Distributions (1/2)

- **Typically, the emphasis is on direct measurement and then either organising the data in a structured manner as a means of examining variability within a range of values or distinguishing between populations within or across different domains.**
- **Direct measurement to determine probabilities is a standard technique and all geotechnical practitioners should be familiar with the statistical measures of central tendency and scatter, notably the expected value (E[*x*]), the standard deviation (σ[*x*]), and the coefficient of variation (V(*x*))**

$$\mathrm{V}(x) = \frac{\sigma[x]}{E[x]} \text{ x } 100\ (\%)$$

- **Generally, coefficients of about 10% are considered to be low and values greater than 30% high. If the expected value of a parameter is unknown, than one can be estimated and the uncertainty quantified with an appropriate coefficient of variation.**

Relative Frequency Concepts & Probability Distributions (2/2)

- In addition to the simple concept of the coefficient of variation, geotechnical practitioners should also be aware of the fact that, because the expected value is obtained from the probability distribution function of a random variable, the individual outcomes may have quite different probabilities of occurring
- Should also have a working knowledge of cumulative distribution functions, which provide the means of progressively estimating the likelihood that the occurrence of a given phenomenon will equal or exceed a given set of values
- Also the binomial, uniform, normal, and lognormal distributions.

[Milton E Harr (1996). ‘Reliability-Based Design in Civil Engineering’. Dover Press]

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Reporting Data Uncertainty – Geotechnical Reporting Code

- **Project stages and levels of effort**
- **Target levels of confidence by project stage**
- **Target levels of confidence relative to the JORC code**

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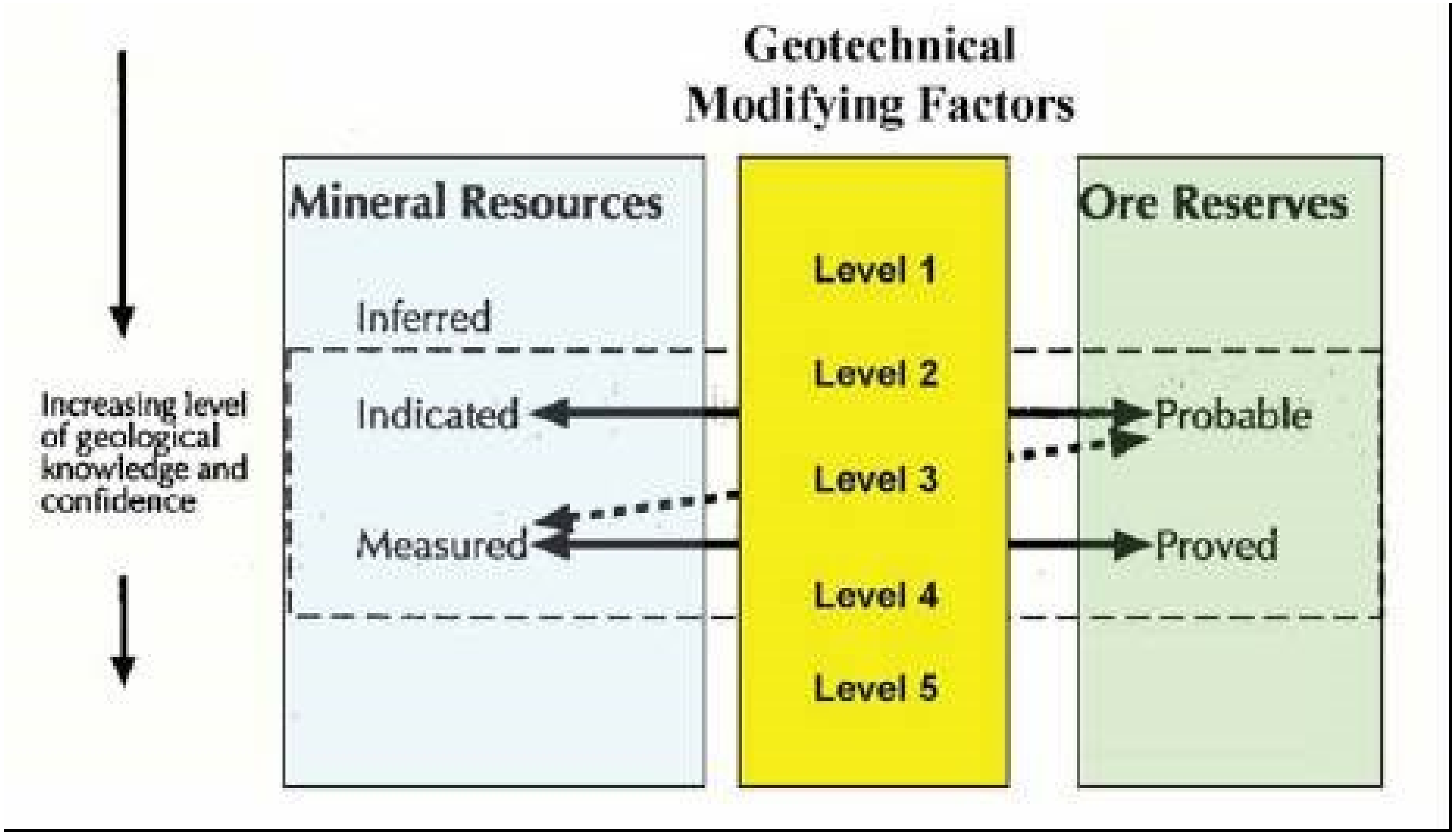
	PROJECT STAGES & LEVELS OF EFFORT				
Project Level Status	**Conceptual**	**Pre-Feasibility**	**Feasibility**	**Design and Construction**	**Operations**
Geotechnical Level Status	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Geological Model	Regional literature; advanced exploration mapping & core logging; database established; initial country rock model	Mine scale mapping & core logging, enhancement of geological database; initial 3D geological model.	Infill drilling and mapping, further enhancement of geological database & 3D model	Targeted drilling & mapping; refinement of geological database & 3D model	Ongoing pit mapping & drilling; further refinement of geological database & 3D model
Structural Model (Major features)	Aerial photos & initial ground proofing	Mine scale outcrop mapping; targeted oriented drilling; initial structural model	Trench mapping; infill oriented drilling; 3D structural model	Refined interpretation of 3D structural model	Structural mapping on all pit benches; further refinement of 3D model
Structural Model (Fabric)	Regional outcrop mapping	Mine scale outcrop mapping; targeted oriented drilling; database established initial stereographic assessment of fabric data; initial structural domains established	Infill trench mapping & oriented drilling; enhancement of database; advanced stereographic assessment of fabric data; confirmation of structural domains	Refined interpretation of fabric data and structural domains	Structural mapping on all pit benches; further refinement of fabric data and structural domains

Project Stages & Target Levels of Confidence

	PROJECT STAGES				
Project level Status	**Conceptual**	**Pre-Feasibility**	**Feasibility**	**Design and Construction**	**Operations**
Geotechnical levels status	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Target Levels of Confidence					
Geology	>50%	50% to 70%	65% to 85%	80% to 90%	>90%
Structural	>20%	40% to 50%	45% to 70%	60% to 75%	>75%
Hydrogeological	>20%	30% to 50%	40% to 65%	60% to 75%	>75%
Rock Mass	>30%	40% to 65%	60% to 75%	70% to 80%	>80%
Geotechnical	>30%	40% to 60%	50% to 75%	65% to 85%	>80%

Geotechnical Modifying Factors relative to the JORC Code



Target Confidence Levels (1/3)

Level 1. Model inferred entirely from existing reports and interpretations based on available regional data gathered from mines in similar geological environments. This preliminary data may be supplemented by aerial photographic interpretations of the regional lithology and structure and any outcrop mapping that may have been performed during exploratory project surveys. Overall, the information will be sufficient only for providing indicative slope designs and the planning of pre-feasibility stage investigations.

At this stage of the project the data assessments will almost entirely have been performed subjectively (*Level 1 Slope Angle*)

Level 2. Model inferred from interpretations based on the information provided during the conceptual stage of development augmented by data obtained from outcrops, exposures in road cuttings and river banks, trenches, pits, underground workings and oriented drill holes at the proposed mine site. All of this data may be limited or variably distributed and/or of uncertain quality. Any sampling, field testing and laboratory testing procedures must be sufficient to satisfy designated international standards for site investigation and laboratory testing (eg, ISRM, ASTM). The information will be sufficient to form working plans and Level 2 pre-feasibility slope design studies.

At this stage of the project the data assessments will still have largely been performed subjectively, but they will have been supplemented by quantitative assessments as measurable data became increasingly available (*Level 2 Slope Angle*)

Target Confidence Levels (2/3)

Level 3. **For the chosen option the interpretations will have been based on the results of the mine site feasibility investigations. Sampling locations will have been spaced closely enough to sustain three-dimensional interpretations of the domain boundaries to the limits of mining based on boundary intersections and the continuity of the structural fabric, rock mass properties and hydrogeological parameters within each domain. Some structural mapping will have been performed utilising estimates of joint frequencies, lengths and conditions. All major features and joint sets should have been identified.** ***Testing (small sample) for the physical properties of the in situ rock and joint surfaces will have been carried out. Similarly, groundwater data will be based on piezometer readings, and airlift, pumping and packer tests*****. All sampling, field testing and laboratory testing procedures must be sufficient to satisfy designated international standards for site investigation and laboratory testing (eg, ISRM, ASTM). At the completion of the investigations variations may occur and alternative interpretations may be possible, but in the view of a competent person would be unlikely to affect the potential economic viability of the project.**

At Level 3, project features such as structural and lithological domain boundaries, especially those at depth, will still mostly have been assessed subjectively. However, there will have been a significant increase in the availability of measurable data, enabling the uncertainty in the values assigned to the structural, rock mass and hydrogeological parameters within each domain to be assessed quantitatively (***Level 3 Slope Angle*****)**

Target Confidence Levels (3/3)

Level 4. Performance based work to confirm the results obtained during the feasibility investigations. The work will include detailed mapping, observation of slope behaviour, the possible installation of trial slopes, observation of groundwater behaviour and confirmation of pumping parameters, field testing, and laboratory testing. All sampling, field testing and laboratory testing procedures must be sufficient to satisfy designated international standards for site investigation and laboratory testing (eg, ISRM, ASTM). The data will be sufficient to confirm the results of the Level 3 feasibility slope design.

At Level 4, the uncertainty in the values assigned to the structural, rock mass and hydrogeological parameters within each domain will mostly have been assessed quantitatively. With the increased amount of outcrop and subsurface information, it will also have become possible to apply quantitative assessments to geological boundaries that previously were only assessed subjectively (*Level 4 Slope Angle*)

Level 5. Operations stage, commencing with mining. It is marked by the ongoing maintenance and refinement of the geotechnical database and the ongoing comparison of the expected mining conditions with reality.

At this advanced stage of the project the majority of the data assessments will have been performed quantitatively (*Level 5 Slope Angle*)

Note on the Reliability of Geological Data (1/2)

- A modelling issue relating to the level of confidence in the geological information shown on the exampled cross section
- Before computer graphics became established in the industry, geological maps and cross sections were hand drawn. With these hand drawn maps and cross sections it was standard practice to designate only established or known geological boundaries and structures with solid lines
- Uncertain or inferred geological boundaries and structures were shown either as dashed lines or dashed lines with question marks placed between the dashes
- Since the introduction of computer graphics systems, this practice has fallen by the wayside and all boundaries are shown as solid lines, with the consequence that any lack of certainty in features such as lithological boundaries and major faults is not reflected in the drawing (plan or section)

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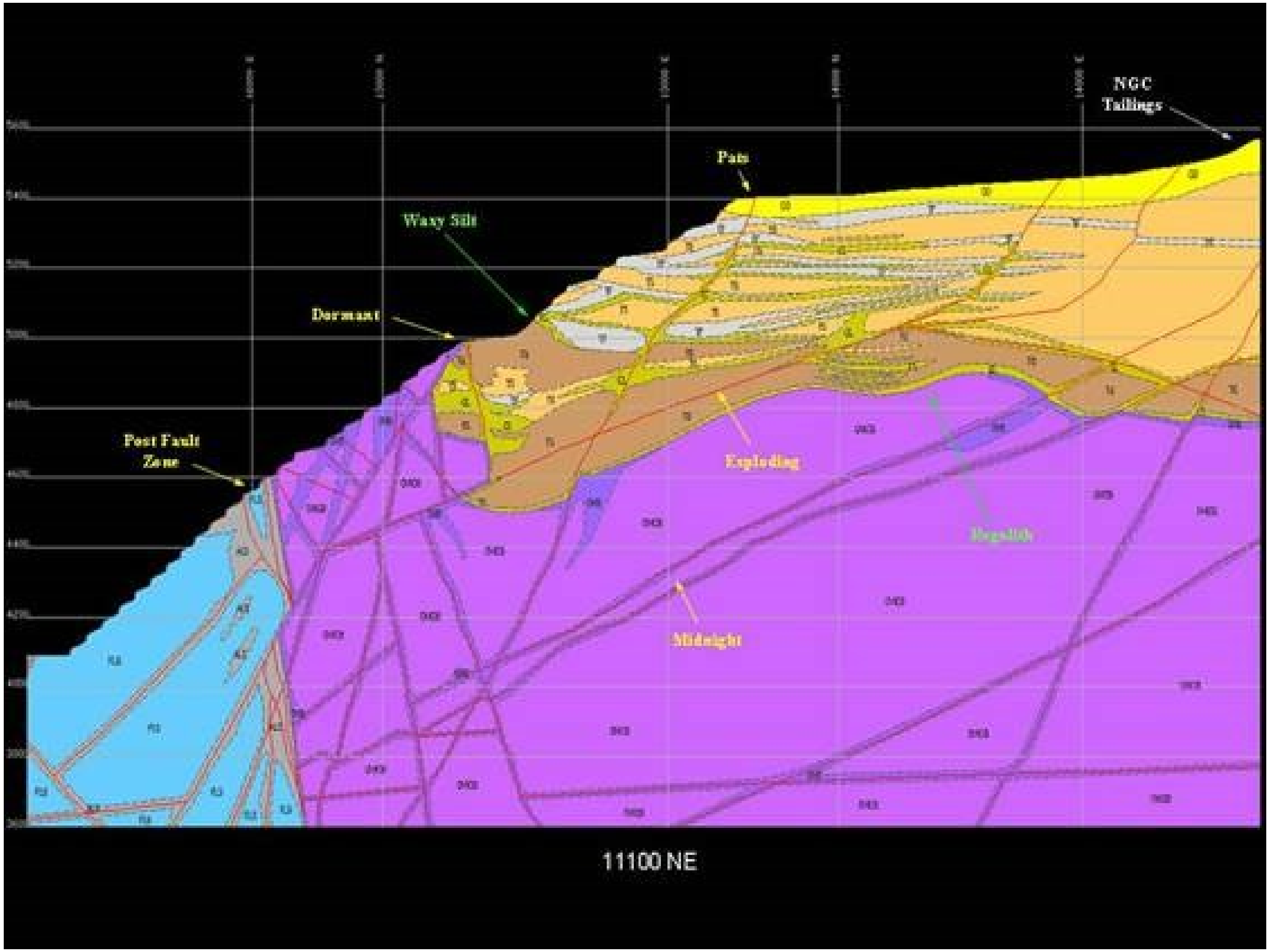
Example Geological Cross Section



Note on the Reliability of Geological Data (2/2)

- **In the cross section exampled the spacing of the horizontal grid lines is 200 feet**
- **In keeping with this scale, it is reasonable to assume that the geological boundaries shown in the upper 200 feet of the section are based on surface exposure and drill hole intersections and can be regarded as well established**
- **It is equally likely that the deeper boundaries (as for example towards the lower right hand side of the section) are based on projected data rather than on drill hole intersection or other real data**
- **This introduces an element of uncertainty into the reality of their locations which is not reflected in the solidity of the boundaries shown on the section**
- **A suggested way of addressing this uncertainty is illustrated in the next figure, which is a section across folded metasediments intruded by a dolerite dyke**
- **The figure shows the locations of the drill holes on each section and the estimated levels of certainty (80%, 66% and 33%) in the interpreted geology with depth**
- **Although the levels of certainty shown are only estimates, they do reflect the density of drilling shown on the sections and give the reader a clear idea of which boundaries are likely to be well established and which are not.**

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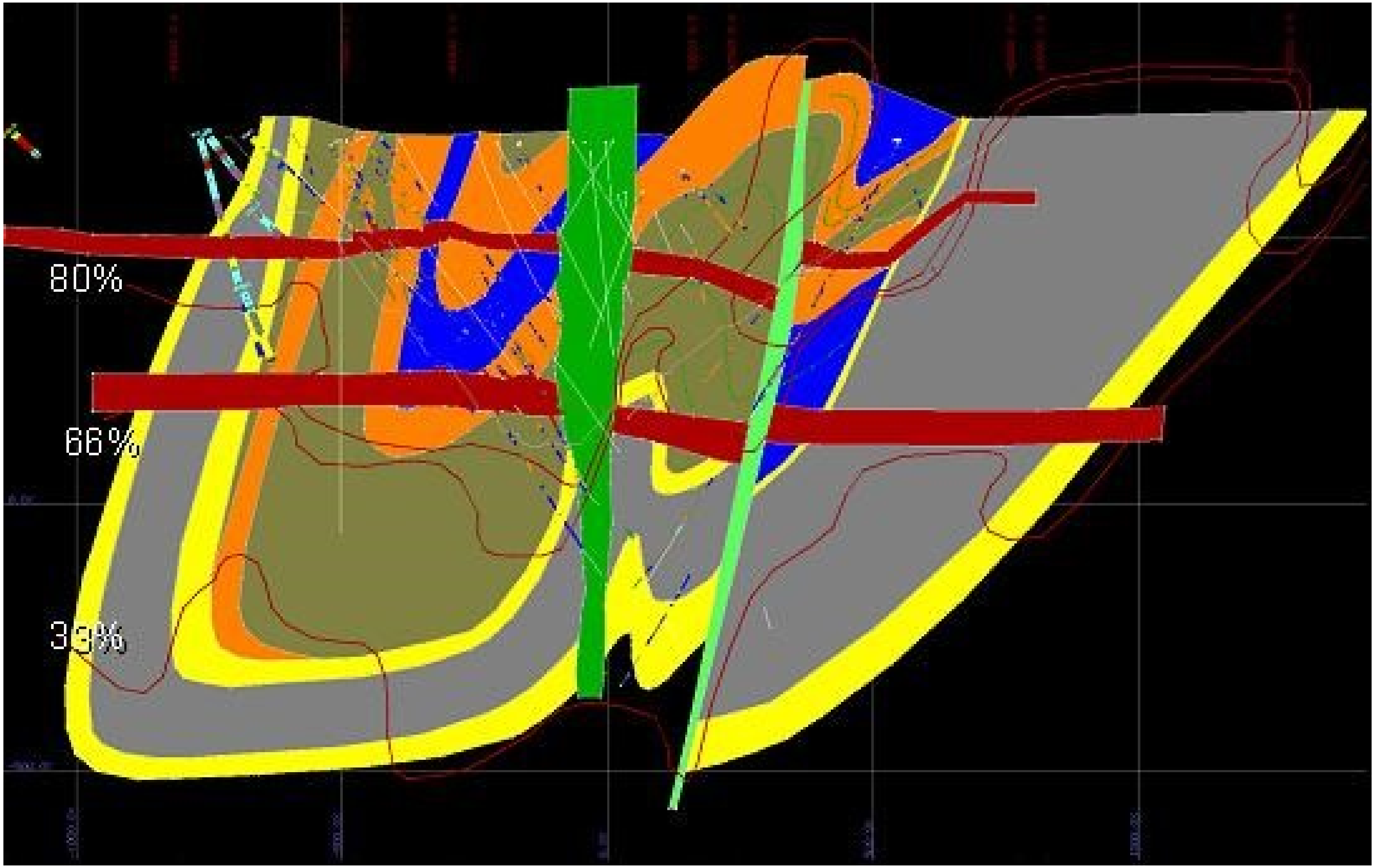
Example Cross Section showing Estimated level Confidence in the Data



Assessment Criteria Check List (1/2)

- When assessing the levels of confidences in the boundaries of the geotechnical domains and design sectors, key items that must be checked include the following:
  - The nature of the information used to set the domain boundaries. Was the geological and other information qualitative or quantitative? What was the spacing and distribution of the data relative to the complexity of the deposit, especially at depth below surface to the limits of mining? Were core and other field samples logged to a level of detail sufficient to support the interpretation? And what assumptions were made when preparing the interpretation?
  - The effect, if any, of alternative interpretations of the data;
  - The results of any audits or reviews of the data and interpretations; and
  - The nature and scale of planned further work

Assessment Criteria Check List (2/2)

- When assessing the levels of confidence in the structural, hydrogeological and rock mass parameters within each geotechnical domain and design sector particular attention paid to the following items.
  - The integrity of the data base. What quality control procedures were adopted?
  - The nature and quality of sampling (eg, disturbed, undisturbed)
  - Field sampling techniques (eg, chip, diatube, hand-trimmed cube, moisture loss protection)
  - Drilling techniques (eg, auger, core, core diameter, triple tube, orientation of core)
  - Drilling bias, especially with respect to the orientation of the borehole relative to any major structure.
  - Drill sample recovery
  - Core logging techniques (eg, qualitative, quantitative, level of detail)
  - Sample bias, especially with respect to the possibility of only the stronger materials remaining intact following core recovery and handling
  - Sample preparation (eg, hand-trimmed, cut, sawn)
  - Laboratory testing (eg, nature, quality and appropriateness of test procedures used)
  - The location of data points (eg, nature and accuracy of surveys used to locate field sample points and borehole collars)
  - The nature and scale of planned further sampling and laboratory testing work

Ratification of Data by Competent Person

- It is suggested that the quantity, distribution and quality of data and the levels of confidence that are attached to the data at each of the five project stages listed above should be ratified by a 'geotechnically competent person' and/or reviewer
- It is also suggested that the basic criteria for a geotechnically competent person should be:
  - an appropriate graduate degree in engineering or a related earth science;
  - a minimum of 10 years post-graduate experience in pit slope geotechnical design and implementation; and
  - an appropriate professional registration

Acceptance Criteria

- **The next stage of the slope design process is to apply the data collected and the reliability assigned to it at each level of project development to the iterative DESIGN and ANALYSIS components of the process**
- **Before the final designs can be accepted however, they must be aligned with the slope failure criteria that have been specified by the owner**
- **Currently, assessments of the performance of open pit mine slopes are routinely made on the basis of the allowable Factor of Safety (FoS) and the Probability of Failure (PoF)**
- **The FoS is the ratio of the nominal capacity (*C*) and demand (*D*) of the system. Limiting equilibrium occurs when the factor of safety is equal to 1.0.**
- **The PoF recognises the FoS as a random variable and seeks the probability of it being equal to or less than 1.0**

Tolerable Values for FoS and PoF

Slope Scale	Consequences of Failure	Acceptance Criteria*		
		FoS (min) (Static)	FoS (min) (Dynamic)	PoF (max) P[FoS≤1]
Bench	Low - high**	1.1	NA	25% - 50%
Inter-ramp	Low	1.15 - 1.2	1.0	25%
	Medium	1.2	1.0	20%
	High	1.2 – 1.3	1.1	10%
Overall	Low	1.2 – 1.3	1.0	15% - 20%
	Medium	1.3	1.05	10%
	High	1.3 – 1.5	1.1	5%

Notes: * Needs to meet all acceptance criteria

**** Semi-quantitatively evaluated**

Risk Model Acceptance Process (1/3)

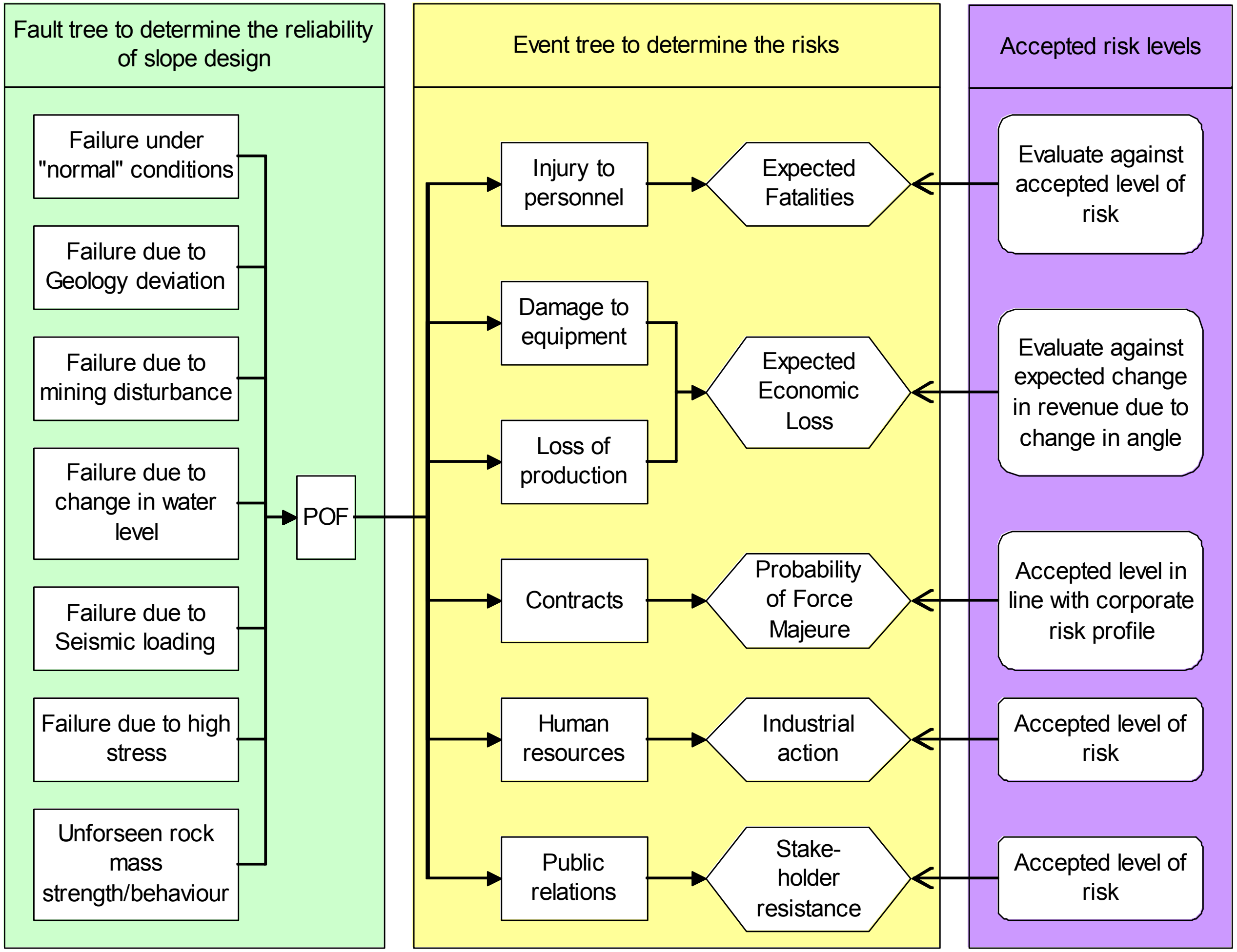
Recently, attention has been given to a risk model (bow tie) process that:

- **seeks to define the risks of slope development in terms of safety and economics;**
- **quantify the risk levels for different slope configurations;**
- **quantify the economic value added for increased levels of risk; and**
- **Assess the estimated risk level against the acceptance level**

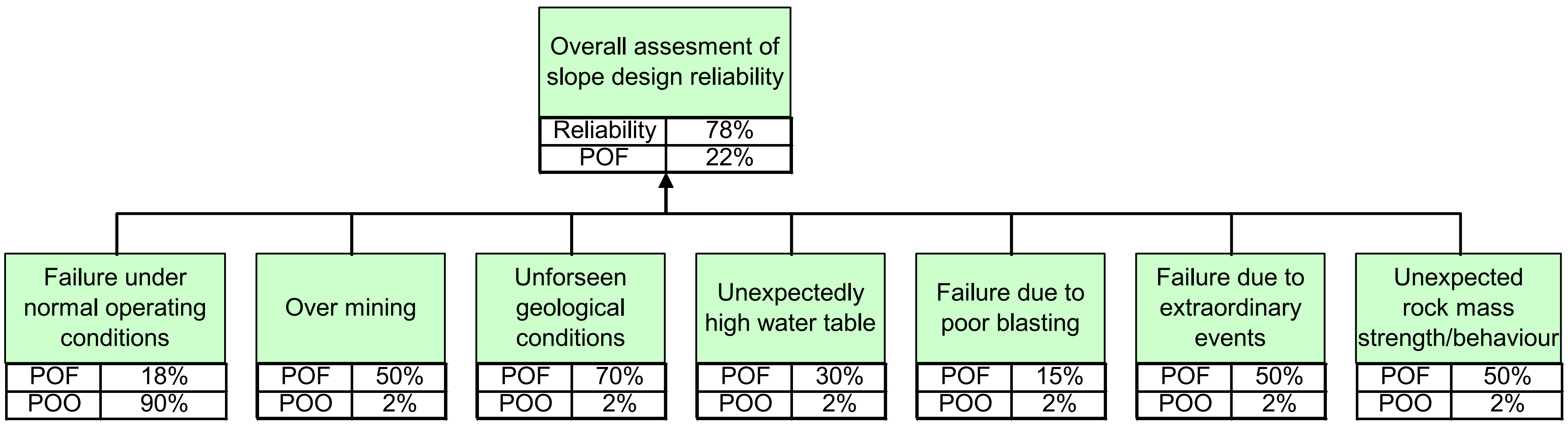
Risk Model Acceptance Process (2/3)

1. A fault tree analysis to determine the probability of failure of the slope; this is the Probability of Failure (POF) shown in the first column of the next slide and is termed the Top Fault. The process is a geotechnical function which allows for different levels of uncertainty to be included in the overall assessment of the reliability of the design
2. An event tree analysis to determine the risks that may be associated with a slope failure. The probabilities used in the event tree are knowledge-based probabilities as distinct from the frequency-based probabilities used to estimate the Top Fault probability of failure and are determined subjectively with input from experienced, site-based personnel
3. Carriage of the Top Fault value into the Event Tree, where the risk of a defined incident (eg, fatality, economic loss) is evaluated. This part of the analysis is known as the risk/consequence analysis and can be performed independently to determine the appropriate slope design reliability to achieve the desired level of confidence in achieving the mine plan, or to ensure the desired safety level at the mine
4. A comparison of the outcome of the Top Fault/Event Tree analysis against the risk levels decreed by management.

Risk Model Acceptance Process (3/3)



Example Fault Tree Analysis to Determine PoF

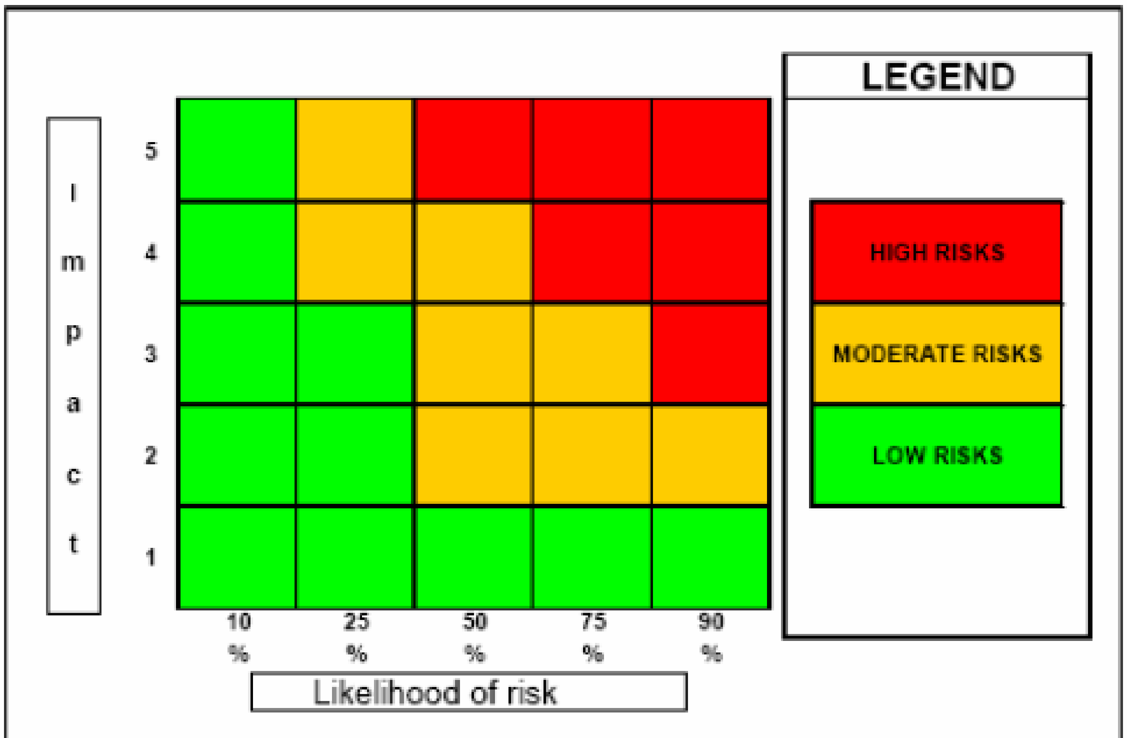


The probability of failure for the normal operating condition is first determined (POF = 0.180 and then combined with its estimated probability of occurrence (POO = 0.90). The resultant value is 0.162.

The combined values of the PoF and the POO for each contributing factor are then determined and progressively added to the combined initial value to provide the overall assessment. In the example given in, the resultant final probability of failure is 0.22 (22 percent), which is a reliability of 78 percent.

Risk Matrices (1/4)

Qualitative & Semi-quantitative Risk Evaluation



Example of semi-quantitative risk matrix

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Risk Matrices (2/4)

Qualitative & Semi-quantitative Risk Evaluation

Consequences for personal injury

Level	Descriptor	Example of Description
1	Insignificant	No injuries
2	Minor	First aid treatment
3	Moderate	Medically treated injury
4	Major	Extensive injuries / permanent disability
5	Catastrophic	Fatality

Qualitative measures of likelihood

Level	Descriptor	Description
A	Almost Certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Might occur at some time
D	Unlikely	Could occur at some time
E	Rare	May occur only in exceptional circumstances

Qualitative risk matrix

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
A	H	H	E	E	E
B	M	H	H	E	E
C	L	M	H	E	E
D	L	L	M	H	E
E	L	L	M	H	H

E: Extreme risk: Immediate action required; unacceptable risk
H: High risk: Senior management attention required; unacceptable risk without action
M: Moderate risk: Management responsibility; acceptable with control measures
L: Low risk: Manage by routine procedures; acceptable risk

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Risk Matrices (3/4)

Qualitative & Semi-quantitative Risk Evaluation

Strategic Influence of Slope Design					
	Scoping	Pre-Feas	Feasibility	Operational	Closure
Capex	Low	Low	High	Moderate	Low
Opex	Low	Low	Low	Moderate	Low
Safety	Low	Low	Moderate	High	High
Impact Of Incorrect Geotechnical Design					
Capex	Low	Moderate	High	High	Low
Opex	Low	Low	Moderate	Moderate	Low
Safety	Low	Low	Low	High	High

$ Value	Opex / Capex
Low	<10 Million
Moderate	10 to 100 Million
High	> 100 million

Semi-quantitative strategic residual risk profile

Risk Matrices (4/4)

Qualitative & Semi-quantitative Risk Evaluation

Cost of remediation (USD)	Production delays	Lost production (tonnes)	Possible consequences	Acceptability of design criteria
>$10M	Pit closed	> 2,000,000	Total wall failure	Unacceptable Total redesign required
$5M to $10M	< 6 months closure	500,000 to 1,000,000	Wall failure; lost revenue	Seek management and stakeholder approvals. Minor modifications to mine life of plan
$1M to $5M	<1 week	100,000 to 500,000	Remedial work required	Acceptable with management approval. Ground support and/or pit drainage required
<$1M	1-2 shifts	< 500,000	Minor damage to mine equipment	Acceptable Remedial work required

Example of a generalised risk vs return matrix for the financial consequences of geotechnical risk in the operating stage of an open pit project

Risk Management Process

R = PoF x Consequences

Consequences

- **Fatalities & injuries**
- **Damage to equipment & infrastructure**
- **Economic impacts on production (removing slope debris, slope remediation, haul road & access repair, equipment re-deployment, unrecoverable ore)**
- **Force Majeur**
- **Industrial action**
- **Legal action**
- **Public relations**

Management requires hierarchy of overarching management steps and control measures

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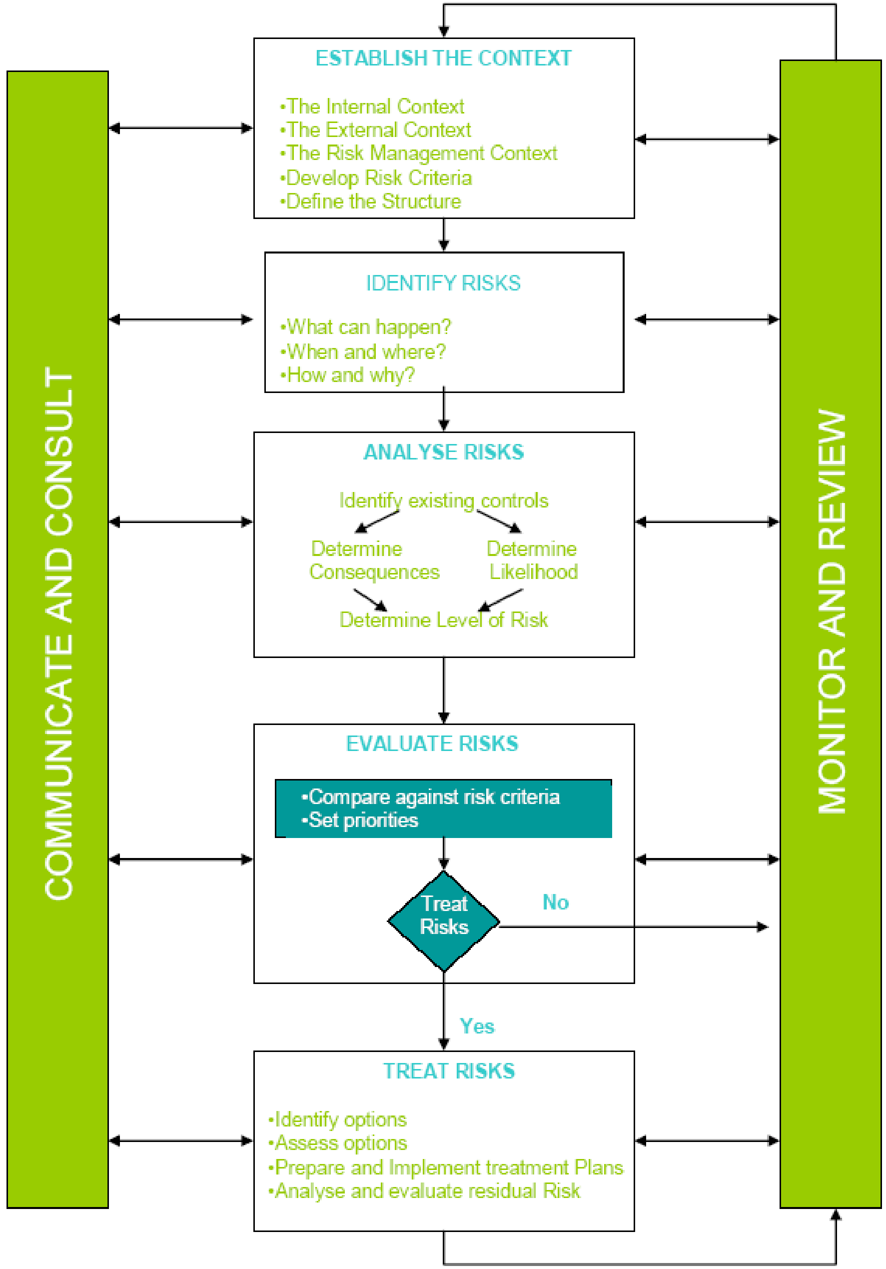
Risk Analysis:

Steps 1, 2 & 3

Risk Assessment:

Steps 1, 2 & 3 plus Risk Evaluation



Risk Management Process

AS/NZ4360:2004

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Strategic	1	**Corporate Governance – Establish the overarching Risk or Safety Management System.**
	2	**Policy – Company directed policy on occupational health and safety (OHS) and acceptance criteria for geotechnical considerations in the life of the open pit**
	3	**Planning – covering Stages 1-5 (Conceptual through Operations)** 3.1 Risk management and generic business continuity management 3.2 Legal requirements and compliance with standards 3.3 Business objectives, targets, plans, risk benefit analysis, geotechnical model, pit design
Operational Technical	4	**Implementation of plans, procedures, standard operating procedures (SOPs) and records at the** design, operational and closure/transitional levels 4.1 Organisational structure, roles and responsibility 4.2 Operational risk management – geotechnical model, pit design, implementation, slope management plan, geotechnical procedures (eg, mapping &b monitoring) 4.3 Business continuity management 4.4 Consultation, communication and reporting 4.3 Training and competency 4.5 Documentation and data control
	5	**Monitor and Evaluate – stability management, mine to design, design performance** 5.1 Monitoring and measurement 5.2 Incident investigation, corrective action and preventative action 5.3 Records and record management 5.4 Audit - internal and external
Operational	6	**Management Review**

Overarching Method for Managing the Risk of Open Pit Failure

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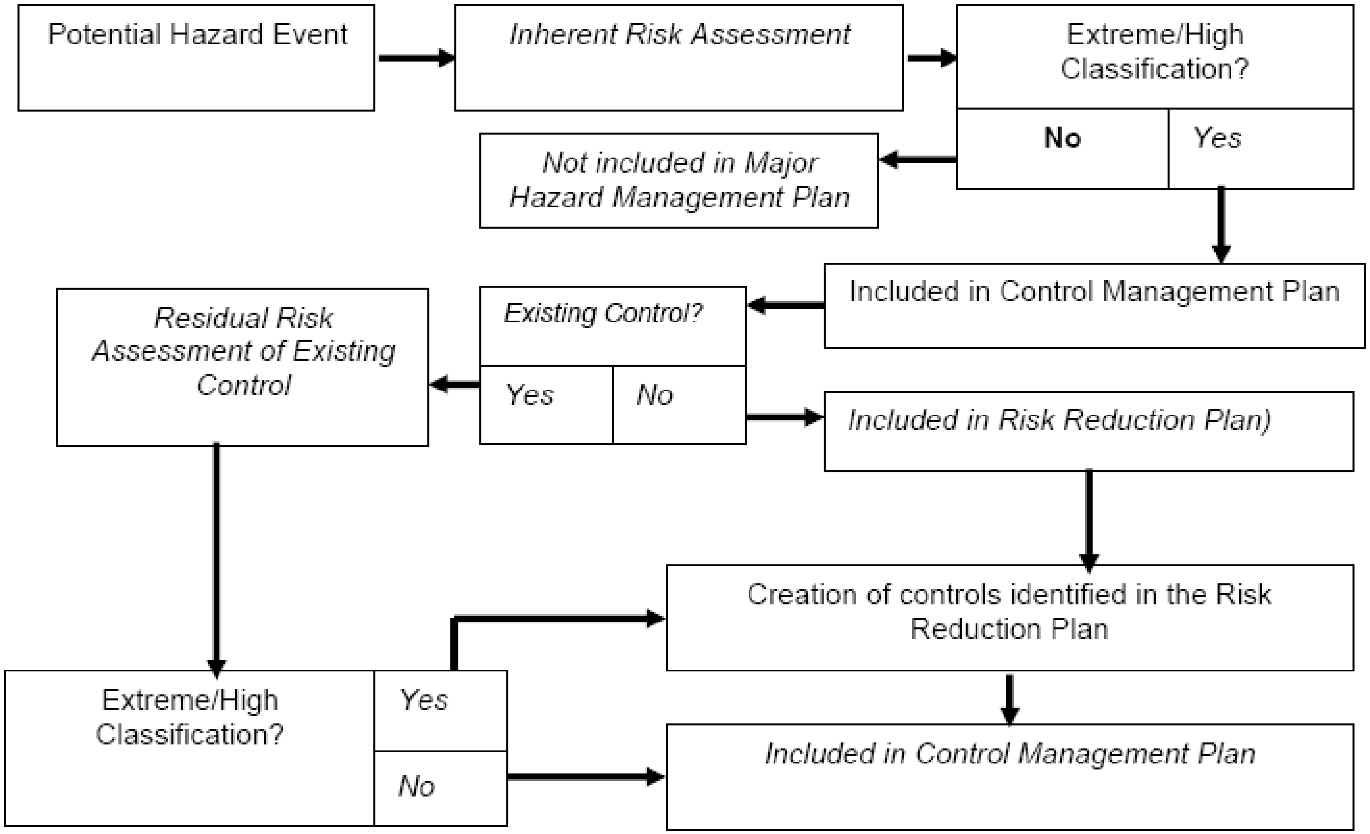

Example Operational Risk Management Decision-making Process

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Risk Management Process

Hierarchy of controls		
1	**Elimination**	If possible eliminate the risk so it doesn't reach the worker
2	**Substitution**	Can the job be reorganised or different area mined in order to reduce the risk?
3	**Isolation**	Perform the task when personnel are not around
4	**Engineering Controls**	Change the design or put guards / monitoring in place to make the process safer
5	**Administration**	General procedures including JSA/JHA, competency training
6	**Personal Protective Equipment (PPE)**	Safety boots, hard hats, gloves, ear muffs etc (last resort; relies on worker behaviour to reduce risk)

Hierarchy of Controls for a Risk Endangering Personal Safety

Risk Management Process

	Hazard / Risk	Control Measures
1	**Detect slope movement**	Slope monitoring, radar, mapping, extensometers, wall prisms, piezometers etc
2	**Reduce impact of rock falls**	Increased berm width, catch fences, reducing slope angle, bunding at base of slope, secondary support – mesh
3	**Control slope movement**	Dewatering, good blasting, audit exposure against mine design, rock buttresses

Common Open Pit Slope Geotechnical Control Measures

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Risk Management Process

Hazard: Gravitational energies triggering slope failure potentially causing loss of life and / or property damage		
No	**Strategy**	**Examples**
1	**Prevent the marshalling of the energy**	• Don't mine
2	**Reduce the amount of energy marshalled**	• Use flatter slope angles • Use dewatering measures to depressurise the slope
3	**Prevent the release of energy**	• Robust mine design and procedures • Leave a buttress at the toe of the slope
4	**Modify the rate of release or spatial distribution of the energy**	• Slow the rate of extraction within the mine schedule • Increase the rate of dewatering
5	**Separate the energy release and the susceptible structure in time or space**	• Allow a settling period after blasting • Monitoring, geotechnical management plans and evacuation procedures
6	**Separate the energy release from the susceptible structure by a barrier**	• Install catch fences and safety berms • Increase the berm widths on benches

Strategies to Prevent & Manage the Effects of Gravitational Energy Triggering a Slope Failure

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Risk Management Process

Questions	Yes	No	Weight
Can increased monitoring mitigate safety risk?	1		1
Can we modify work practices/schedules?	1		1
Do we know the mechanism and severity of the failure?	1		1
Are the technical and management skills available?	1		1
Can local slope be buttressed?		1	1
Can we use catch berms?	1		1
Can we use catch fences?		1	1
Can we use catch benches?	1		1
Can we install ground support?		1	1
Can we dewater/depressurize the slope?	1		1
Can we modify/improve blasting?	1		1
Can we accelerate/induce the failure?		1	1
Can we mine out the failure zone?		1	1
Can the design be changed?	1		1
Total	9	5	14
Suggested Probability	64%	36%	
Selected Probability	64%	36%	

Example Check List of Possible Open Pit Slope Geotechnical Control Measures

Risk Mitigation – Necessary Tools (1/2)

***Ground Control Management Plan* – documenting the geotechnical responsibilities at the mine and the basis for the slope design, their implementation and the associated monitoring systems. The Ground Control Management Plan provides a form of communication and corporate governance and is vital to the safe conduct of mining operations in that it forms a bridge between the risk management and risk mitigation processes**

***Slope Stability Plan* – some companies may have a Slope Stability Plan which may be a subset of an overarching Ground Control Management Plan or exist as a separate entity. The plan may contain, but not be limited to information on control and risk reduction management, trigger action responses, emergency response procedures, roles, accountabilities and competencies required, location of documents and records, definitions, and auditing and review reporting processes**

***Mitigation Plan* – communicating the results of the risk assessment and the selection of control measures and assessment of their likely effects. Generally, the Mitigation Plan is based on the Hazard Identification Plan**

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Risk Mitigation – Necessary Tools (2/2)

Hazard Identification Plan **– illustrating areas of instability, rockfall hazards, drainage hazards, and any other area where operating care is required. It is developed by the geotechnical engineers in consultation with the mine operations group. It should be posted in the crew rooms and copies should be given to the mine field supervisors**

Trigger Action Responses or TARPS **– noting who should do what in response to changes in the condition of the pit slopes**

Emergency Response Plan **– outlining emergency training and evacuation procedures and mechanisms that ensure those procedures are implemented**

Recovery and Business Continuity Response Plans **– to minimise the downstream effects of corrective action and the impacts of processing, commodity supply and business continuity**