

CERTIFICATE IN ROCK MECHANICS

LEARNING GUIDE FOR: PART 3.4 : SURFACE MINING (HARD AND SOFT ROCK)



**SOUTH AFRICAN
NATIONAL INSTITUTE OF
ROCK ENGINEERING**



**CHAMBER OF MINES
OF SOUTH AFRICA**



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PAPER 3.4: SURFACE MINING (HARD AND SOFT ROCK)

PAPER 3.4 SYLLABUS

TOPICS COVERED

This is a specific mining type paper covering rock mechanics practice applicable in surface mining operations in hard and soft rock. The rock engineering knowledge required here is therefore of a specific nature, relating to the surface mining of ore bodies in hard and soft rock.

CRITICAL OUTCOMES

The examination is aimed at testing the candidate's abilities in the six cognitive levels: knowledge, comprehension, application, analysis, synthesis and evaluation. Thus, when being examined on the topics detailed in this syllabus candidates must demonstrate their capacity for:

- Comprehending and understanding the general rock engineering principles covered in this syllabus and applying these to solve real-world mining problems;
- Applying fundamental scientific knowledge, comprehension and understanding to predict the behaviour of rock materials in real-world mining environments;
- Performing creative procedural design and synthesis of mine layouts and support systems to control and influence rock behaviour and rock failure processes;
- Using engineering methods and understanding of the uses of computer packages for the computation, modelling, simulation and evaluation of mining layouts; and
- Communicating, explaining and discussing the reasoning, methodology, results and ramifications of all the above aspects in a professional manner at all levels.

PRIOR LEARNING

This portion of the syllabus assumes that candidates have prior learning and good understanding of:

- The field of fundamental mechanics appropriate to this part of the syllabus;
- The application and manipulation of formulae appropriate to this part of the syllabus as outlined in the relevant sections of this document; and
- The terms, definitions and conventions appropriate to this part of the syllabus as outlined in the relevant sections of this document.

STUDY MATERIAL

This portion of the syllabus assumes that candidates have studied widely and have good knowledge and understanding of:

- The reference material appropriate to this part of the syllabus as outlined in the relevant sections of this document;
- Other texts that are appropriate to this part of the syllabus, but that may not be specifically referenced in this document; and
- Information appropriate to this part of the syllabus published in

journals, proceedings and documents of local mining, technical and research organisations.



This syllabus is available in PDF format on the SANIRE webpage

2. GEOTECHNICAL CHARACTERISTICS

2.1. GEOLOGY

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Identify and describe the rock types associated with hard rock and soft rock surface mining operations;
- Describe, explain and discuss how the rock types associated with surface mining operations were formed;
- Sketch, describe and discuss geological sequences associated with surface mining operations;
- Sketch, describe and discuss major geological structures associated with surface mining operations;
- Sketch, describe and discuss the influence that major geological structures have on the stability surface mining operations;
- Sketch, describe and discuss the effect that major geological structures have on surface mining operations;
- Sketch, describe and discuss pervasive geological structures associated with surface mining operations;
- Sketch, describe and discuss the influence that pervasive geological structures have on the stability of surface mining operations;
- Sketch, describe and discuss the effect that pervasive geological structures have on surface mining operations; and
- Describe, explain, discuss and apply the concept of 'defect analysis' in respect of major and minor geological features.

2.2. ROCKMASS CLASSIFICATION

2.2.1. CLASSIFICATION SYSTEMS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the geotechnical characteristics of rock types associated with hard rock and soft rock surface mining operations ore bodies;
- Describe, explain, discuss and apply standard rockmass classification and assessment systems to predict excavation stability;
- Describe, explain, discuss and apply Terzaghi's descriptive classification to classify rockmasses;
- Describe, explain, discuss and apply Lauffer's stand-up time classification to classify rockmasses;
- Describe, explain, discuss and apply Deere's rock quality designation index to classify rockmasses;
- Describe, explain, discuss and apply Barton's Q system to classify rockmasses;
- Describe, explain, discuss and apply Bieniawski's RMR system to classify rockmasses;
- Describe, explain, discuss and apply Laubscher's MRMR system to classify rockmasses;
- Apply rockmass classification results to determine the stability of

mining excavations;

- Apply rockmass classification results to determine the stability of mining slopes;
- Apply rockmass classification results to determine the support requirements of excavations;
- Describe and explain how rock quality designation (RQD) may be determined from borehole core;
- Describe and explain how rock quality designation (RQD) may be determined from the *in situ* rockmass;
- Describe and explain the formulation and components of Barton's Q system of rockmass classification;
- Describe and explain the formulation and components of Bieniawski's RMR system of rockmass classification;
- Describe and explain the formulation and components of Laubscher's MRMR system of rockmass classification;
- Compare and contrast these three rockmass classification systems and their respective applications; and
- Describe and explain what modifications are necessary to apply rockmass classification systems to local conditions.

2.2.2. CLASSIFICATION METHODOLOGY

2.2.2.2 DATA COLLECTION

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain, discuss and apply core logging techniques to collect rockmass data;
- Define and describe the standard terminology for core logging;
- Describe, explain, discuss and apply scan line mapping techniques to collect rockmass data;
- Describe and explain the implications of the orientation of the scan line on the representivity of recorded data;
- Describe, explain, discuss and apply cell mapping techniques to collect rockmass data;
- Describe and explain the implications of the orientation of the cell surface on the representivity of recorded data;
- Describe, explain, discuss and apply the techniques to capture rockmass data;
- Describe, explain and discuss the characteristics of rockmasses that are measured, mapped and captured to facilitate rockmass classification; and
- Describe, explain, discuss and evaluate the problems associated with characterising weathered rock.

2.2.2.3 DATA INTERPRETATION

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and evaluate the implications and impact of the orientation of survey lines on the interpretation of recorded data;
- Describe, explain and discuss the application of stereonet to interpret and analyse rockmass structure data;
- Apply stereonet techniques to analyse and interpret given rockmass structure data;
- Analyse and interpret rockmass structure data presented in the

form of stereonet; and

- Identify joint trends, failure mechanisms, and other features presented in the form of stereonets.

2.2.3. ROCK AND ROCKMASS STRENGTH

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the compressive strengths of rock types associated with hard rock and soft rock surface mining operations;
- Describe, explain and discuss the tensile strengths of rock types associated with massive hard rock and soft rock surface mining operations;
- Describe, explain and discuss the relative rockmass strengths of rock types associated with hard rock and soft rock surface mining operations;
- Describe, explain and discuss the shear strengths of rockmasses associated with hard rock and soft rock surface mining operations;
- Describe, explain and discuss the shear strengths of geological structures associated with hard rock and soft rock surface mining operations; and
- Apply the above knowledge to the design of workings in surface mining operations.

3. ROCK AND ROCKMASS BEHAVIOUR

3.1. SLOPE STABILITY AND SLOPE FAILURE BASIC MECHANICS OF SLOPE FAILURE

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the concept of continuum mechanics as applied to slope stability;
- Describe, explain and discuss the concept of rockmass failure as applied to slope stability;
- Describe, explain and discuss the role of discontinuities in slope stability and slope failure;
- Describe, explain and discuss the role of step path failure in slope stability and slope failure;
- Describe, explain and discuss the role of shear strength in slope stability and slope failure;
- Describe, explain and discuss the role of friction, cohesion and unit weight in slope stability and slope failure;
- Describe, explain and discuss the role of sliding due to gravitational loading in slope stability and slope failure;
- Describe, explain and discuss the influence of water and water pressure in slope stability and slope failure;
- Describe, explain and discuss the influence of water pressure on shear strength;
- Describe, explain and discuss the influence of water pressure in discontinuities; and
- Describe, explain and discuss the concept of effective stress.

3.2. SLOPE FAILURE MECHANISMS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the phenomenon of plane failure;
- Sketch, describe, explain and discuss the phenomenon of wedge failure;
- Sketch, describe, explain and discuss the phenomenon of circular slip failure;
- Sketch, describe, explain and discuss the phenomenon of toppling failure; and
- Sketch, describe, explain and discuss the phenomenon of tensile failure.

3.3. GROUNDWATER EFFECTS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the phenomenon of groundwater in terms of the following aspects:
 - Rockmass permeability, groundwater flow, groundwater pressure,
- Sketch, describe, explain and discuss the effects of groundwater on the stability of surface mining operations; and
- Describe, explain and discuss the measures that can be taken to reduce the effects of groundwater on mining operations.

3.4. HARD ROCK SLOPE STABILITY

3.4.1. HOMOGENEOUS ROCKMASS SLOPES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain, discuss and apply empirical rockmass classification techniques to evaluate slope stability;
- Describe, explain, discuss and apply the MRMR classification system to evaluate slope stability;
- Describe, explain, discuss and apply the RMRB classification system to evaluate slope stability;
- Describe, explain, discuss and apply the Haines and Terbrugge approach to evaluate slope stability; and
- Evaluate slopes using the above techniques.

3.4.2. STRUCTURALLY CONTROLLED SLOPES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain, discuss and apply analytical techniques to evaluate slope stability;
- Evaluate slopes exposed to planar failure;
- Evaluate slopes exposed to wedge failure;
- Evaluate slopes exposed to toppling failure; and
- Evaluate slopes exposed to step path failure.

3.4.3. SOIL AND LOOSE ROCK SLOPE STABILITY

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the investigation, analysis and evaluation of slopes comprising the following types of materials:
 - Soil and overburden,
 - Deeply weathered rock,
 - Spoil piles.

3.5. ADVANCED EVALUATION TECHNIQUES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain, discuss and apply the following advanced techniques to evaluate the stability of slopes:
 - Limit equilibrium analyses,
 - Factor of safety, probability of failure,
 - Numerical analyses,
 - Flac, Udec
- Describe, explain and discuss the circumstances in which the application of the above techniques is warranted.

3.6. EARTHQUAKE LOADING

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the effects of earthquake loading on surface mining operations;
- Describe, explain and discuss measures to minimise the effects of earthquake loading on surface mining operations;
- Describe, explain and discuss the phenomenon of localised seismicity and its effects on surface mining operations; and
- Describe, explain and discuss measures to minimise the effects of localised seismicity on surface mining operations.

4. MINING LAYOUT STRATEGIES**4.1. SURFACE MINING METHODS**

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the fundamental mining and rock engineering principles associated with the following surface mining methods:
 - Quarrying,
 - Open pit mining,
 - Strip mining.

4.2. SLOPE DESIGN PRINCIPLES**4.2.1. SLOPE STABILITY**

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the principles associated with the concept of the factor of safety of a slope;

- Describe, explain and discuss the stability and failure of slopes for which factors of safety can be calculated;
- Describe, explain and discuss the stability and failure of slopes for which factors of safety cannot be calculated;
- Sketch, describe, explain and discuss the relationship between critical slope height and critical slope angle; and
- Sketch, describe, explain, discuss and apply the probabilistic approach to slope design.

4.3. SLOPE GEOMETRY

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the role and importance of the following slope geometry constituents:
 - Bench, bench stack, spill berm, ramp berm, overall slope,
- Determine optimum slopes for given rockmass and mine layout circumstances.

4.4. GEOTECHNICAL SECTORS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the principles associated with determining geotechnical sectors in surface mining operations; and
- Determine geotechnical sectors for given rockmass and mine layout circumstances.

4.5. MINING LAYOUTS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the role and importance of the following surface mining layout aspects:
 - Geology, structure, geotechnical sectors,
 - Slope geometry, wall curvature,
 - Service life, temporary walls, active walls, final walls,
 - Mining sequences, push backs.

4.6. SERVICE LAYOUTS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the role and importance of access roadways in surface mining layouts.

4.7. LAYOUT DESIGN CRITERIA

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and apply appropriate criteria to design of surface mining layouts.

5. MINING SUPPORT STRATEGIES

5.1. SLOPE SUPPORT STRATEGIES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the fundamental rock engineering principles associated with supporting rock slopes.

5.2. SERVICE SUPPORT STRATEGIES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the fundamental rock engineering principles associated with supporting roadways.

5.3. SUPPORT DESIGN CRITERIA

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the principles of reinforcement to prevent sliding; and
- Describe, explain and discuss slope support requirements in terms of:
 - Initial stiffness, yieldability,
 - Areal coverage, containment.

5.4. SUPPORT AND SUPPORT SYSTEM TYPES AND CHARACTERISTICS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Apply rockmass classification systems to design and select appropriate support for slopes;
- Describe and discuss the following rockwall support types and their application:
 - Mechanically anchored bolts, cable bolts, friction bolts,
 - Cement grouted bolts, Resin bonded bolts,
 - Full-column grouted/bonded bolts,
 - Pre-stressed tendons,
 - Shotcrete, Gunitite, Thin sprayed linings,
 - Wire mesh, Rope lacing, Tendon straps
- Characterise the following aspects of the above units:
 - Their principles of operation,
 - Their technical specifications,
 - Their load-deformation characteristics,
 - The methods of ensuring support unit quality,
 - Their installation/application procedures,
 - The methods of ensuring their installed quality
- Design and evaluate the use of appropriate support units, support

systems, support patterns and installation procedures for given rockmass conditions; and

- Describe and discuss the following rockfall protection measures and their application and design:
 - Catch fences, catch walls, berm widths,
 - Thin sprayed linings.

6. INVESTIGATION TECHNIQUES

6.1. SITE INVESTIGATION

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain, discuss and apply site investigation techniques, procedures and assessments covering the following aspects:
 - Drilling, logging, mapping, sampling, measuring, testing
- Describe, explain and discuss the application of such site investigation techniques and procedures to the characterisation and assessment of the following aspects:
 - Geology, rockmass, groundwater, slope stability
- Describe, explain, discuss and apply the following site investigation techniques and procedures to classify, characterise and assess rockmass conditions:
 - Scanline mapping, cell mapping, window mapping, photogrammetric mapping, stereographic projection.

6.2. SLOPE STABILITY ANALYSIS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain, discuss and apply the following slope stability evaluation techniques and procedures:
 - Empirical analyses,
 - Kinematic analyses,
 - Limit equilibrium analyses,
 - Numerical analyses,
 - Finite element analyses, finite difference analyses
- Describe, explain, discuss and apply the stereographic projection techniques to analyse and evaluate slope stability; and
- Describe, explain, discuss and apply techniques and procedures for dealing with isolated rockfalls.

6.3. ROCK TESTING

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss various rock testing procedures; and
- Interpret and incorporate test results in analysis and design.

6.4. MONITORING**6.4.1. ROCK SLOPE MONITORING**

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the reasons for monitoring rock-mass movement and slope stability in surface mining operations;
- Sketch, describe, explain and discuss the techniques used to measure deformations in surface mining excavations;
- Describe, explain and discuss the equipment used to measure deformations in surface mining excavations;
- Describe, explain and discuss how displacements in the rockmass are determined;
- Describe, explain and discuss how the components of ground movement may be derived from these determinations;
- Calculate components of ground movement from given sets of monitoring data;
- Interpret given ground movement data and determine the effect on slope stability;
- Describe, explain and discuss the use of piezometers to measure and monitor groundwater levels and pore water pressures in surface mining excavations;
- Interpret given groundwater data and determine the effect on slope stability; and
- For given sets of surface mining conditions:
 - State, describe, explain and discuss what types of measurements need to be made and monitored,
 - Describe, explain and discuss required monitoring station layouts,
 - Describe, explain and discuss appropriate monitoring programmes,
 - Interpret practical monitoring data and determine slope failure modes and the behaviour of slopes with time.

6.5. MODELLING**6.5.1. NUMERICAL MODELLING**

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the selection of appropriate codes to tackle various problems;
- Describe, explain and discuss the application of the following codes to tackle various problems:
 - Flac, Udec, dips
- Describe, explain and discuss the input of appropriate parameters to investigate various problems; and
- Describe, explain and discuss the interpretation of output in the investigation of various problems.

6.6. RISK MANAGEMENT

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the various elements of a comprehensive risk management strategy for an open pit mine; Describe,

explain, discuss and generate information for the following elements of a risk assessment and hazard control programme:

- Hazard maps, ground control management plans, evacuation procedures, engineering interventions, and
- Describe, explain, discuss and generate information on acceptable limits on surface mine slope design.

6.7. AUDITING FOR BEST PRACTICE

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the concept of monitoring for understanding, prediction and design.

7. ROCK BREAKING IN SURFACE MINING

7.1. CUTTING TECHNIQUES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss geotechnical aspects associated with various non-explosive rock breaking procedures used in surface mining operations; and
- Describe, explain and discuss the methodologies and applications of these techniques.

7.2. DRILLING TECHNIQUES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the different blast hole layouts used in surface mining operations;
- Describe, explain and discuss the spacing of blast holes in surface mining operations;
- Describe, explain and discuss the direction of drilling of blast holes in surface mining operations;
- Describe, explain and discuss the drilling of long holes in surface mining operations;
- Describe, explain and discuss the types of initiation used in the above layouts;
- Describe, explain and discuss the sequence of initiation of blast holes in surface mining operations; and
- Describe, explain and discuss the importance of blast hole drilling accuracy in the following applications:
 - Temporary walls, moving walls, final walls
 - Back damage
 - Trim blasting, buffer blasting
 - Cushion blasting, smooth blasting, pre-split blasting
 - Long hole drilling.

7.3. BLASTING PRACTICES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the effect of the following parameters on blast damage:
 - Explosive type, initiation method,
 - Initiation sequence, hole orientation
- Describe, explain and discuss the objectives and effects of decoupling explosives;
- Describe, explain and discuss the methods by which decoupling of explosives is achieved;
- Describe, explain and discuss the following excavation cushion blasting and smooth blasting techniques:
 - Pre-splitting, angled pre-splitting
 - Concurrent smooth blasting
 - Post-splitting
- Describe, explain and discuss the methodologies and typical applications of each technique;
- List and discuss the advantages and disadvantages of these techniques;
- Evaluate and determine blasting requirements for the variety of surface mining applications making use of knowledge of explosives;
- Evaluate and determine appropriate blasting rounds to suit given conditions in surface mining operations;
- Evaluate and determine appropriate explosive types to suit given conditions in surface mining operations;
- Evaluate and determine appropriate initiation techniques to suit given conditions in surface mining operations;
- Evaluate and determine appropriate detonating techniques to suit given conditions in surface mining operations;
- Evaluate and determine appropriate blasting techniques to suit given conditions in surface mining operations; and
- Evaluate and determine appropriate slope geometries and dimensions to achieve optimum blasting efficiencies.

8. ENVIRONMENTAL EFFECTS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the possible effects and consequences of given surface mining methods on the following issues:
 - Blast vibration damage to buildings and structures
- Describe, explain and discuss techniques and design tools to limit potential blast vibration damage;
- Describe, explain and discuss the concept of peak particle velocity in this regard;
- Describe, explain and discuss techniques and design tools to limit the effects of air blasts;
- Describe, explain and discuss techniques and design tools to limit the effects of mining on groundwater; and
- Describe, explain and discuss techniques and design tools for:
 - Spoil heaps,
 - Tailings dumps,

- Long-term rehabilitation of the ground surface,
- Ultimate closure of the mine.

9. MINING STRATEGIES IN DIFFICULT CIRCUMSTANCES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the geotechnical aspects of dealing with the following difficult circumstances:
 - Mining in major geological structures or disturbances,
 - Mining in localised disturbed, weak or poor ground conditions,
 - Mining in highly weathered conditions,
 - Mining in localised high or anomalous stress situations,
 - Dealing with excessive over-break situations,
 - Dealing with excessive back damage situations.



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2. GEOTECHNICAL CHARACTERISTICS

2.1. GEOLOGY

- Lurie J 1987 South African Geology for Mining, Metallurgical, Hydrological and Civil Engineering Lexicon Publishers Jhb Chapters 6, 9

2.2. ROCKMASS CLASSIFICATION

2.2.1. CLASSIFICATION SYSTEMS

- [Stacey TR](#) 2001 Best Practice Rock Engineering, Handbook for 'Other' Mines SIMRAC Jhb Chapter 1
- Hoek E & Brown ET 1980 Underground Excavations in Rock IMM London Chapter 2
- Brady BHG & Brown ET 1993 Rock Mechanics for Underground Mining Chapman & Hall New York Chapter 3

2.2.2. CLASSIFICATION METHODOLOGY

2.2.2.2 DATA COLLECTION

- [Stacey TR](#) 2001 Best Practice Rock Engineering Handbook for 'Other' Mines SIMRAC Jhb Chapter 1
- Hoek E & Brown ET 1980 Underground Excavations in Rock IMM London Chapters 3, 4
- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapters 3, 4

2.2.3. DATA INTERPRETATION

- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapter 3

2.3. ROCK AND ROCKMASS STRENGTH

- Brady BHG & Brown ET 1993 Rock Mechanics for Underground Mining Chapman & Hall New York Chapter 4
- [Ryder JA & Jager AJ](#) 2002 Rock Mechanics for Tabular Hard Rock Mines SIMRAC Jhb Chapter 2
- Obert L & Duvall WI 1967 Rock Mechanics and the Design of Structures in Rock John Wiley & Sons New York Chapters 10, 11
- Jaeger JC & Cook NGW 1969 Fundamentals of Rock Mechanics Chapman & Hall London Chapter 4, 6
- [Budavari S](#) (ed.) 1986 Rock Mechanics in Mining Practice SAIMM Jhb Chapter 2
- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapter 5

3. ROCK AND ROCKMASS BEHAVIOUR

3.1. SLOPE STABILITY AND SLOPE FAILURE

3.1.1. BASIC MECHANICS OF SLOPE FAILURE

3.1.1.2 SLOPE FAILURE MECHANISMS

- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapter 2
- [Stacey TR](#) 2001 Best Practice Rock Engineering Handbook for 'Other' Mines SIMRAC Jhb Chapter 3

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3.2. GROUNDWATER EFFECTS

- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapter 6
- [Stacey TR](#) 2001 Best Practice Rock Engineering Handbook for 'Other' Mines SIMRAC Jhb Chapter 3

3.3. HARD ROCK SLOPE STABILITY

3.3.1. HOMOGENEOUS ROCKMASS SLOPES

- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapter 2
- [Stacey TR](#) 2001 Best Practice Rock Engineering Handbook for 'Other' Mines SIMRAC Jhb Chapter 3

3.3.2. STRUCTURALLY CONTROLLED SLOPES

- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapters 7, 8, 9, 10
- [Stacey TR](#) 2001 Best Practice Rock Engineering Handbook for 'Other' Mines SIMRAC Jhb Chapter 3

3.4. SOIL AND LOOSE ROCK SLOPE STABILITY

- [Stacey TR](#) 2001 Best Practice Rock Engineering Handbook for 'Other' Mines SIMRAC Jhb Chapter 3

3.5. ADVANCED EVALUATION TECHNIQUES

- [Stacey TR](#) 2001 Best Practice Rock Engineering Handbook for 'Other' Mines SIMRAC Jhb Chapter 3

3.6. EARTHQUAKE LOADING

- [Stacey TR](#) 2001 Best Practice Rock Engineering Handbook for 'Other' Mines SIMRAC Jhb Chapter 3

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4.1.1. SLOPE DESIGN PRINCIPLES

4.1.2. SLOPE STABILITY

4.1.3. SLOPE GEOMETRY

4.1.4. GEOTECHNICAL SECTORS

4.2. MINING LAYOUTS

- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapter 12

4.3. SERVICE LAYOUTS

4.4. LAYOUT DESIGN CRITERIA

5. MINING SUPPORT STRATEGIES

5.1. SLOPE SUPPORT STRATEGIES

- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapter 12

5.2. SERVICE SUPPORT STRATEGIES

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5.2.2. SUPPORT AND SUPPORT SYSTEM TYPES AND CHARACTERISTICS

6. INVESTIGATION TECHNIQUES

6.1. SITE INVESTIGATION

6.1.1. SLOPE STABILITY ANALYSIS

6.1.2. ROCK TESTING

- [Ryder JA & Jager AJ](#) 2002 Rock Mechanics for Tabular Hard Rock Mines SIMRAC Jhb Chapter 2

6.2. MONITORING

6.2.1. ROCK SLOPE MONITORING

- Hoek E & Bray JW 1977 Rock Slope Engineering IMM London Chapter 12

7. MODELLING

7.1. NUMERICAL MODELLING

- [Ryder JA & Jager AJ](#) 2002 Rock Mechanics for Tabular Hard Rock Mines SIMRAC Jhb Chapter 8
- [Jager AJ & Ryder JA](#) 1999 Rock Engineering Practice for Tabular Hard Rock Mines SIMRAC Jhb Chapter 11
- [Lightfoot N & Maccelari MJ](#) 1998 Numerical Modelling of Mine Workings SIMRAC Jhb Chapters 1-11

7.2. RISK MANAGEMENT

7.2.1. AUDITING FOR BEST PRACTICE

- [Jager AJ & Ryder JA](#) 1999 Rock Engineering Practice for Tabular Hard Rock Mines SIMRAC Jhb Chapter 10

8. ROCK BREAKING IN SURFACE MINING

8.1. CUTTING TECHNIQUES

8.1.1. DRILLING TECHNIQUES

8.1.2. BLASTING PRACTICES

- Brady BHG & Brown ET 1993 Rock Mechanics for Underground Mining Chapman & Hall New York Chapter 17

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8.2. ENVIRONMENTAL EFFECTS

- Naismith WA 1984 The Influence of Large-Scale Blasting on the Stability of Underground Coal Mine Workings SAIMM Symposium Series No.6 - Ed: Gay NC & Wainwright EH Jhb Pgs. 183-191

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LEARNING OUTCOMES

2. GEOTECHNICAL CHARACTERISTICS

2.1. GEOLOGY

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- Sketch, describe and discuss geological sequences associated with surface mining operations;
- Sketch, describe and discuss major geological structures associated with surface mining operations;
- Sketch, describe and discuss the influence that major geological structures have on the stability surface mining operations;
- Sketch, describe and discuss the effect that major geological structures have on surface mining operations;
- Sketch, describe and discuss pervasive geological structures associated with surface mining operations;
- Sketch, describe and discuss the influence that pervasive geological structures have on the stability surface mining operations;
- Sketch, describe and discuss the effect that pervasive geological structures have on surface mining operations; and
- Describe, explain, discuss and apply the concept of 'defect analysis' in respect of major and minor geological features.

2.2. ROCKMASS CLASSIFICATION

2.2.1. CLASSIFICATION SYSTEMS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the geotechnical characteristics of rock types associated with hard rock and soft rock surface mining operations ore bodies;
- Describe, explain, discuss and apply standard rockmass classification and assessment systems to predict excavation stability;
- Describe, explain, discuss and apply Terzaghi's descriptive

classification to classify rockmasses;

- Describe, explain, discuss and apply Lauffer's stand-up time classification to classify rockmasses;
- Describe, explain, discuss and apply Deere's rock quality designation index to classify rockmasses;
- Describe, explain, discuss and apply Barton's Q system to classify rockmasses;
- Describe, explain, discuss and apply Bieniawski's RMR system to classify rockmasses;
- Describe, explain, discuss and apply Laubscher's MRMR system to classify rockmasses;
- Apply rockmass classification results to determine the stability of mining excavations;
- Apply rockmass classification results to determine the stability of mining slopes;
- Apply rockmass classification results to determine the support requirements of excavations;
- Describe and explain how rock quality designation (RQD) may be determined from borehole core;
- Describe and explain how rock quality designation (RQD) may be determined from the *in situ* rockmass;
- Describe and explain the formulation and components of Barton's Q system of rockmass classification;
- Describe and explain the formulation and components of Bieniawski's RMR system of rockmass classification;
- Describe and explain the formulation and components of Laubscher's MRMR system of rockmass classification;
- Compare and contrast these three rockmass classification systems and their respective applications; and
- Describe and explain what modifications are necessary to apply rockmass classification systems to local conditions.

2.2.2. CLASSIFICATION METHODOLOGY

2.2.2.1 DATA COLLECTION

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain, discuss and apply core logging techniques to collect rockmass data;
- Define and describe the standard terminology for core logging;
- Describe, explain, discuss and apply scan line mapping techniques to collect rockmass data;
- Describe and explain the implications of the orientation of the scan line on the representivity of recorded data;
- Describe, explain, discuss and apply cell mapping techniques to collect rockmass data;
- Describe and explain the implications of the orientation of the cell surface on the representivity of recorded data;
- Describe, explain, discuss and apply the techniques to capture rockmass data;
- Describe, explain and discuss the characteristics of rockmasses that are measured, mapped and captured to facilitate rockmass classification; and

- Describe, explain, discuss and evaluate the problems associated with characterising weathered rock.

2.2.2.2 DATA INTERPRETATION

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and evaluate the implications and impact of the orientation of survey lines on the interpretation of recorded data;
- Describe, explain and discuss the application of stereonet to interpret and analyse rockmass structure data;
- Apply stereonet techniques to analyse and interpret given rockmass structure data;
- Analyse and interpret rockmass structure data presented in the form of stereonets; and
- Identify joint trends, failure mechanisms, and other features presented in the form of stereonets.

2.3. ROCK AND ROCKMASS STRENGTH

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the compressive strengths of rock types associated with hard rock and soft rock surface mining operations;
- Describe, explain and discuss the tensile strengths of rock types associated with massive hard rock and soft rock surface mining operations;
- Describe, explain and discuss the relative rockmass strengths of rock types associated with hard rock and soft rock surface mining operations;
- Describe, explain and discuss the shear strengths of rockmasses associated with hard rock and soft rock surface mining operations;
- Describe, explain and discuss the shear strengths of geological structures associated with hard rock and soft rock surface mining operations; and
- Apply the above knowledge to the design of workings in surface mining operations.

2. GEOTECHNICAL CHARACTERISTICS

2.1. GEOLOGY

LEARNING OUTCOME 2.1.1

Identify and describe the rock types associated with hard rock and soft rock surface mining operations

Three basic rock types exist:

- igneous,
- sedimentary and
- metamorphic rocks.

Within each of these basic categories, a large number of different rock types exist. Typical rock types that can be found in South Africa are summarised in Table 1.

Igneous rocks	Sedimentary rocks	Metamorphic rocks
Andesite – an intermediate volcanic rock Anorthosite – an igneous ultramafic rock Diabase or dolerite – an intrusive mafic rock forming dykes or sills Diorite – a coarse grained intermediate plutonic rock Dunite – an ultramafic cumulate rock Lamprophyre – an ultramafic, intrusive rock Norite – a hypersthene bearing gabbro Pegmatite – an igneous rock (or metamorphic rock) with giant-sized crystals Pyroxenite – a coarse grained plutonic rock consisting of >90% pyroxene Syenite – a plutonic rock dominated by orthoclase feldspar Tuff – a fine grained volcanic rock formed from volcanic ash Granite – a common type of intrusive, igneous rock that is granular and consists mainly of quartz, mica, and feldspar. Dolerite – a mafic, subvolcanic rock equivalent to volcanic basalt that is typically shallow intrusive bodies	Argillite – a sedimentary rock composed primarily of clay-sized particles Banded iron formation – a fine grained chemical sedimentary rock Chert – a fine grained chemical sedimentary rock composed of silica Coal – a sedimentary rock formed from organic matter Conglomerate – a sedimentary rock composed of large rounded fragments of other rocks Diamictite – a poorly sorted conglomerate Dolomite – a carbonate rock composed of the mineral dolomite Jaspillite – an iron-rich chemical sedimentary rock similar to chert or banded iron formation Lignite – a sedimentary rock composed of organic material; otherwise known as Brown Coal Limestone – a sedimentary rock composed primarily of carbonate minerals Mudstone – a sedimentary rock composed of clay and muds Sandstone – a clastic sedimentary rock Shale – a clastic sedimentary rock Siltstone – a clastic sedimentary	Anthracite – a type of coal Mylonite – a metamorphic rock formed by shearing Pseudotachylite – a glass formed by melting within a fault via friction Quartzite – a metamorphosed sandstone Serpentinite – a metamorphosed ultramafic rock dominated by serpentine minerals Slate – a low-grade metamorphic rock formed from shale or silts Schist – constitutes a group of medium-grade metamorphic rocks, and by definition contains more than 50% platy and elongated minerals Gneiss – a common and widely distributed type of rock formed by high-grade regional metamorphic processes from pre-existing formations that were originally either igneous or sedimentary rocks.

Table 1: Typical rock types in South African hard rock, tabular environments

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PAPER 3.4: CHAPTER 2



Figure 1: Andesite (igneous rock)



Figure 2: Limey shale overlain by limestone (sedimentary rocks)

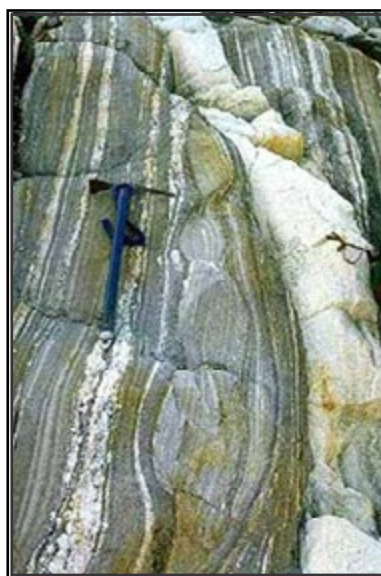


Figure 3: Banded gneiss (metamorphic rock)

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LEARNING OUTCOME 2.1.2

DESCRIBE, EXPLAIN AND DISCUSS HOW THE ROCK TYPES ASSOCIATED WITH SURFACE MINING OPERATIONS WERE FORMED.**INTERESTING INFO**

Rocks deep within the Earth melt because of the existing high pressure and temperature levels. The molten rock (magma) flows upward or erupts from a volcano onto the surface. When magma cools slowly (well below surface), crystals grow slowly and a coarse-grained rock forms. When the magma cools rapidly on the surface, the crystals are extremely small, and a fine-grained rock results. (Courtesy of Wikipedia)

Igneous rocks

Igneous rocks are crystalline solids that form from the cooling of magma, i.e. are formed from melted rock that has cooled down and solidified. This is an 'exothermic' process (i.e. it loses heat) and involves a phase change from a liquid to a solid state.

The melted lava (magma) is made up of different chemical elements and different types of minerals and therefore forms different rocks when it solidifies:

- If the magma crystallises below the earth's surface, it forms igneous rocks such as granite, pyroxenite with large grain sizes.
- If the magma crystallises above the earth's surface, it forms igneous rocks such as basalt with fine grain sizes

Igneous rocks are given names based on:

- composition (chemicals and minerals they are made of, especially the silica content that relates to brightness)
- colour;
- mode of occurrence
- grain size
- hardness etc.

Sedimentary Rocks

In most places on the earth's surface (either in water or on land), the igneous rocks (which make up the majority of the crust) are covered by a thin layers of loose sediment formed through either fluvial, Aeolian, ice or solution processes.

These sediments are layered accumulations of fragments formed by the breakaway or weathering of other rocks, minerals, animal or plant material. The layers are compacted and cemented together, forming hard rocks (clastic sedimentary rocks) but can also be formed through chemical accumulation (non-clastic sedimentary rocks).

Sedimentary rocks are called secondary, because they are the result of the accumulation of small pieces broken off of pre-existing rocks. There are three main types of sedimentary rocks:

- **Clastic:** The basic sedimentary rock consist of accumulations of little pieces of broken up rock which have piled up, compacted and cementated.
- **Chemical:** Many rock types form when standing water evaporates, leaving dissolved minerals behind.
- **Organic:** The accumulation of sedimentary debris caused by organic processes. Animals consist of calcium-rich shells, bones and teeth.

The calcium can pile up on the seafloor and accumulate into a thick enough layer to form an "organic" sedimentary rock.

INTERESTING INFO

The sedimentary layers are normally parallel or nearly parallel to the earth's surface. If they are at high angles to the surface, twisted or broken, it is the result of earth movements. Sedimentary rocks are forming around us all the time. Sand and gravel on beaches or in river beds look like sandstone and conglomerate, which they will become with time. Compacted and dried mud hardens into shale with time.

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INTERESTING INFO

Rock-forming and rock-de-
stroying processes have been
active for billions of years.

- Today, in the Guadalupe Mountains of western Texas, you can stand on limestone, a sedimentary rock, that used to be a coral reef in a tropical sea about 250 million years ago.
- In Vermont's Green Mountains you can see schist, a metamorphic rock, that was once mud in a shallow sea.
- Half Dome in Yosemite Valley, California, which now stands nearly 8,800 feet above sea level, is composed of quartz monzonite, an igneous rock that solidified several thousands of feet below the earth's surface. (Courtesy of Wikipedia)

Metamorphic Rocks

Metamorphic comes from the words 'meta' (change) and 'morph' (form). Any rock (sedimentary or igneous rocks) can be metamorphosed into a new rock type. All that is required is for the rock to be transformed, either physically or chemically, under the influence of temperature or pressure. The metamorphic changes in the minerals are governed by the 'parent' rock and therefore determine the type of metamorphic rock that will be formed, e.g. limestone is metamorphosed to marble and granite is metamorphosed to a gneiss.

The process of metamorphism does not melt the rocks, but instead transforms them into denser, more compact rocks. New minerals are created either by rearrangement of mineral components or by reactions with fluids that enter the rocks.



Some kinds of metamorphic rocks (such as granite gneiss and biotite schist) are strongly banded or foliated (the parallel arrangement of certain mineral grains that gives the rock a striped appearance) (Figure 3). Pressure or temperature can even change previously metamorphosed rocks into new types.

INTERESTING INFO

The formation of the earth that finally consist of the three basic rock types described above, is found to be based on a number of theories, including, although may not be limited to the following:

- Creation: The earth was created by God in a process described in the Holy Bible over a period of 7 days, according to His divine plan and through His power, as part of the total creation, consisting of a great number of solar systems;
- Nebular hypothesis: The solar system originally consisted of spinning nebula of gaseous material that, as it cooled down, ejected 'outer rings' that formed the planets, planets ejected rings to form moons;
- Meteoric theory: The sun and other stars were formed by compaction of a number of meteorites;
- Planetismal hypothesis: The earth from a vast number of smaller meteorites revolving around the sun;
- Tidal theory: A star passing too close by the sun, drew (through gravitational forces) a cigar-shaped mass that broke up into several lumps, each solidifying into a planet;
- Impact theory: The start mentioned above, collided with the sun;
- Von Weizsacker's theory: The stars and planets originated as 'centres of condensation' and the sun attracted material to itself, becoming hotter;
- Big bang theory: The universe is the remainder of a large fire-ball that exploded. The debris of the explosion are constantly moving away from the position of the explosion.

CONNECTION 1

Also refer to [Paper 2](#), Outcomes 2.1.1.1 and 2.1.1.2



- Page 14, 25, 35, Lurie, J. 1987. South African Geology.

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LEARNING OUTCOME 2.1.3

CONNECTION 2

Also refer to [Paper 2](#), Outcome 2.12 and [Paper 3.1](#) Outcome 2.1.3

SKETCH, DESCRIBE AND DISCUSS GEOLOGICAL SEQUENCES ASSOCIATED WITH SURFACE MINING OPERATIONS.

Due to the vast number of surface mining environments, all the geological sequences discussed in Paper 2, 3.1 and 3.2 are appropriate and should be referred to.



Since mining will be conducted on surface, the impact of weathering on the environments described in the outcomes above should also be considered.

With surface mining, the focus will be on the shallow materials within the geological sequence, which would potentially include:

- Soils,
- Different stages of weathered material and
- Fresh material, of different origin and type.

The depths at which these materials are encountered will be determined on a case-by-case basis as it is not constant, even across a small area with similar materials.

LEARNING OUTCOME 2.1.4

CONNECTION 3

Refer to [“LEARNING OUTCOME 2.1.5”](#) on page 26

SKETCH, DESCRIBE AND DISCUSS MAJOR GEOLOGICAL STRUCTURES ASSOCIATED WITH SURFACE MINING OPERATIONS.

Major geological structures are defined as those that occur less commonly over the pit area, but that are persistent and present across large parts of the pit walls, such as faults and dykes.



- Page 14, 25, 35, Lurie, J. 1987. South African Geology.

LEARNING OUTCOME 2.1.5

SKETCH, DESCRIBE AND DISCUSS THE INFLUENCE THAT MAJOR GEOLOGICAL STRUCTURES HAVE ON THE STABILITY SURFACE MINING OPERATIONS.



Major geological structures are defined as those that occur less commonly over the pit area, but that are persistent and present across large parts of the pit walls, such as faults and dykes.

Structure	Residual impact	Subsequent impact
Faults	Form sympathetic faults with smaller throws parallel to the main structure, reducing rock-mass strength and quality. Affect rockmass around it due to metamorphism of the rockmass and may improve or reduce rock-mass strengths and quality. Form 'infilling' on the plane that affects the occurrence of natural earthquakes. Assist water flow through the rockmass by providing alternative flow paths.	Create wedges in highwalls with other structures that must be catered for in the design, risk assessment or support measures to maintain stability. Reduce rockmass quality and therefore increase risk of failure, affecting the final design. Increase potential for instability if poor frictional strength due to infilling material. Water presence significantly reduces the strength of the planes and increases potential for slope failure.
Dykes / sills	Affect rockmass around it due to metamorphism of the rockmass and may improve or reduce rock-mass strengths and quality. Assist water flow through the rockmass by providing alternative flow paths.	Poor rockmass quality in dykes could affect failure of local modes.
Folding	Schistosity (foliation), fracture cleavages and tension gashes are created within the rock mass.	Form dip slopes (orientation semi-parallel to the natural slope). Create variable plane orientations within a single mining area leading to a series of possible failure mechanisms in adjacent areas.

Table 2: Geological structures and their impact on geotechnical behaviour



NOTE

For the purpose of this outcome, it is understood that 'residual impacts' refer to the impact that remained in the rockmass after the formation of the structure and 'subsequent impacts' refer to those impacts that occur specifically due to mining practices.

LEARNING OUTCOME 2.1.6

CONNECTION 4

Refer to "[LEARNING OUTCOME 2.1.5](#)" on page 26



NOTE

SKETCH, DESCRIBE AND DISCUSS THE EFFECT THAT MAJOR GEOLOGICAL STRUCTURES HAVE ON SURFACE MINING OPERATIONS.

Major geological structures are defined as those that occur less common over the pit area, but are important, such as faults and dykes.

LEARNING OUTCOME 2.1.7

SKETCH, DESCRIBE AND DISCUSS PERVASIVE GEOLOGICAL STRUCTURES ASSOCIATED WITH SURFACE MINING OPERATIONS.



NOTE

Pervasive geological structures are defined as those that are general, widespread or extensive in their occurrence, such as joints.

Structure	Residual impact	Subsequent impact
Bedding planes / laminations / weak planes	Assist water flow through the rockmass by providing alternative flow paths.	Create surface on which failure can occur, especially if infilling is soft or weak and water is present.
Joints	Create poorer rockmass quality and strength. Create blocky ground. Allow water flowing through the rockmass.	Reduce rockmass quality and therefore increase wall design requirements or even support measures in worst cases. Create 'blocky' ground conditions leading to any of the standard failure modes. Create wedges with other structures that must be catered for in the wall design. Water presence significantly reduces the strength of the planes and increases potential for slope failure.
Pinnacles	Local changes within the composition of the rock mass to be mined.	Stability of slopes affected by material strengths and structure orientations within the rock mass. Water presence if structures are still conduits after water flow and shear strength of structures.
Erosion channels		
Shear bands		

Table 3: Geological structures and their impact on geotechnical behaviour

LEARNING OUTCOME 2.1.8

CONNECTION 5

Refer to "LEARNING OUTCOME 2.1.7" on page 27

SKETCH, DESCRIBE AND DISCUSS THE INFLUENCE THAT PERVASIVE GEOLOGICAL STRUCTURES HAVE ON THE STABILITY SURFACE MINING OPERATIONS.

Pervasive geological structures are defined as those that are general, widespread or extensive in their occurrence, such as joints.

NOTE

LEARNING OUTCOME 2.1.9

CONNECTION 6

Refer to "LEARNING OUTCOME 2.1.7" on page 27

SKETCH, DESCRIBE AND DISCUSS THE EFFECT THAT PERVASIVE GEOLOGICAL STRUCTURES HAVE ON SURFACE MINING OPERATIONS.

Pervasive geological structures are defined as those that are general, widespread or extensive in their occurrence, such as joints.

NOTE

LEARNING OUTCOME 2.1.10

DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE CONCEPT OF 'DEFECT ANALYSIS' IN RESPECT OF MAJOR AND MINOR GEOLOGICAL FEATURES.

Note:

Per definition, 'defect analysis' refers to the process where defects are classified into categories to identify possible causes of the defects in order to direct remedial action.

NOTE

Defects in the open cast environment would refer to instabilities on bench, stack or highwall slope scale. Since design of the different scales normally considers different issues, the following should indicate the process:

1. Bench scale:
 - Stability is normally affected by minor features such as joints, bedding, foliations or faults;
 - Classifying failures that occur into the standard failure modes, but also listing the structures involved that will assist in determining the appropriate remedial action;
 - E.g. joints causing small wedge failures may indicate the need to place cover support against the wall, while faults creating wedges require a relook at the wall slope (bench face angle) and/or bench height.
2. Stack and highwall slope scale:
 - Failure of this nature is normally related to large/major structures or very weak (low shear strength) material.
 - Classifying failures in terms of structure or material impacts allows for redesign where presence of faults may warrant an increase in bench widths to reduce loading on the planes or a change in highwall orientation, while poor material requires a reduction in slope angles.

2.2. ROCKMASS CLASSIFICATION

2.2.1. CLASSIFICATION SYSTEMS

LEARNING OUTCOME 2.2.1.1

DESCRIBE, EXPLAIN AND DISCUSS THE GEOTECHNICAL CHARACTERISTICS OF ROCK TYPES ASSOCIATED WITH HARD ROCK AND SOFT ROCK SURFACE MINING OPERATION ORE BODIES.

Table 4 to Table 7 show summaries of some of the geotechnical characteristics of the most common rock types associated with the mining of different ore bodies.



The list of rock types and common geotechnical characteristics is not suggested to be complete for all environments and the user is urged to gather information from the specific mining environment in the same manner as shown below.

Ore body	Rock types	Geotechnical characteristics	Impact on designs
Platinum reefs (Ryder and Jager, Page 42-48)	Pyroxenite, Norite, Anorthosite, Chromotite	Rock material strengths are mostly relatively high, except for the pyroxenite in some areas and chromotite, for which lower strengths have been reported. Rockmass quality is mostly a function of the joint sets found in these rock types, but is generally high (e.g. 90). The quality varies across the material types and across the mining areas and does not allow simple listing of characteristics. Joint spacings vary but mostly occur in at least three sets and at variable dips (although mostly steep) and dip directions. Joint infilling is often serpentinised increased potential for instability on joints, while other filling such calcite and pegmatoid result in high strength joints. Structures present in this environment include faults (mostly low density with small throws), and dykes (dolerite, diabase, syenite and lamprophyre). Overburden mostly consists of the same materials as those noted above, even though weathering at shallow depths is often significant.	High rock material strength allows for generally stable and steep walls, except when affected by other geotechnical conditions. Jointing requires adequate evaluation of wedge, planar and toppling failure modes in the design. The presence of ground water and serpentinised filled joints affects the highwall design layout as it assists joint controlled failures. Structures must be taken into consideration when determining the risk of wall failures. Cater for designs of material prone to circular failure due to highly weathered conditions.

Table 4: Geotechnical characteristics of most common rock types in platinum environment

Ore body	Rock types	Geotechnical characteristics	Impact on designs for total or partial extraction mining methods
Chrome reefs (Ryder and Jager, Page 40-42, 49)	Pyroxenite, Norite	Rock material strengths are mostly relatively high, except for the chromotite, where lower strengths have been reported. Joint spacings are mostly wide, but blocky conditions due to small spacings have been observed. Structures present in this environment include faults, and dykes (dolerite, diabase, syenite and lamprophyre). Overburden typically consists of norite, pyroxenite and anorthosite, which are competent except in shallow areas, where the state of weathering can be severe.	Lower rock material strengths affect the overall highwall layout in that shallower slope angles could be the result. Larger failures are possible due to larger joint spacings and need to be considered in bench design. Structures must be taken into consideration when determining the risk of wall failures. Cater for designs of material prone to circular failure due to highly weathered conditions.

Table 5: Geotechnical characteristics of most common rock types in chrome environment

Ore body	Rock types	Geotechnical characteristics	Impact on designs for total or partial extraction mining methods
Gold deposit	Banded Ironstone, Greywacke, Schist	Some of the gold ore bodies are surrounded by banded ironstone formations that are very strong, but laminated and well jointed. The presence of foliated schist increases laminated nature of the environment. Greywacky is siliceous sandstone that is often quite jointed. Shallower areas are often significantly weathered.	Strength of material in most cases indicates possible steep batter angles. The impact of BIF and schist laminations on highwall stability must be considered. Impact of joint densities and orientations is critical in final wall designs. Cater for designs of material prone to circular failure due to highly weathered conditions.

Table 6: Geotechnical characteristics of most common rock types in gold environment

Ore body	Rock types	Geotechnical characteristics	Impact on designs for total or partial extraction mining methods
Manganese or Iron deposit	Manganese, banded ironstone, shale, quartzite, clay, calcrete	The manganese ore bodies are surrounded by banded ironstone formations that are very strong, but laminated and well jointed. Joint sets are present and consist of several sets, mostly vertical and if infilling is present, it is normally a calcite infilling (although quartz filled joints can also be found). Joint spacings vary quite significantly. Faulting is less significant in that large throw faults are present, but small throw faults (although present) are much less of a concern than on the other areas discussed in this section. Dyke intrusions are normally of significant thickness and reduce the quality of the rockmass around the structures due to increased joint density and calcite infilling. Other rock types such as shale, quartzite, tillite, clay and calcrete are exposed in the overburden and can cause some ground control problems. Weathered material present at shallow depths.	Strength of material in most cases indicates possible steep batter angles. Due to commonly shallow dipping BIF laminations, their impact on highwall stability is practically zero. Impact of joint densities and orientations is critical in that toppling failure is a real possibility, with columns being formed rather than wedge or planar failures. Faults and dykes affect the wall designs only as far as providing slip surfaces and should be considered in the designs. Clay swelling and displacement when stressed in a highwall is a huge concern and should be considered in the design. Blasting of the softer overburden is a concern as material strengths within a bench can vary significantly. Cater for designs of material prone to circular failure due to highly weathered conditions.

Table 7: Geotechnical characteristics of most common rock types in Manganese environment

Ore body	Rock types	Geotechnical characteristics	Impact on designs for total or partial extraction mining methods
Iron deposit	Banded ironstone, shale, quartzite, clay, calcareous	Iron ore deposits are present in several different environments. The most common of these include: Clay, calcareous and banded ironstone environment in the Sishen area; ... in the Black Mountain area; Banded ironstone, shale and dolomite in the Thabazimbi area. Weathered material in shallow areas differs in composition, but is always present at different thickness.	Refer to impacts in manganese environment for Northern Cape ore bodies. Cater for designs of material prone to circular failure due to highly weathered conditions.

Table 8: Geotechnical characteristics of most common rock types in iron ore body environment

Ore body	Rock types	Geotechnical characteristics	Impact on designs
Coal	Coal, sandstone, siltstone, shale, dolerite	Rock material strengths are mostly relatively low. Rockmass quality is mostly a function of the joint sets found in these rock types, but also if the laminations within the sedimentary rock types, and can vary from high (massive sandstone) to low (laminated shale). The quality varies across the material types and across the mining areas and does not allow simple listing of characteristics. Joint spacings vary, but mostly occur in several sets and at variable dips and dip directions, even though laminations dominate in certain materials. Structures present in this environment include faults (mostly low density with small throws) and dykes (dolerite) mostly in the form of horizontal sills. Overburden mostly consists of the same materials as those noted above, even though weathering at shallow depths is often significant.	Low rock material strength allows for generally stable, but flatter walls. Jointing requires adequate evaluation of wedge, planar and toppling failure modes in the design. The presence of ground water affects the highwall design layout as it assists joint controlled failures. Structures must be taken into consideration when determining the risk of wall failures. Cater for designs of material prone to circular failure due to highly weathered conditions.

Table 9: Geotechnical characteristics of most common rock types in coal environment



- Page 5-50, [Ryder J.A. and Jager A.J.](#), *A textbook on rock mechanics for tabular, hard rock mines*, 2002.

LEARNING OUTCOME 2.2.1.2

CONNECTION 7

Refer to
[Paper 1](#) Outcome 6.2
[Paper 2](#) Outcome 3.1
[Paper 3.1](#) Outcome 2.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY STANDARD ROCKMASS CLASSIFICATION AND ASSESSMENT SYSTEMS TO PREDICT EXCAVATION STABILITY.

LEARNING OUTCOME 2.2.1.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY TERZAGHI'S DESCRIPTIVE CLASSIFICATION TO CLASSIFY ROCKMASSES.

The earliest reference to the use of rockmass classification for the design of tunnel support is in a paper by Terzaghi (1946).



While it is not currently in use for tunnel or slope design purposes, it is interesting to note some of Terzaghi's notes in his description of the rockmass:

- *Intact rock contains neither joints nor hair cracks.*
- *Stratified rock consists of individual layers with little or no resistance against separation and where layers may or may not be weakened by transverse joints.*
- *Moderately jointed rock contains joints and hair cracks, but the blocks between joints*
- *are interlocked.*
- *Blocky and seamy rock consists of almost intact rock fragments that are entirely separated from each other and imperfectly interlocked.*
- *Squeezing rock slowly advances into the tunnel without any perceptible volume increase.*
- *Swelling rock advances into the tunnel chiefly on account of expansion. The capacity to swell seems to be limited to those rocks that contain clay minerals with a high swelling capacity.*



- Page 16, Underground excavations in rock, Hoek and Brown, 1980
- Page 117, Guidelines for open pit design, J Read, 2009
- http://www.rocscience.com/hoek/corner/3_Rock_mass_classification.pdf

LEARNING OUTCOME 2.2.1.4

DESCRIBE, EXPLAIN, DISCUSS AND APPLY LAUFFER'S STAND-UP TIME CLASSIFICATION TO CLASSIFY ROCKMASSES.

Lauffer (1958) proposed that the stand-up time for an unsupported span is related to the quality of the rockmass in which the span is excavated.



While it is not currently in use for tunnel or slope design purposes, it is interesting to note the following:

- *In a tunnel, the unsupported span is defined as the span of the tunnel or the distance between the face and the nearest support, if this is greater than the tunnel span.*
- *The original system as developed by Lauffer is by many regarded as obsolete, but his ideas are incorporated in modern rock mechanics science, such as the relation between the span of a tunnel and the stand-up time, and notably in the New Austrian Tunnelling Method.*



- Page 18, Underground excavations in rock, Hoek and Brown, 1980
- http://www.rocscience.com/hoek/corner/3_Rock_mass_classification.pdf
- Insight into the New Austrian Tunnelling Method Karakus

LEARNING OUTCOME 2.2.1.5

CONNECTION 8

Refer to
[Paper 2](#) Outcome 3.1.2

DESCRIBE, EXPLAIN, DISCUSS AND APPLY DEERE'S ROCK QUALITY DESIGNATION INDEX TO CLASSIFY ROCKMASSES.

- Page 18, Underground excavations in rock, Hoek and Brown, 1980

LEARNING OUTCOME 2.2.1.6

CONNECTION 9

Refer to
[Paper 1](#) Outcome 6.2
[Paper 2](#) Outcome 3.1.2
[Paper 3.1](#) Outcome 2.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY BARTON'S Q SYSTEM TO CLASSIFY ROCKMASSES.

LEARNING OUTCOME 2.2.1.7

CONNECTION 10

Refer to
[Paper 1](#) Outcome 6.2
[Paper 2](#) Outcome 3.1.2
[Paper 3.1](#) Outcome 2.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY BIENIAWSKI'S RMR SYSTEM TO CLASSIFY ROCKMASSES.

LEARNING OUTCOME 2.2.1.8

CONNECTION 11

Refer to
[Paper 1](#) Outcome 6.2
[Paper 2](#) Outcome 3.1.2
[Paper 3.1](#) Outcome 2.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY LAUBSCHER'S MRMR SYSTEM TO CLASSIFY ROCKMASSES.

LEARNING OUTCOME 2.2.1.9

CONNECTION 12

Refer to
[Paper 1](#) Outcome 6.2
[Paper 2](#) Outcome 3.1.2
[Paper 3.1](#) Outcome 2.3

APPLY ROCKMASS CLASSIFICATION RESULTS TO DETERMINE THE STABILITY OF MINING EXCAVATIONS.

LEARNING OUTCOME 2.2.1.10

APPLY ROCKMASS CLASSIFICATION RESULTS TO DETERMINE THE STABILITY OF MINING SLOPES.

Rock slope failure mechanisms traditionally include simple planar, wedge, circular and toppling failure modes. In analysing the planar and wedge failure mechanisms, the quality of the rockmass forming the slope is not considered due to the nature of the mechanism, which is shear displacement. Even though the shear displacement on a plane or intersection surface between planes is affected by issues normally included into rockmass ratings (water, infilling, continuity, stress conditions, etc), the failure is not affected by a specific rock quality parameter.

CONNECTION 13

Refer to
[Paper 1](#) Outcome 6.2.2
[Paper 2](#) Outcome 6.4

Circular failure, however, suggests that the failure is not governed by a specific plane, but more by the composition of the material itself and that a failure plane is formed within the rock material at the point of least resistance. In analysing this mechanism, it is intuitively felt that a very poor quality, broken-up rockmass (low quality rating) would more easily result in failure than a good quality (high quality rating), massive rockmass. This is confirmed when one realises that soil, the ultimate material to yield circular failures, would report an extremely low rockmass quality if it could be rated. Weathered rock material would also tend to fail according to this mechanism and it is known that weathered material usually results in very low rockmass quality ratings. However, circular failure is governed by the shear strength of the material and since large rockmass slopes may contain a large number of structures, an accurate method of evaluating the stability using simple shear failure on structures is impossible. This resulted in the description of the rockmass strength in

a manner that was failure mode independent, namely the Hoek-Brown failure criteria, where the rockmass is viewed to be so broken up that it behaves as a continuum. In determining the Hoek-Brown strength of the rockmass, the quality parameters m and s can be calculated using the RMR or GSI ratings, both systems that are rockmass quality rating systems.

Rockmass classification is a structured and more comprehensive form of empirical slope design. The RMR system was modified into a slope rockmass quality system (SMR), especially for rock slopes where the RMR rating is modified according to four adjustment factors accounting for joint and slope geometry and blasting methods. As an example, Table 10 shows how this rockmass classification is also used to determine the stability of slopes.

Class	SMR	Description	Stability	Failures	Support
I	81-100	Very good	Completely stable	No failures	None
II	61-80	Good	Stable	Some blocks	Occasional
III	41-60	Normal	Partially stable	Planar failure in some joints and many wedge failures	Systematic
IV	21-40	Bad	Unstable	Planar failures in many joints or big wedge failures	Important / connective
V	0-20	Very bad	Completely unstable	Big planar or soil-like	Re-excavation

No table nr?

Haines and TerBrugge based their slope stability charts on the MRMR, as developed by Laubscher. In this relationship, the slope height and MRMR ratings are used to estimate the stable slope angle.

Adjusted MRMR rating	100	90	80	70	60	50	40	30	20	10	0
Overall Slope Angle	>75°	75°	70°	65°	60°	55°	50°	45°	40°	35°	<35°

Table 10: Correlation between adjusted mining rockmass rating (MRMR) values and overall rock slope angles

Table 10 is best suited to the preliminary determination of overall slope angles, while the design chart shown in Figure 4 below is well suited to the selection of inter-ramp or bench stack angles.

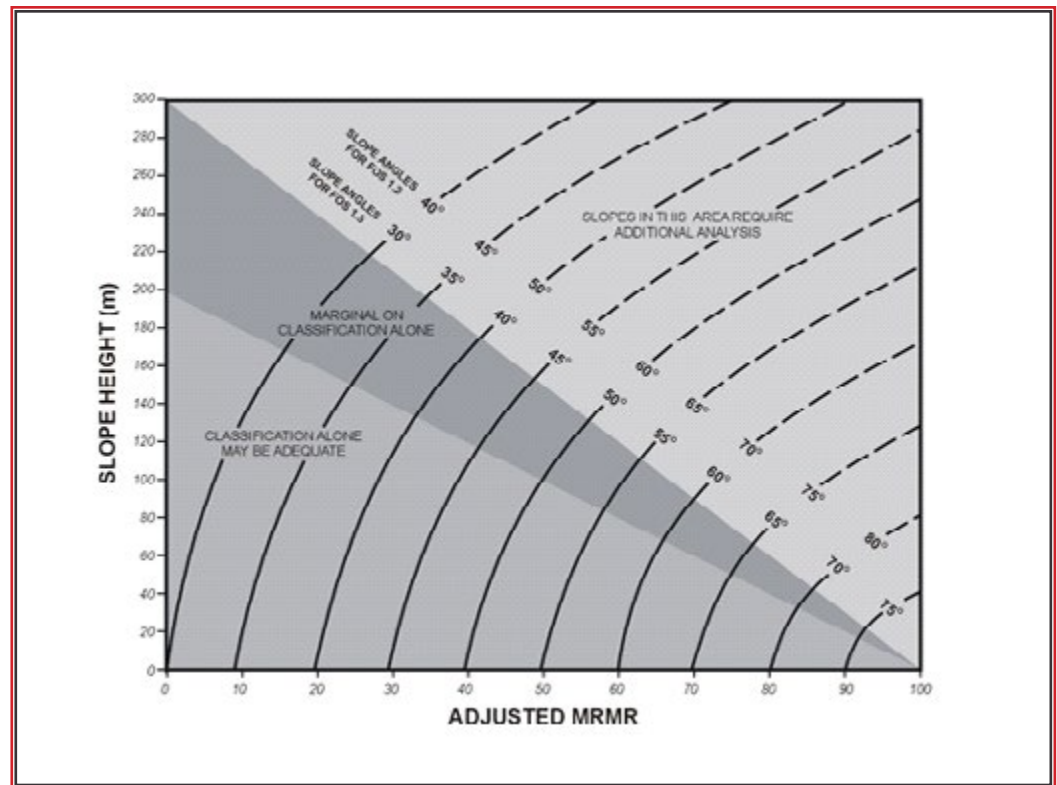


Figure 4: Empirical slope design chart (Haines and Terbrugge, 1991)

All classification systems show the same weakness in that they are not precise enough for the design of final slopes in open pit mining, but are applicable to small-scale slopes and first estimates of stable slopes in low accuracy investigations.



- Chapter 3 Rockmass classifications – [Hoek's notes](#).
- Rockmass Strength - A review by Catrin Edelbro. Technical report No. ISSN: 1402-1536-ISRNLTU-TR-03/16-SE)
- A.J. Li et al. / International Journal of Rock Mechanics & Mining Sciences 45 (2008) 689-700)
- Sjöberg J, Large scale slope stability review, Lulea University of technology, 1987

LEARNING OUTCOME 2.2.1.11

APPLY ROCKMASS CLASSIFICATION RESULTS TO DETERMINE THE SUPPORT REQUIREMENTS OF EXCAVATIONS.

Slope support methods can be separated into:

- Stabilisation: Slopes that have experienced some failures or movement. Common methods include placing rock fill buttress along the toe.
- Repair: Slopes that have undergone some failure and can be repaired. Methods include benching of the failed surface and replacement with compacted material.
- Artificial support: Include retaining walls, rock or cable bolts or structures such as piles, geotextiles, etc.

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PAPER 3.4: CHAPTER 2

As with all other support design, the conditions will determine the support precautions selected, of which the rockmass classification is one of the methods that could assist in describing the conditions to be supported. The others include:

- Rock properties (soft vs. stiff materials);
- Potential failure surfaces;
- Water;
- Water chemistry (corrosion);
- Seismic activity, etc.

In essence, rockmass classification systems will assist in indicating the need for general support types, rather than suggesting specific support precautions. The utilisation of areal coverage support systems such as mesh or shotcrete will follow poor rockmass quality areas where unravelling is potentially high. If plane or wedge failures with massive, high quality material are probable, the utilisation of rock bolts or cable anchors becomes more appropriate.



The Slope Mass rating system is related to support measures.



- Geomechanical classification for slopes [Romana](#)

LEARNING OUTCOME 2.2.1.12

CONNECTION 14

Refer to
[Paper 2](#) Outcome 3.1.2

DESCRIBE AND EXPLAIN HOW ROCK QUALITY DESIGNATION (RQD) MAY BE DETERMINED FROM BOREHOLE CORE.

LEARNING OUTCOME 2.2.1.13

CONNECTION 15

Refer to
[Paper 1](#) Outcome 6.2
[Paper 2](#) Outcome 3.1.2.2
[Paper 3.1](#) Outcome 2.3

DESCRIBE AND EXPLAIN HOW ROCK QUALITY DESIGNATION (RQD) MAY BE DETERMINED FROM THE *IN SITU* ROCKMASS

LEARNING OUTCOME 2.2.1.14

CONNECTION 16

Refer to
[Paper 1](#) Outcome 6.2
[Paper 2](#) Outcome 3.1.2.2
[Paper 3.1](#) Outcome 2.3

DESCRIBE AND EXPLAIN THE FORMULATION AND COMPONENTS OF BARTON'S Q SYSTEM OF ROCKMASS CLASSIFICATION.

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LEARNING OUTCOME 2.2.1.15

CONNECTION 17

Refer to
[Paper 1](#) Outcome 6.2
[Paper 2](#) Outcome 3.1.2.2
[Paper 3.1](#) Outcome 2.3

DESCRIBE AND EXPLAIN THE FORMULATION AND COMPONENTS OF BIENIAWSKI'S RMR SYSTEM OF ROCKMASS CLASSIFICATION

LEARNING OUTCOME 2.2.1.16

CONNECTION 18

Refer to
[Paper 1](#) Outcome 6.2
[Paper 2](#) Outcome 3.1.2.2
[Paper 3.1](#) Outcome 2.3

DESCRIBE AND EXPLAIN THE FORMULATION AND COMPONENTS OF LAUBSCHER'S MRMR SYSTEM OF ROCKMASS CLASSIFICATION.

LEARNING OUTCOME 2.2.1.17

CONNECTION 19

Refer to
[Paper 2](#) Outcome 3.1.2

COMPARE AND CONTRAST THESE THREE ROCKMASS CLASSIFICATION SYSTEMS AND THEIR RESPECTIVE APPLICATIONS.

LEARNING OUTCOME 2.2.1.18

CONNECTION 20

Refer to
[Paper 2](#) Outcome 3.1.2.7

DESCRIBE AND EXPLAIN WHAT MODIFICATIONS ARE NECESSARY TO APPLY ROCKMASS CLASSIFICATION SYSTEMS TO LOCAL CONDITIONS.

2.2.2. CLASSIFICATION METHODOLOGY

2.2.2.1 DATA COLLECTION

LEARNING OUTCOME 2.2.2.1

DESCRIBE, EXPLAIN, DISCUSS AND APPLY CORE LOGGING TECHNIQUES TO COLLECT ROCKMASS DATA.

- Core logging
 - Core logging is a method of basic data collection. It is the analysis of drill core where certain characteristics of the core are inspected and recorded.
 - Core logging is required to determine rock strength, rock quality, founding input parameters for design and ground control district classification and additionally provides early knowledge of the ground conditions and potential geotechnical fatal flaws for a certain area.
 - Logging core can either be done geologically or geotechnically and different properties are recorded accordingly. Geological logging is done whereby the core is logged according to the

changes in geology along the core. Geotechnical logging involves the assessment of the characteristics of both the rock material and the fractures within it (bedding planes, joints, foliation, and cleavage).

- The logging procedure
 - Core should be carefully placed in core boxes to represent the column of rock from the drill hole. Separations in the core should be marked and indicated clearly in the box.
 - Before logging is carried out, ideally, the site geologist should check the core at the drill rig to confirm the depth and core recovery. Any core loss or gain should be recorded.
 - Each core box must be marked with permanent, waterproof markers, recording the project name, the borehole number, the 'to' and 'from' depths that the core was taken from and the box number (Figure 5).

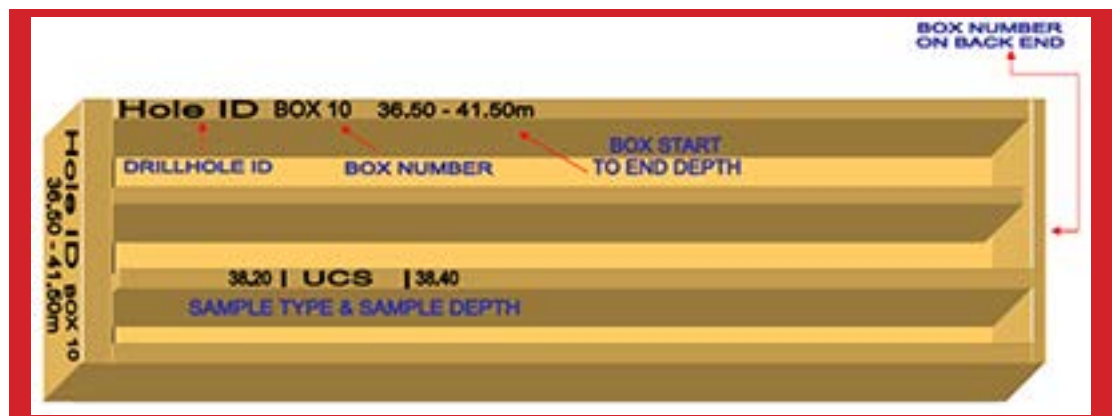


Figure 5: An example of a core box labelling (Middindi, 2010)

The format for describing the geotechnical characteristics of a rockmass is based on international standard practice, and is structured to provide all data necessary for rockmass classification schemes. It provides a simplified field guide that assumes a general working knowledge of geology, geologic terms and geologic processes. This is presented on a log sheet, an example of which is shown in Figure 6.

[illegible]

Figure 6: An example of a logging sheet (Middindi Consulting)

The following basic parameters are required from geotechnical core logging:

- Depth;
- Description (rock type);
- Core recovery;
- RQD – rock quality designation;
- Strength of intact rock (rock hardness);
- Weathering/alteration;

- Discontinuity type;
- Discontinuity frequency;
- Dip angle of structure with respect to core axis;
- Discontinuity condition.

Geological and geotechnical core logging is usually carried out for each 1.5 to 3m core run. Logging intervals of a uniform length (e.g. 1.5 or 3 meters) are preferred for statistical analysis of core. A log interval of 1 to 1.5m is generally preferred for rockmass classification of open pit mines. The recorded depth is the length along core axis from the beginning (From) of the hole and to the end (To) of the logged interval. Example: An interval from 15.7m to 20.7m would be recorded as: From: 15.7 m ... To: 20.7 m

In order to remove any sampling bias and to provide a consistent system of measurement, data should be collected over uniform intervals of drill core, such as core runs.

The intervals within a geotechnical log are divided into geotechnical units or domains that are mainly defined by stratigraphic units or subdivisions within the same stratigraphic unit. The subdivision is based on similarities of RQD, fracture abundance, fracture orientation, grain size and weathering.

Rock material in its fresh, unweathered state can vary in strength from relatively soft (e.g. chinks, marls, clay stones) to extremely hard (e.g. dolerite, hornfels, quartzite). The strength along fractures can also vary significantly depending on the fracture condition.

The main rock type is recorded for each core run using either its proper name or a code. The names used to identify rock types must remain consistent throughout a project to avoid confusion when identifying geologic units. Uniform application of nomenclature is usually more critical than absolute accuracy of that nomenclature.

There are different types of discontinuities in rock and these should be recorded. The table below lists the different types of discontinuities as well as a description of each.

Fracture	A discontinuity of uncertain origin (e.g. possible mechanical break).
Joint	A natural discontinuity that is generally not parallel to lithological variations and that shows no signs of shear displacement. Joints can be open, filled or healed. Such features are often not very persistent.
Fault	A discontinuity across which there has been substantial movement, which can be demonstrated to have occurred; for example by the relative displacement of marker horizons or by the presence of slickensides, or gouge. The magnitude and direction of movement may, or may not, be measurable. Infill will be relatively thick.
Shear	A discontinuity across which there has been limited movement. Infill will be relatively thin, generally associated with polished or slickensided surfaces. Compactional slickensides would apply to this category.
Bedding	A discontinuity associated with sedimentary processes (e.g. mud seam in sandstone) and is very often a prominent weakness direction. Such features are often very persistent and can be traced for hundreds of feet.
Foliation	Metamorphic layering that should be treated in the same way as bedding. Foliation exhibits a preferential direction of structural weakness in the rock due to alignment of weak, platy minerals (e.g. micas), caused by metamorphism.
Vein	A discontinuity infilled or healed by another mineral (e.g. quartz). Veins are generally of limited interest unless material is particularly weak or broken. 'Healed' joints can be classified as veins, and as such are not necessarily planes of weakness.
Contact	The boundary between two distinct rock types. Contacts are not always regular and well defined, nor do they necessarily form the site of a discontinuity, particularly in metamorphic and igneous rock.

Table 11: Different discontinuities that can occur in rock

The discontinuity frequency is how many or often a discontinuity is encountered in a specific run. The spacing between joints must also be measured for each individual joint.

Condition of discontinuities accounts for the separation or aperture of joints, their continuity, the surface roughness, the wall condition (hard or soft), the weathering and the presence of infill materials in the joints.

Core recovery records the total amount of core recovered over the measured length drilled for each core run. Core recovery is expressed as a percentage to the nearest 1%.

Recovery is often an indicator of the quality of the ground being drilled, but must be considered with caution. A competent rockmass (e.g. sandstone) may yield a low recovery if it is very brittle and highly fractured. High recoveries are possible in highly argillised and unfractured ground. Low recoveries generally indicate the presence of faulting, extreme fracturing, or weak rockmass intervals.

Core losses are an important indication of potentially poor geotechnical conditions, since they most commonly occur in weak, highly fractured rock, or fault zones that may be important for the determination of rockmass properties. Rubble, re-drill, or slough recovered at the top of a core lift that was not in place is not counted as recovered core and should be discarded or clearly labelled to avoid subsequent misclassification.

It is not uncommon for some core to slip through the core lifter and to be dropped out of the core tube. This problem frequently indicates a worn or unsuitable core lifter that should be replaced. Core should be represented on the log at the location it occupied in the ground. This requires some interpretation when rock cored during one run is dropped and is recovered during a subsequent run. Core recoveries should not exceed 100 percent of any logged interval. Core, which was drilled in a previous run, can often be identified by marks from drilling, or from the core lifter.

The dip angle or range of dip angles for fractures observed in the core has to be recorded.

For un-orientated core, runs of core (commonly ~ 3 metres long) are extracted from a core barrel. The extraction process rotates the core randomly, so that once the core is laid out in core boxes its original orientation is lost, although the orientation of the core axis is generally known.

With orientated core (Figure 7), the β (beta) angle is also measured. β is the linear angle between the lowest point of the ellipse of the discontinuity and the top of core reference line, measured clockwise looking down the borehole. A description of the alpha and beta angles is provided below and is illustrated by Figure 8.

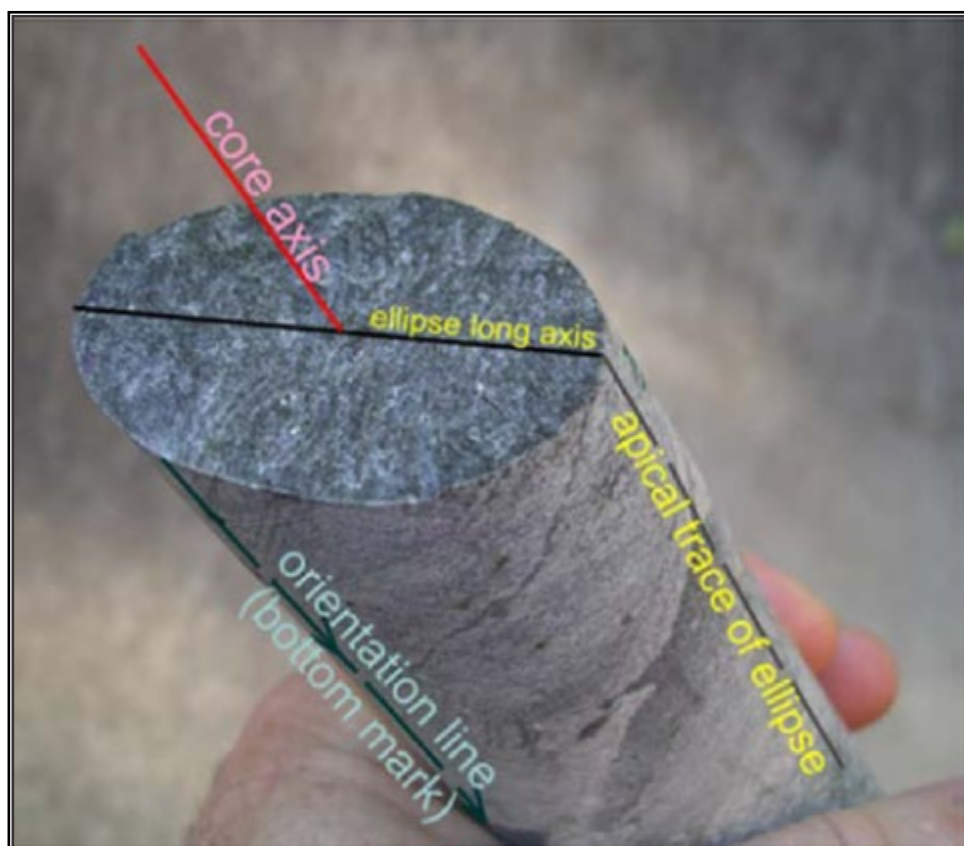


Figure 7: Figure showing the orientation line and core axis on orientated core (Middindi, 2010).

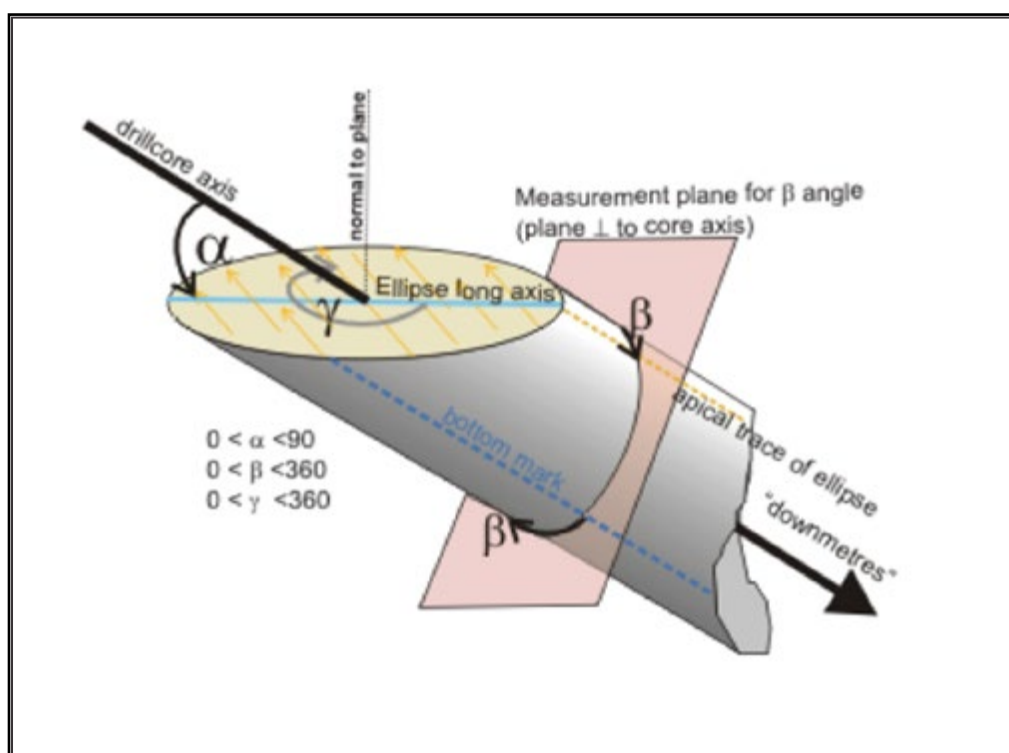


Figure 8: Figure showing the difference between α - and β -angle along a core axis (Middindi, 2010)

Alpha angle (α -angle): The acute angle between the core axis and the long axis of the ellipse ($0-90^\circ$). (Alpha angle can also refer to the angle between the core axis and a line that passes through the centre of the core).

- Beta angle (β -angle): The angle between a reference line along the core and the ellipse apical trace measured in a clockwise sense (0-360°). In 'oriented core', the reference line is the 'orientation mark' or 'bottom mark' and the beta angle of the apical trace of the ellipse is measured clockwise from this line. A Goniometer can be used to measure the β -angle of the core.
- The Rock Quality Designation (RQD) provides a general idea of the quality of rock. It is used mainly as a component of the RMR and Q rockmass classification systems.
 - The RQD is measured according to ASTM international standards for geotechnical logging, ASTM D6032-08: Standard Test Method for Determining Rock Quality Designation of Rock Core. RQD is calculated as the percentage of intact core lengths longer than 100mm per stratigraphic unit.
 - To determine RQD, rock lengths bounded by natural fractures, such as joints or shears, result in surfaces of separation that are longer than 100mm and are measured and the cumulative length determined (Figure 9).
 - Artificial fractures caused by drilling are identified by the rough, fresh surfaces and should be excluded from the RQD determination.
- For more information on the properties needed for core logging, refer to Outcome Paper 2 Learning material, chapter 3.1.1.1.

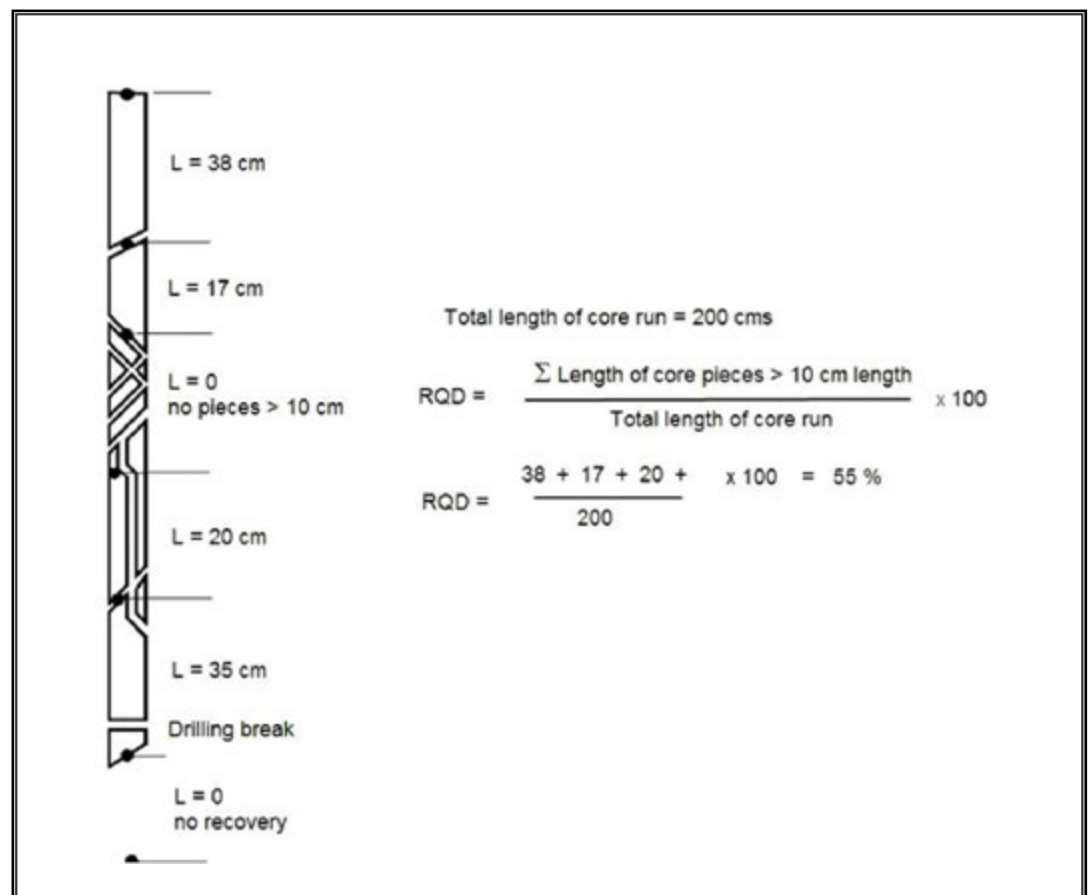


Figure 9: Procedure for the calculation of RQD (after Deere, 1989)

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CONNECTION 21

Refer to
[Paper 2](#) Outcome 3.1.1

Core logging requirements

- Logging requires one to have a basic knowledge of the aspects discussed above.
- When physically logging core, a pencil, logging sheet, clino-rule or protractor and a camera are needed.
- Some core yards or sheds may also have hoses or water containers, as wetting the core can help to assist with clearer rock and discontinuity identification.
- Page 26, Guidelines for open pit design, J Read, 2009



LEARNING OUTCOME 2.2.2.2

CONNECTION 22

Refer to
[Paper 2](#) Outcome 3.1.1
["LEARNING OUTCOME 2.2.2.1"](#) on page 39

DEFINE AND DESCRIBE THE STANDARD TERMINOLOGY FOR CORE LOGGING.

LEARNING OUTCOME 2.2.2.3

CONNECTION 23

Refer to
[Paper 2](#) Outcome 3.1.1.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY SCAN LINE MAPPING TECHNIQUES TO COLLECT ROCKMASS DATA.

Scanline mapping: A direct method of collecting data from the field is from mapping the actual outcrops or free standing faces of the rockmass.

- Mapping involves the assessment of the rockmass and the recording of relevant information required. There are different types of mapping, including geological, structural, as well as geotechnical mapping. Scanline mapping is a geotechnical method.
- A scanline is the line of direction on which geotechnical data is recorded. It usually a tape measure that is placed on the face.
- Scanlines are usually 30m long, but can be less. 1m intervals can be demarcated on the face with spray paint.
- Every discontinuity that intersects this line has to be recorded. The dip and dip direction can be recorded with a compass.
- Scanlines are also usually done in two or three orthogonal directions. This accounts for differently orientated discontinuities.
- The figure below shows an example of a scanline done horizontally. Another scanline in a vertical orientation should also be done to account for discontinuities that do not intersect the horizontal one. Scanline orientations should be chosen so that the majority of discontinuities pass through the line. Scanlines parallel to many discontinuities should be avoided.
- Information that needs to be collected regarding discontinuities are:

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- Position – along the scanline and on the face.
- Orientation – dip and dip direction.
- Persistence – the trace length and type of termination.
- Discontinuity condition – Type, roughness, infilling, alteration, water conditions, aperture and wall strength.



Figure 10: An example of a scanline.



- Page 19, Guidelines for open pit design, J Read, 2009

LEARNING OUTCOME 2.2.2.4

CONNECTION 24

Refer to
[Paper 2](#) Outcome 3.1.1.3

DESCRIBE AND EXPLAIN THE IMPLICATIONS OF THE ORIENTATION OF THE SCAN LINE ON THE REPRESENTIVITY OF RECORDED DATA.

LEARNING OUTCOME 2.2.2.5

DESCRIBE, EXPLAIN, DISCUSS AND APPLY CELL MAPPING TECHNIQUES TO COLLECT ROCKMASS DATA.

Cell mapping or window mapping

This method of mapping also includes the collection of data from mapping the actual outcrops or free standing faces of the rockmass. However, only a portion of the rockmass or face is selected and only certain structures are mapped within the window or cell.

- Figure 11 shows an example of cell mapping, where only the area in black is mapped. All the discontinuities (in red) within this area are recorded.
- The cell or window that is selected for mapping needs to represent the rockmass as a whole, and so an area that is deemed acceptable as including all major discontinuities can be used. If a cell or window that is selected has too many joints in it, it can

cause the rockmass properties to be underestimated. However, if the cell or window has too few discontinuities, then the rockmass properties can be overestimated.



Figure 11: An example of cell or window mapping



- Page 19, Guidelines for open pit design, J Read, 2009

LEARNING OUTCOME 2.2.2.6

DESCRIBE AND EXPLAIN THE IMPLICATIONS OF THE ORIENTATION OF THE CELL SURFACE ON THE REPRESENTIVITY OF RECORDED DATA.

Cells or windows should be located at regular intervals along the highwall at spacings that should provide for a 10 to 20% coverage of the wall, depending on the complexity of the geology. If geology is more complex, a decrease in cell spacings is required to ensure that the quality of the material is not over estimated.



This method can cause subjective decision-making on which structures should be mapped and which not.



- Page 19, Guidelines for open pit design, J Read, 2009

LEARNING OUTCOME 2.2.2.7

DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE TECHNIQUES FOR CAPTURING ROCKMASS DATA.

Techniques for rockmass data capture

Data capture is the process of gathering information from rockmasses for the use of technical interpretation after processing and conversion. The different methods of this data acquisition involve direct and indirect methods.

- Indirect methods are:
 - Literature surveys. These involve the collection and analysis of historical records, regional and local geological maps, topographical and infrastructure maps and any scientific papers, or any useful documents.
- Direct methods are:
 - Drilling of core. This is the retrieval of rock core from the ground in its natural state.
 - Core logging. This is the analysis of core that has been drilled for the collection of the required data. It may be orientated or un-orientated core.
 - Mapping. Mapping is the collection of data directly from the rockmass. It can be geological, structural or geotechnical.
 - Photogrammetry. This is a method whereby digital cameras and computer software can be used to assess and gather data from rockmasses.
 - Laser scanning. This method involves the use of scanners that obtain a direct 3D image of outcrops or rock faces. Together with computer software, data can be acquired.
- Page 19, Guidelines for open pit design, J Read, 2009



LEARNING OUTCOME 2.2.2.8

DESCRIBE, EXPLAIN AND DISCUSS THE CHARACTERISTICS OF ROCKMASSES THAT ARE MEASURED, MAPPED AND CAPTURED TO FACILITATE ROCKMASS CLASSIFICATION.

Characteristics of rockmass for data acquisition

- When undergoing the process of acquiring data about rockmasses, certain aspects of the rockmass need to be taken into account; this is also linked to the type of work that has been carried out and the reason for the work.
- Data is collected in order for a rockmass to be classified and interpreted for further engineering purposes. There are two main classification systems in use today. These are Bieniawski's Rockmass Rating (RMR_{89}) system and Barton's Q system.
- For a full description of the rating parameters mentioned above, the reader is referred to Stacey (2001) and Practical rock engineering, Chapter 3, Hoek (2007).
- The classification system that will be used will determine the type

of information that needs to be gathered from the field. In some cases, both classification systems will be used and all necessary parameters need to be collected for assessment.

- Rockmass characteristics that need to be determined for the RMR_{89} system are:
 - Strength of intact material – which can be determined in the field or through lab testing.
 - RQD – is determined from the rock face or core as explained above.
 - Spacing of joints – determined from the rock face or drill core by measuring the distance between joint sets.
 - Condition of joints – This is done by assessing the types of infill, weathering, and joint roughness.
 - Ground water conditions – This is usually determined from the rock face or hydrological reports, as it cannot be done from drill core.
- Rockmass characteristics that need to be determined for the Q system are:
 - RQD
 - Number of joint sets (J_n)
 - Joint roughness (J_r)
 - Joint alteration (J_a)
 - Joint water reduction factor (J_w)

LEARNING OUTCOME 2.2.2.9

DESCRIBE, EXPLAIN, DISCUSS AND EVALUATE THE PROBLEMS ASSOCIATED WITH CHARACTERISING WEATHERED ROCK.

Weathering is the process whereby fresh rock is broken down by physical disintegration, chemical decomposition, biological activity, or a mixture of one or more processes. Weathered rock can cause problems to rock classification schemes as this material is a transitional material from soil to rock. Weathering influences the strength and appearance of fresh rock and therefore it is important to assess the degree of weathering.

The degree of weathering of the rock is rated on a scale from 1 to 5 as follows:

1. Un-weathered
2. Slightly weathered
3. Moderately weathered
4. Highly weathered
5. Completely weathered

Table 12 below provides a more descriptive guide on the weathering degree, while Figures 12, 13 and 14 show examples of the different degrees of weathering.

Term	Sym- bol	Description	Discolora- tion extent	Fracture condition	Surface charac- teristics
Fresh (FW)	W1	No visible sign of rock material weathering	None	Closed or discolored	Unchanged
Slightly weathered (SW)	W2	Discoloration indicates weathering of rock material on discontinuity surfaces. Less than 5% of rock mass altered.	<20% of fracture spacing on both sides of fracture	Discolored. May contain thin filling	Partial discoloration
Moderately weathered (MW)	W3	Less than 50% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones	>20% of fracture spacing on both sides of fracture	Discolored. May contain thick filling	Partial to complete discoloration, not friable except poorly cemented rocks
Highly weathered (HW)	W4	More than 50% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones	Throughout	Filled with alteration minerals	Friable and possibly pitted
Completely weathered (CW)	W5	100% of the rock material is decomposed and/or disintegrated to a soil. The original mass structure is still largely intact	Throughout	Filled with alteration minerals	Resembles soil
Residual soil	W6	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume but the soil has not been significantly transported	Throughout	N/a	Resembles soil

Table 12: Table indicating weathering classification for core logging

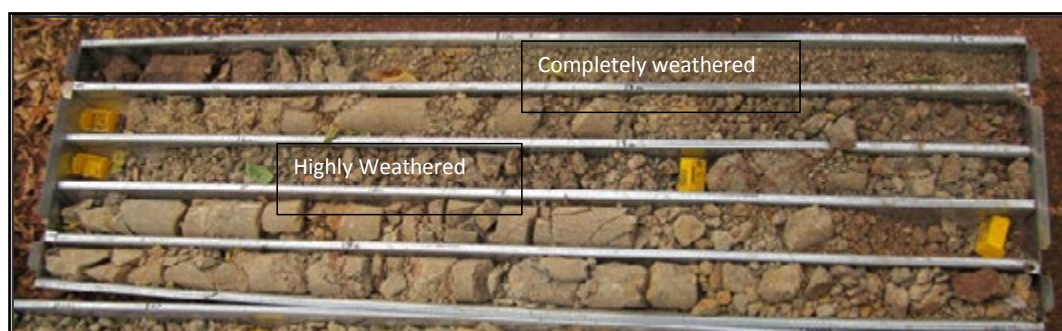


Figure 12: Completely and highly weathered material

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PAPER 3.4: CHAPTER 2

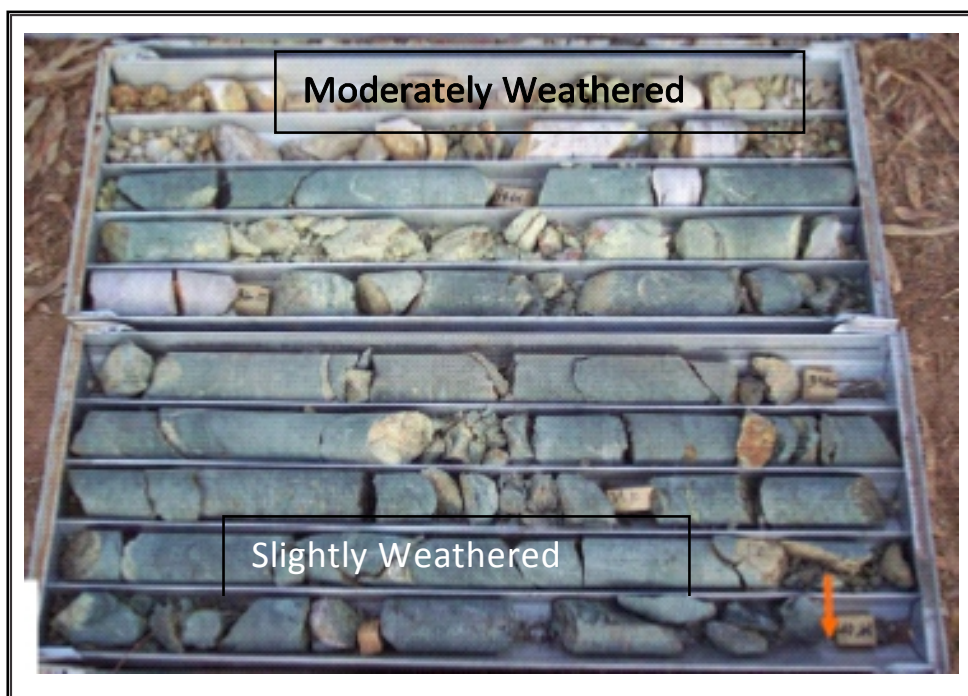


Figure 13: Moderately weathered and slightly weathered material



Figure 14: Un-weathered or fresh rock



- Practical Rock Engineering, [Hoek](#), 2007
- Best practice rock engineering handbook for 'other' mines. [T.R. Stacey. \(2001\).](#)
- Safety In Mines Research Advisory Committee (SIMRAC).
- Society for mining and metallurgy and exploration Inc.

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PAPER 3.4: CHAPTER 2

2.2.3. DATA INTERPRETATION

LEARNING OUTCOME 2.2.3.1

CONNECTION 25

Refer to
[Paper 2](#) Outcome 3.1.1

DESCRIBE, EXPLAIN AND EVALUATE THE IMPLICATIONS AND IMPACT OF THE ORIENTATION OF SURVEY LINES ON THE INTERPRETATION OF RECORDED DATA.

LEARNING OUTCOME 2.2.3.2

CONNECTION 26

Refer to
[Paper 2](#) Outcome 3.1.1

DESCRIBE, EXPLAIN AND DISCUSS THE APPLICATION OF STEREOONETS TO INTERPRET AND ANALYSE ROCKMASS STRUCTURE DATA.

LEARNING OUTCOME 2.2.3.3

CONNECTION 27

Refer to
[Paper 2](#) Outcome 3.1.1

APPLY STEREOONET TECHNIQUES TO ANALYSE AND INTERPRET GIVEN ROCKMASS STRUCTURE DATA.

LEARNING OUTCOME 2.2.3.4

CONNECTION 28

Refer to
[Paper 2](#) Outcome 3.1.1

ANALYSE AND INTERPRET ROCKMASS STRUCTURE DATA PRESENTED IN THE FORM OF STEREOONETS.

LEARNING OUTCOME 2.2.3.5

CONNECTION 29

Refer to
[Paper 2](#) Outcome 3.1.1

IDENTIFY JOINT TRENDS, FAILURE MECHANISMS, AND OTHER FEATURES PRESENTED IN THE FORM OF STEREOONETS.

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2.2.4. ROCK AND ROCKMASS STRENGTH

LEARNING OUTCOME 2.2.4.1

DESCRIBE, EXPLAIN AND DISCUSS THE COMPRESSIVE STRENGTHS OF ROCK TYPES ASSOCIATED WITH HARD ROCK AND SOFT ROCK SURFACE MINING OPERATIONS.

Materials encountered in a surface mine are similar to those encountered around specific ore bodies in underground environments, except that the state of weathering could have some impact on material competency and rockmass competency.



NOTE

Refer to all related Outcomes 2.2 in each of [Papers 3.1](#) and [3.2](#).

LEARNING OUTCOME 2.2.4.2

DESCRIBE, EXPLAIN AND DISCUSS THE TENSILE STRENGTHS OF ROCK TYPES ASSOCIATED WITH HARD ROCK AND SOFT ROCK SURFACE MINING OPERATIONS.

Materials encountered in a surface mine are similar to those encountered around specific ore bodies in underground environments, except that the state of weathering could have some impact on material competency and rockmass competency.



NOTE

Refer to all related Outcomes 2.2 in each of [Papers 3.1](#) and [3.2](#).

LEARNING OUTCOME 2.2.4.3

DESCRIBE, EXPLAIN AND DISCUSS THE RELATIVE ROCKMASS STRENGTHS OF ROCK TYPES ASSOCIATED WITH HARD ROCK AND SOFT ROCK SURFACE MINING OPERATIONS.

Materials encountered in a surface mine are similar to those encountered around specific ore bodies in underground environments, except that the state of weathering could have some impact on material competency and rockmass competency.



NOTE

Refer to all related Outcomes 2.2 in each of [Papers 3.1](#) and [3.2](#).

LEARNING OUTCOME 2.2.4.4

DESCRIBE, EXPLAIN AND DISCUSS THE SHEAR STRENGTHS OF ROCKMASSES ASSOCIATED WITH HARD ROCK AND SOFT ROCK SURFACE MINING OPERATIONS.

Materials encountered in a surface mine are similar to those encountered around specific ore bodies in underground environments, except that the state of weathering could have some impact on material competency and rockmass competency.



NOTE

Refer to all related Outcomes 2.2 in each of [Papers 3.1](#) and [3.2](#).

LEARNING OUTCOME 2.2.4.5

CONNECTION 29

Refer to
[Paper 1](#) Outcome 4

DESCRIBE, EXPLAIN AND DISCUSS THE SHEAR STRENGTHS OF GEOLOGICAL STRUCTURES ASSOCIATED WITH HARD ROCK AND SOFT ROCK SURFACE MINING OPERATIONS.

LEARNING OUTCOME 2.2.4.6

CONNECTION 29

Refer to
[Paper 1](#) Outcome 3

APPLY THE ABOVE KNOWLEDGE TO THE DESIGN OF WORKINGS IN SURFACE MINING OPERATIONS.

PAPER 3.4: SURFACE MINING (HARD AND SOFT ROCK)

LEARNING OUTCOMES

3. ROCK AND Rock mass BEHAVIOUR

3.1. SLOPE STABILITY AND SLOPE FAILURE BASIC MECHANICS OF SLOPE FAILURE

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the concept of continuum mechanics as applied to slope stability;
- Describe, explain and discuss the concept of rock mass failure as applied to slope stability;
- Describe, explain and discuss the role of discontinuities in slope stability and slope failure;
- Describe, explain and discuss the role of step path failure in slope stability and slope failure;
- Describe, explain and discuss the role of shear strength in slope stability and slope failure;
- Describe, explain and discuss the role of friction, cohesion and unit weight in slope stability and slope failure;
- Describe, explain and discuss the role of sliding due to gravitational loading in slope stability and slope failure;
- Describe, explain and discuss the influence of water and water pressure in slope stability and slope failure;
- Describe, explain and discuss the influence of water pressure on shear strength;
- Describe, explain and discuss the influence of water pressure in discontinuities; and
- Describe, explain and discuss the concept of effective stress.

3.2. SLOPE FAILURE MECHANISMS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the phenomenon of plane failure;
- Sketch, describe, explain and discuss the phenomenon of wedge failure;
- Sketch, describe, explain and discuss the phenomenon of circular slip failure;
- Sketch, describe, explain and discuss the phenomenon of toppling failure; and
- Sketch, describe, explain and discuss the phenomenon of tensile failure.

3.3. GROUNDWATER EFFECTS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the phenomenon of groundwater in terms of the following aspects:
 - Rock mass permeability, groundwater flow, groundwater pressure
- Sketch, describe, explain and discuss the effects of groundwater on the stability of surface mining operations; and
- Describe, explain and discuss the measures that can be taken to reduce the effects of groundwater on mining operations.

3.4. HARD ROCK SLOPE STABILITY

3.4.1. HOMOGENEOUS Rock mass SLOPES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain, discuss and apply empirical rock mass classification techniques to evaluate slope stability;
- Describe, explain, discuss and apply the MRMR classification system to evaluate slope stability;
- Describe, explain, discuss and apply the RMRB classification system to evaluate slope stability;
- Describe, explain, discuss and apply the Haines and Terbrugge approach to evaluate slope stability; and
- Evaluate slopes using the above techniques.

3.4.2. STRUCTURALLY CONTROLLED SLOPES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain, discuss and apply analytical techniques to evaluate slope stability;
- Evaluate slopes exposed to planar failure;
- Evaluate slopes exposed to wedge failure;
- Evaluate slopes exposed to toppling failure; and
- Evaluate slopes exposed to step path failure.

3.5. SOIL AND LOOSE ROCK SLOPE STABILITY

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the investigation, analysis and evaluation of slopes comprising the following types of materials:
 - Soil and overburden,
 - Deeply weathered rock,
 - Spoil piles.

3.6. ADVANCED EVALUATION TECHNIQUES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain, discuss and apply the following advanced techniques to evaluate the stability of slopes:
 - Limit equilibrium analyses,
 - Factor of safety, probability of failure,
 - Numerical analyses,
 - Flac, Udec
- Describe, explain and discuss the circumstances in which application of the above techniques is warranted.

3.7. EARTHQUAKE LOADING

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the effects of earthquake loading on surface mining operations;
- Describe, explain and discuss measures to minimise the effects of earthquake loading on surface mining operations;
- Describe, explain and discuss the phenomenon of localised seismicity and its effects on surface mining operations; and
- Describe, explain and discuss measures to minimise the effects of localised seismicity on surface mining operations.

3. ROCK AND Rock mass BEHAVIOUR

3.1. SLOPE STABILITY AND SLOPE FAILURE BASIC MECHANICS OF SLOPE FAILURE

LEARNING OUTCOME 3.1.1

DESCRIBE, EXPLAIN AND DISCUSS THE CONCEPT OF CONTINUUM MECHANICS AS APPLIED TO SLOPE STABILITY.

The rock mass does not consist of a continuous material with the same properties through-out as it is known to include joints, faults, dykes and variations in material composition. The tendency to represent this rock mass as a continuous rock mass, as suggested by continuum mechanics is therefore flawed. However, the use of limit equilibrium computer models to model discontinuous rock mass as a continuum is not totally without merit or use.



Care should be taken when applying continuum mechanics to an actual discontinuous rock mass.

- Page 18, Rock slope engineering, Hoek and Bray, 1999

INTERESTING INFO

Continuum modelling

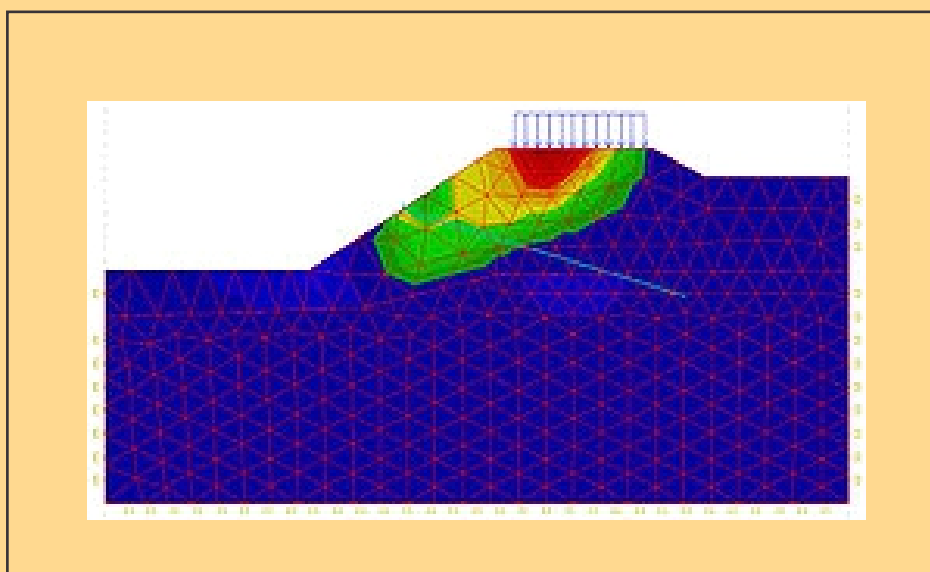


Figure 1: Finite element mesh

Modelling of the continuum is suitable for the analysis of soil slopes, massive intact rock or heavily jointed rock masses. This approach includes the finite-difference and finite element methods that discretise the whole mass to a finite number of elements with the help of generated mesh (Figure 1) such as GEO5 SLOPE, Flac/slope.

Discontinuum modelling

The discontinuum approach is useful for rock slopes controlled by discontinuity behaviour where the rock mass is considered as an aggregation of distinct, interacting blocks subjected to external loads and assumed to undergo displacement. Discontinuum modelling allows for sliding between the blocks or particles and includes programs such as UDEC, 3DEC and *particle flow* codes such as **PFC2D/3D**.

LEARNING OUTCOME 3.1.2

DESCRIBE, EXPLAIN AND DISCUSS THE CONCEPT OF ROCK MASS FAILURE AS APPLIED TO SLOPE STABILITY.

CONNECTION 1

Also refer to [Paper 1](#)
Outcome 4.1.7

Failure of the rock mass contained in a slope will mostly occur in shear and then when the shear stress induced by the highwall weight exceeds the shear strength of either:

- discontinuities;
- the rock material.

When failure is controlled by discontinuities, the following issues become important when discussing stability/failure:

- the orientation of the discontinuities in relation to the highwall orientation,
- the persistence of discontinuities indicating the need to shear through solid rock material or not;
- surface properties of discontinuities (friction angle and cohesion).

Properties can be determined from shear box tests.



CONNECTION 2

Also refer to [Paper 1](#)
Outcome 4.1 and [Paper 2](#)
Outcome 6.1

When failure is controlled by the shear strength of the rock material, the internal angle of friction and cohesion (which according to Mohr-Coulomb determines the strength of the material in shear) is critical to estimating the potential for failure.

In deep pits, typically > 400m, rock mass failure can also occur due to induced tensile or compressive stresses created by the in-situ stress field and the particular highwall layout. The rock mass strength can be estimated using the Hoek-Brown failure criterion and the stability impact of these induced stresses are typically analysed using numerical modelling packages.



Properties can be determined from shear tests on intact samples or estimated from tri-axial tests.

The Hoek-Brown rock mass strength parameters (m , s , a) can be estimated using the rock properties (UCS, stiffness, m_i) and rock mass quality (GSI, blasting practices) as provided in the RocScience software package RocData.



- Page 19, Rock slope engineering, Hoek and Bray, 1999

LEARNING OUTCOME 3.1.3

CONNECTION 4

Also refer to "[LEARNING OUTCOME 3.1.2](#)" on page 60

DESCRIBE, EXPLAIN AND DISCUSS THE ROLE OF DISCONTINUITIES IN SLOPE STABILITY AND SLOPE FAILURE.

LEARNING OUTCOME 3.1.4

DESCRIBE, EXPLAIN AND DISCUSS THE ROLE OF STEP PATH FAILURE IN SLOPE STABILITY AND SLOPE FAILURE.

A 'step-path' failure method indicates failure along a series of critical failure paths through a jointed rock slope. The shear strength is a function of both sliding along optimally orientated geological discontinuities and/or shearing through the intact rock or rock mass.

Rock slope failures may involve several mechanisms and may include:

- sliding on one or more major geological discontinuities;
- sliding along circular failure paths through the intact rock; and
- composite modes, involving two or more of the above mechanisms.

At the same time, slope failure may be progressive and failure along the actual 'failure path', a combination of the above, may occur at different stages.

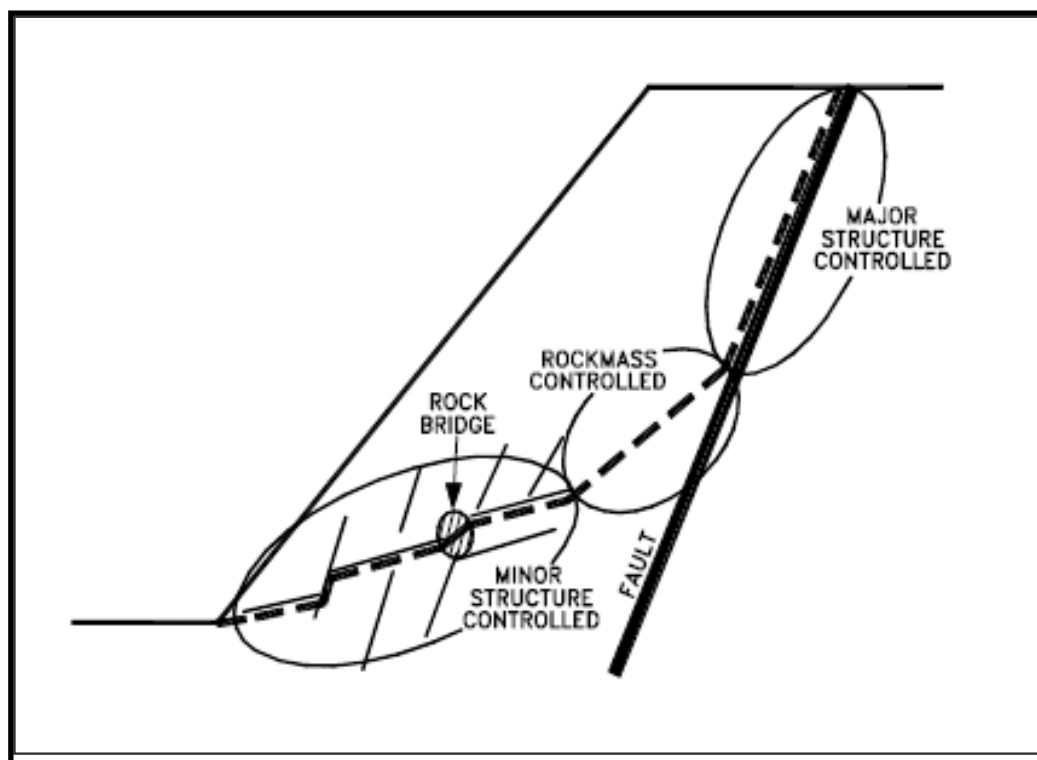


Figure 2: Step-path Failure (Baczynski)



LEARNING OUTCOME 3.1.5

CONNECTION 5

Also refer to "LEARNING OUTCOME 3.1.2" on page 60

DESCRIBE, EXPLAIN AND DISCUSS THE ROLE OF SHEAR STRENGTH IN SLOPE STABILITY AND SLOPE FAILURE.

LEARNING OUTCOME 3.1.6

CONNECTION 6

Also refer to "LEARNING OUTCOME 3.1.2" on page 60

DESCRIBE, EXPLAIN AND DISCUSS THE ROLE OF FRICTION, COHESION AND UNIT WEIGHT IN SLOPE STABILITY AND SLOPE FAILURE.

If failure occurs in shear, the shear strength (as suggested by Mohr-Coulomb) is a function of (1) the friction angle and cohesion on a structure or (2) the internal friction angle and cohesion of a rock material.

$$\text{Shear strength} = C_o + \mu \cdot \sigma_n$$

where C_o is the cohesion and μ is the co-efficient of friction given by $\tan \phi$, with ϕ the friction angle.

For failure to occur, shear stress should exceed the shear strength determined by the properties above. Shear stress is a function of the weight (force) of the rock material within a highwall/bench acting on the surface area (m^2) of a failure surface. The unit weight (or density) of the rock material determines the weight (force) acting on the failure surface area, and therefore also the level of shear stress that is generated on the failure surface.

$$\text{Shear stress} = (\rho \cdot g \cdot h) / m^2$$

with ρ the density, g gravitational acceleration and h the height of the rock material.



$$\text{Unit weight} = \rho \cdot g$$

When a slope is analysed for possible shear failure, forces along a potential failure surface is analysed to establish whether shear could occur along this surface.

Simplified, it can be explained using a simple tilt test as shown below.

If the inclined surface makes an angle " i " with the shear stress (τ) direction, the shear (τ_i) and normal (σ_i) stresses acting on the failure surface is given by:

$$\tau_i = \tau \cos^2 i - \sin(i) \cdot \cos(i) \quad \text{and} \\ \sigma_i = \sigma \cos^2 i + \sin(i) \cdot \cos(i)$$

If it is assumed that the failure surface has zero cohesion, it shear strength is given by $\tau_i = \sigma_i \tan \phi$ where ϕ is the surface friction angle.

Substituting this into the previous equations yield the following

relationship between the actual applied stresses and the failure plane properties given by the friction and inclination angles:
 $\tau = \sigma \tan(\phi + i)$

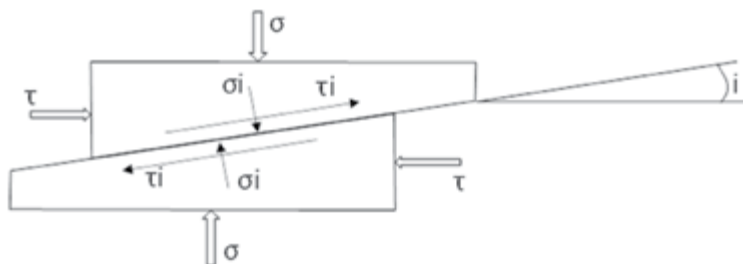


Figure 3 : Tilt test



- Page 83, and 89 Rock slope engineering, Hoek and Bray, 1999

INTERESTING INFO

Failure through intact rock suggests that the shear stress on some failure surface exceeds the shear strength of the material along that surface. The relationship between the shear strength and shear stress provides a Factor of Safety for the specific surface. To analyse the stability of these slopes, Janbu (Modified method of slices) and Bishop (Simplified method of slices) proposed mathematical methods, based on analysing stresses acting on "slices" taken through the "assumed failed zone". Each "slice" is analysed by evaluating the shear and normal stresses acting on the slice, taking note of the inclination of the base of the slice (similar to that discussed in the simple tilt test above). For this analysis:

- the angle of the "slices" base, the vertical stress acting on the base (based on unit weight as discussed earlier in the outcome), water pressure (pore pressure) acting on the base and the width of the slice is specified.
- The shear strength is given by the material's internal friction angle and inherent cohesion.
- The Factor of Safety (FoS) for the slope is calculated through a number of iterations for the sum of the results of all the "slices" until the change in the calculated FoS drops below an acceptable level, giving the FoS for the specific slope analysed.



The difference between the Janbu and Bishop methods is simply that Bishop assumes a circular failure surface (circular and passing through the toe of the slope) whilst Janbu assumes a general shape to the failure surface (also passing through the toe of the slope). In analysing the slope stability, the two methods are very similar to apply, but yield different results.



It is critical to select the most appropriate method when applying the Janbu and Bishop slice methods. Hoek and Bray suggest that:

- Janbu can provide serious errors when applied to rock material with deep slip surface and low friction angles (typically $< 30^\circ$);
- Bishops method for non-linear failure should be used when the material indicates a non-linear failure criterion.



- Hoek and Bray, Page 247

LEARNING OUTCOME 3.1.7

CONNECTION 7

Also refer to "[LEARNING OUTCOME 3.1.2](#)" on page 60 and "[LEARNING OUTCOME 3.1.6](#)" on page 62

DESCRIBE, EXPLAIN AND DISCUSS THE ROLE OF SLIDING DUE TO GRAVITATIONAL LOADING IN SLOPE STABILITY AND SLOPE FAILURE.

As stipulated in the outcomes above, shear failure can occur either on structures or through intact material. In both cases, the loading is determined by the weight of the material under gravitational loading and the consequence of shear failure is that sliding occurs either on the structure or on a shear surface created within the material.

The creation of a shear surface within the rock material is known as the 'slices' method (utilised in limit equilibrium design methods). This method suggests that the rock mass is divided into a number of slices, often of circular shape on which the shear strength and shear stress levels are resolved to indicate the potential for failure.

INTERESTING INFO

Different varieties of this method exist, including:

- Fellenius OMS,
- Bishop's simplified;
- Janbu's simplified;
- Spencer etc.



- Page 248, Guidelines for Open pit slope design, Stacey P, Read J, 2009
- Page 83, Rock slope engineering, Hoek and Bray, 1999

LEARNING OUTCOME 3.1.8

CONNECTION 8

Refer to [Paper 1](#) Outcomes 4.1.16 and 4.2.4 and [Paper 2](#) Outcome 2.1.4

DESCRIBE, EXPLAIN AND DISCUSS THE INFLUENCE OF WATER AND WATER PRESSURE IN SLOPE STABILITY AND SLOPE FAILURE



- Page 24, 127, Rock slope engineering, Hoek and Bray, 1999
- Page 40, 141, 249, Guidelines for Open pit slope design, Stacey P, Read J, 2009

LEARNING OUTCOME 3.1.9

CONNECTION 9

Refer to [Paper 1](#) Outcomes 4.1.16 and 4.2.4 and [Paper 2](#) Outcome 2.1.4

DESCRIBE, EXPLAIN AND DISCUSS THE INFLUENCE OF WATER PRESSURE ON SHEAR STRENGTH.



- Page 24, 127, Rock slope engineering, Hoek and Bray, 1999
- Page 40, 141, 249, Guidelines for Open pit slope design, Stacey P, Read J, 2009

LEARNING OUTCOME 3.1.10**CONNECTION 10**

Refer to [Paper 1](#) Outcomes 4.1.16 and 4.2.4 and [Paper 2](#) Outcome 2.1.4

**DESCRIBE, EXPLAIN AND DISCUSS THE INFLUENCE OF WATER PRESSURE IN DISCONTINUITIES.**

- Page 24, 127, Rock slope engineering, Hoek and Bray, 1999
- Page 40, 141, 249, Guidelines for Open pit slope design, Stacey P, Read J, 2009

LEARNING OUTCOME 3.1.10**CONNECTION 11**

Refer to [Paper 1](#) Outcomes 4.1.16 and 4.2.4 and [Paper 2](#) Outcome 2.1.4

**DESCRIBE, EXPLAIN AND DISCUSS THE CONCEPT OF EFFECTIVE STRESS.**

- Page 24, 127, Rock slope engineering, Hoek and Bray, 1999
- Page 40, 141, 249, Guidelines for Open pit slope design, Stacey P, Read J, 2009

3.2. SLOPE FAILURE MECHANISMS**LEARNING OUTCOME 3.2.1****SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE PHENOMENON OF PLANE FAILURE.**

The stability of surface excavation in rock is frequently controlled by the orientation of discontinuities within the rock mass. Reliable knowledge of the true orientation of discontinuities that will be encountered during the development of slopes is therefore required for engineering design. These orientations determine the different types methods in which failure on slopes can occur.

Plane failure

A plane failure occurs when sliding takes place in one plane or area of rock. Certain geometrical conditions must be in place for this to happen, these are:

- The plane or geologic discontinuity on which sliding occurs must strike within $\pm 20^\circ$ of the strike direction of the slope face.
- The failure plane must have a dip that is smaller than the dip of the slope.
- The dip of the failure plane must be greater than the angle of friction of this plane.
- Boundaries that define the extent of the failure plane need to provide negligible resistance to sliding.

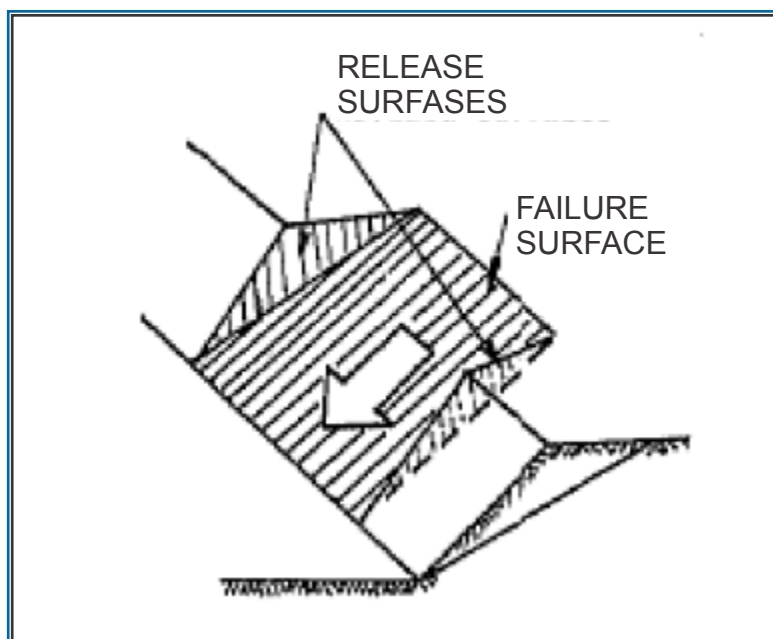


Figure 4: The geometry of planar failure (Hoek & Bray, 1981)

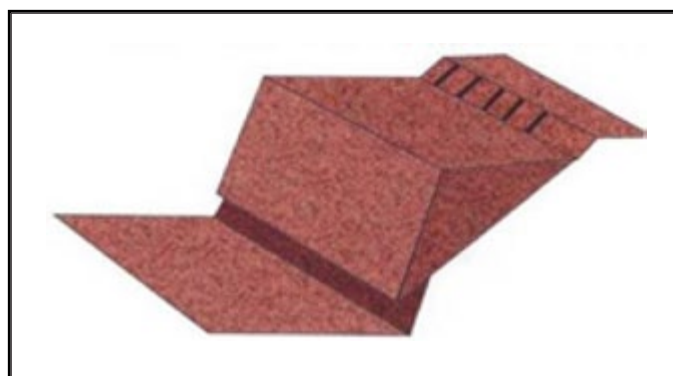


Figure 5: Schematic diagram showing planar failure (Middindi)



Figure 6: Plane failure in a rock slope (Rocscience website)



- Page 150, Rock slope engineering, Hoek and Bray, 1999

LEARNING OUTCOME 3.2.2

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE PHENOMENON OF WEDGE FAILURE.

Wedge failure

- Wedge failure can occur when two or more geological discontinuities intersect to form an unstable wedge.
- In order for such a wedge to fail, the line of intersection of the wedge must dip out of the slope at an inclination that is shallower than the inclination of the slope, but steeper than the effective angle of friction along the discontinuities.
- Wedge failures will only develop to a significant extent if the azimuth of the line of intersection lies within $\pm 45^\circ$ of the dip direction of the slope face.
- Wedge failure is usually more common in slopes and occurs more often than planar or toppling failures.

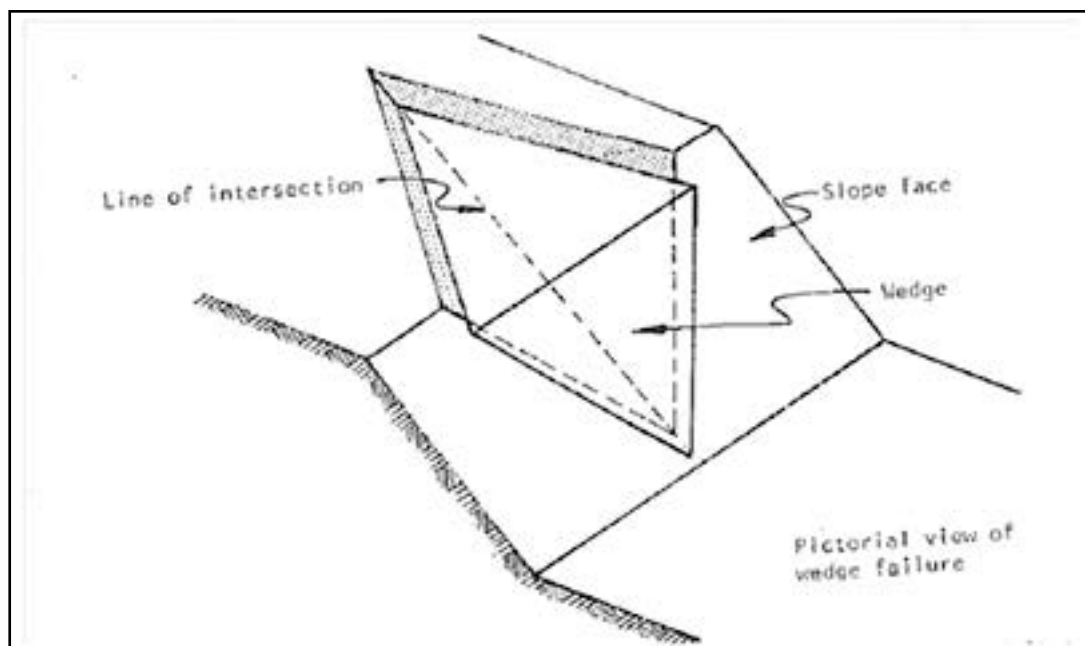
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Figure 7: The geometry of wedge failure (Hoek & Bray, 1981)

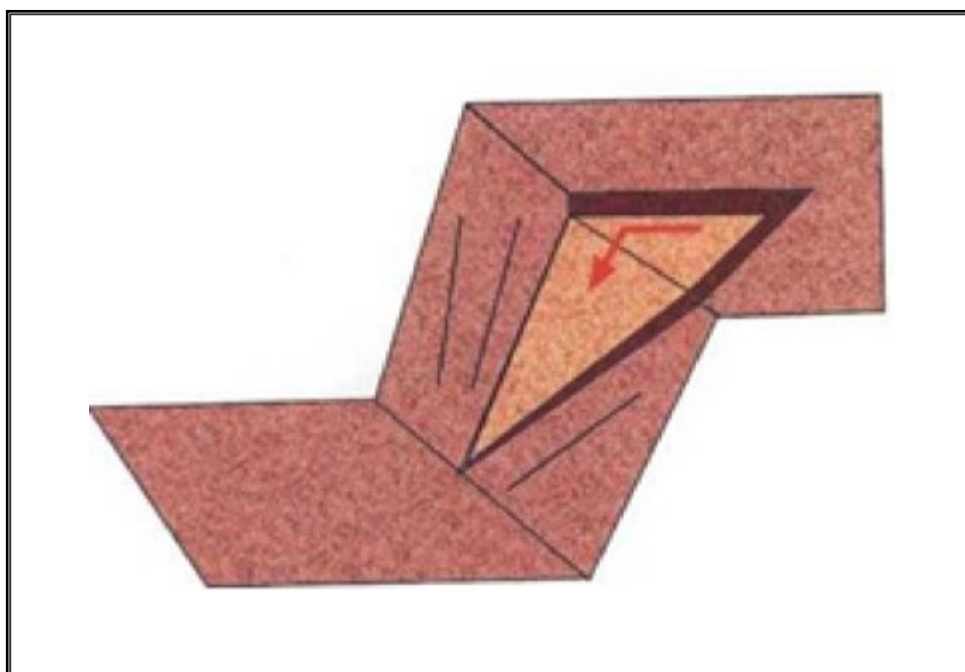


Figure 8: A schematic diagram of wedge failure (Middindi)

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Figure 9: A typical example of wedge failure in a slope face (Hoek, 2007)



Figure 10: A steeper type of wedge failure (Middindi, 2010)

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- • Page 199, Rock slope engineering, Hoek and Bray, 1999

LEARNING OUTCOME 3.2.3

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE PHENOMENON OF CIRCULAR SLIP FAILURE.

Circular slip failure

- Rotational slips occur characteristically in homogeneous soft rocks or soils; the movement taking place along a curved shear surface in such a way that the slipping mass slumps down near the top of the slope and bulges near the toe.

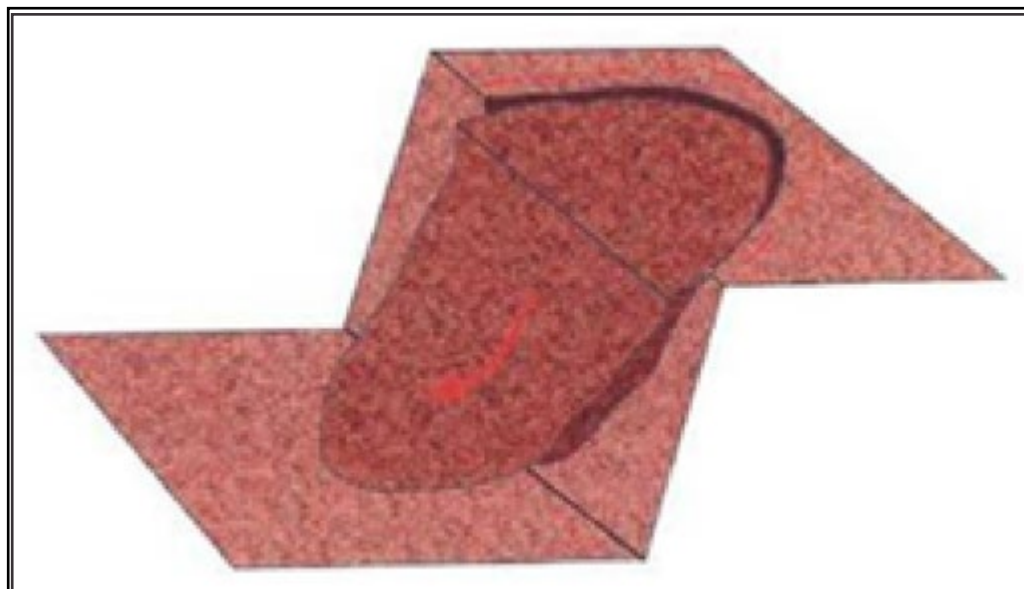


Figure 11: Schematic diagram of circular slip failure

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Figure 12: A typical example of circular failure in a soil slope (Rocscience)



- Page 226, Rock slope engineering, Hoek and Bray, 1999

LEARNING OUTCOME 3.2.4

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE PHENOMENON OF TOPPLING FAILURE

Toppling failure

- Toppling failures may develop when a rock mass contains multiple, parallel, steeply dipping continuous geologic structures, such as bedding or foliation planes, that dip into the face and strike within $\pm 20^\circ$ of the strike of the rock face direction.

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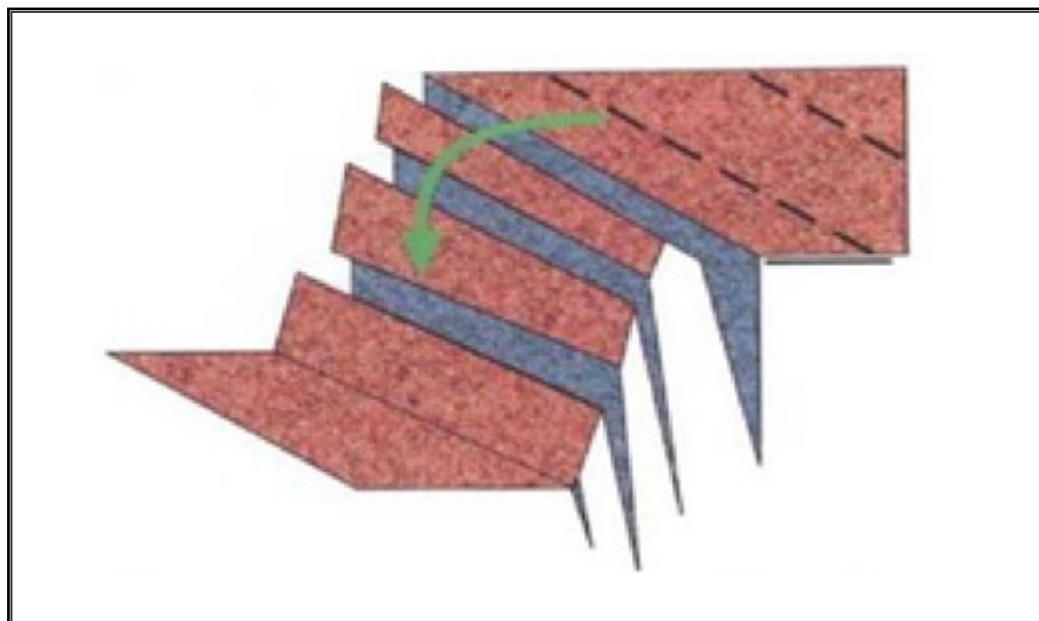


Figure 13: Schematic diagram of toppling failure (Middindi)



Figure 14: Steeply jointed rock in which toppling failure is highly likely



- Page 257, Rock slope engineering, Hoek and Bray, 1999

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LEARNING OUTCOME 3.2.5**SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE PHENOMENON OF TENSILE FAILURE.****Tensile failure**

- When tensile stresses in rock or soil material are exceeded, a formation of a tension crack develops. This is usually indicative of a large-scale slope failure.
- Tension cracks form when material is removed to form a pit or void. When the remaining material is no longer in equilibrium, it becomes unstable and starts to pull away from its original position.

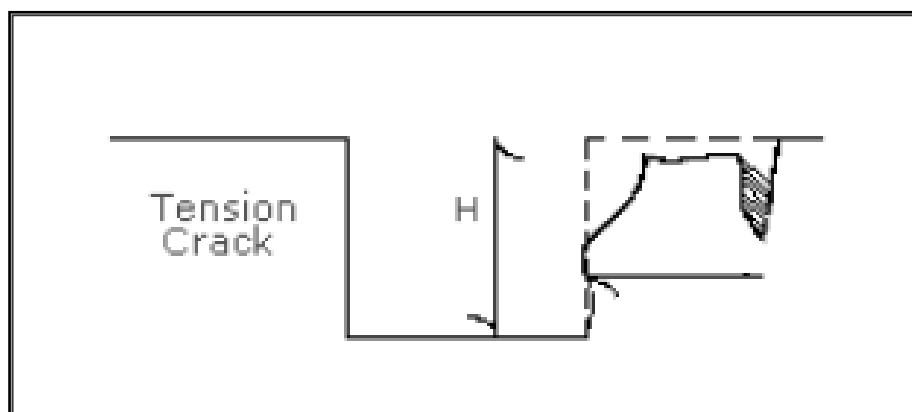


Figure 15: A schematic diagram of a formation of a tension crack

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Figure 16 An example of tension cracks that have formed in soft material (Middindi, 2010)

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Figure 17: An example of a tension crack that has formed in hard material (Middindi, 2010)[Link](#)



- Failure modes in jointed rock [Hamman](#)
- [Failure mechanism for high slopes in hard rock](#)



- Hoek, E. & Bray, J.W. (1981). Rock Slope Engineering. Institution of Mining and Metallurgy, London. Chapters 7, 8, 9 and 10.
- Hoek, E (2007). Practical Rock Engineering Pdfs, www.rocscience.com/education/hoekscorner
- The RocScience website www.rocscience.com

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3.3. GROUNDWATER EFFECTS**LEARNING OUTCOME 3.3.1****CONNECTION 12**

Paper 2 Outcome 2.1.4

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE PHENOMENON OF GROUNDWATER IN TERMS OF THE FOLLOWING ASPECTS:

- Rock mass permeability,
- groundwater flow,
- groundwater pressure
- Page 24, 127, Rock slope engineering, Hoek and Bray, 1999
- Page 40, 141, 146, 151, Guidelines for Open pit slope design, Stacey P, Read J, 2009

**LEARNING OUTCOME 3.3.2****CONNECTION 13**

Refer to "LEARNING OUTCOME 3.1.8" on page 64 to Learning Outcome 3.1.11

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE EFFECTS OF GROUNDWATER ON THE STABILITY OF SURFACE MINING OPERATIONS.**Groundwater can have the following impacts on surface mining operations:**

- Water pressure;
- Increased unit weight of overburden: Causes increased levels of weathering, but also increases in loading;
- Freezing of water in cracks: This freezing causes expansion, but also blocking of water draining and a build-up of water pressure;
- Erosion: High velocity flow causes erosion and could lead to instability;
- Liquefaction: Soils are most susceptible to liquefaction, which reduces the weight of the soil due to 'uplift'.



- Page 24, 127, Rock slope engineering, Hoek and Bray, 1999
- Page 40, 141, Guidelines for Open pit slope design, Stacey P, Read J, 2009

LEARNING OUTCOME 3.3.3**DESCRIBE, EXPLAIN AND DISCUSS THE MEASURES THAT CAN BE TAKEN TO REDUCE THE EFFECTS OF GROUNDWATER ON MINING OPERATIONS.**

Drainage is probably the most important method to reduce the effects of groundwater on slopes and may include:

- Drainage systems around the pit to prevent surface water from entering the pit;
- Pumping of water accumulated in the pit to reduce the impact of seeping water into highwall materials that will only be exposed at

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a later stage;

- Drainage of groundwater from the area around the pit via pumping from boreholes to create a drawdown and to ensure little water within the pit walls.
- Page 313, Rock slope engineering, Hoek and Bray, 1999
- Page 180, Guidelines for Open pit slope design, Stacey P, Read J, 2009

**3.4. HARD ROCK SLOPE STABILITY****3.4.1. HOMOGENEOUS Rock mass SLOPES****LEARNING OUTCOME 3.4.1.1****CONNECTION 14**

Refer to

[Paper 2](#) Outcome 3.1.2[Paper 1](#) Outcome 6.2[Paper 3.1](#) Outcome 2.3

SKETCH, DESCRIBE, EXPLAIN, DISCUSS AND APPLY EMPIRICAL ROCK MASS CLASSIFICATION TECHNIQUES TO EVALUATE SLOPE STABILITY.

LEARNING OUTCOME 3.4.1.2**CONNECTION 15**

Refer to

[Paper 2](#) Outcome 3.1.2[Paper 1](#) Outcome 6.2[Paper 3.1](#) Outcome 2.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE MRMR CLASSIFICATION SYSTEM TO EVALUATE SLOPE STABILITY.

LEARNING OUTCOME 3.4.1.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE RMRB CLASSIFICATION SYSTEM TO EVALUATE SLOPE STABILITY.



No reference to an RMRB classification system could be found.

INTERESTING INFO

Reference to a SLOPE MASS RATING is not made in the syllabus, but it is added to this section for your interest and reference.

The slope rock mass rating system is a system applied to slope design and was developed as a tool for the preliminary assessment of slope stability. It provides some simple rules about instability modes and the required support measures. It cannot be a substitute for the detailed analysis of each slope, which must combine both good common sense engineering and sound analytical methods.

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SMR classification is a development of the Bieniawski 'rock mass rating' (RMR) system that has become known worldwide, and is applied by many technicians as a systematic tool to describe rock mass conditions. The RMR concept has been proven to be particularly useful in assessing the need for support in tunnel studies.

The application of the RMR system to slopes has not been possible to date. The SMR system provides adjustment factors, field guidelines and recommendations on support methods, which allow a systematic use of geomechanical classification for slopes.

The proposed 'slope mass rating' (SMR) is obtained from RMR by subtracting a factorial adjustment factor depending on the joint-slope relationship and adding a factor depending on the method of excavation

$$SMR = RMR + (F1 \cdot F2 \cdot F3) + F4$$

The RMR is computed according to Bieniawski's 1979 proposal, adding rating values for five parameters: (i) strength of intact rock; (ii) RQD (measured or estimated); (iii) spacing of discontinuities; (iv) condition of discontinuities; and (v) water inflow through discontinuities (estimated in the worst possible conditions). RMR has a total range of 0-100.

The adjustment rating for joints (see Table 2) is the product of three factors as follows:

- a. F1 depends on parallelism between joints and slope face strikes. Its range is from 1.00 (when both are near parallel) to 0.15 (when the angle between them is more than 300 and the failure probability is very 100). These values were established empirically, but afterwards were found to approximately match the relationship $F1 = (1 - \sin A)^2$, where A denotes the angle between the strikes of the slope face and the joint.
- b. F2 refers to joint dip angle in the planar mode of failure. In a sense, it is a measure of the probability of joint shear strength. Its value ranges from 1.00 (for joints dipping more than 45°) to 0.15 (for joints dipping less than 20°). Also established empirically, it was found afterwards to match approximately the relationship $F2 = \tan^2 \beta_j$, where β_j denotes the joint dip angle. For the toppling mode of failure, F2 remains 1.00.
- c. F3 reflects the relationship between the slope face and joint dip. Bieniawski's 1976 figures have been kept. In the planar mode of failure, F3 refers to the probability that joints 'daylight' in the slope face. Conditions are fair when slope face and joints are parallel. When the slope dips 100 more than joints, very unfavourable conditions occur.

The adjustment factor for the method of excavation (see Table 3) has been fixed empirically as follows:

- a. Natural slopes are more stable, because of long-time erosion and built-in protection mechanisms (vegetation, crust desiccation, etc.): $F4 = + 15$.
- b. Presplitting increases slope stability for half a class: $F4 = \pm 10$.
- c. Smooth blasting, when well done, also increases slope stability: $F4 = \pm 8$.
- d. Normal blasting, applied with sound methods, does not change slope stability: $F4 = 0$.

	Case	Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
P	$\alpha_j - \alpha_s$	$>30^\circ$	$30^\circ - 20^\circ$	$20^\circ - 10^\circ$	$10^\circ - 5^\circ$	5°
T	$ \alpha_j - \alpha_s - 180^\circ$					
P/T	F_1	0.15	0.4	0.7	0.85	1.00
P	$ \beta_j $	$>20^\circ$	$20^\circ - 30^\circ$	$30^\circ - 35^\circ$	$35^\circ - 45^\circ$	45°
P	F_2	0.15	0.4	0.7	0.85	1.00
T	F_2	1	1	1	1	1
P	$\beta_j - \beta_s$	$>10^\circ$	$10^\circ - 0^\circ$	0°	$0^\circ - 10^\circ$	$<10^\circ$
T	$\beta_j - \beta_s$	$<110^\circ$	$110^\circ - 120^\circ$	$>120^\circ$	-	-
P/T	F_3	0	6	25	50	60

Table 1: Adjustment rating for joints

Method	Natural Slope	Presplitting	Smooth Blasting	Blasting or Mechanical	Deficient Blasting
F_4	+15	+10	+8	0	-8

Table 2: Adjustment rating for methods of extracting slopes

- e. Deficient blasting, often with too much explosives, no detonation timing and/or nonparallel bores, damages stability: $F_4 = -8$.
- f. Mechanical excavation of slopes, usually by ripping, can be done only in soft and/or very fractured rock, and is often combined with some preliminary blasting. The plane of slope is difficult to finish. The method neither increases nor decreases slope stability: $F_4 = 0$.

A tentative description of the SMR classes is given in Table 3.

Class	SMR	Description	Stability	Failures	Support
I	81-100	Very Good	Completely stable	None	None
II	61-80	Good	Stable	Some blocks	Occasional
III	41-60	Normal	Partially Stable	Some joints or many wedges	Systematic
IV	21-40	Bad	Unstable	Planar or big wedges	Important / Corrective
V	0-20	Very Bad	Completely Unstable	Big planar or soil-like	Re-excavation

Table 3: Tentative Description of SMR Classes

Class	SMR	Support
I _a	91-100	None
I _b	81-90	None, Scaling
II _a	71-80	None. (Toe ditch or fence) Spot Bolting
II _b	61-70	Toe Ditch or Fence. Nets Spot or Systematic Bolting
III _a	51-60	Toe Ditch and/or Nets Spot or Systematic Bolting Spot Shotcrete

Class	SMR	Support
III _b	41-50	(Toe Ditch and/or Nets) Systematic Bolting. Anchors Systematic Shotcrete Toe Wall and/or Den- tal Concrete
IV _a	31-40	Anchors Systematic Shotcrete Toe Wall and/or Concrete (Re-excavation)Drainage
IV _b	21-30	Systematic Rein- forced Shotcrete Toe Wall and/or Concrete Re-excavation Deep Drainage
V _a	11-20	Graviry or Anchored Wall Re-excavation

Table 4: Recommended Support Measures for each Stability Class

*Very often, several support measures are used on the same slope.
Less usual support measures are in brackets*



- Geomechanical classification for slopes [Romana](#)
- [SMR geomechanics classification](#)

LEARNING OUTCOME 3.4.1.4

CONNECTION 16

Refer to

[Paper 2](#) Outcome 3.1.2

[Paper 1](#) Outcome 6.2

[Paper 3.1](#) Outcome 2.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE HAINES AND TERBRUGGE APPROACH TO EVALUATE SLOPE STABILITY.

LEARNING OUTCOME 3.4.1.5

EVALUATE SLOPES USING THE ABOVE TECHNIQUES.

EXAMPLE

The overburden materials include topsoil, unconsolidated alluvium, colluvium, and saprolitic residual soils. The overburden materials were assumed to be up to approximately 3m deep and could easily be pre-stripped. The weathered rock underlies the overburden and will form the upper

portion of the pit walls. The weathered rock is assumed on average to be 10m thick, but in some areas of the pit it could be thicker depending on the presence and condition of major geological structures. The weathered rock is assumed to consist of saprolitic materials, weathered siltstones, shales and sandstones and a small proportion of weathered UMZ. Fresh rock will predominantly consist of consolidated sediments and the ore bearing horizons (MMZ and LMZ).

Slope geometry

The bench face angles were determined using the empirical Haines and Terbrugge design nomograms. The bench face geometry comprised the following components:

- Bench face angle (BFA): This is a maximum allowed angle to ensure minimal structural instability, i.e. instability is reduced to an acceptable level. These maximum angles may be reduced to a shallower angle due to a change in overall pit geometry due to (say) open pit optimisation or the use of alternative equipment.
- Berm or bench widths: Bench widths are selected to facilitate containment of potential failing material (small wedges and blocks) so as to ensure that loose material does not become hazardous to men and equipment.
- Bench height: Mining equipment used to drill and blast the rock determines the bench height. Currently, most large mining operations drill and blast on 12 to 15 metre intervals, with 15 metres being the most common.

Empirical relationships were used to optimise berm width for containment and catching failure volumes:

- Bench width (m) = $0.2 \times \text{bench height} + 4.5 \text{ m}$; recommended by the SME Mine Engineering Handbook (1992).

Slope results

Bench face angles

The MRMR values for the different stratigraphic units were applied to the design nomogram for final pit slope depths of 150m and 200m below surface (Figure 16).

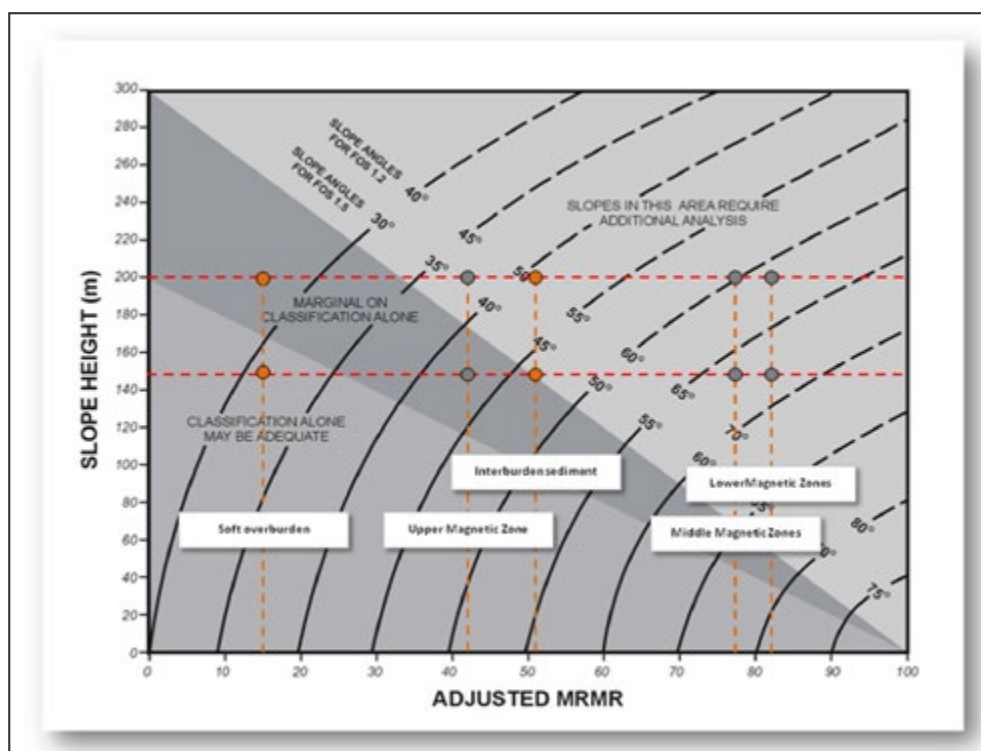


Figure 18: Empirically derived bench face angles

The threshold safety factors adopted were 1.5 for units that are expected to be weathered or transitional and 1.2 for fresh rock. The resulting BFAs for 150m and 200m final pit depths are summarised in Table 5.

Geological unit	Threshold safe- ty factor	Bench face angles (degrees)	
		150m slope height	200m slope height
Weathered sediment	1.5	32	28
Upper magnetic zone	1.5	43	37
Inter-burden fresh rock sediment	1.2	56	52
Middle magnetic zone 3	1.2	67	60
Middle magnetic zone 2	1.2	67	60
Middle magnetic zone 1	1.2	67	60
Inter-burden fresh rock sediment	1.2	67	60
Lower magnetic zone 2	1.2	69	62
Lower magnetic zone 1	1.2	69	62
Floor sediment	1.2	N/A	N/A

Table 5: Summary of bench face angles

Berm widths

The berm widths based on maximum expected bench heights for each of the stratigraphic units are shown in Table 6.

Berm widths based on bench material		
Rock type	SME guidelines	
	Bench height (m)	Berm width (m)
Weathered sediment	5	5.5
Upper magnetic zone	10	6.5
Inter-burden fresh rock sediment	15	7.5
Middle magnetic zones	15	7.5
Inter-burden fresh rock sediment	15	7.5
Lower magnetic zones	15	7.5
Averages	12.50	7.00

Table 6: Summary of berm widths**Final slope geometry and overall angles**

Using the individual slope geometrical parameters listed in previous sections of this report, the full scale pit slope can be constructed to calculate the overall slope angles. A summary of the individual and overall angles is shown in Table 7 and Figure 18.

Design sector		Maximum slope height (m)	Maximum bench height (m)	Bench face angle (°)	Berm width (m)	Overall angle
Weathered material	Weathered sediment	10	5	32	5.5	44° for 150m total slope height
Transitional	Upper magnetic zone	20	10	43	6.5	
	Inter-burden fresh rock sediment	30	15	56	7.5	
	Middle magnetic zone 3	12		67	7.5	
	Middle magnetic zone 2	8	15	67	7.5	
Fresh material	Middle magnetic zone 1	10		67	7.5	40° for 200m total slope height
	Inter-burden fresh rock sediment	15	15	67	7.5	
	Lower magnetic zone 2	20		69	7.5	
	Lower magnetic zone 1	15	15	69	7.5	
	Floor sediment	N/A	N/A	N/A	N/A	

Table 7: Summary of slope configurations

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PAPER 3.4: CHAPTER 3

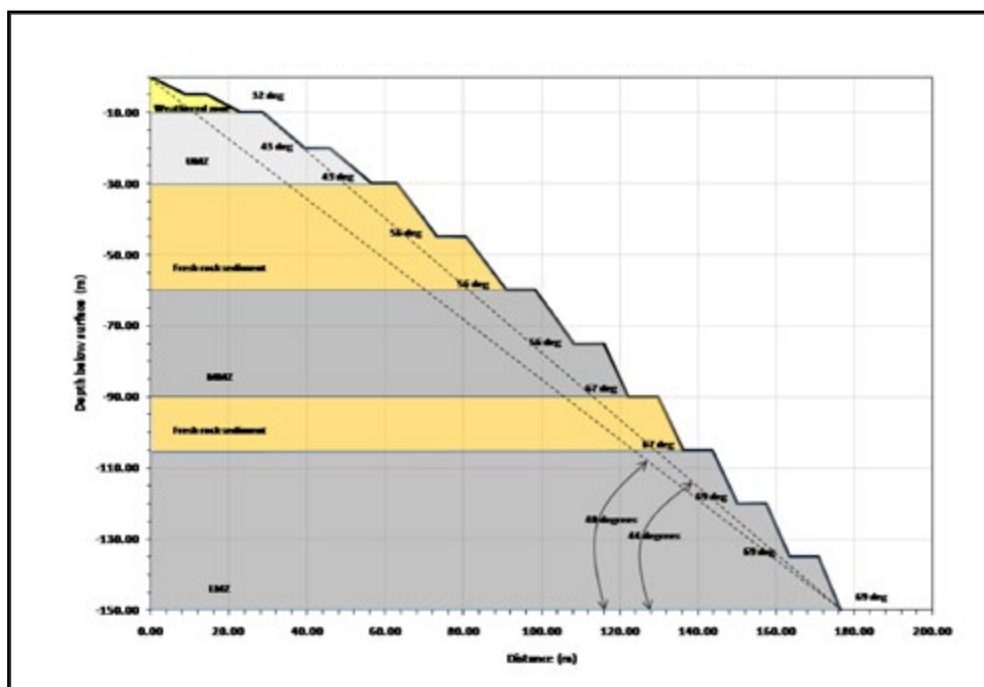


Figure 19: Graphical representation of slope geometry

- [Rock mass properties for surface mines](#)

3.4.2. STRUCTURALLY CONTROLLED SLOPES

LEARNING OUTCOME 3.4.2.1

SKETCH, DESCRIBE, EXPLAIN, DISCUSS AND APPLY ANALYTICAL TECHNIQUES TO EVALUATE SLOPE STABILITY.

CONNECTION 17

Refer to "[LEARNING OUTCOME 3.1.6](#)" on page 62 for Limit equilibrium methods and refer to [Paper 2](#) Outcome 3.1.1

Methods to evaluate structurally controlled slopes include:

- Kinematic analysis:
 - Stereographic analysis and limited to bench designs;
- Limit equilibrium:
 - Structurally controlled analysis in bench and stack (inter-ramp) design.

LEARNING OUTCOME 3.4.2.2

CONNECTION 18

[Paper 2](#) Outcome 3.1.1

EVALUATE SLOPES EXPOSED TO PLANAR FAILURE.

LEARNING OUTCOME 3.4.2.3

CONNECTION 19

[Paper 2](#) Outcome 3.1.1

EVALUATE SLOPES EXPOSED TO WEDGE FAILURE.

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LEARNING OUTCOME 3.4.2.4

CONNECTION 20

Paper 2 Outcome 3.1.1

EXAMPLE

EVALUATE SLOPES EXPOSED TO TOPPLING FAILURE.

Since the mode of potential failure of slopes (Table 8) is related to the rock mass properties, presence/absence of discontinuities and the constituent material make-up (unconsolidated versus consolidated) of slopes, different techniques were applied to test the validity of the geometrical parameters provided.

Parameter	Mode of failure			
Illustration	Circular	Topping	Planar	Wedge
Occurrence	Weathered material	None	Pit 3 & 2	Pit 3 & 2
Validation technique	Numerical modeling	Empirical	Lime equilibrium	Lime equilibrium

Table 8: Slope failure modes

The outputs from the techniques used to assess the change in geometry on different modes of failure are normally benchmarked against safety factors (FOS). Commonly adopted FOSs for surface mining operations are shown in Table 9. It is assumed for this operation that the pits will comprise either small temporary slopes or permanent slopes and therefore an FOS of 1.3 and 2.0 is used to benchmark stability.

Consequence of failure	Example	Minimum FOS
Not serious	No person-entry	1.2
	Individual benches small temporary slopes not adjacent to haul roads	1.3
Moderately serious	Any slope of a semi-permanent or permanent nature	1.6
Very serious	Medium sized and high slopes carrying major haul-age roads or underlying permanent mine installations	2.0

Table 9: Acceptable FoS**Circular failure in weathered material**

Due to the broken and unconsolidated nature of weathered material, the most common mode of failure is circular or rotational. The FLAC/slope programme was chosen to validate slope geometrical configurations for the planned weathered sections due to its ability:

- to adequately represent both rock and soil materials;
- to incorporate parametric studies;
- to naturally define failure surfaces;
- to be kinematically feasible; and
- to incorporate phreatic surfaces.

FLAC/slope (FSP) is a mini-version of FLAC (FLAC, 2005) that is designed specifically to perform factor of safety (FOS) calculations for slope stability analysis. FLAC/slope provides an alternative to traditional 'limit equilibrium' programs to determine the FOS. Limit equilibrium codes use an approximate scheme – typically based on the method of slices, in which a number of assumptions are made, e.g. the location and angle of the inter-slice forces. Several assumed failure surfaces are tested, and the one giving the lowest FOS is chosen. Equilibrium is only satisfied on an idealised set of surfaces.

In contrast, FLAC/slope provides a full solution of the coupled stress/displacement, equilibrium and constitutive equations. Given a set of properties, the system is determined to be stable or unstable. By automatically performing a series of simulations while changing the strength properties, the FOS can be found to correspond with the point of stability, and the critical failure slip surface can be located.

The following primary advantages of FLAC/slope over limit equilibrium analysis prompted its use for this analysis:

- Any failure mode develops naturally; there is no need to specify a range of trial surfaces.
- No artificial parameters (e.g. functions for inter-slice force angles) need to be provided as input.
- Multiple failure surfaces evolve naturally, if the conditions give rise to them.
- Structural interaction (e.g. rock bolt, soil nail or geogrid) is modelled realistically as fully coupled deforming elements, not simply as equivalent forces.
- The solution consists of mechanisms that are kinematically feasible.

Calculation of the FOS

The FSP uses the strength reduction technique, which is typically applied in FOS calculations by progressively reducing the shear strength of the material to bring the slope to a state of limiting equilibrium. The FOS is defined according to the equations:

$$C_{\text{trial}} = (1/F)^c$$

$$\Phi_{\text{trial}} = \text{ArcTan}(1/F) \cdot \text{Tan}\Phi$$

A series of simulations are made using trial values of the factor F_{trial} to reduce the cohesion, c , and friction angle, θ , until slope failure occurs. A given number of steps are executed for a bracket of FOS. If the unbalanced force ratio is less than 10^{-3} , then the system is in equilibrium. If the unbalanced force ratio is greater than 10^{-3} , then stepping is continued. The FOS solution stops when the difference between the upper and lower bracket values becomes smaller than 0.005.

Plane failure in unweathered material

In order for sliding to occur on a single plane, the following geometrical conditions must be satisfied:

- The plane on which sliding occurs must strike parallel or nearly parallel (within approximately 20 degrees) to the slope face.
- The failure plane must 'daylight' in the slope face. This means that its dip must be smaller than the dip of the slope face.
- The dip of the failure plane must be greater than the angle of friction of this plane.

- Release surfaces, which provide negligible resistance to sliding, must be present in the rock mass to define the lateral boundaries of the slide. Alternatively, failure can occur on a failure plane passing through the convex 'nose' of a slope.

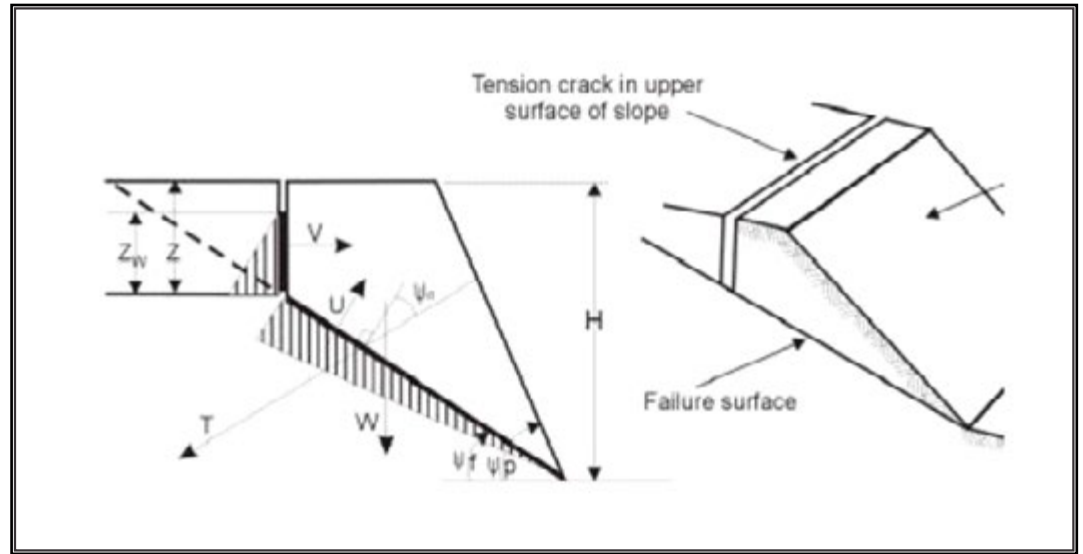


Figure 19: Geometrical cross section of a slope for plane failure

With reference to Figure 19, the FOS for plane failure is calculated using the equations shown in Figure 20. For this operation, no tension crack is assumed to exist at the slope face and the failure path is assumed to follow the trace of the discontinuity. The kinematic feasibility of plane failure occurring was tested prior to conducting the validation of slope angles.

$$F = (cA + (W \cos \phi_p - U - V \sin \phi_p) \tan \phi) / (W \sin \phi_p + V \cos \phi_p)$$

$$A = (H - z) \times \text{Cosec} \phi_p$$

$$U = 1/2 \gamma_w \times Z_w (H - z) \cdot \text{Cosec} \phi_p$$

$$V = 1/2 \times \gamma_w \times Z_w^2$$

For tension crack in the upper slope surface

$$W = 1/2 \gamma \times H^2 [(1 - (z/H)^2) \times \cot \phi_p + \cot \phi_f]$$

Figure 20: Equations for analysis of plane failure

Wedge failure in unweathered material

The calculation of the FOS resulting from wedge failure is complicated and relies on prior knowledge existing on the three-dimensional layout of wedges in relation to the slope face and crest. Additionally, this analysis is normally done using angles of intersection obtained from stereonets. For this exercise, the methods and procedures adopted are not explained and if in-depth information is required, the reader is referred to Hoek and Bray (1983). With reference to Figure 3, the FOS for wedge failure is calculated using the following equation:

$$F = 3/\gamma H (c_A \cdot X + c_B \cdot Y) + (A - \gamma_w/2\gamma \cdot X) \tan \phi_A + (B - \gamma_w/2\gamma \cdot Y) \tan \phi_B$$

Where

c_A and c_B are cohesive strengths of planes A and B

ϕ_A and ϕ_B are the angles of friction of planes A and B

γ is the unit weight of the rock

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γ_w is the unit weight of water
 H is the height of wedge
 X, Y, A, B are dimensionless factors

$$A = (\cos \phi_a - \cos \phi_b \cdot \cos \theta_{(na.nb)}) / (\sin \phi_5 \cdot \sin \theta_{(na.nb)}^2)$$

$$B = (\cos \phi_b - \cos \phi_a \cdot \cos \theta_{(na.nb)}) / (\sin \phi_5 \cdot \sin \theta_{(na.nb)}^2)$$

$$X = (\sin \theta_{24}) / (\sin \theta_{45} \cdot \cos \theta_{2na})$$

$$Y = (\sin \theta_{13}) / (\sin \theta_{35} \cdot \cos \theta_{1nb})$$

Where

ψ_a and ψ_b are the dips of planes A and B
 ψ_5 is the dip of the line of intersection 5
 na and nb are the dips of Planes A and B
 numbers refer to angles as stipulated below:

1. Intersection of plane A with slope face
2. Intersection of plane B with slope face
3. Intersection of Plane A with upper slope surface
4. Intersection of Plane B with upper slope surface
5. Intersection of Planes A and B



The use of the stereonet to determine the intersection angles is suggested.

- Hoek and Bray Page 206

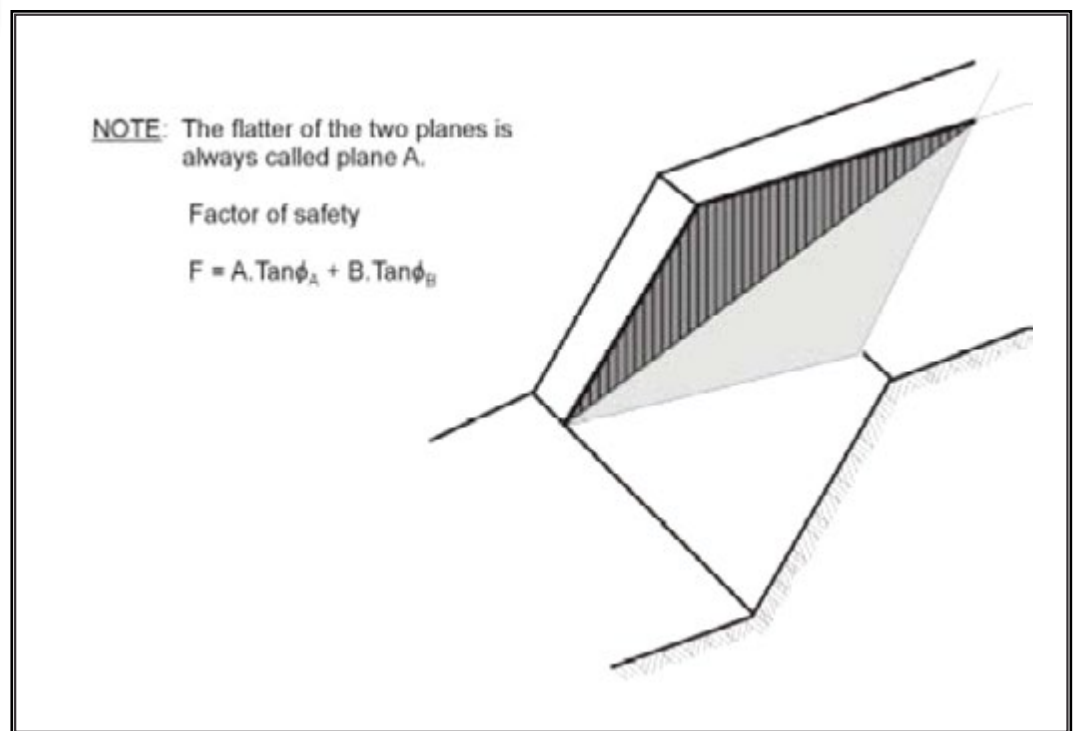


Figure 21: Isometric view of a slope containing a wedge

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Rock properties used for validation

Weathered material

The provision of Coulomb failure criteria for soil through a testing programme for this operation yielded the following results:

- Internal friction angle of 35.30
- Cohesion of 14.1kPa
- The density of weathered material was taken as the bulk density of the diabase unit, which equates to 1823.75kg/m³

Completely saturated and fully drained models for weathered material used the abovementioned properties.

Unweathered material

Joint cohesion

Since the potential modes of failure will be largely driven by the presence of discontinuities, the properties of joints (cohesion and friction) are critical to establish slope geometrical constraints for unweathered material. The joint cohesion selected for the validation exercise is based on Barton's shear strength formulation and equates to 71.13kPa (dry) and 59.27kPa (saturated):

$$\tau = \sigma_n \tan[JRC JCS / \sigma_n + \Phi]$$

where JRC is the joint roughness coefficient and JCS the joint wall compressive strength.

The values selected to determine the joint cohesion were based on:

- The lowest UCS of 36MPa
- An average density of 3070kg/m³
- The lowest JRC value of 2.8
- An average friction angle of 37.50 based on direct shear tests
- Normal stress values of 0.08MPa/m which is based on a depth of 55mbs and a joint dipping at 450
- 10% reduction in joint shear strength in 50% partially saturated conditions

Mean joint orientations

Joint orientations for Pit 2 and 3 (Table 10 and Table 11) are based on the values reported previously.

Description	Dip direction	Dip
NE pit slope	043	To be validated
NW pit slope	313	
SW pit slope	223	
Joint set 1	203	75
Joint set 2	297	78
Joint set 3	063	34
Joint set 4	340	51
Joint set 5	147	53

Table 10: Orientation of slope face and major joint sets (pit 3)

Description	Dip direction	Dip
Pit 2A	228	To be validated
Pit 2Bb	295	
Pit 2C	030	
Pit 2D	115	
Joint set 1	277	16
Joint set 2	090	75
Joint set 3	071	26
Joint set 4	116	35

Table 11: Orientation of slope face and major joint sets (pit 2)

Results and discussion

Optimum slope angles (weathered material)

The results of the FSP programme (Figure 22) have indicated that slope angles of 37° based on an FOS=1.3 are permissible in weathered material using:

- A bench face angle of 52°
- A bench height of 10m
- Step outs of 5.6m

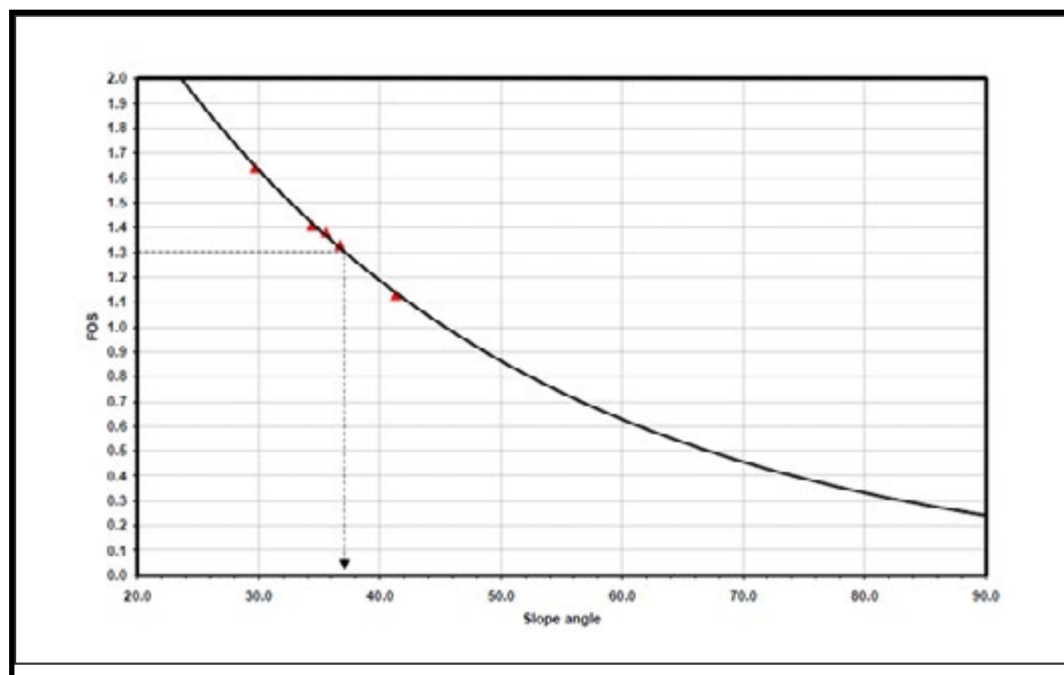


Figure 22: Optimum slope angle for weathered material (pit 2 and 3)

The 37° slope angle is applicable to both Pit 2 and Pit 3 and correlates reasonably well with the 35° slope angle suggested by previous designs. The 2° improvement in angle will necessitate the planning of bench faces at 52°. FOS coupled with shear strain plots from the programme is shown in Figure 23.

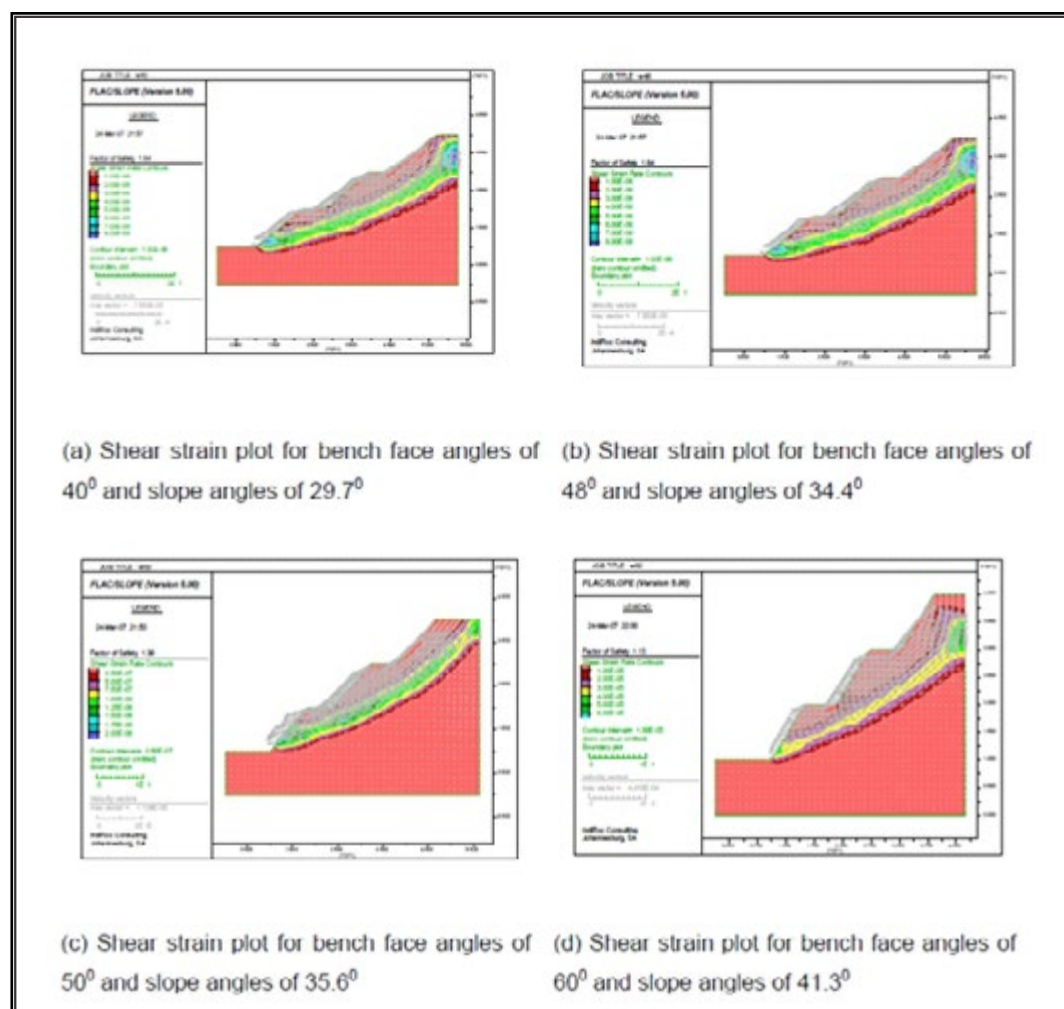


Figure 23: Shear strain plots indicating likely failure paths for weathered material (pit 2 and 3)

Optimum slope angles (unweathered material) Pit 3 wedge failure

There are 10 and 6 combinations of joints that could form wedges in Pit 3 and Pit 2, respectively (Table 12) (Examples in Appendix). The combinations were tested for kinematic feasibility and FOS for wedge failures. The conditions that need to be met to cause wedge failure are described in Hoek and Bray (1983) and are not repeated here.

Pit 2	J1	J2	J3	J4
J1				
J2				
J3				
J4				

Pit 3	J1	J2	J3	J4	J5
J1					
J2					
J3					
J4					
J5					

Table 12: Matrices for joint combinations forming wedges (pit 2 and 3)

Pit 3 – Overall slope angles

The combinations of joints that allow wedge failure to be kinematically feasible are shown in Table 12. The FOS for wedge failure was then calculated for the kinematically feasible combinations.

Pit 3 NE	J1	J2	J3	J4	J5
J1		N	Y	N	N
J2			Y	Y	N
J3				Y	Y
J4					Y
J5					

Pit 3 NW	J1	J2	J3	J4	J5
J1		N	N	Y	N
J2			Y	Y	N
J3				N	N
J4					N
J5					

Pit 3 SW	J1	J2	J3	J4	J5
J1		Y	N	Y	N
J2			N	N	Y
J3				N	N
J4					N
J5					

Table 13: Kinematic feasibility for forming wedges (pit 3)

Although wedges are formed in pit walls northeast and southwest, the FOSs are sufficiently large (Figure 24 and Figure 25) to limit wedge failure. Overall slope angles of 52° based on the MRMR values reported previously are therefore applicable for all slopes in Pit 3 (Figure 26).

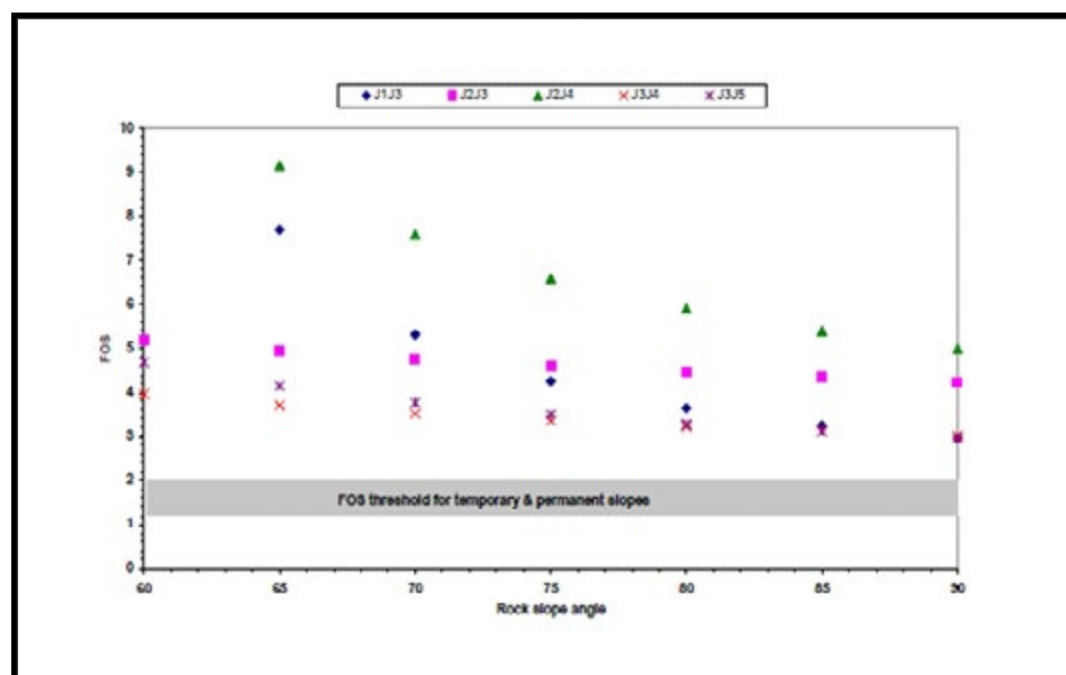


Figure 24: FOS for wedge failure, Pit 3 NE

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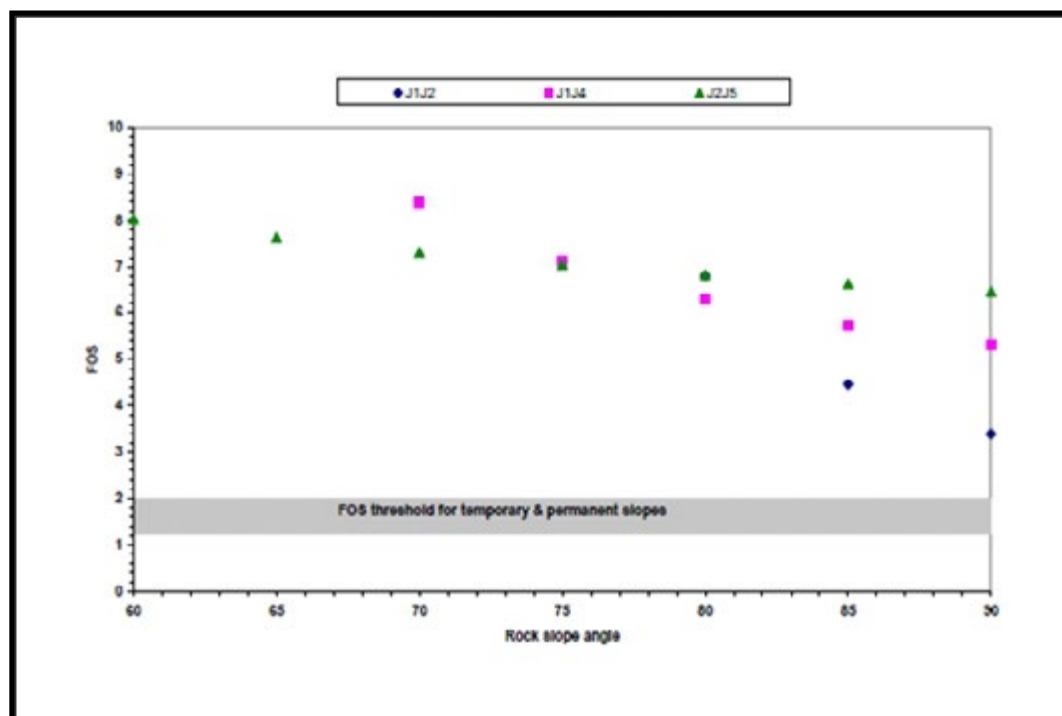


Figure 25: FOS for wedge failure, Pit 3 SW

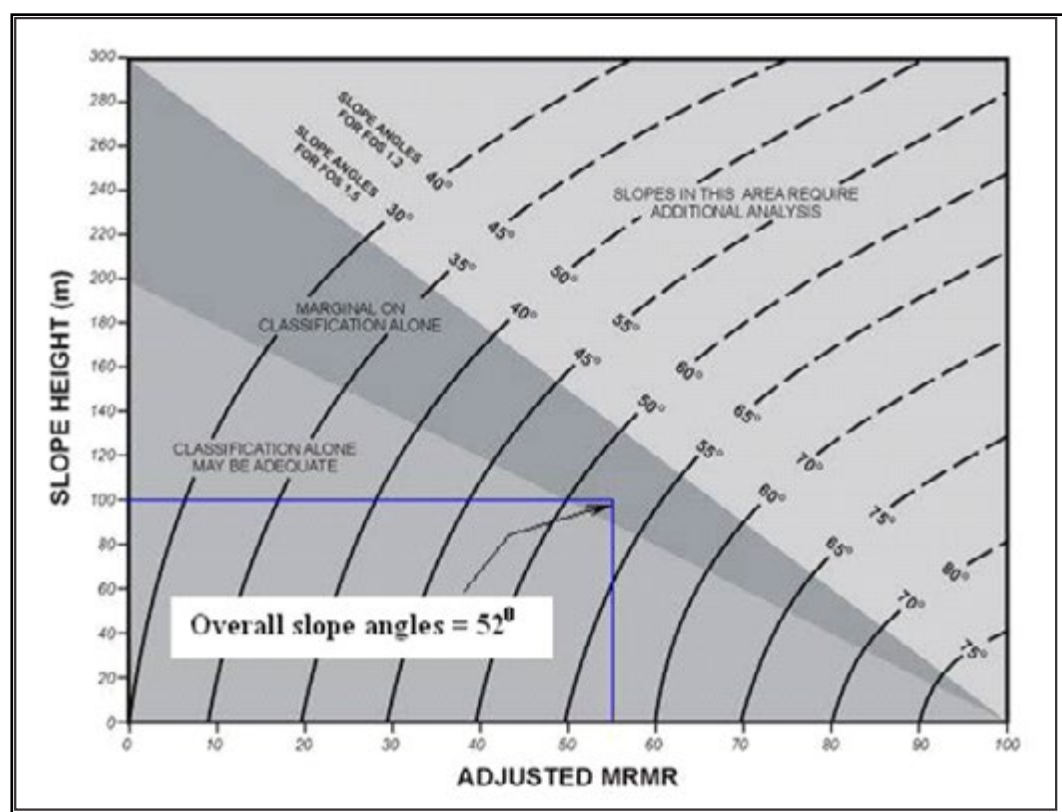


Figure 26: Overall slope angles for Ne and SW slopes

Pit 3 – Stack angles

Wedge failure analyses of the northwest slopes have indicated optimum stack angles of 66° as shown in Figure 27.

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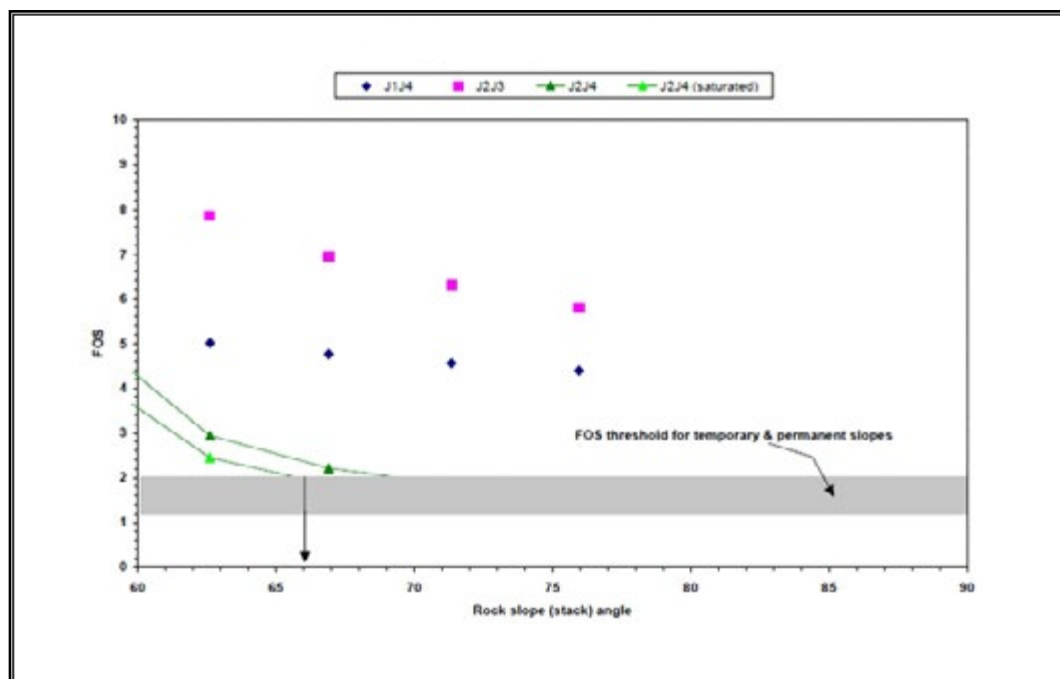


Figure 27: Stack angles based on wedge failure in NW slopes

Pit 3 plane failure

The kinematic feasibility for plane failure is only possible in slopes north-west and southwest (Table 10).

Plane failure					
Pit 3 slopes	J1	J2	J3	J4	J5
NE	n	n	n	n	n
NW	n	y	n	y	n
SW	y	n	n	n	n

Table 14: Kinematic feasibility for plane failure

The analysis of FOS related to stack angles correlates extremely well with the wedge failure analysis and angles of 67.5° are suggested compared to the 66° obtained from the wedge failure analysis.

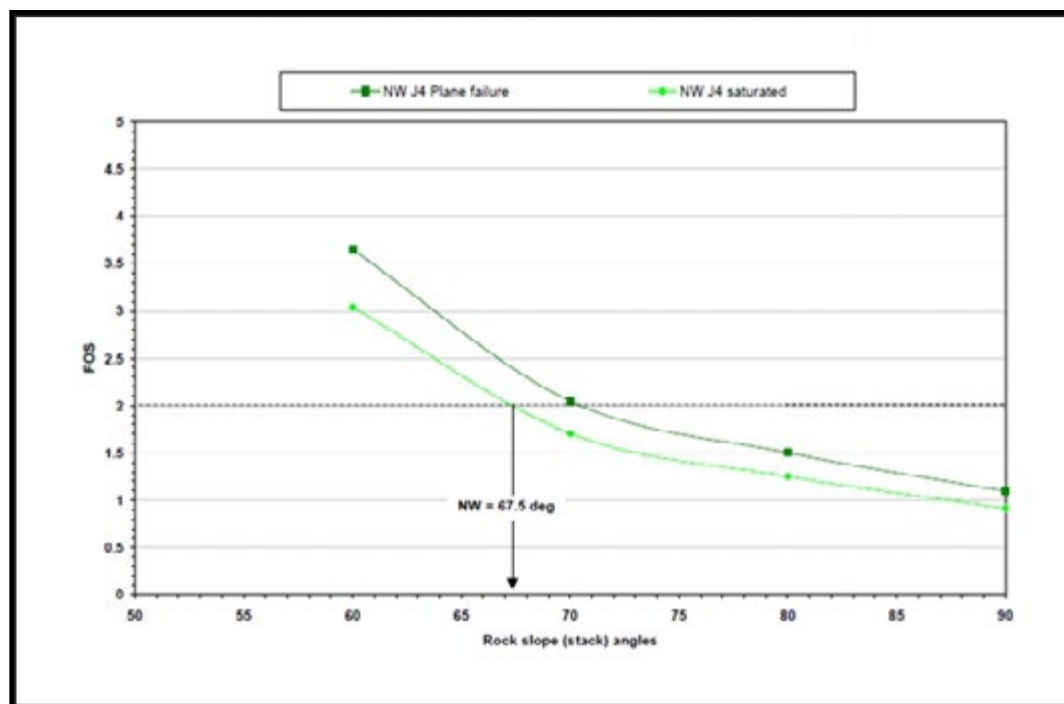


Figure 28: Stack angles based on plane failure in NW slopes

Pit 2 wedge and plane failure

Although wedge failure is kinematically feasible (Table 15) for all slopes, the probability of failure occurring, based on FOS calculations, is highest for the 2D slopes (Figures 29-32).

Pit 2A	J1	J2	J3	J4
J1		n	n	n
J2			n	y
J3				n
J4				

Pit 2B	J1	J2	J3	J4
J1		n	y	n
J2			y	n
J3				n
J4				

Pit 2C	J1	J2	J3	J4
J1		n	y	n
J2			y	n
J3				y
J4				

Pit 2D	J1	J2	J3	J4
J1		n	n	y
J2			n	y
J3				y
J4				

Table 15: Kinematic feasibility for wedge failure (pit 2)

The 2C and 2D slopes indicate kinematic feasibility for plane failure, but the likelihood of this occurring is very limited due to the high joint friction

angles and the orientation of the joints relative to the slope faces. Assuming that the MRMR data provided for Pit 3 is also applicable for Pit 2, the results indicate that overall slope angles for Pit 2A, 2B and 2C should not exceed 52° . Stack angles of 66° are suggested. For Pit 2D (Figure 15), stack angles of 48° (0% saturation) are suggested, which would result in overall slope angles of 41.2° .

Plane failure				
Pit 2 slopes	J1	J2	J3	J4
2A	n	n	n	n
2B	n	n	n	n
2C	n	y	n	n
2D	n	y	n	n

Table 16: Kinematic feasibility for plane failure (pit 2)

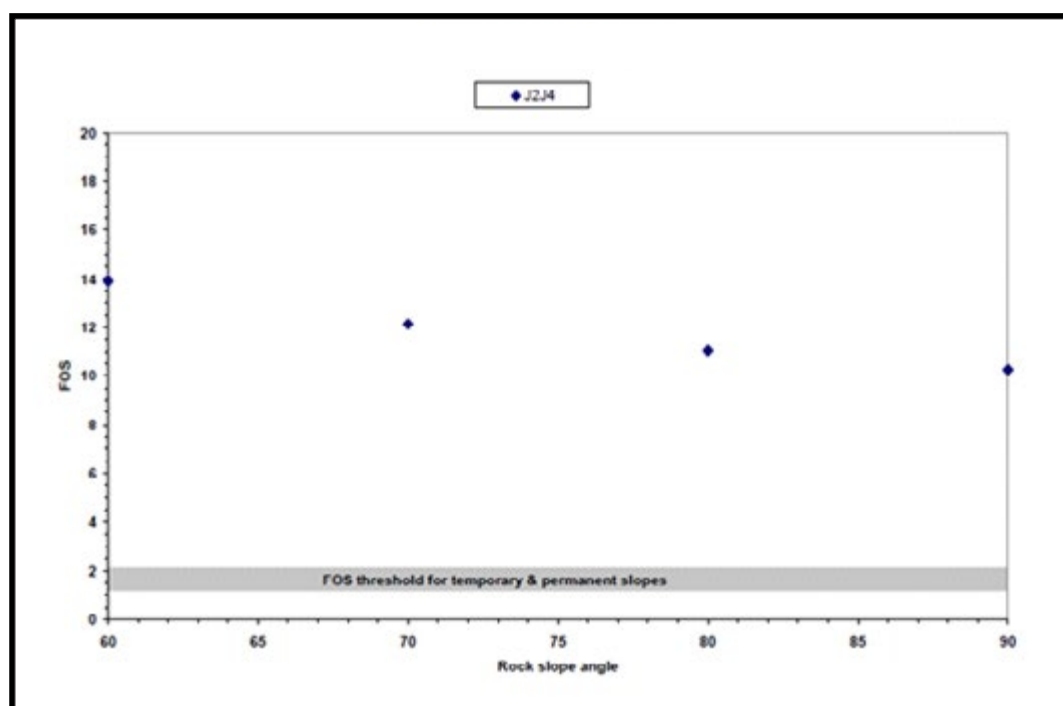


Figure 29: Wedge FOS, Pit 2A

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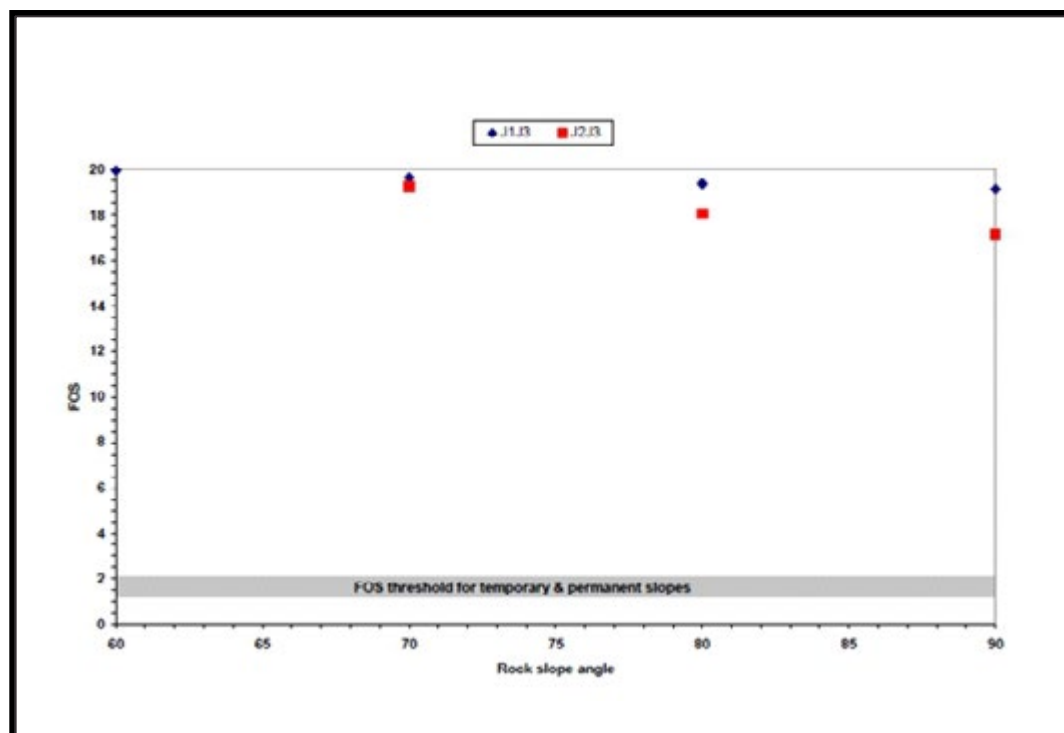


Figure 30: Wedge FOS, Pit 2B

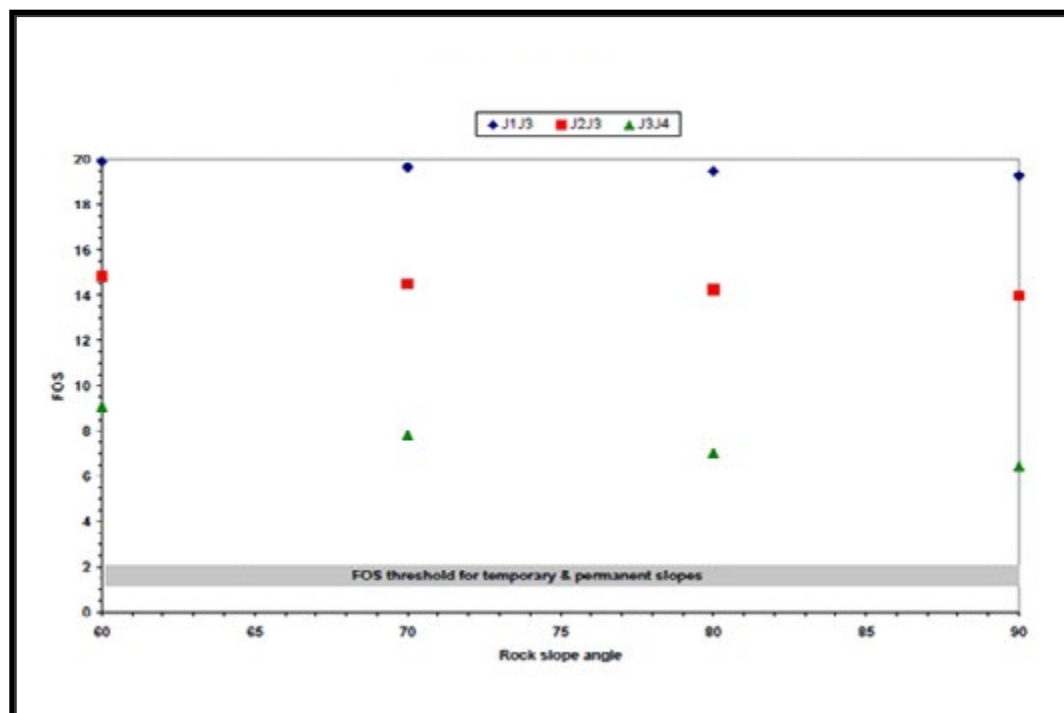


Figure 31: Wedge FOS, Pit 2C

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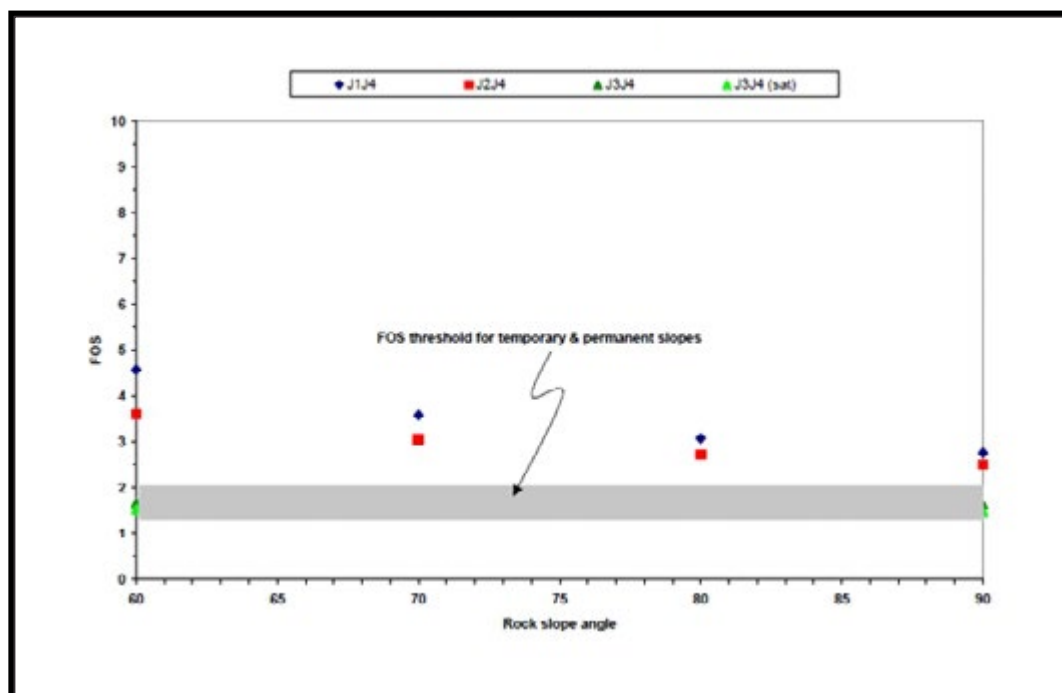


Figure 32: Wedge FOS, Pit 2D

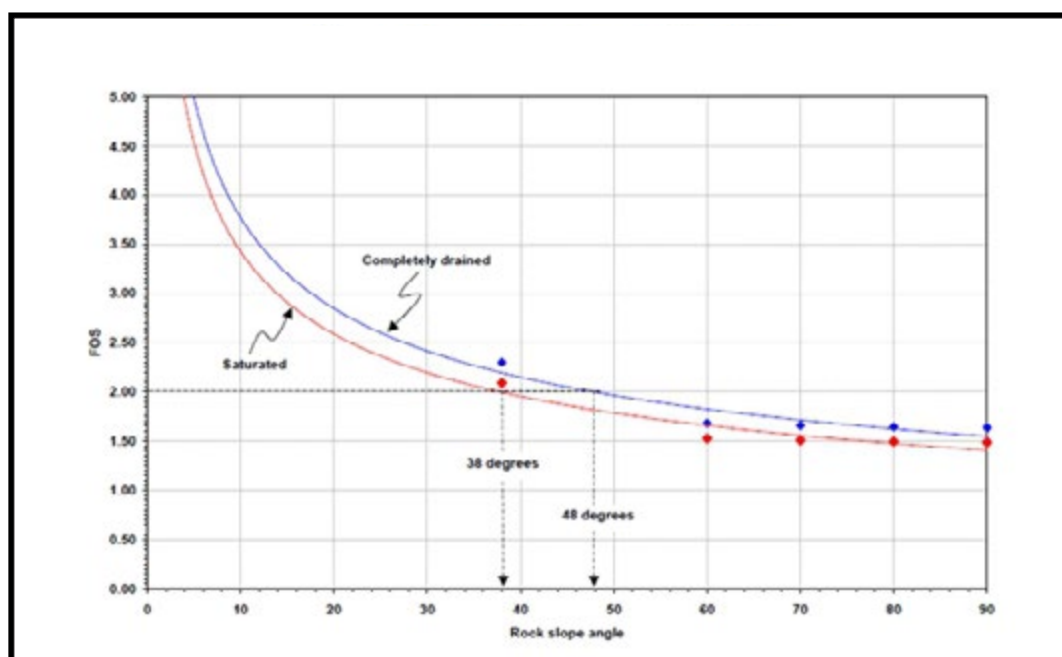
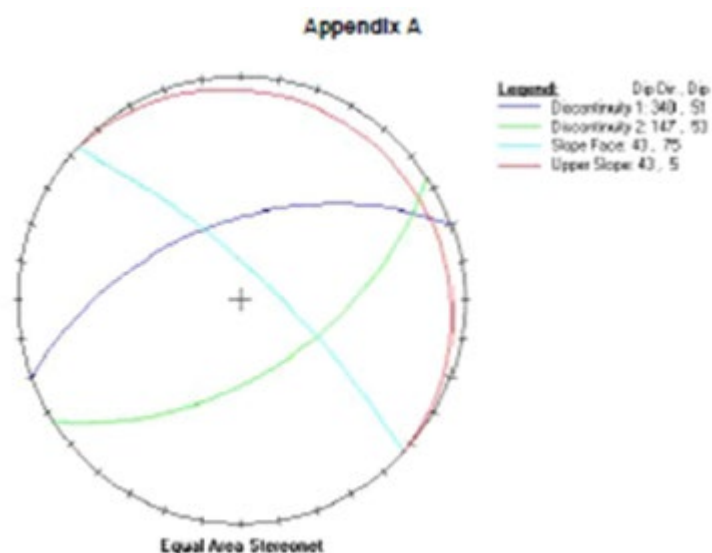


Figure 33: Optimum stack angles, Pit 2D

Conclusions

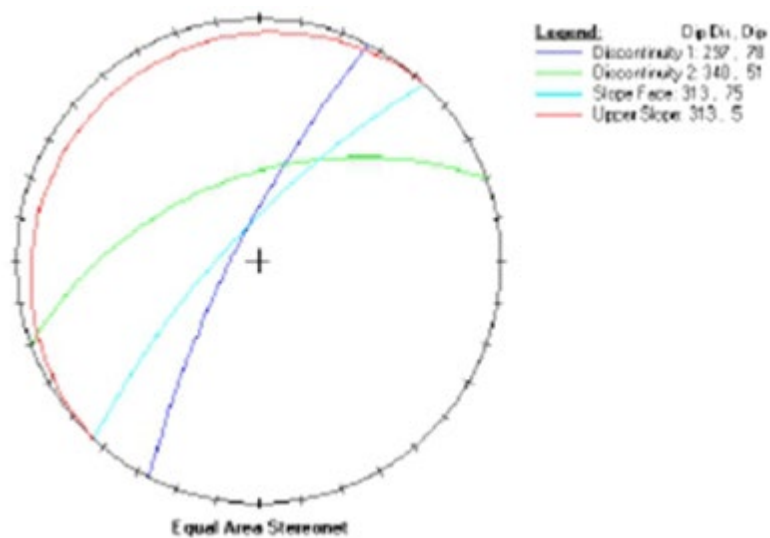
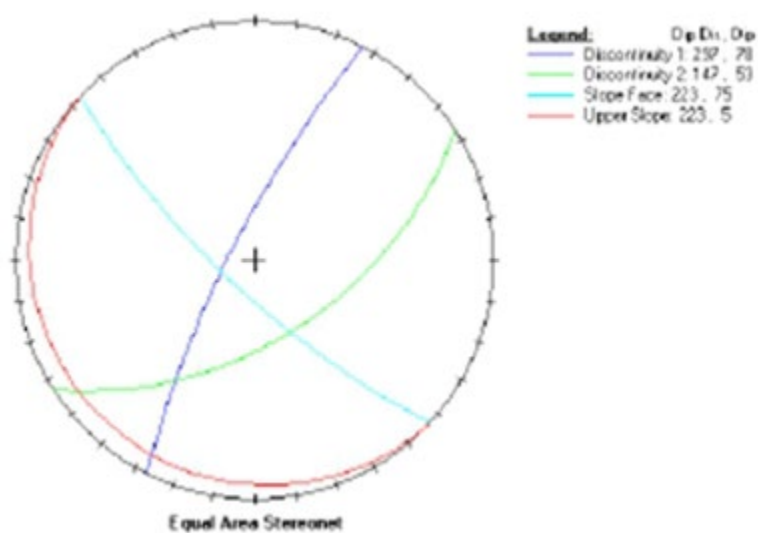
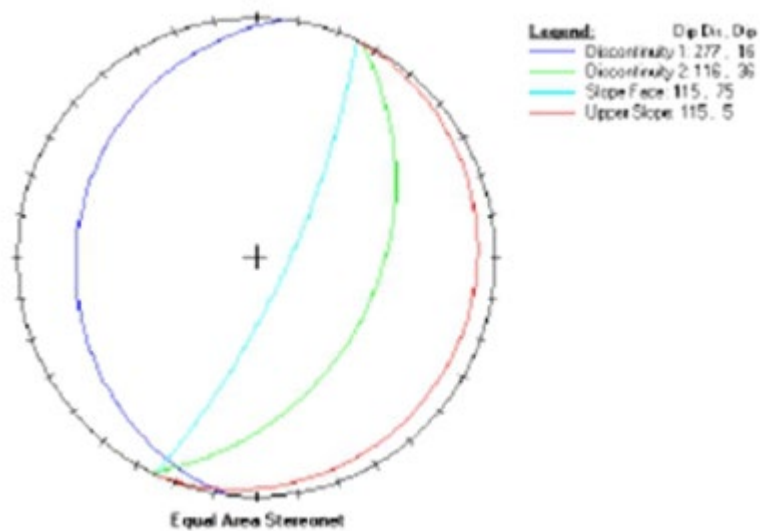
Minor variations are suggested to the geometrical constraints suggested previously shown in the accompanying tables. The closeness of the results obtained from this independent validation to that suggested previously indicates that the methods and techniques used in previous studies are sound.

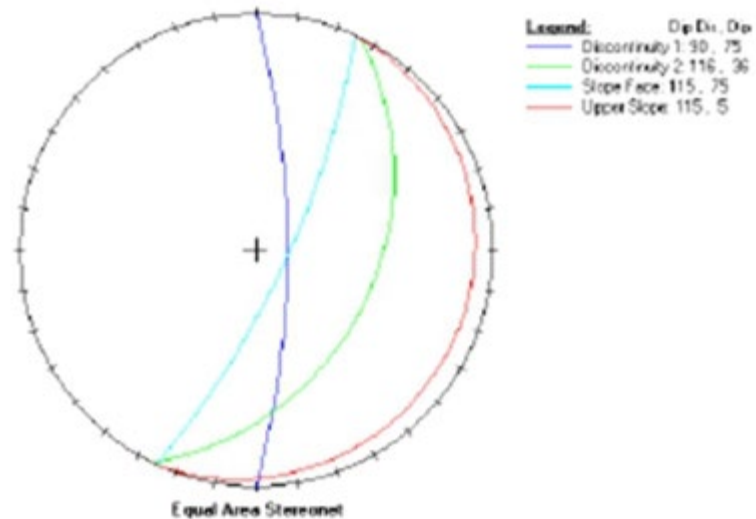
Slope geometrical parameter	James (2007)	Validation exercise
Pit 2 and 3 (Weathered material)		
Bench angles	50	52
Slope angles	35	37
Inner stack berms (stepouts)	5.6	5.6
Pit 3		
Bench angles	80-85	80
Slope angles	50	52
Inner stack berms (stepouts)	5.6	5.6
Stack angle	67	66
Stack height	40	40
Pit 2 A,B,C		
Bench angles	80-85	80
Slope angles	55	52
Inner stack berms (stepouts)	5.6	5.6
Stack angle	67	66
Stack height	40	40
Pit 2 D		
Bench angles	80-85	80
Slope angles	45	41.2
Inner stack berms (stepouts)	9.7	9.7
Stack angle	54	48
Stack height	40	40

Table 17: Validated slope geometrical constraints**Appendix****Pit 3 NE J4J5 wedges**

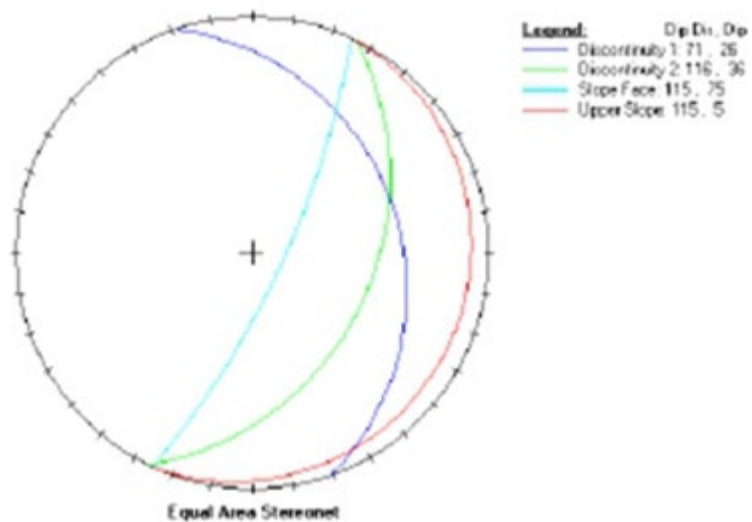
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**Pit 3 NW J2J4 wedges****Pit 3 SW J2J5 wedges****Pit 2D J1J4 wedges**
[back](#)



Pit2D J2J4 wedges



Pit2D J3J4 wedges

LEARNING OUTCOME 3.4.2.5

EVALUATE SLOPES EXPOSED TO STEP PATH FAILURE.

Rock masses are systems comprising intact rock and geological discontinuities. As conceptually shown in Figure 34, high rock slope failures may involve several mechanisms. Typical failure modes may include:

- sliding on one or more major geological discontinuities;
- sliding along circular failure paths through the intact rock or across rock mass fabric;
- toppling; and
- composite modes, involving two or more of the above mechanisms.

Slope failure may be progressive and the assessment of which failure mode(s) is/are relevant to the stability of the slope being considered is important.



The step path failure approach is only applicable where the predominant failure mode is 'sliding'.

Sliding may occur along large numbers of short, adversely dipping, geological discontinuities within the rock mass. This process is often accompanied by dilation of the mass as the failure path 'steps up' on other discontinuities within the rock mass by shearing through and/or tensile failure of the intact rock and/or rock mass 'bridges' between the discontinuities.

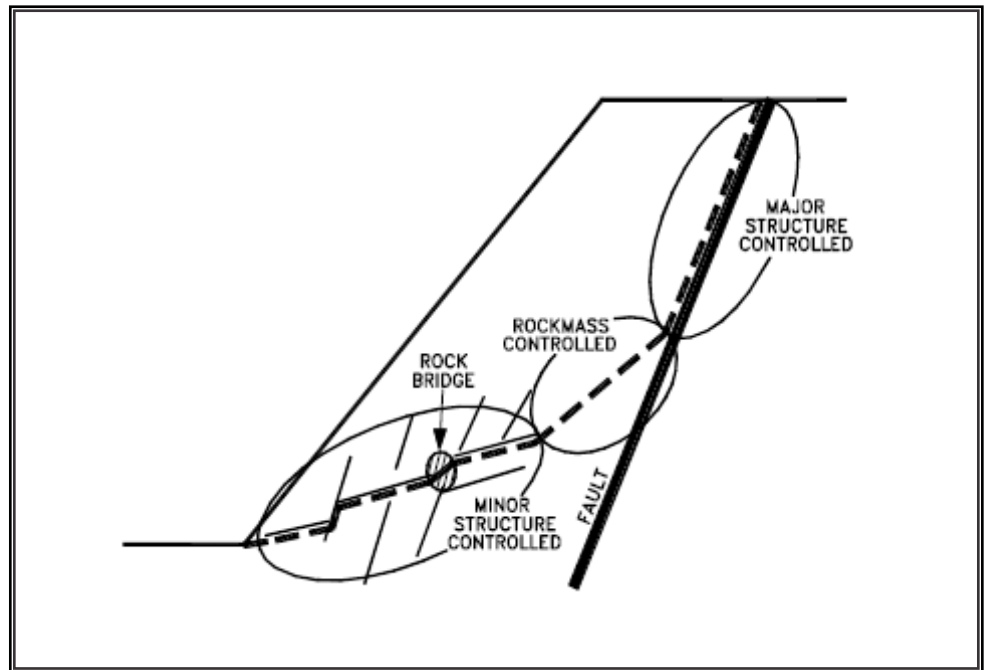


Figure 34: Step path failure through the rock mass

Different techniques have been developed to deal with sets of non-persistent discontinuities that assist or contribute towards failure.

For example, using stochastic techniques, Einstein made an attempt at relating rock mass stability with persistence in the geometry and spatial variability of discontinuities. However, this approach was based on the limit equilibrium analysis and therefore remained limited in reproducing and understanding the progressive nature of slope failure.



Stochastic programmes work by using probabilistic methods to solve problems.

More recently, numerical methods have led to significant enhancements in rock slope stability analysis, taking into account complex issues such as anisotropy, fracture generation, 3D effects, non-linear behaviour, etc.

EXAMPLE

- the application of a particle flow code can provide valuable insight into the stability analysis of heavily jointed rock slopes;
- a coupled FEM/DEM formulation can reproduce observed failure mechanisms by taking advantage of both continuous and discrete approaches;
- A step further is to use 3D models that can reproduce the complex combination of intact material fracturing and yielding within discontinuity planes.



- [Step path failure: Mechanism](#)
- [Step path failure: Massive rock slopes](#)
- Step path failure: Rocscience
- [Step path failure Baczynski](#)

INTERESTING INFO

Link to:

- [Step path failure in alpine rock slopes](#)
- [Combined failure mechanisms in rock slopes](#)

3.5. SOIL AND LOOSE ROCK SLOPE STABILITY

LEARNING OUTCOME 3.5.1

DESCRIBE, EXPLAIN AND DISCUSS THE INVESTIGATION, ANALYSIS AND EVALUATION OF SLOPES COMPRISING THE FOLLOWING TYPES OF MATERIALS:

- Soil and overburden
- Deeply weathered rock
- Spoil piles.

EXAMPLE

The issues are described based on the example below.

The primary objective in the planning of the waste rock dump (WRD) is to minimise adverse environmental impacts while also selecting a site that is economical to develop, operate and decommission. Siting a WRD involves technical, environmental and social factors.

The site selection process involves identifying all potential sites within an economical transport distance from the open pit (WRDs) or mill (ore stockpiles) and then examining them against specific constraints and criteria for suitability as a waste disposal facility. Site selection criteria should include minimising environmental impacts, maximising disposal capacity, and minimising haul distances. A crude geotechnical rating of the site is contained in Table 18 where 1 is unfavourable and 5 extremely favourable. The unfavourable parameters are further addressed in the risk assessment.

Table 18: Site selection matrix for the SOUTHERN WRD

Sub-surface conditions

The sub-surface characteristics described below have been derived from the appropriate geological and geotechnical databases.

- The immediate soil layer can be described as Aeolian, loose, sandy and transported rather than residual soil;
- The mean thickness of the soil layer is 4.72m (Table 19) and is not expected to exceed this thickness in the footprint areas of the WRDs (Figure 35);
- The Kalahari sand has a friction angle of 34 degrees and an unsaturated density of 1900kg/m³;

- The equivalent Mohr-Coulomb properties for the calcretes are listed in Table 20. Note that these parameters were converted to rock fill parameters that are shown in later sections of this report.

Rock/Soil	Mean	Std dev	Min	Max
Kalahari sand	4.72	2.03	1.00	13.00
Soft calcrete	14.57	5.22	2.00	25.00
Hard calcrete	7.88	5.50	0.70	26.00

Table 19: Sub-surface soil and rock thickness below WRDs

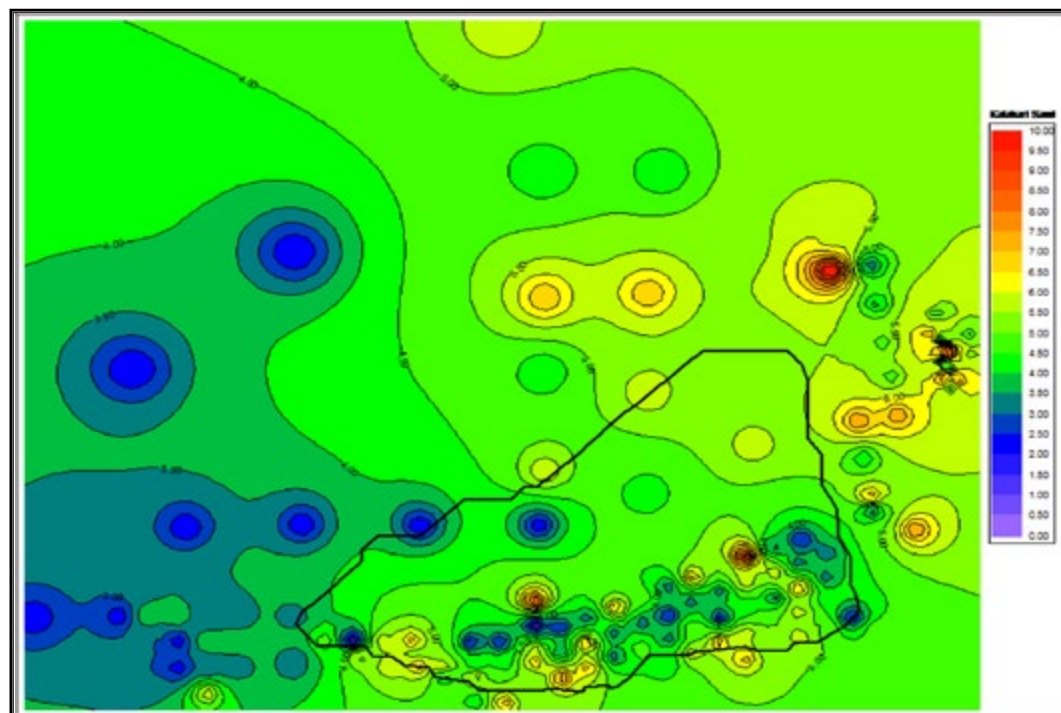


Figure 35: Colour density thickness plot of Kalahari Sands

Properties	Units	Kalahari sand	Soft calcrete	Hard calcrete
ρ	kg/m ³	1900	2190.00	2190.00
c	kPa	0	180.34	492.12
θ	degrees	34	32.95	43.01

Table 20: Sub-surface rock and soil geotechnical properties

Waste material characterisation

The waste material will consist of an assortment of rocks belonging to the Kalahari Formation, Mooidraai Formation and Hotazel Formation. Unsorted dumping of material is assumed. Due to the aseismic signature of the area, no seismic coefficient was applied to the design. The properties of the different types of waste material (Table 21 and Figure 36) were derived using statistical methods that incorporate the following parameters into the accompanying set of equations to determine the waste secant friction angle.

- Angularity was measured on a scale from 1 to 8 with 8 being extreme angularity and 1 low angularity
- Fines – percentage of fines passing 0.075mm (%)
- Coefficient of curvature
- UCS – Unconfined compressive strength of the rock (MPa)

$$\Phi = a + b\sigma_c^n$$

$$\Phi' = \text{secant}^n \text{ friction angle}$$

$$a = 36.43 - 0.276\text{ANC} - 0.172\text{FINES} + 0.756(\text{C}-2) + 0.0459(\text{UCS}-150)$$

$$b = 69.51 + 10.27\text{ANG} + 0.594\text{FINES} - 5.105(\text{C}-2) - 0.408(\text{UCS}-150) - 0.408$$

$$c = 0.3974$$

WASTE TYPE	ANG	FINES	cc	UCS (MPa)	Density (kg/m ³)	Normal stress (kPa)	a	b	c	f
Soft calcrete	3	30	0	5.13	2190	1289.95	22.31	185.70	-0.40	33.09
Hard calcrete	5	30	0	19.65	2190	1289.95	22.44	200.31	-0.40	34.07
Gravel	4	40	0	12.56	2190	1289.95	20.66	198.43	-0.40	32.18
Clay	1	60	0	2.95	1900	1119.14	17.58	182.52	-0.40	28.79
Dolomite	6	20	0	156.04	2717	1600.37	30.15	149.45	-0.40	38.12
Banded Ironstone	7	10	0	295.56	3156	1858.95	38.01	97.30	-0.40	42.90

Table 21: Properties for waste material

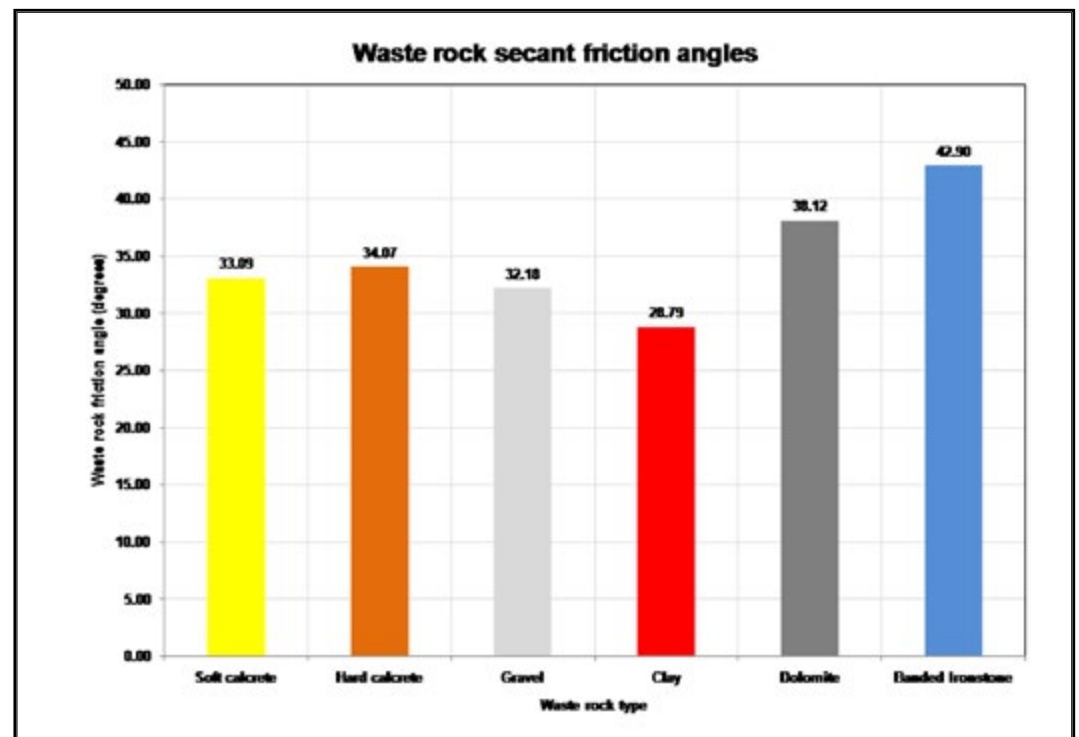


Figure 36: Graphical representation of waste rock friction angles

Validation of slope angles for WRDs

The Rocscience programme SLIDE was used to validate slope angles used for the bankable design of the WRDs. The output of SLIDE is the slope safety factor (SF), which is based on both Bishops and Janbu's methods

of slices for rotational or circular failure. The limiting or threshold SF used for the WRDs is 1.3 (Table 22) as suggested by Stacey (2002).

Consequences of failure	Examples	Minimum FOS
Not serious	No person-entry	1.2
	Individual benches, small temporary slopes not adjacent to haul roads	1.3
Moderately serious	Any slope of a permanent or semi-permanent nature	1.6
Very serious	Medium sized and high slopes carrying major haulage roads or underlying permanent mine installations	2.0

Table 22: Threshold Safety Factors for WRDs (SF = 1.3)

Slope geometrical parameters used for design

The validation process entailed setting up slope geometries in accordance with that used for the WRDs and assessing their SFs against the threshold of 1.3. The slope angles provided by the mine design engineers are shown in Table 23.

Slope parameter	Southern WRD
Lift height (m)	20
Bench face angle (BFA)	35
Berm width (m)	65
Overall slope angle	18

Table 23: Design angles of WRDs for validation

Limit equilibrium model setup

The bench scale geometry suggested for the in and out pit WRDs was constructed in SLIDE (Figure 37) and limit equilibrium analyses performed using the Mohr coulomb failure criteria with the properties listed in earlier sections of this report. The SFs were noted for the different material types for fully drained conditions.

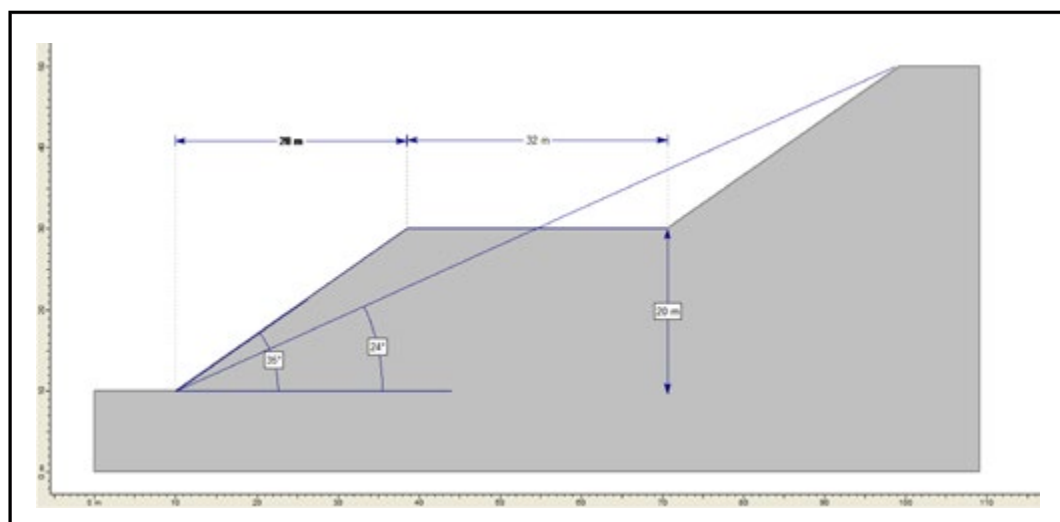


Figure 37: Construction of WRD bench geometries showing BFA and overall slope angles

Results and discussion

The SFs indicate that the BFAs need to be in the range of 26-36 degrees for all materials except the clay (Figure 38 and Table 24, Appendix A).

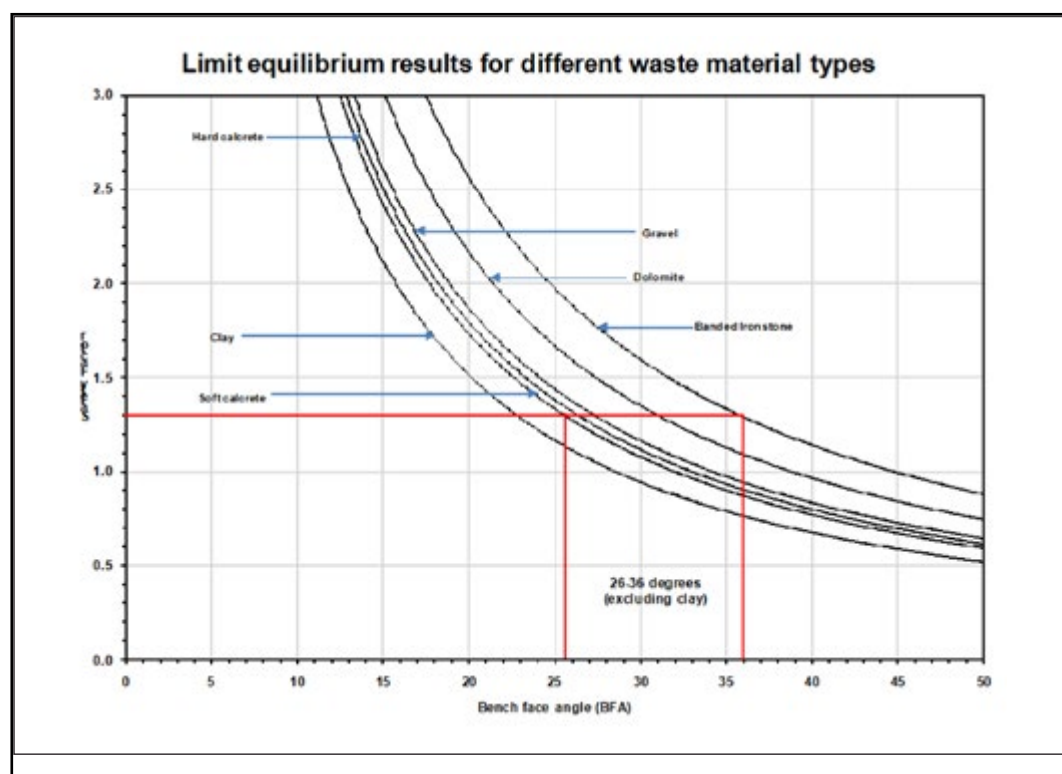


Figure 38: Limit equilibrium results of Safety Factor related to bench face angles

BFA	Waste rock types					
	Soft calcrete	Hard calcrete	Gravel	Clay	Dolomite	Banded ironstone
35	0.9	1.0	0.9	0.8	1.1	1.3
30	1.1	1.2	1.1	1.0	1.4	1.6
20	1.8	1.9	1.7	1.5	2.2	2.6

Table 24: Safety factors as a function of waste material type and BFA

The following slope geometrical constraints and operating practices are suggested:

- If indiscriminate (i.e. no material sorting), dumping is to be practised, bench face angles for both the northern and southern pits should **not exceed 26 degrees** under the following provisos:
 - The clay material must not form the outer walls of the waste rock dumps;
 - The soft calcrete material must not form the outer walls of the waste rock dumps;
 - The clay and soft calcrete must not be placed on the first 20m dump lift; and
 - Toe drains must be constructed at the bottom of each lift bench and the water directed to appropriate disposal or treatment facilities.
- To provide an overall slope angle of 18 degrees, the **berm width will need to be increased to 42m** if lift heights are to remain at 20m.

- Some consideration should be given to **reducing lift heights from 20 to 15m** to accommodate crest settlement due to the potential high clay content of waste material.
- A **safety berm (windrow) is to be used as a back stop** at all times at the platform crest. The minimum berm height should be one half the height of the highest haul truck tire.
- Dump surfaces must be developed to **provide positive drainage to prevent ponding and infiltration**. This is accomplished by maintaining a drainage gradient on the platform so that water drains away from the crest.
- An appropriate **monitoring strategy** must be developed and implemented for the WRDs, the most effective being formalised planned task observations of:
 - Excessive surface cracking;
 - Safety berms will not stay in place;
 - Surface build up required;
 - Bulging of the dump face;
 - Toe or foundation creep and bulging; and
 - Changes in the rate or quality of seepage from the dump toe.
- The main purposes of the surveillance of the waste dumps will be:
 - To protect the personnel and equipment working on and below the dumps;
 - To minimise the risk to infrastructure located below the dumps during the life of the mine;
 - To provide early warning of impending failure so that personnel and equipment can be removed from the area at risk; and
 - To collect and assess data that will confirm or negate the assumptions made during the design process and allow the design of the dump to be modified during the life of the mine to improve the performance of the dump.

3.6. ADVANCED EVALUATION TECHNIQUES

LEARNING OUTCOME 3.6.1

DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE FOLLOWING ADVANCED TECHNIQUES TO EVALUATE THE STABILITY OF SLOPES:

- Limit equilibrium analyses
- Factor of safety, probability of failure
- Numerical analyses
- Flac, Udec

Limit equilibrium and finite element models **Limit equilibrium analysis**

The limit equilibrium methods investigate the 'equilibrium' of the soil/rock mass intending to slide under the influence of gravity on assumed or known potential slip surfaces in the soil or rock mass.

All methods are based on the comparison of forces (or stresses) resisting slip within the rock mass and those causing instability. These methods assume that the shear strengths of the materials along the potential

failure surface are governed by the relationship between shear strength and the normal stress on the failure surface. The calculations determine that slip surface shows the lowest value of factor of safety, and denotes it as the critical slip surface.

Analysis provides a factor of safety, defined as a ratio of available shear resistance (capacity) to that required for equilibrium. If the value of factor of safety is less than 1.0, the slope is unstable. The most common limit equilibrium techniques are methods of slices where soil mass is discretised into vertical slices (Janbu or Bishop).



- Page 247, Rock slope engineering, Hoek and Bray, 1999



The program **FLAC/Slope** (*Fast Lagrangian analysis of continua in two dimensions for slopes*) is an advanced factor-of-safety determination for rock and soil slopes. Solution is based on explicit finite-difference method (FDM) that can model complex behaviours, such as large displacements and strains.

Another limit equilibrium program, *SLIDE*, provides 2D stability calculations in rocks or soils using these analysis methods, which include Spencer, Morgenstern-Price/General limit equilibrium and Bishop simplified and Janbu simplified/corrected.

It also allows for a probabilistic analysis using Monte Carlo simulation techniques, where any input parameter can be defined as a random variable.

Rock slope stability analysis based on limit equilibrium techniques may consider the following modes of failure:

- *Planar failure*: Rock mass sliding on a single surface (special case of general wedge type of failure); two-dimensional analysis may be used according to the concept of a block resisting on an inclined plane at limit equilibrium;
- *Wedge failure*: Three-dimensional analysis enables modelling of the wedge sliding on two planes in a direction along the line of intersection;
- *Toppling failure*: Long thin rock columns formed by the steeply dipping discontinuities may rotate about a pivot point located at the lowest corner of the block applying the concept of moments around the base of the block where toppling occurs if driving moments exceed resisting moments.

Where Flac models the rock mass as a continuum, UDEC views and analyses the rock mass as a discontinuum. Discontinuum approaches are useful for rock slopes controlled by discontinuity behaviour where the rock mass can be seen as the combination of distinct, interacting blocks subjected to external loads and assumed to displace within the rock mass. This method allows for sliding between the blocks or particles. The *distinct-element* approach describes the mechanical behaviour of both the discontinuities and the solid material where joints are treated as boundary conditions.

UDEC (universal distinct element code) is suitable for high jointed rock slopes subjected to static or dynamic loading. Two-dimensional analysis

INTERESTING INFO

Numerical models that assist with kinematic analysis

- Kinematic analysis examines which modes of failure can possibly occur in the rock mass. Analysis requires the detailed evaluation of rock mass structure and the geometry of existing discontinuities contributing to block instability. Stereographic representation (stereonets) of the planes and lines is used.

- A program DIPS allows for the visualisation of structural data using stereonets, the determination of the kinematic feasibility of rock mass and statistical analysis of the discontinuity properties.

- Joint set intersections and discontinuity data can be imported to the program SWEDGE to compute factor of safety against wedge failure by limit equilibrium technique.

allows for the simulation of large displacements, modelling deformation or material yielding.

CONNECTION 21

Paper 2 Outcome 6.4



- Slope stability using phase 2 [Rocscience](#)
- [SSR vs LE Hammah](#)
- [SSR method for GHB Hammah](#)

Factor of safety

The index 'Factor of safety', as it applies to slopes, is determined differently in the different methods of slope stability analysis:

- Kinematic analysis: FOS is the ratio of the total force available to resist sliding on a surface to the total force that wants to induce sliding;
- Finite element: Phase 2 software applies the process of SSR (shear strength reduction) to run a number of analyses and determine the factor (SRF or strength reduction factor) by which the shear strength must be reduced to allow failure to occur, which is reported as the critical SRF ;
- Limit equilibrium: SLIDE/Flac reports FOS as the ratio between the resisting shear forces and disturbing shear forces on a critical failure surface;
- Other options include the ratio of resisting to disturbing moments for toppling failure, etc.

Probability of failure

Probabilistic analysis determines the probability of failure that provides a better representation of the level of risk than purely FOS. This method allows the provision of input parameters as a range rather than specific single values, as represented by the mean value and the standard deviation of a set of property values. In the analysis, the phase 2 software will apply a number of parameter combinations and provide output in the following formats (not necessary all models):

- Mean FOS/SRF;
- Standard deviation of the FOS/SRF values obtained by the modelling;
- A probability of failure that is determined by assuming a normal distribution for all input and output values and then calculating the probability that the critical SRF is less than 1.

EXAMPLE

In the kinematic analysis, acceptance levels based on the guidelines issued by Stacey (2002) have been implemented (Table 25) and a probability of failure (PoF = 25%) has been adopted as the threshold. This is within industry accepted norms provided geotechnical risk mitigating measures are implemented proactively during the operational phase. The probabilities of toppling, planar and wedge failures were assessed

Highlighted areas of failure were analysed for the current mining direction with all joint sets and fault planes at 80°/315° and 80°/135° and for two possible directions of the highwall striking at 180° and 360° if mining were to be done along strike of the ore body.

Probability of failure (%)	Design criteria on basis of which probability of failure is established		
	Serviceable life	Minimum surveillance required	Frequency of evident slope failure
50-100	Effectively zero	Serves no purpose (excessive probability tantamount to failure)	Slope failures generally evident
20-50	Very short term (temporary open-pit mines – untenable risk of failure in temporary civil works)	Continuous intensive monitoring with sophisticated instruments	Significant number of unstable slopes
10-20	Very short term (quasi-temporary slopes in open pit mines – undesirable risk of failure in quasi-temporary civil works)	Continuous monitoring with sophisticated instruments	Some unstable slopes evident
5-10	Short term (semi-temporary slopes in open-pit mines, quarries of civil works)	Continuous monitoring with simple/rudimentary instruments	Occasional unstable slope evident
0-5	Medium term (semi-permanent slopes)	Conscious superficial monitoring	No ready evidence of unstable slopes

Table 25: Comparative significance of probability of failure (Stacey, 2002)

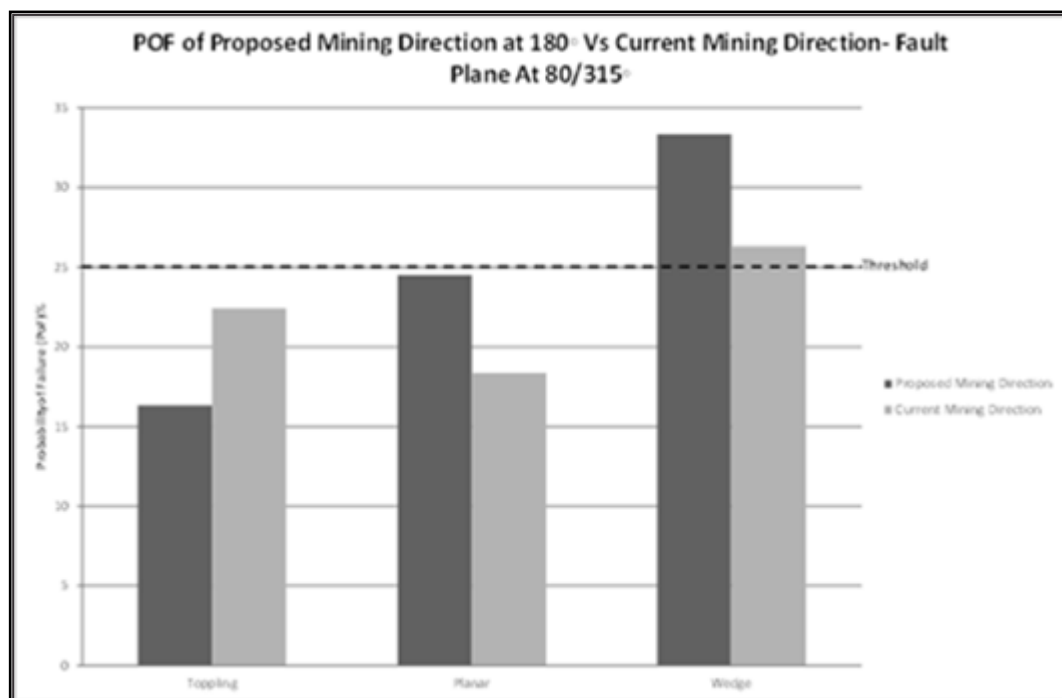


Figure 39: PoF: 180° highwall strike orientation with faulting at 80°/315°

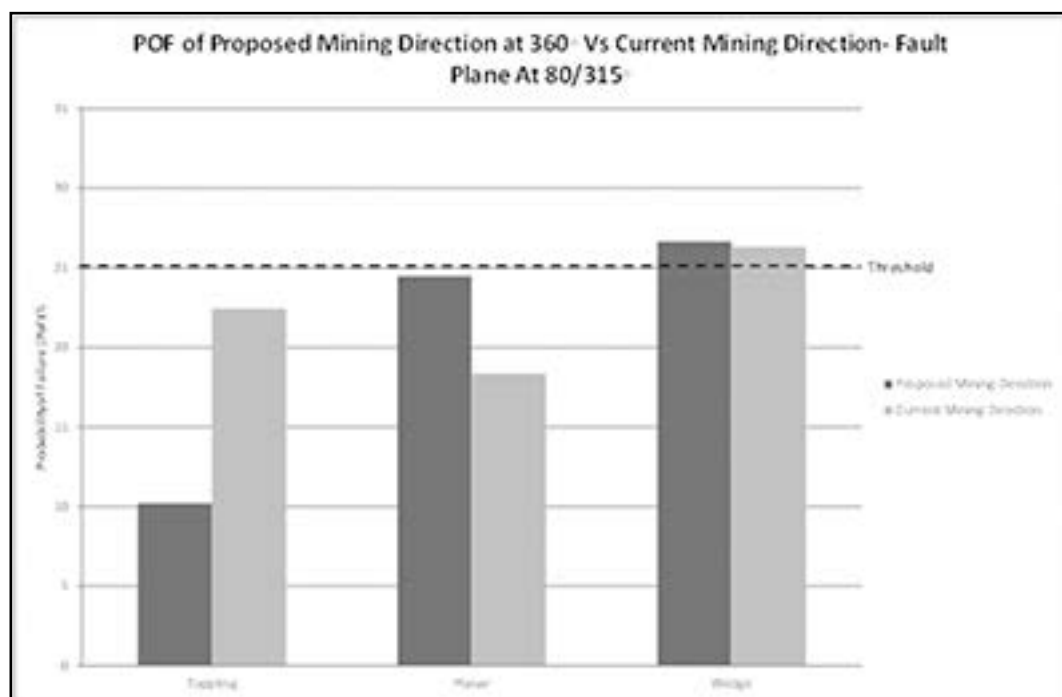


Figure 40: PoF: 360° highwall strike orientation with faulting at 80°/315°

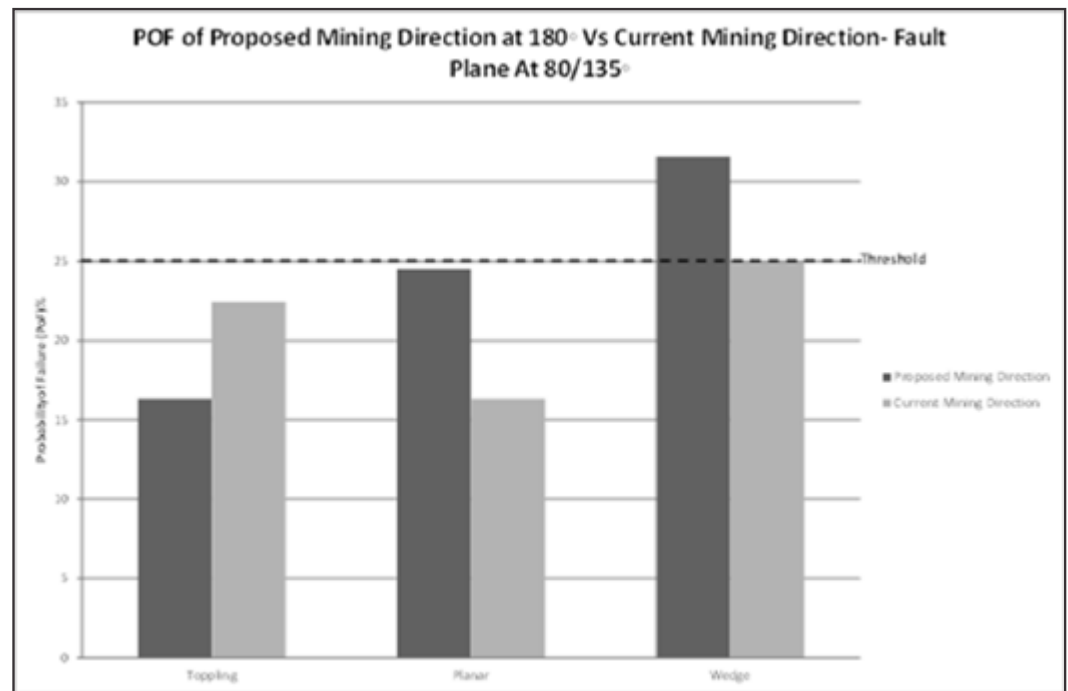


Figure 41: PoF: 180° highwall strike orientation with faulting at 80°/135°

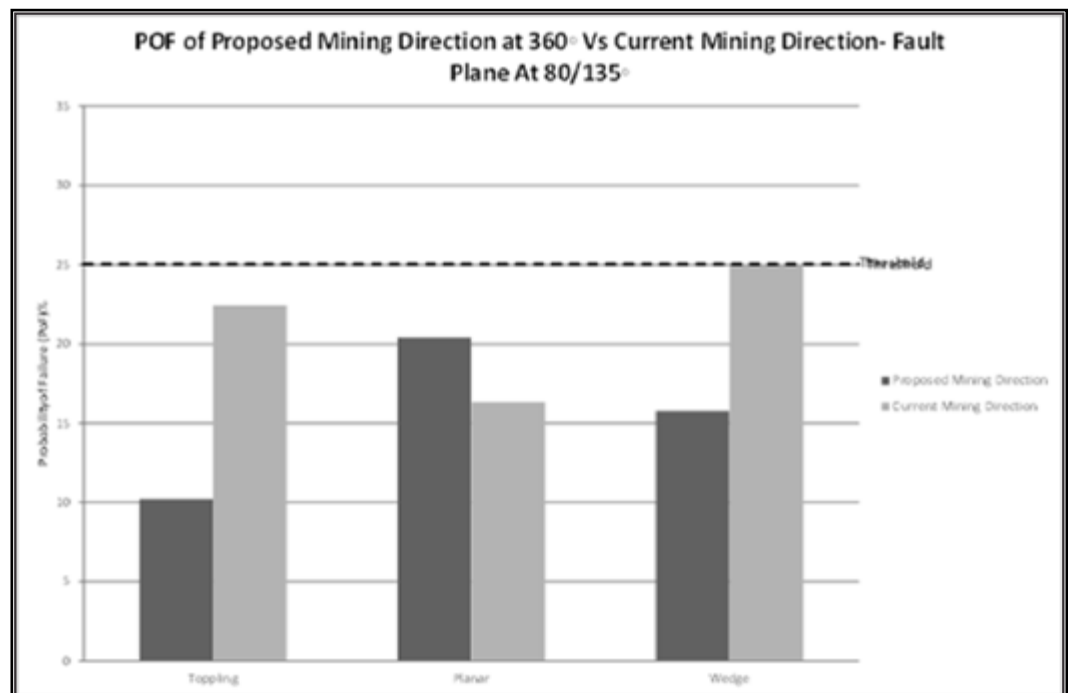


Figure 42: PoF: 360° highwall strike orientation with faulting at 80°/135°

The results expressed can be summarised as follows:

1. Toppling failure mechanism:
 - Lower risk levels are to be experienced in the proposed new direction highwalls than in the current highwalls;
 - Probability levels are lower than the acceptable threshold;
2. Planar failure mechanism:
 - Higher risk levels to experience planar failures will exist in the proposed new highwalls compared to the current highwalls;

- Probability levels will still be lower than the acceptable threshold; but
 - Precautions should be put in place to manage this increased risk;
3. Wedge failure:
- Increased risk levels to experience wedge failures in the proposed new highwall;
 - Probability levels for this type of failure are above the acceptable threshold; and
 - Indicate that highwalls must be temporary and that monitoring is critical.



- [Rock mass properties for surface mines](#)
- [Slope height vs slope angle data base](#)



- Page 213, 223, 432, Guidelines for open pit design, J Read, 2009

LEARNING OUTCOME 3.6.2

CONNECTION 22

Refer to "[LEARNING OUTCOME 3.1.6](#)" on page 62

DESCRIBE, EXPLAIN AND DISCUSS THE CIRCUMSTANCES IN WHICH APPLICATION OF THE ABOVE TECHNIQUES IS WARRANTED.

3.7. EARTHQUAKE LOADING

LEARNING OUTCOME 3.7.1

DESCRIBE, EXPLAIN AND DISCUSS THE EFFECTS OF EARTHQUAKE LOADING ON SURFACE MINING OPERATIONS.

The following impacts are possible:

- Ground motions can trigger landslides;
- Sudden displacements along faults can occur on ground surface, disrupting roads;
- Settling or consolidation of soils may cause damage to structures if foundation deformation occurs; and
- Ground accelerations may induce additional (inertial) forces to the rock mass, affecting the stability of the highwalls.



The impact of seismic loading on slopes is more pronounced in weak, soil-like materials, especially when saturated, where liquefaction of the soils has been reported.

Very few cases of seismic interaction with the stability of hard rock pit slopes have been reported, and where some damage was reported it was of small scale and limited to shallow slides and rockfalls that did not affect the overall stability of the mine.



Liquefaction: A process by which water-saturated sediment temporarily loses strength and acts as a fluid.



- For more detailed seismic information for sites across the world, refer to www.earthquake.usgs.gov



- Page 65, Guidelines for open pit design, J Read, 2009

LEARNING OUTCOME 3.7.2

DESCRIBE, EXPLAIN AND DISCUSS MEASURES TO MINIMISE THE EFFECTS OF EARTHQUAKE LOADING ON SURFACE MINING OPERATIONS.

Seismic activity cannot be prevented or affected by any surface mine strategy, but the impact of the seismic waves' indication with the high-walls can be minimised by:

1. Design
 - Include seismic loading in the design using limit equilibrium models specifying a horizontal, static loading (similar to gravity) under pseudo-static loading. A suitable seismic coefficient must be selected
2. Risk management
 - The utilisation of remedial actions identified through baseline, issue-based and continuous risk assessments before and during the mining of the pit is critical in ensuring that the possible impact of seismic loading is considered and addressed.



- Page 381, Guidelines for open pit design, J Read, 2009

LEARNING OUTCOME 3.7.3

CONNECTION 23

Refer to "LEARNING OUTCOME 3.1.7" on page 64
Also refer to [Paper 2](#) Outcomes 3.2.1, 6.3 and to [Paper 3.1](#) Outcome 3.4

DESCRIBE, EXPLAIN AND DISCUSS THE PHENOMENON OF LOCALISED SEISMICITY AND ITS EFFECTS ON SURFACE MINING OPERATIONS.

Earthquake loading (outcome 3.1.7.1) and local seismic activity have similar effects on the surface mines, except that the levels of ground motion may theoretically be higher in the case of local seismic activity, since local seismic sources will be situated closer to the pit, reducing the amount of wave attenuation that might occur. At the same time, though, local seismic activity in most cases will be much smaller in magnitude (also levels of displacement, ground acceleration) than large earthquakes, reducing the impact of the surface mine.

LEARNING OUTCOME 3.7.4

CONNECTION 24

Refer to "[LEARNING OUTCOME 3.1.7](#)" on page 64

DESCRIBE, EXPLAIN AND DISCUSS MEASURES TO MINIMISE THE EFFECTS OF LOCALISED SEISMICITY ON SURFACE MINING OPERATIONS.



- [Influence of seismic events on slope stability](#)

PAPER 3.4: SURFACE MINING (HARD AND SOFT ROCK)

LEARNING OUTCOMES

4. MINING LAYOUT STRATEGIES

4.1. SURFACE MINING METHODS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the fundamental mining and rock engineering principles associated with the following surface mining methods:
 - Quarrying,
 - Open pit mining,
 - Strip mining.

4.2. SLOPE DESIGN PRINCIPLES

4.2.1. SLOPE STABILITY

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the principles associated with the concept of the factor of safety of a slope;
- Describe, explain and discuss the stability and failure of slopes for which factors of safety can be calculated;
- Describe, explain and discuss the stability and failure of slopes for which factors of safety cannot be calculated;
- Sketch, describe, explain and discuss the relationship between critical slope height and critical slope angle; and
- Sketch, describe, explain, discuss and apply the probabilistic approach to slope design.

4.2.2. SLOPE GEOMETRY

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the role and importance of the following slope geometry constituents:
 - Bench,
 - bench stack,
 - spill berm,
 - ramp berm and

- overall slope
- Determine optimum slopes for given rockmass and mine layout circumstances.

4.2.3. GEOTECHNICAL SECTORS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the principles associated with determining geotechnical sectors in surface mining operations; and
- Determine geotechnical sectors for given rockmass and mine layout circumstances.

4.2.4. MINING LAYOUTS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the role and importance of the following surface mining layout aspects:
 - Geology, structure, geotechnical sectors
 - Slope geometry, wall curvature
 - Service life, temporary walls, active walls, final walls
 - Mining sequences, push backs.

4.2.5. SERVICE LAYOUTS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the role and importance of access roadways in surface mining layouts.

4.3. LAYOUT DESIGN CRITERIA

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and apply appropriate criteria to design of surface mining layouts.

4. MINING LAYOUT STRATEGIES

4.1. SURFACE MINING METHODS

LEARNING OUTCOME 4.1.1

CONNECTION 1

Refer to [Paper 3.2](#)
Outcome 4.1.5

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE FUNDAMENTAL MINING AND ROCK ENGINEERING PRINCIPLES ASSOCIATED WITH THE FOLLOWING SURFACE MINING METHODS:

- Quarrying
- Open pit mining
- Strip mining.

4.2. SLOPE DESIGN PRINCIPLES

4.2.1. SLOPE STABILITY

LEARNING OUTCOME 4.2.1.1

CONNECTION 2

Refer to ["LEARNING OUTCOME 3.1.6"](#) on page 62

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE PRINCIPLES ASSOCIATED WITH THE CONCEPT OF THE FACTOR OF SAFETY OF A SLOPE.

Factor of safety is a measure of the ratio between forces that are resisting slope failure and those that are driving the environment towards failure, or, in other terms (where the term in brackets relates to the more well-known relationship used in support design):

$$\text{FOS} = (\text{Resisting forces}) / (\text{Driving forces}) = \text{Capacity} / \text{Demand} = ((\text{strength})) / ((\text{stress}))$$

INTERESTING INFO

The FOS concept became well known in the 20th century only when geotechnical engineering began developing as an engineering discipline on its own. In 1940, it was defined as the ratio between the average shear strength of the material in the slope and the average shear stress generated along a failure surface OR the factor by which the shear strength must be divided to result in failure.

In essence, this definition of the FOS concept means that at an FOS = 1, the system is at limiting equilibrium. However, it also assumes that all points/materials along the slope are at the same FOS and therefore that the FOS relates to a single representative strength for the whole slope.

Not included in this assumption of the FOS concept are:

- Strain softening of materials under constant stress;
- Time-related changes in material strengths; and
- Progressive failure within the slope.



For this reason, methods other than a simple strength/stress ratio were developed using numerical codes and techniques such as the 'shear strength reduction'.

- Page 221, Guidelines for open pit design, J Read, 2009

Acceptable levels of FOS have been published by a number of authors and are briefly indicated below.



It is the responsibility of the user to ensure that the acceptable levels applied are appropriate to the designs executed.

Author	Summary	Reference
Priest and Brown	Mining rock slopes: 1.2-2.0	Page 223, Guidelines for open pit design, J Read, 2009
Civil engineering applications	Slopes: Cohesive soils: 1.5 Permanent conditions: 1.5 Temporary conditions: 1.25	Page 224, Guidelines for open pit design, J Read, 2009
Priest and Brown	Consequences Not serious: FOS = 1.3, PoF [FOS<1] = 10% Very serious: FOS = 2.0, PoF [FOS<1] = 0.3%	Page 225, Guidelines for open pit design, J Read, 2009
Swan et al	Several different conditions are indicated of which the following is an example: Final inter ramp wall: < 25% of ramp affected, < 5 ktons/m, FOS > 1.2, PoF < 25%	Page 227, Guidelines for open pit design, J Read, 2009

Table 1: Acceptable FoS levels



These may not be the only published acceptable FOS levels available in the industry.

LEARNING OUTCOME 4.2.1.2

DESCRIBE, EXPLAIN AND DISCUSS THE STABILITY AND FAILURE OF SLOPES FOR WHICH FACTORS OF SAFETY CAN BE CALCULATED.

FOS is the ratio between forces that resist and drive failure or instability. To be able to calculate this ratio, failure on a specific plane is required to that the forces can be resolved mathematically.

These slopes include the following:

- Plane failures:
 - Page 150, Rock slope engineering, Hoek and Bray, 1981
 - "LEARNING OUTCOME 3.1.2" on page 60
- Wedge failures:
 - Page 199, Rock slope engineering, Hoek and Bray, 1981
 - "LEARNING OUTCOME 3.1.2" on page 60
- Circular failures:
 - Page 226, Rock slope engineering, Hoek and Bray, 1981
 - "LEARNING OUTCOME 3.1.3" on page 61
- Page 28, Rock slope engineering, Hoek and Bray, 1981



LEARNING OUTCOME 4.2.1.3

DESCRIBE, EXPLAIN AND DISCUSS THE STABILITY AND FAILURE OF SLOPES FOR WHICH FACTORS OF SAFETY CANNOT BE CALCULATED.

Once failure does not occur on a specific plane, even if strength properties are known, it is impossible to calculate a FOS. These include:

- Toppling failure:
 - Page 257, Rock slope engineering, Hoek and Bray, 1981
 - "LEARNING OUTCOME 3.1.4" on page 61
- Ravelling slopes:
 - In very poor conditions, circular failure methods may be used but in general this involves processes such as the impact of weathering.
- Page 28, Rock slope engineering, Hoek and Bray, 1981



LEARNING OUTCOME 4.2.1.4

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE RELATIONSHIP BETWEEN CRITICAL SLOPE HEIGHT AND CRITICAL SLOPE ANGLE.

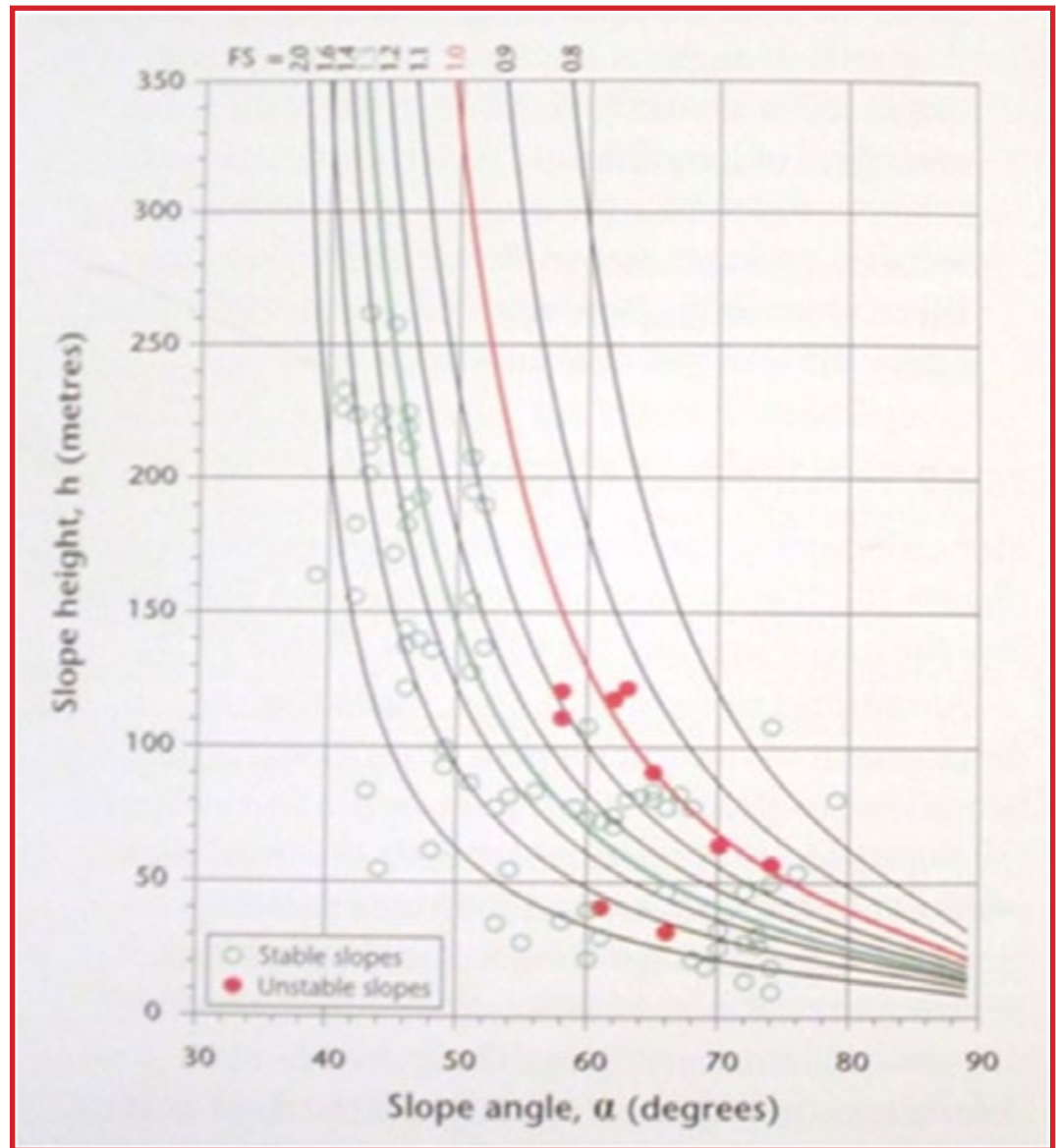


Figure 1: Relationship between slope height and angle



- Page 246, Guidelines for open pit design, J Read, 2009

LEARNING OUTCOME 4.2.1.5

SKETCH, DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE PROBABILISTIC APPROACH TO SLOPE DESIGN.

Due to the variability inherent to the rockmass within which mining is conducted, some probability that a slope may not perform as expected or designed will always exist. The probability of failure as a design criterion takes into account the traditional FOS 'capacity' and 'demand' concepts, but includes some variability into each in one of the following ways:

- Use FOS as a random variable and evaluate the probability that the $FOS \leq 1$, i.e. $PoF = P [FOS \leq 1]$;
- Use the demand and capacity as variables and evaluate the probability that the demand will exceed the capacity, i.e. PoF

$$= P [(C-D) \leq 0].$$

To determine the probability of failure, the statistical distributions defining the variability of each of the parameters involved in the analysis should be known or assumed. This requires that each of the input parameters is sampled and a stability analysis carried out using a suitable method to obtain a result (e.g. $(C - D)$ or FOS).

In jointed rock slopes, the process will involve the generation of possible failure surfaces from the sampling of joint statistical distributions.

Monte Carlo simulation approach

The sampling and stability analysis process is repeated a large number of times to determine a distribution of the results (the probability density function). The probability of failure is then determined by the area under the probability density function to the left of the criterion value.

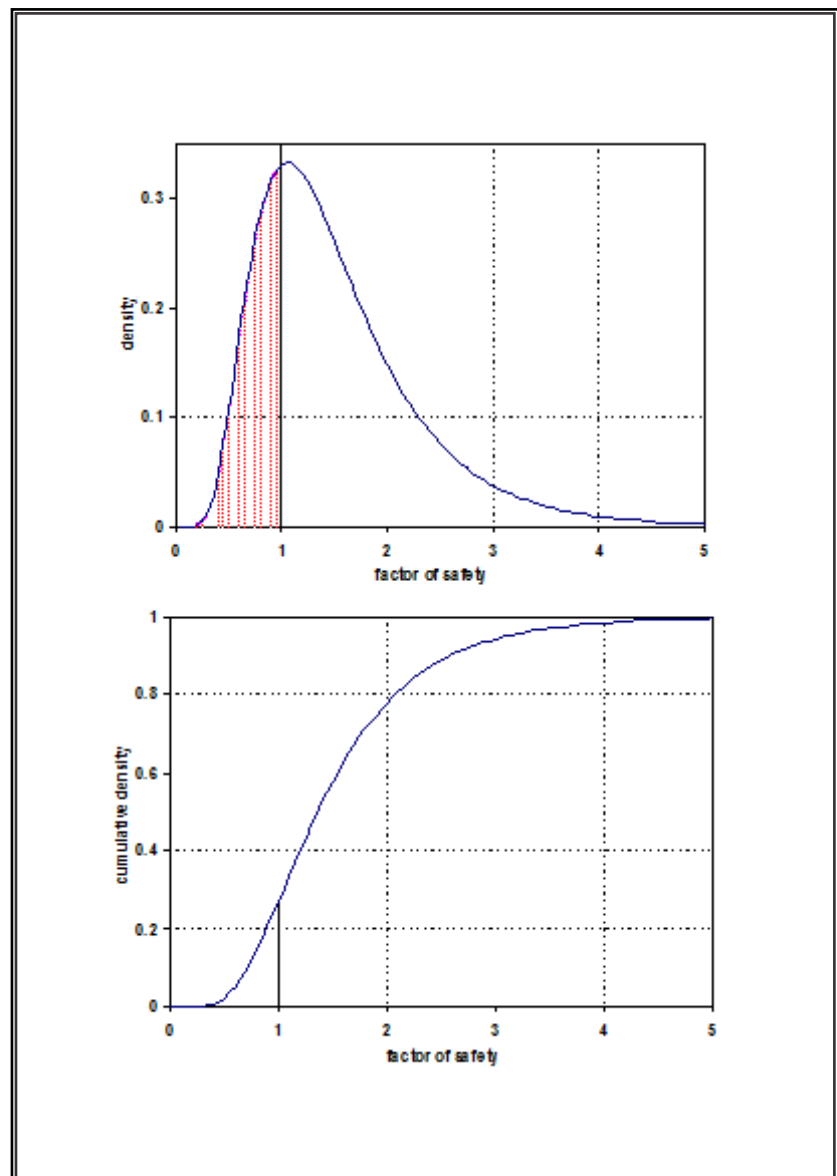


Figure 2: Monte Carlo simulation results to ascertain appropriate FoS (Stacey et al., 2001)

Point estimate method approach

A simplified approach, which is applicable when a small number of variables are involved, is to use the point estimate method. In this

EXAMPLE

approach, the number of variables is selected and the FOS determined for each of the possible different input parameter combinations.

For two input parameters c and Φ (assumed to be normally distributed independent variables), four separate analyses, one analysis for each combination of the 'point estimates of the variables', are required. The number of total possible combinations is equal to 2^n , i.e. for two variables ($n=2$), there are $2^2 = 4$ combinations, for 3 variables ($n=3$), there are $2^3 = 8$ combinations, etc.

The two point estimates for each of the variables are defined as follows:

- $C_- = C_{mean} - C_{std}$
- $C_+ = C_{mean} + C_{std}$
- $\phi_- = \phi_{mean} - \phi_{std}$
- $\phi_+ = \phi_{mean} + \phi_{std}$

Where the subscript 'mean' refers to the mean value, and 'std' refers to the standard deviation.

The factor of safety for each of the following combinations of the four point estimates can be determined:

- FOS_{--} : using c_- and ϕ_-
- FOS_{-+} : using c_- and ϕ_+
- FOS_{+-} : using c_+ and ϕ_-
- FOS_{++} : using c_+ and ϕ_+
-

The mean and standard deviation of the factor of safety of the slope are given by the mean and standard deviation determined from the four calculated FOS values. The values for the mean and standard deviation of the FOS can be used to calculate the probability of failure of the slope.

The significance of the probability of failure of a slope as given in Table 2 indicates the probabilities of failure for which open pit mine slopes should be designed.

Probability of failure (%)	Design criteria on basis of which probability of failure is established		
	Serviceable life	Minimum surveillance required	Frequency of evident slope failure
50-100	Effectively zero	Serves no purpose (excessive probability tantamount to failure)	Slope failures generally evident
20-50	Very short term (temporary open-pit mines – untenable risk of failure in temporary civil works)	Continuous intensive monitoring with sophisticated instruments	Significant number of unstable slopes
10-20	Very short term (quasi-temporary slopes in open pit mines – undesirable risk of failure in quasi-temporary civil works)	Continuous monitoring with sophisticated instruments	Some unstable slopes evident

Probability of failure (%)	Design criteria on basis of which probability of failure is established		
	Serviceable life	Minimum surveillance required	Frequency of evident slope failure
5-10	Short term (semi temporary slopes in open-pit mines, quarries of civil works)	Continuous monitoring with simple/rudimentary instruments	Occasional unstable slope evident
0-5	Medium term (semi-permanent slopes)	Conscious superficial monitoring	No ready evidence of unstable slopes

Table 2: Comparative significance of probability of failure

- Page 79, Best Practice rock engineering handbook for other mines, [Stacey et al](#), 2001



Acceptable levels of PoF have been published by a number of authors and are briefly indicated below.



It is the responsibility of the user to ensure that the acceptable levels applied are appropriate to the designs executed.

Author	Summary	Reference
Priest and Brown	Consequences Not serious: FOS = 1.3, PoF [FOS<1] = 10% Very serious: FOS = 2.0, PoF [FOS<1] = 0.3%	Page 225, Guidelines for open pit design, J Read, 2009
Kirsten	Short-term slopes: PoF = 5 – 10% Long-term slopes: PoF = 0.5 – 1.5%	Page 226, Guidelines for open pit design, J Read, 2009
SRK consulting	Critical slopes where failure will have impact on continuous operation: PoF < 5% Slopes where failure will have significant impact on cost and safety: PoF < 15% Slope where failure will have no impact: PoF < 30%	Page 226, Guidelines for open pit design, J Read, 2009
Swan et al	Several different conditions are indicated of which the following is an example: Final inter ramp wall: < 25% of ramp affected, < 5 ktons/m, FOS > 1.2, PoF < 25%	Page 227, Guidelines for open pit design, J Read, 2009

CONNECTION 3

Refer to "[LEARNING OUTCOME 3.1.6](#)" on page 62

Table 3: Acceptable PoF levels

These may not be the only published acceptable PoF levels available in the industry.

Interesting information

Although the probability of failure criterion has been around since the 1980s, it has only recently found general acceptance from geotechnical engineers.



- Page 223, Guidelines for open pit design, J Read, 2009
- Page 105, Chapter 8, Practical Rock engineering, [Hoek E](#), 2006
- [Probabilistic slope design SRK](#)
- [Risk evaluation SRK](#)
- [Numerical modelling statistical analysis example](#)

Continuing on this probabilistic design approach is the suggestion of a risk/consequence approach that takes the use of the probability of failure a bit further.

"Slope design has over the years become the responsibility of specialist geotechnical practitioners but even though this has had some benefit, it has also alienated the responsibility of the risk versus reward relationship from the mine design engineer" – SRK Consulting (Steffen et al., Risk consequence approach to slope design)

From SRK Consulting (Steffen et al., Risk consequence approach to slope design), the following quotation indicates the place for probabilistic slope design in practice:

"The design process allows the owner to determine the level of risk that is acceptable to him and allows the geotechnical specialist to develop the steepest angles that can satisfy the risk criteria. Risk criteria are therefore set on the basis of consequences of potential failures, which develop a joint ownership of the selected slope angles. No longer is there abdication of responsibility from management to the technical specialist, who is not qualified to determine the acceptable risk levels. The risk/consequence process incorporates the mining business context of the slope into the design criterion. It also enables the identification of areas where geotechnical exploration would maximise the risk reduction."

SRK goes further to relate this new approach to the traditional approach:

Traditional design approach	Risk/consequence approach
• Collect all the geotechnical data that could be required for design to a confidence level appropriate for the application. • Design the slope to an FOS or POF criterion commonly used by geotechnical engineers. • Provide the resulting slope angles to the mine planners for their design and economic calculations. • Apply monitoring procedures to determine the adequate performance of the slope according to the expectations of the geotechnical engineer.	• Determine the risk criteria for each consequence at the outset. • Establish best practice management tools for the slope performance required. • Calculate the required POF for slope design. • Perform the slope design to the required reliability at the required level of design. • Collect geotechnical data appropriate for the next required level of design confidence.

Table 4: Traditional vs. risk/consequence design approach

"This reversal of the traditional approach to slope design has the objective of delivering a design in conformance with the business requirements of the project. The corollary to this is that the business objectives have to be decided a priori."



- [Risk consequence approach to slope design SRK](#)

4.2.2. SLOPE GEOMETRY

LEARNING OUTCOME 4.2.2.1

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE ROLE AND IMPORTANCE OF THE FOLLOWING SLOPE GEOMETRY CONSTITUENTS:

- Bench,
- bench stack,
- spill berm,
- ramp berm,
- overall slope

Open pit mines each has unique terminology with regard to their certain environments. It is therefore important to be aware of these terms and their meaning within the context of open pit mining. Every pit has a specific geometry or shape that is standard practice in the industry. The terms used to describe pit geometry are discussed below. These terms may differ slightly according to the country.

Bench

The flat area between bench faces used for rockfall catchment. The bench needs to provide a safe working environment for machinery and personnel. Different number of benches makes up an open pit slope; this is determined by the scale of the operation or the depth of the pit, and can range from a few benches, to many stacks of benches.

Bench width

Bench width is how wide a bench is and is selected to facilitate containment of potential failing material (small wedges and blocks) so as to ensure that loose material does not become hazardous to men and equipment.

Bench height

Mining equipment used to drill and blast the rock determines the bench height. Currently, most large mining operations drill and blast on 12 to 15 metre intervals, with 15 metres being the most common.

Bench stack

A stack usually refers to several production benches between catch benches so that the vertical catch bench separation is a multiple (usually two, three, or four) of the production bench height. Occurs when there are multiple benches in a slope design.

Crest

The top of a pit slope or bench in a pit is referred to as the crest. The pit crest is the top of the entire pit, while the bench crest is the top of an individual bench.

Toe

The bottom of a pit or bench is known as the toe. It can either be the toe of the entire pit or pit floor, or can refer to a bench toe.

Spill berm

Is also known as a safety berm. This is a pile of rock material that runs parallel to the bench crest. When any loose rocks or debris fall from the bench face, then it will fall onto the bench width area. Therefore, material can be contained and large slope failure propagation can be avoided. Spill berms differ in terms of the size, but are usually proportionate to the scale of the operation and the bench heights, as well as the type of material being used. Common spill berm heights are 1.5 to 2.5 meters high. Berms should be left at least 3 meters from the edge of the bench crest to prevent material from falling.

Ramp berm

A ramp berm is the same as a spill berm, with the difference being that it is on the side of the ramp.

Ramp

This is a wide area used for access into and out of a pit, and is also known as a haulage road. Ramps need to be wide enough for traffic flow. The incorporation of ramps onto a wall will result in a slope that has a shallower overall slope angle than the inter-ramp angle.

Overall slope

The overall slope incorporates all of the above terms. It is the entire pit from the crest to the floor.

Overall slope angle

The overall slope angle is formed by a series of inter-ramp slopes separated by haul roads and corresponds with the angle formed by the line joining the toe of the lowest bench with the pit slope crest.

Inter-ramp angle

The inter-ramp angle or stack angle is formed by a series of uninterrupted benches and corresponds with the inclination from the horizontal of a line joining the toes of the benches.

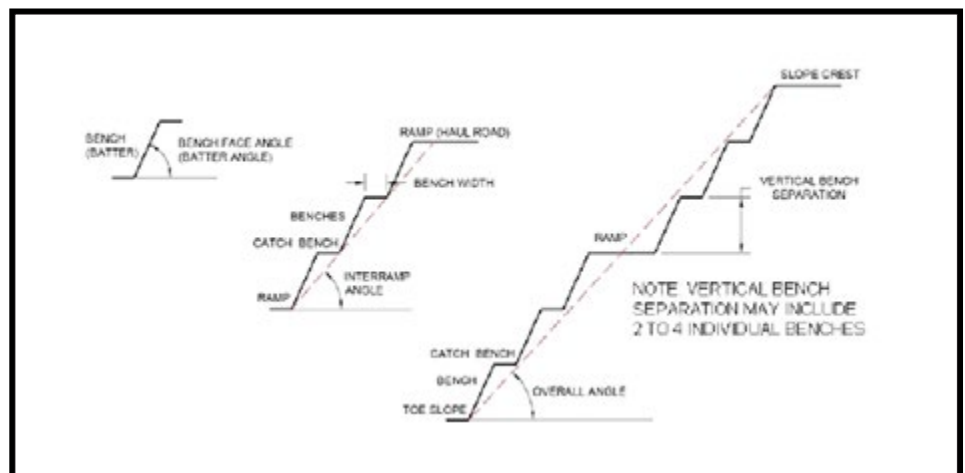


Figure 3: The slope geometry of an entire pit slope, made up of benches and ramps (Middindi, 2009)



Figure 4: An example of an operational open pit

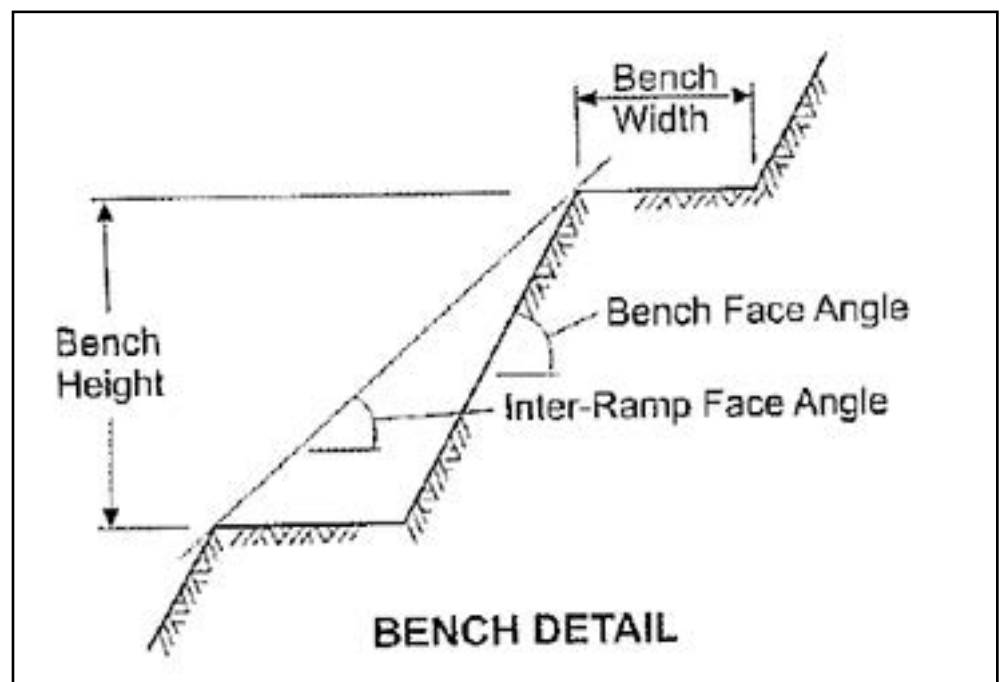


Figure 5: A schematic diagram of bench geometry (Read & Stacey, 2009)



Figure 6: Benches in an open pit mine

LEARNING OUTCOME 4.2.2.1

DETERMINE OPTIMUM SLOPES FOR GIVEN ROCKMASS AND MINE LAYOUT CIRCUMSTANCES.

Optimum pit slope's angles have to be determined by means of assessing all the necessary components involved. It usually consists of finding a compromise between having the pit steep enough to be economical, yet flat enough to be safe.

The processes involved in optimal pit slope design are summarised in Figure 7. Information on the geology, structure, rockmass and hydrogeology for the project area must be gathered and analysed. This process leads to the determination of a geotechnical model.

Geotechnical model

This is derived from the data mentioned above, which allows for geotechnical domains to be derived. These are areas in a pit with similar geotechnical character.

Domains

The pit can be divided into different domains or sectors based on similar characteristics (geological, geotechnical, structural etc.). Once these sectors have been determined, certain types of failure that may occur in these areas can be assessed.

Design

Once a pit has been assessed, it can be divided into design sectors. These are the sectors used on which the pit can be designed. Each parameter mentioned above is taken into account and refined to produce specific sectors upon which the design can take place. Design involves stability analysis of slopes as well as design specifications of slopes.

At each stage of these processes, information required is shown in the left hand side of Figure 7.

Once all of this information is gathered and analysed and pit sectors are derived, optimal pit determination can be achieved.

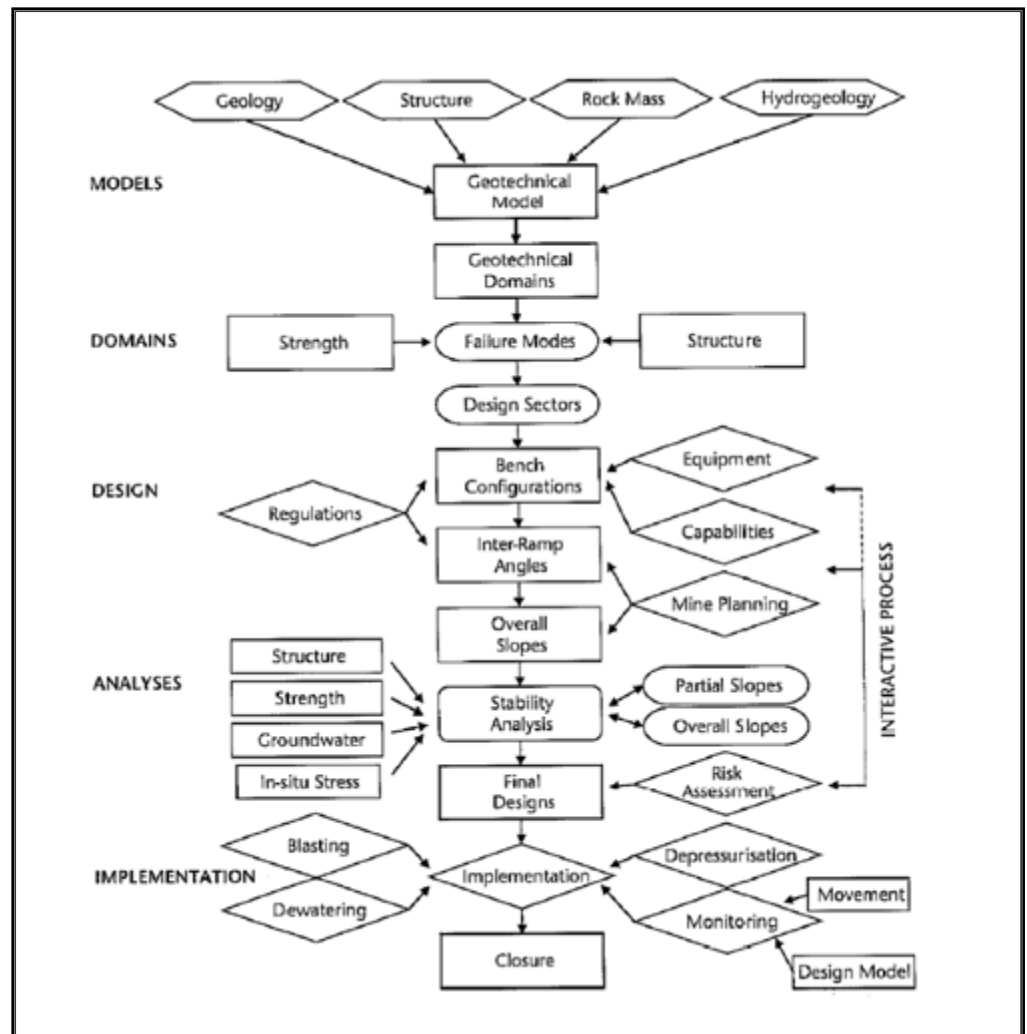


Figure 7: The design process for pit optimisation

- Guidelines for open pit design, J Read, 2009



4.2.3. GEOTECHNICAL SECTORS

LEARNING OUTCOME 4.2.3.1

DESCRIBE, EXPLAIN AND DISCUSS THE PRINCIPLES ASSOCIATED WITH DETERMINING GEOTECHNICAL SECTORS IN SURFACE MINING OPERATIONS.



Geotechnical sectors can be defined as those sectors/areas on the mine where the rockmass is so different that different designs should be executed for those areas, also referred to as design sectors.

All data gathered in the design process are utilised to create a geotechnical model of the planned mining area/rockmass, and will include data from:

- Geological data / model:
 - Deposit types;
 - Material types;
 - State of weathering;
 - Seismic activity;
 - *In situ* stress field etc.;
- Structural model:
 - Major structures (faults etc.);
 - Minor structures (joints etc.);
- Rockmass model:
 - Intact rock strengths;
 - Rockmass quality:
 - Rockmass strength etc.;
- Hydrogeological model:
 - Groundwater;
 - Permeability;
 - Pore pressures etc.;
- Mine model:
 - Pit depth;
 - Highwall orientations etc.

The aim of the geotechnical model is to find/indicate areas of significant difference where different designs should be implemented to ensure stability.

Several methods are available to present the data so gathered and determined to allow the creation of the geotechnical model, *inter alia*:

- Graphs (changes with depth down boreholes, distribution of mean values, etc.);
- Statistical results (mean, minimum, maximum, etc.);
- Contours (distribution across target area / pit footprint, etc.);
- Vulcan™, DataMine™, Surpac™, etc.;
- Block models showing 3D distribution of parameters.

The final selection of design sectors must take into account, based on the engineering judgement of the design engineer, the following:

- Expected failure mechanisms;
- Geotechnical parameters in the geotechnical model that will play a role in the failure mechanisms expected.



- Page 203, Guidelines for open pit design, J Read, 2009

LEARNING OUTCOME 4.2.3.2

DETERMINE GEOTECHNICAL SECTORS FOR GIVEN ROCKMASS AND MINE LAYOUT CIRCUMSTANCES.

EXAMPLE

Target ore body and host rock are very competent, but extremely folded, making the selection of design sectors based on material strength type impossible. Since stability was anticipated to be driven by structural features, and therefore the combination of pit wall and structure orientations, the following method of design sector selection was followed:

- Correlate alpha angles of discontinuities for each of the boreholes with increasing depth (Figure 8);
- From all available boreholes, find the representative structural domains with common structure dips (Figure 9);
- Select design sectors based on highwall orientations (Figure 10); and
- Perform designs for each structural domain within each design sector.

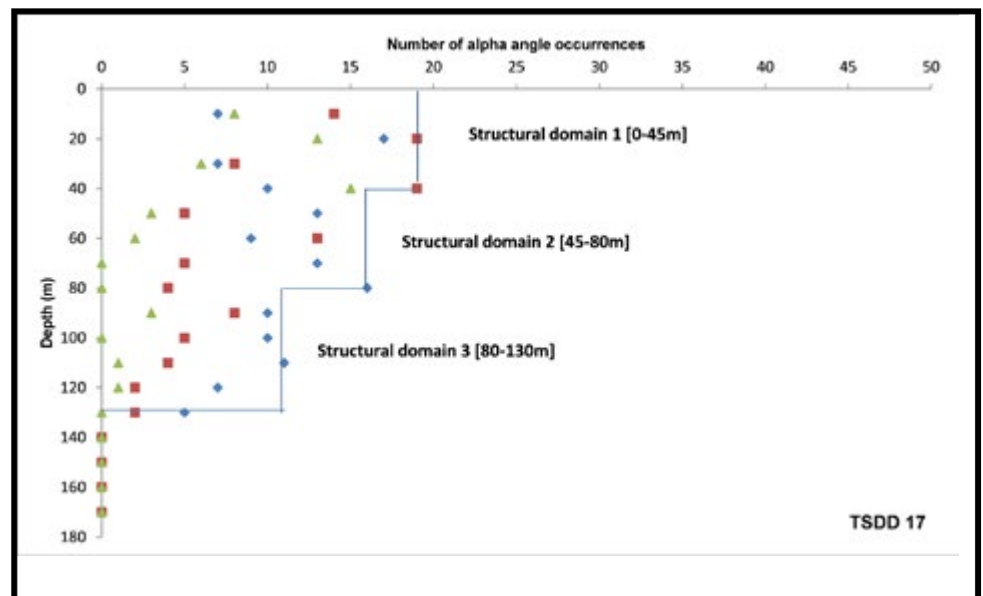


Figure 8: Alpha angle distributions with depth (structural domains), for example borehole

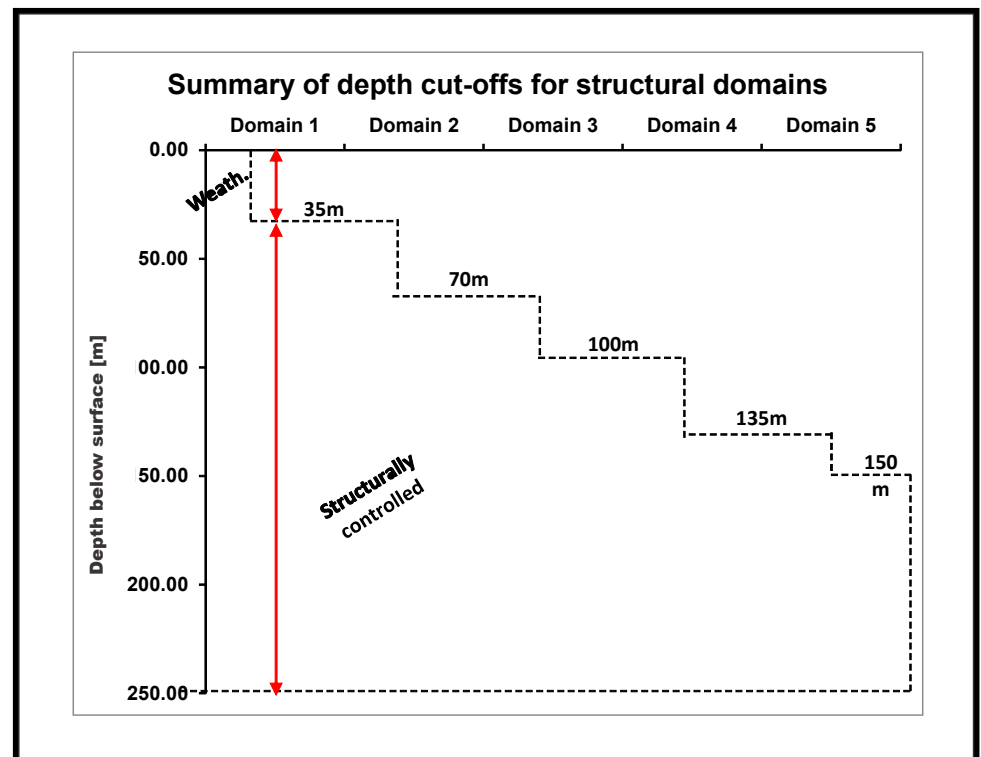


Figure 9: Representative domains from all boreholes

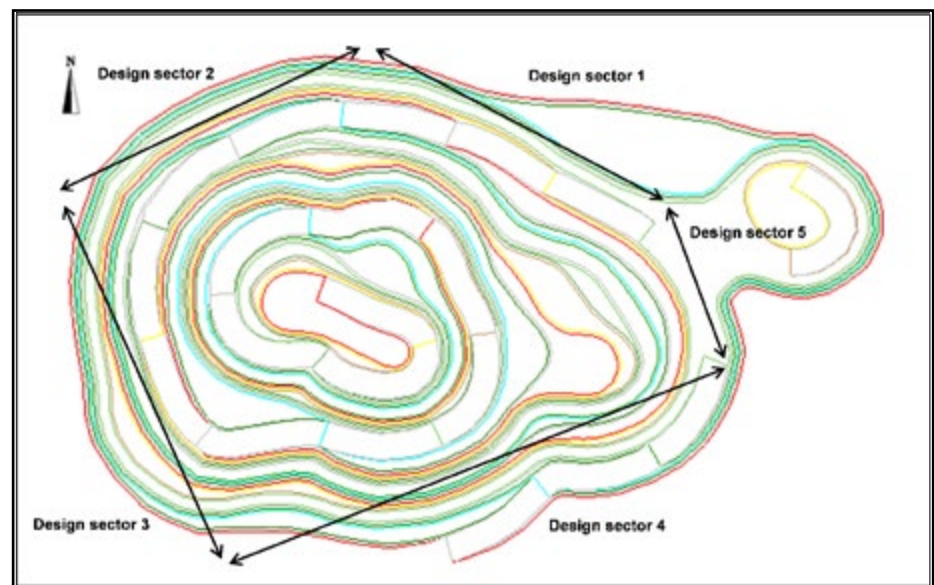


Figure 10: Design sectors based on pit geometry

EXAMPLE

The target ore body and host rock are stratigraphically bound with limited large structures, but with the presence of minor structures within some of the material. Geotechnical stratigraphic domains were selected along the material types and can therefore be classified into the following geotechnical domains:

- Soft materials:
 - Sand;
 - Calcrete;
 - Gravel;
 - Clay;

- Hard materials:
 - Dolomite;
 - Banded ironstone and
 - Manganese.

Failure of the soft materials is governed by its inherent material properties, while the hard material behaviour is controlled by discontinuities (Table 5).

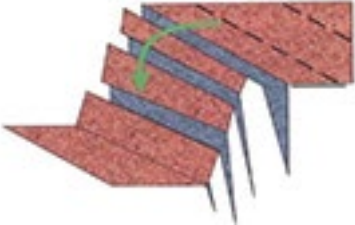
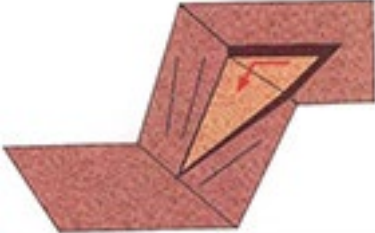
Schematic description	Geotechnical or geological domain
	Soft materials consisting of: Sands Calcretes Gravels Clays
	Hard materials consisting of: Dolomites Banded Ironstones Manganese
	
	

Table 5: Failure modes for the various geological formations

Design sectors are usually selected to group areas where similar geometrical design principles can be implemented. For this project area, the selection of design sectors was based on material type, thickness and strength as well as discontinuity presence and orientation, where applicable.

4.2.4. MINING LAYOUTS

LEARNING OUTCOME 4.2.4.1

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE ROLE AND IMPORTANCE OF THE FOLLOWING SURFACE MINING LAYOUT ASPECTS:

- Geology, structure, geotechnical sectors
- Slope geometry, wall curvature
- Service life, temporary walls, active walls, final walls
- Mining sequences, push backs.

CONNECTION 4

Refer to "[LEARNING OUTCOME 3.1.4](#)" on [page 61](#) to 3.1.10

Geology and Structure

CONNECTION 5

Refer to "[GEOTECHNICAL SECTORS](#)" on [page 131](#)

Geotechnical sectors and Slope geometry**Wall curvature**

Highwall curvature	Comment
Straight	Highwall shape along strike is a straight line. Material in the wall is free to move towards pit, but is confined along strike and in vertical direction.
Concave	Highwall along strike has a concave shape. This releases some confinement and allows additional material movement in the highwall and subsequent scaling/failure. The worst example of a concave highwall is the creation of a 'nose' within the highwall that is not confined in most directions.
Convex	Highwall along strike has a convex shape. This shape increases confinement in most directions and improves stability against scaling/failure, but increases potential for blast damage.

Table 6: Highwall curvature

CONNECTION 6

Refer to "[SLOPE STABILITY](#)" on [page 119](#)

Service life

Service life determines acceptable FOS and PoF levels.

CONNECTION 7

Refer to "[SLOPE STABILITY](#)" on [page 119](#)

Temporary walls

Temporary walls refer to walls that are being mined and will remain static for short periods only. These walls can be designed at lower FOS and higher PoF levels.

CONNECTION 8

Refer to "[SLOPE STABILITY](#)" on [page 119](#)

Active walls

Active walls refer to walls that are being mined. These walls can be designed at lower FOS and higher PoF levels.

CONNECTION 9

Refer to "[SLOPE STABILITY](#)" on page 119

Final walls

Final walls refer to walls that will form the long-term, static highwalls around the pit/open cast mine. These walls are also referred to as 'final pushback walls'. Since they will be permanent and static, the acceptable design must take into consideration time impacts on the stability.

Mining sequences

Mining sequences are planned to allow adherence to the designed layout at all times. It refers to the blasting/extraction of ore or waste material from the pit walls in a sequence that will allow safe loading, drilling and transport of blasted material for the life of the mine. Typically, poor sequencing will endanger:

- the economic life of the mine when insufficient or incorrect waste walls are mined to allow access to the ore body for extraction or too much waste is mined, resulting in an excessive strip ratio;
- the stability of the walls when insufficient berm widths are created due to 'over-mining' of a bench, increasing the overall slope height and potential for slope failures.



Strip ratio: The ratio between the volume of waste removed and the volume of ore removed. This ratio varies for different commodities and target areas and must be determined as part of the feasibility study of the mine and managed during extraction.

Mining sequencing therefore needs to be planned around the pit, but also in depth to ensure that:

- the strip ratio is not exceeded;
- sufficient ore is exposed for mining;
- sufficient berm widths are maintained to allow safe working practices (transport/drilling) and stable highwalls;
- access to the pit bottom is maintained;
- access to all benches is maintained, etc.

Push backs

The term 'push back' is typically used within the following contexts:

- 'push back the bench' – To move a waste bench, i.e. blast a waste bench in the direction of its final position;
- 'the push back position' – To indicate the final position of a bench/highwall as designed to form the outer limit of the pit at that elevation.

4.2.5. SERVICE LAYOUTS**LEARNING OUTCOME 4.2.5.1****SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE ROLE AND IMPORTANCE OF ACCESS ROADWAYS IN SURFACE MINING LAYOUTS.**

Access roadways and ramps are continuously created to allow access to the individual benches and the pit bottom. These ramps/roadways can be situated:

- a. Within a single wall:
 - The layout could include a ramp positioned in the ore body footwall, allowing the hangingwall of the ore body to be mined at the optimum bench and berm layout without having to cater for wide berms to facilitate transport. At the same time, this layout allows for a permanent ramp that could be supported and protected along the long-term, push-back (footwall) highwall, catering for material deterioration using support systems and safety berms.
 - Placement in the hangingwall of the ore body requires continuous movement of the ramp as benches moves past the ramp position.
- b. Around the open pit:
 - In cases where walls are mined in different directions to ensure sufficient push back of waste benches, ramps/roadways are constantly recreated as benches are moved.



Poor mining sequencing could result in the inability to access a certain area with a roadway and therefore the inability to mine those inaccessible benches. This could exacerbate the mining sequence concerns and cause substantial delays in production.

4.3. LAYOUT DESIGN CRITERIA

LEARNING OUTCOME 4.3.1

CONNECTION 10

Refer to
"SLOPE STABILITY AND
 SLOPE FAILURE BASIC
 MECHANICS OF SLOPE
 FAILURE" on page 59

"LEARNING OUTCOME
 3.1.2" on page 60,

"LEARNING OUTCOME
 3.1.6" on page 62,

"LEARNING OUTCOME
 3.1.7" on page 64, and

"SLOPE STABILITY" on page 119

DESCRIBE, EXPLAIN AND APPLY APPROPRIATE CRITERIA TO DESIGN OF SURFACE MINING LAYOUTS.

PAPER 3.4: SURFACE MINING (HARD AND SOFT ROCK)

LEARNING OUTCOMES

5. MINING SUPPORT STRATEGIES

5.1. SLOPE SUPPORT STRATEGIES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the fundamental rock engineering principles associated with supporting rock slopes.

5.2. SERVICE SUPPORT STRATEGIES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the fundamental rock engineering principles associated with supporting roadways.

5.3. SUPPORT DESIGN CRITERIA

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the principles of reinforcement to prevent sliding;
- Describe, explain and discuss slope support requirements in terms of:
 - Initial stiffness, yieldability
 - Areal coverage, containment.

5.4. SUPPORT AND SUPPORT SYSTEM TYPES AND CHARACTERISTICS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Apply rockmass classification systems to design and select appropriate support for slopes;
- Describe and discuss the following rockwall support types and their applications:
 - Mechanically anchored bolts, cable bolts, friction bolts,
 - Cement grouted bolts, resin bonded bolts,
 - Full-column grouted/bonded bolts,
 - Pre-stressed tendons,
 - Shotcrete, gunite, thin sprayed linings,
 - Wire mesh, rope lacing, tendon straps

- Characterise the following aspects of the above units:
 - Their principles of operation,
 - Their technical specifications,
 - Their load-deformation characteristics,
 - The methods of ensuring support unit quality,
 - Their installation/application procedures,

5. The methods of ensuring their installed quality

- Design and evaluate the use of appropriate support units, support systems, support patterns and installation procedures for given rockmass conditions;
- Describe and discuss the following rockfall protection measures and their application and design:
 - Catch fences, catch walls, berm widths,
 - Thin sprayed linings

5. MINING SUPPORT STRATEGIES

5.1. SLOPE SUPPORT STRATEGIES

LEARNING OUTCOME 5.1.1

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE FUNDAMENTAL ROCK ENGINEERING PRINCIPLES ASSOCIATED WITH SUPPORTING ROCK SLOPES.

Slopes are normally designed based on the ability of the material it consists of, to remain inherently stable under the given conditions. These conditions could include the following, but may not be present in all situations:

- Rockmass strength;
- Rockmass quality;
- Presence of geological structures;
- Presence of groundwater and water pressures;
- *In situ* stress field and
- Seismic activity.

However, when stability cannot be maintained by the inherent ability of the rockmass/material, some form of assistance or support practices are suggested.



In some cases, steepening of the walls may be required to ensure economic feasibility of the project. Steepening of the bench face, stack or overall highwall layout may create conditions where certain behaviours are induced and for which support will be required to ensure stability.

Slope support practices can be separated into the following categories:

- a. Stabilisation:
 - Slopes have already shown some movement or failure, but can be stabilised using:
 - Rock fill buttress at the toe and
 - Dewatering practices.
- b. Repair:
 - Slopes have already shown some movement or failure, but can be repaired by:
 - Removing the failed material;
 - Replacing it with new materials.
- c. Artificial support:
 - Instability of slopes is prevented by:
 - Retaining walls;
 - Cable bolts;
 - Piles;
 - Geotextile reinforcement.



There may be cheaper and easier precautions to be out in place than installing cable bolts of significant length and strength to maintain stability.

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PAPER 3.4: CHAPTER 5



INTERESTING INFO

Experience has shown that artificial supporting of slopes beyond a 100m height has been unsuccessful due to failure of the highwall beyond the depth to which the support could be installed.

The use of support in civil engineering rock slopes such as in road cuttings is common practice and can be observed in many areas, such as the route along Chapman's Peak.

- Page 189, Hoek and Bray, Rock slope Engineering, 1981

The purpose of the installed support can be summarised as the provision of an increase in the forces that will resist failure, through the following:

- Increasing the shear strength of the material or
- Increasing the shear strength of structures within a slope.



- Page 313, Guidelines for open pit slope design, Read and Stacey, 2009



- <http://www.chapmanspeakdrive.co.za/engineering.php>

Support methods used in civil applications include:

- Vegetation
- Shotcrete
- Pre-cast concrete units
- Gabions (wire baskets filled with waste rock)
- Wire mesh.



- Page 317, Hoek and Bray, Rock slope engineering, 1981

5.2. SERVICE SUPPORT STRATEGIES

LEARNING OUTCOME 5.2.1

CONNECTION 1

Refer to "[LEARNING OUTCOME 5.1.1](#)" on page 141 for the basic rock engineering principles that also apply to roadways.

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE FUNDAMENTAL ROCK ENGINEERING PRINCIPLES ASSOCIATED WITH SUPPORTING ROADWAYS.

Roadways/haul roads are normally long-term access routes into the pit where stability will be maintained over long periods of time so that the access remains operational and safe to allow complete extraction

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of ore from the mine. This normally requires larger factors of safety in the design of the slopes and/or greater protection against rock-related failures. The following rock-related concerns may exist:

- Scaling of rock pieces from the slopes into/onto the roadway and
- Slope failure that may consist of several possible mechanisms.

CONNECTION 2

Refer to "[LEARNING OUTCOME 3.1.4](#)" on page 61

INTERESTING INFO

The creation of haul roads has substantial engineering implications, which includes surface conditions and load carrying ability etc. The following are provided for your interest.

Since personnel and equipment are present along these access routes for the most part of any day, the risk of damage to equipment or injury to personnel is high unless sufficient precautions are in place. In achieving this, the following practices may be appropriate:

- Areal coverage support to prevent scaling from gathering speed and rolling/falling into the roads;
- The use of catch fences and berms to prevent rocks rolling into the road after the material has fallen from the highwall;
- The utilisation of roads wide enough to provide sufficient space to place catch berms along its length;
- Placing buttresses along the toe of the slope along the road;
- Place safety berms (windrows) along the highwall to limit exposure of personnel and equipment to possible rolling / falling rock;



- [Haul road design guidelines USA](#)
- [Haul road design Tannant](#)

5.3. SUPPORT DESIGN CRITERIA

LEARNING OUTCOME 5.3.1

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE PRINCIPLES OF REINFORCEMENT TO PREVENT SLIDING.

CONNECTION 3

Refer to [Paper 3.1](#) Outcomes 5.2.1.9 for basic principles applicable to this section.

Critical to support being installed to resist/prevent sliding on some plane is to ensure that the support unit is anchored beyond the possible failure plane and is strong enough to prevent failure.

Reinforcement includes the installation of tensioned anchors or fully grouted, untensioned cables. The selection of the most suitable types is based on the site geology, the required capacity of the reinforcement force, drilling equipment availability, access to the area to be supported and time required for installation.



Untensioned cables will provide less reinforcement than tensioned anchors of the same dimensions. If the slope has already been created and has 'relaxed' due to presence of the free face, causing the normal force on the sliding plane to reduce, it is advisable to install tensioned anchors to apply normal and shear forces on the sliding plane.



Normal forces applied by support on the sliding plane will increase the shear strength of the plane and shear forces induced along the plane will reduce the potential for sliding under gravity.

If the reinforcement can be installed before the slope is created, fully grouted intentioned cables can be successful as it will resist the sliding when relaxation occurs when the free face is created. However, it has also been successful when the rockmass is significantly jointed and the overall rockmass is strengthened, thereby resisting failure.

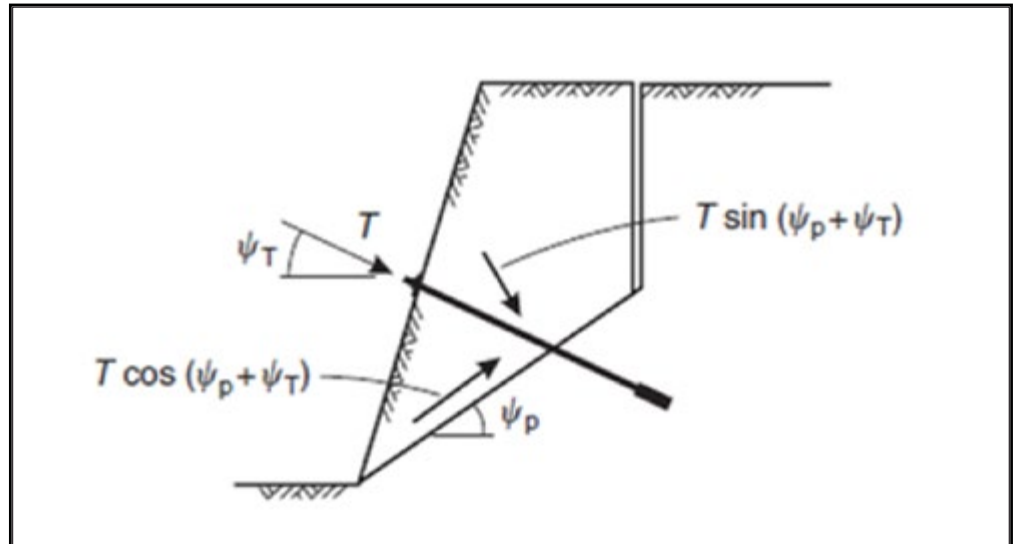


Figure 1: Support design against sliding in a slope

The factor of safety against sliding is given (Hoek & Bray) by:

$$FS = \frac{(cA + (W \cos \psi_p - U - V \sin \psi_p + T \sin(\psi_p + \psi_T)) \cdot \tan \Phi)}{(W \sin \psi_p + V \cos \psi_p - T \cos(\psi_p + \psi_T))}$$

where

- ψ_p is the dip of the sliding plane (from horizontal);
- ψ_T is the dip of the installed support unit (from horizontal);
- T is the reinforcement force per metre provided by the support installed at an angle ψ_T from the horizontal;
 - the normal component of the anchor force on the plane is $(T \sin(\psi_p + \psi_T))$
 - the shear component of the anchor force on the plane is $(T \cos(\psi_p + \psi_T))$ where
 - $(\psi_p + \psi_T) < 90^\circ$ (when equal to 90° , the support unit will be installed perpendicular or normal to the plane);
- U and V are forces exerted on the plans and in the tension crack respectively;
- Φ is the friction angle of the sliding plane;
- C is the cohesion on the sliding plane and
- A is the area on the plane on which sliding will potentially occur.



Reference for calculation of U and V

- Page 154, Hoek and Bray, Rock slope engineering, 1981

The optimum angle (ψ_T) for a tensioned support unit can be given by:

$$\psi_T = (\Phi - \psi_p)$$

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This means that the optimum installation angle for a tensioned bolt is flatter than 90° or normal to the sliding plane.

Bolts installed at an angle steeper than 90° or normal to the sliding plane ($(\psi_p + \psi_T) > 90^\circ$) will assist sliding along the plane since the shear component of the tension increases the displacing force.

The stability analysis of plane failures assumes a 1m thick slice of the slope. This means that T has units of kN/m.

The process to design a bolting pattern is as follows:

- the tension provided by each anchor is T_B (kN);
- a pattern of bolts will be installed so that there are 'n' anchors in each vertical row;
- the total support force in each vertical row is then $(T_B \cdot n)$;
- the required (to ensure stability) anchor force is T (kN/m);
- then the horizontal spacing S between each vertical row can be determined from:

$$S = (T_B \cdot n) / T \text{ (metres)}$$



The use of computer simulation programs to assess the impact or need for slope support is finding wide acceptance rather than executing these stringent calculations, as it can assess a large variation of slope layouts, materials, structures, support types etc. However, it is deemed important to understand the process and concepts involved.

EXAMPLE

From Hoek and Bray (Rock slope engineering), the following example is provided to illustrate the process of designing support to prevent sliding.



Explanations have been added to the example to assist the user.

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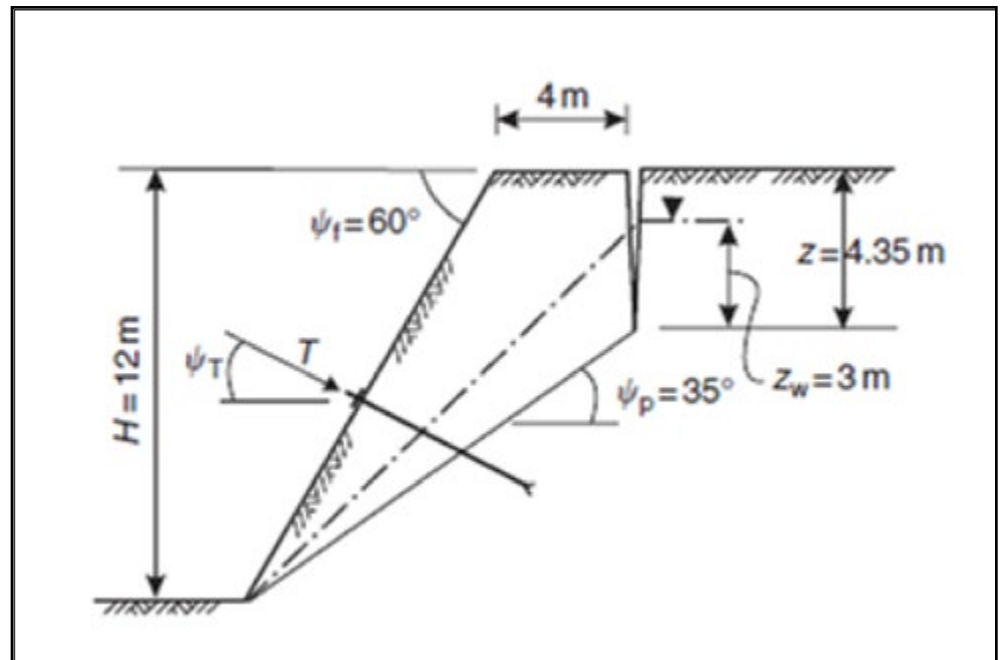


Figure 2: Example support design process

Figure 2 shows the following layout:

- A 12m high (H) rock slope at a face angle of 60° (ψ_f);
- The rockmass in which this slope was created contains persistent bedding planes that dip at an angle of 35° (ψ_p) towards the free face;
- The 4.35m (Z) deep tension crack is 4m behind the crest and is filled with water to a height of 3m (Z_w) above the sliding surface;
- The strength parameters of the sliding surface are as follows:
 - Cohesion, $c = 25\text{kPa}$
 - Friction angle, $\phi = 37^\circ$
- The unit weight of the rock is 26kN/m^3 and
- The unit weight of the water is 9.81kN/m^3 .

Question:

- a. Calculate the factor of safety of the slope for the conditions given above (assuming no support is installed);
- b. Determine the factor of safety if the tension crack were completely filled with water due to run-off collecting on the crest of the slope;
- c. Determine the factor of safety if the slope was completely drained;
- d. Determine the factor of safety if the cohesion was reduced to zero due to excessive vibrations from nearby blasting operations, assuming that the slope was still completely drained;
- e. Determine a pattern of cable bolts if the $FS > 1.5$ and 240kN cable anchors are used to stabilise the sliding block, assuming condition in (d) above is present and 400kN/m resisting force is required from the support. The installation angle is 55° and a support pattern is required.
- f. What would the optimum installation angle for the support units (measured from the horizontal) be, and, if installed at this angle, what would the factor of safety against sliding now

be.

Answer:

a. The factor of safety is calculated using:

$$FS = (cA + (W \cos \psi_p - U - V \sin \psi_p + T \sin(\psi_T + \psi_p)) \cdot \tan \Phi) / (W \sin \psi_p + V \cos \psi_p - T \cos(\psi_T + \psi_p))$$

In this equation:

- the following has been given:
 - c = cohesion = 25kPa
 - ϕ = friction angle = 37°
 - ψ_p = dip of the plane = 35°

however, the following has not been provided and should be calculated before the factor of safety can be determined:

- Area A on which sliding will occur;
- The weight of the block that will potentially slide;
- Water pressures U and V;
- Force T provided by the support.

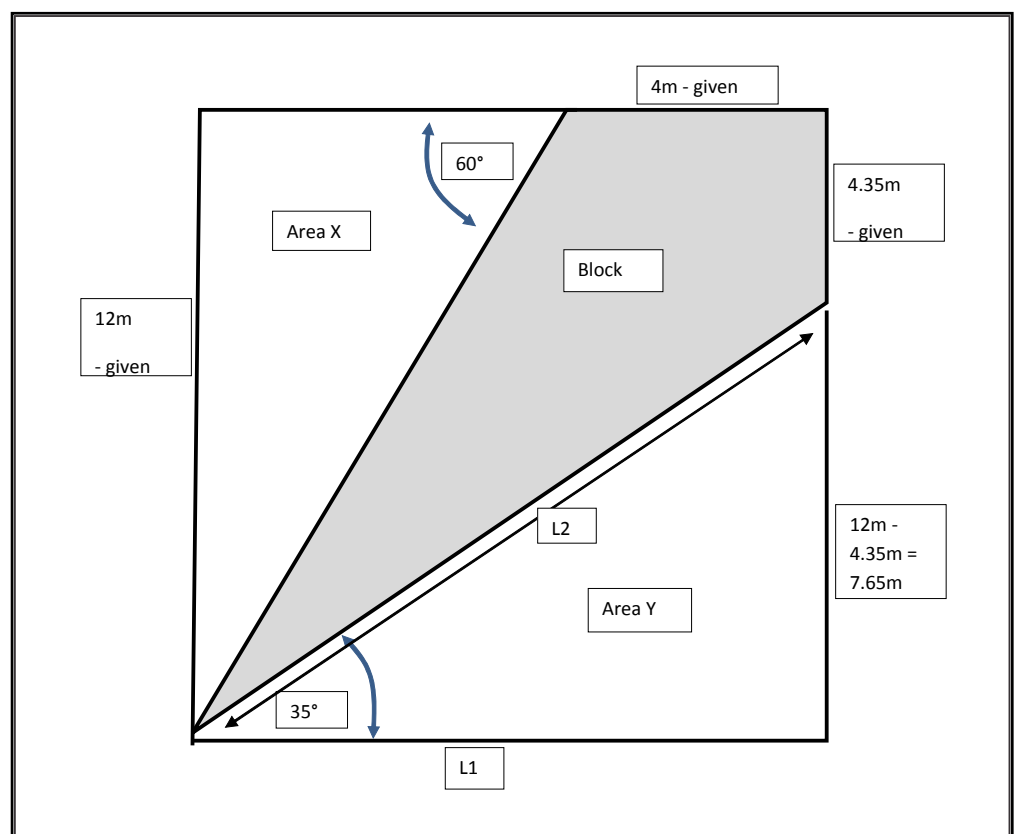


Figure 3: Block dimensions

From Figure 3, area A on which sliding potentially could occur is given by:

- $L_2 \times$ Block thickness, where
- L_2 :
 - $\cos 35^\circ = L_1 / L_2$
 - $L_2 = 10.93\text{m} / \cos 35^\circ$ (Note: see below for calculation of L_1)
 - $L_2 = 13.33\text{m}$

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- Area A = 13.33m x 1m = 13.33m²

Area A can also be calculated using $A = (H-z) \cdot \text{Cosec} \psi_p$ (Hoek and Bray)

To calculate the weight of the block that will potentially slip along the plane, the following process is required:

- Determine the block dimensions;
- Determine the block volume and
- Determine the block weight.

From Figure 3, the weight of the block can be calculated to be:

$$\text{Area}_{\text{block}} = \text{Area}_{\text{Total}} - \text{Area}_x - \text{Area}_y$$

L1:

- $\tan 35^\circ = 7.65\text{m}/L_1$
- $L_1 = 7.65\text{m}/\tan 35^\circ$
- $L_1 = 10.93\text{m}$

$$\begin{aligned} \text{Area}_x &= \frac{1}{2} b \cdot h \\ &= \frac{1}{2} \cdot (L_1 - 4) \cdot 12\text{m} \\ &= \frac{1}{2} (6.93\text{m})(12\text{m}) \\ &= 41.48\text{m}^2 \end{aligned}$$

$$\begin{aligned} \text{Area}_y &= \frac{1}{2} b \cdot h \\ &= \frac{1}{2} \cdot L_1 \cdot 7.65\text{m} \\ &= \frac{1}{2} (10.93\text{m})(7.65\text{m}) \\ &= 41.69\text{m}^2 \end{aligned}$$

$$\begin{aligned} \text{Area}_{\text{Total}} &= L_1 \cdot 12\text{m} \\ &= (10.93\text{m})(12\text{m}) \\ &= 131.1\text{m}^2 \end{aligned}$$

$$\begin{aligned} \text{Area}_{\text{block}} &= \text{Area}_{\text{Total}} - \text{Area}_x - \text{Area}_y \\ &= 131.1\text{m}^2 - 41.48\text{m}^2 - 41.69\text{m}^2 = 47.73\text{m}^2 \end{aligned}$$

Assume the block has a thickness of 1.0m (into the page):

$$\begin{aligned} \text{Volume}_{\text{block}} &= \text{Area}_{\text{block}} \cdot \text{Thickness} \\ &= 47.73\text{m}^2 \cdot 1\text{m} \\ &= 47.73\text{m}^3 \end{aligned}$$

$$\begin{aligned} \text{Weight}_{\text{block}} &= \text{Volume}_{\text{block}} \cdot \text{Density} \\ &= 47.73\text{m}^3 \cdot 26 \text{ kN/m}^3 \\ &= 1241.1 \text{ kN or } 1241.1 \text{ kN/m thickness.} \end{aligned}$$

The water pressures U and V are calculated as follows:

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PAPER 3.4: CHAPTER 5

U (water pressure on the plane):

$$U = \frac{1}{2} \cdot \gamma_w \cdot z_w \cdot (H - z) \cdot \text{Cosec} \psi_p$$

Where γ_w is the unit of weight of water, given as 9.81 kN/m^3 and $z_w = 3 \text{ m}$;

$$\begin{aligned} U &= \frac{1}{2} (9.81 \text{ kN/m}^3)(3 \text{ m})(12 \text{ m} - 4.35 \text{ m}) \cdot \text{Cosec} (35^\circ) \\ &= 196.26 \text{ kN/m} \end{aligned}$$

V (water pressure in the crack):

$$\begin{aligned} V &= \frac{1}{2} \cdot \gamma_w \cdot z_w^2 \\ &= \frac{1}{2} (9.81 \text{ kN/m}^3)(3 \text{ m})^2 \\ &= 44.15 \text{ kN/m} \end{aligned}$$



The forces are calculated per metre thickness.



Reference for calculation of U and V

- Page 154, Hoek and Bray, Rock slope engineering, 1981

Now

$$FS = (cA + (W \cos \psi_p - U - V \sin \psi_p + T \sin(\psi_T + \psi_p)) \cdot \tan \Phi) / (W \sin \psi_p + V \cos \psi_p - T \cos(\psi_T + \psi_p))$$

given that:

$$\begin{aligned} FS &= (25 \text{ kPa}(13.34 \text{ m}^2) + [(1241.1 \text{ kN})(\cos 35^\circ) - (196.31 \text{ kN}) - (44.15 \text{ kN}) \\ &\quad (\sin 35^\circ)] \tan 37^\circ) / [(1241.1 \text{ kN})(\sin 35^\circ) + (44.15 \text{ kN})(\cos 35^\circ)] \end{aligned}$$



T = 0 as no support is installed.

This calculates to a factor of safety (FS) = 1.25

- If the tension crack is completely filled with water, that is, $z_w = 4.35 \text{ m}$, and the new factor of safety is 1.07, it indicates that the slope is close to failure.
- If the slope were drained so that there was no water in the tension crack, that is, $z_w = 0$, then the new factor of safety is 1.54.
- If the slope is drained and the cohesion on the sliding plane is reduced from 25 kPa to zero by blast vibrations, then the new factor of safety is 1.08.



The loss of cohesion shows that stability is very sensitive to changes in the cohesion on the sliding plane.

- For drained conditions with zero cohesion ($c = U = V = 0$) and using 240 kN cable anchors that will provide 400 kN/m resistance, installed at 55° to the horizontal:

Slope stability:

Simplify the factor safety equation, given that some input parameters are zero, i.e.

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$$FS = (cA + (W \cos \psi_p - U - V \sin \psi_p + T \sin(\psi_T + \psi_p)) \cdot \tan \Phi) / (W \sin \psi_p + V \cos \psi_p - T \cos(\psi_T + \psi_p))$$

Becomes

$$FS = ((W \cos \psi_p + T \sin(\psi_T + \psi_p)) \cdot \tan \Phi) / (W \sin \psi_p - T \cos(\psi_T + \psi_p))$$

$$FS = 1.49 \approx 1.5$$

Cable anchor pattern:

Based on the length of the sliding plane (L_2), which is 13.33m, it is assumed that cable anchors every 4m (vertically) would suffice, indicating the installation of 3 units in a vertical line;

Based on $S = (T_B \cdot n) / T$ (metres)
where $T_B = 240$ kN/unit and $T = 400$ kN/m,

The horizontal spacing would be
 $S = (240 \text{ kN} \cdot 3) / (400 \text{ kN/m})$
 $= (720 / 400) \text{ m}$
 $= 1.8 \text{ m}.$

f. The optimum installation angle is given by

$$(\psi_p - \phi) = (37^\circ - 35^\circ)$$

$$= 2^\circ.$$

The FS when installation is executed at this angle is
 $FS = 2.41.$



Execute the same calculation as in (e) above, but utilise 2° instead of 55° for the installation angle ψ_T .

The incorrect installation of support units can nullify the impact on the slope stability. This incorrect installation could be the result of poor installation practices or insufficient knowledge of the actual sliding plane position and orientation.



- Page 166, Hoek and Bray, Rock slope engineering, 1981
- Page 72, [Stacey et al](#), Best practice rock engineering handbook for other mines, 2001



- [Design of open pit wall support Fuller](#)

LEARNING OUTCOME 5.3.2

CONNECTION 4

Refer to
[Paper 2](#) Outcome 5.1
[Paper 3.1](#) Outcome 5.3.1

DESCRIBE, EXPLAIN AND DISCUSS SLOPE SUPPORT REQUIREMENTS IN TERMS OF:

- Initial stiffness, yieldability
- Areal coverage, containment.

5.4. SUPPORT AND SUPPORT SYSTEM TYPES AND CHARACTERISTICS

LEARNING OUTCOME 5.4.1

CONNECTION 5

Refer to

[Paper 1](#) Outcome 6.2

[Paper 2](#) Outcome 3.1.2

[Paper 3.1](#) Outcome 2.3

APPLY ROCKMASS CLASSIFICATION SYSTEMS TO DESIGN AND SELECT APPROPRIATE SUPPORT FOR SLOPES.

No direct empirical or theoretical approach between a rockmass quality parameter and slope support types, spacings, capacities has been established to date. However, the following is important to note:

- Rockmass strengths can be estimated and categorised within a pit using RMR, Q Index or the GSI Rating;
- These rock quality parameters can also be used to estimate the rockmass strength values applied within computer simulation programs, where support units could be added to test the need and impact on stability;
- During the execution of rockmass ratings, the presence and orientation of structures that would require stability analysis are identified.

LEARNING OUTCOME 5.4.2

CONNECTION 6

Refer to

[Paper 2](#) Outcome 5.1

DESCRIBE AND DISCUSS THE FOLLOWING ROCKWALL SUPPORT TYPES AND THEIR APPLICATION:

- Mechanically anchored bolts, cable bolts, friction bolts
- Cement grouted bolts, resin bonded bolts
- Full-column grouted/bonded bolts
- Pre-stressed tendons
- Shotcrete, gunite, thin sprayed linings
- Wire mesh, rope lacing, tendon straps

LEARNING OUTCOME 5.4.3

CONNECTION 7

Refer to

[Paper 2](#) Outcome 5.1

CHARACTERISE THE FOLLOWING ASPECTS OF THE ABOVE UNITS:

- Their principles of operation
- Their technical specifications
- Their load-deformation characteristics
- The methods of ensuring support unit quality
- Their installation/application procedures
- The methods of ensuring their installed quality

LEARNING OUTCOME 5.4.4

CONNECTION 8

Refer to "[LEARNING OUTCOME 5.4.3](#)" on page 151

DESIGN AND EVALUATE THE USE OF APPROPRIATE SUPPORT UNITS, SUPPORT SYSTEMS, SUPPORT PATTERNS AND INSTALLATION PROCEDURES FOR GIVEN ROCKMASS CONDITIONS.

Support design for slopes must take into account the following:

- Function of support: What must the support do? Such as prevent scaling, prevent failure, etc.;
- Geological structures: Orientation with regard to the slope walls, persistence, surface conditions, presence of water, etc.
- *In situ* rockmass strength: Can the material fail in shear due to loading?
- Groundwater regime: Impact of effective stress on stability;
- Behaviour of the intended support under load: Will its strength be exceeded?
- *In situ* stress levels: What is the impact of this on stability?
- Potential for seismic events.

CONNECTION 9

Refer to
[Paper 2](#) Outcome 4.4
[Paper 3.1](#) Outcome
 5.3.1.3, 5.3.1.8, 5.3.2.7

Support-related issues that must be considered:

1. Timing of support installation:
 - The earlier support is installed, the more effective it is. Early support installation will allow the support to respond to the displacements that occur in the rockmass, generating resistance to displacements and thereby reinforcing of the rock material in the wall.
 - This is particularly important when large wedge or plane failures are possible. Support installation following the normal production cycle of blasting, cleaning and making safe an area could result in days lost before support can be installed and could allow substantial displacements on the bounding structure before support can be installed.
2. Service life:
 - Corrosion is the main consideration in terms of service life of support and must be considered in terms of the level of corrosion expected, corrosion agents present, life of the area to be supported within the life of the pit, etc.
3. Quality control:
 - Support is only as effective as the quality of its installation.

Economic considerations:

- The cost of provision of the support units to site;

- The installation cost at the actual intended site where support is required;
- The cost of delays in production to allow access to the area and installation of support;
- Potential savings in steepening up the slopes.

Safety considerations:

- Exposure of personnel to rock related hazards must be minimised and should be taken into account when considering support of slopes;
- Exposure of personnel to potential instability during drilling and installation of support should also be considered;
- The use of elevated platforms etc. should be considered to reduce this risk of exposure;
- Risks should be managed by installation methods, which could include the application of some areal coverage support system prior to the commencement of drilling activities, etc.

Common support types applied to mining slopes can include the following:



Support function	Support types	Description
Bolting systems	Bolts	Steel rods or tendons with mechanical or chemical anchors at one end and a face plate with a nut at the other end. They are used to increase strength of the rock mass or structures due to increased confinement, created by the tension created in the unit between the face plate and end anchor.
	Dowels	Cement grouted steel tendons or friction stabilisers such as split sets that are installed when deformation or stress changes are anticipated. These units depend on the deformation of the rock to induce forces in the support that creates further confinement.
	Cable bolts	Cable anchors that are installed to prevent sliding along structures. The units consist of cables, end-anchors and face plates with pre-stressing devices. They may be partially or fully grouted with cement.
	Shear pins	Reinforcement bars of steel or concrete, installed perpendicular to a specific structures on which sliding is anticipated. The unit increases shear resistance on the structure and its impact is based on the shear strength of the steel pin and the cohesion between the concrete and rock.
	Meshing	When material to be supported is broken into small fragments, mesh (welded) is secured to bolts, dowels or cables. This reduces potential for unravelling of the broken-up materials and contains any unravelling that might occur.
	W straps	Steel straps fastened to bolts on both ends and provide a link between the bolts, increasing areal cover between the units.
Retaining walls	Mass retaining walls	Created out of stone, concrete or composite material are placed as a mass and exercise forces on the host rock material purely based on the mass of the retaining wall. Strong foundation material is required to sustain the weight of the wall.
	Gabions	Steel baskets filled with waste rock material are placed along a wall, i.e. buttressing against the wall. The impact their weight on pit walls below must be considered and strong foundation material is required.

Support function	Support types	Description
Surface treatments	Shotcrete	Sprayed on concrete that locks material into place and prevents unravelling of the material. It can also act as a sealant against water and weathering processes. Reinforcement with mesh is often considered.
	Fibrecrete	Sprayed on concrete that is reinforcement with fibres that could exist of steel or polypropylene materials. These fibres increase the tensile strength of the applied shotcrete and ensure that larger deformations can be sustained before the shotcrete fails.
	Thin skin linings	Spray-on cover that is sprayed onto the rock surface similar to a spray paint and is applied in layers only a few millimetres thick. This material is high in tensile strength due to its composition, which includes a large amount of polypropylene and is applied to prevent unravelling of material or to prevent weathering processes due to exposure.
Buttressing	Construction	Berm consisting of rock material is placed along the toe of the wall, increasing the weight at the toe and creating a force that resists failure of the wall. Broken rock material is better than soil for this purpose due to its higher shear strength.
	Shear trenches	A shear trench is created along the slope to be stabilised, excavated and filled with material of higher shear strength than the <i>in situ</i> slope material.
	Backfilling of voids	Filling of open pits with waste materials to perform a number of functions such as protecting against historic underground workings (use concrete plugs and waste fill).
Rockfall protection	Ditches and bunds	Catch bunds are also called catch berms, created out of waste material and placed along the wall. Bounding / scaling rocks from the slope wall should be contained by this wall. There exists a relation between the slope height and angle and the berm height and distance from the wall.
	Mesh	Mesh hung down the face can contain scaling and small levels of unravelling. When the wall height becomes excessive, wire ropes are used to reinforce the mesh. The mesh is anchored at the top but not at the bottom of the slope to allow the rock to move down the slope under the control of the mesh. Note: the use of tendons to pin the mesh to the walls has also been used to prevent the unravelled material from sliding down the face behind the mesh.
	Catch fences	Catch fences are engineered fences that are designed for specific heights, widths, strengths and yielding capacity based on the expected failure material. These fences are placed along or against the slopes.



- [Open pit rockfall protection](#) (Courtesy of Geobrugg)
- [Pitwall steepening](#) (Courtesy of B Haller, Geobrugg)

INTERESTING INFO

The link provided below indicates the use of many of these methods in civil cuttings and could be of assistance to the user.

Reference guide slope stabilisation options

In-pit tailings storage is the process of backfilling abandoned open pit surface mines with tailings. This method is very attractive to a mine operator as worked -out voids can be filled at a low cost. Another advantage to in-pit storage is that the tailings do not require retaining walls, therefore the risks associated with embankment instability are eliminated.

The stability of underground mines in the vicinity to an in-pit tailings facility may be jeopardised. Liquefied tailings may rush into underground voids resulting in catastrophic consequences or the increasing weight of the overlaying tailings may cause convergence in underground roadways.

Poor consolidation can result in long durations of surface deformation after a pit has been filled. This is mainly due to the low solids content of the tailings and the depth of the stored material. Pits will have to be



- Page 315,318 Read and Stacey, Guidelines for open pit slope design, 2009

LEARNING OUTCOME 5.4.5

CONNECTION 10

Refer to "[LEARNING OUTCOME 5.4.4](#)" on page 151

DESCRIBE AND DISCUSS THE FOLLOWING ROCKFALL PROTECTION MEASURES AND THEIR APPLICATION AND DESIGN:

- Catch fences, catch walls, berm widths
- Thin sprayed linings

PAPER 3.4: SURFACE MINING (HARD AND SOFT ROCK)

LEARNING OUTCOMES

6. INVESTIGATION TECHNIQUES

6.1. SITE INVESTIGATION

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain, discuss and apply site investigation techniques, procedures and assessments covering the following aspects:
 - drilling,
 - logging,
 - mapping,
 - sampling,
 - measuring and
 - testing
- Describe, explain and discuss the application of such site investigation techniques and procedures to the characterisation and assessment of the following aspects:
 - geology,
 - rockmass,
 - groundwater and
 - slope stability
- Describe, explain, discuss and apply the following site investigation techniques and procedures to classify, characterise and assess rockmass conditions:
 - Scanline mapping,
 - cell mapping,
 - window mapping,
 - photogrammetric mapping and
 - stereographic projection.

6.2. SLOPE STABILITY ANALYSIS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain, discuss and apply the following slope stability evaluation techniques and procedures:
 - Empirical analyses,
 - Kinematic analyses,
 - Limit equilibrium analyses,
 - Numerical analyses,
 - Finite element analyses, finite difference analyses
- Describe, explain, discuss and apply the stereographic projection techniques to analyse and evaluate slope stability; and
- Describe, explain, discuss and apply techniques and procedures for dealing with isolated rockfalls.

6.3. ROCK TESTING

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss various rock testing procedures; and
- Interpret and incorporate test results in analysis and design.

6.4. MONITORING

6.4.1. ROCK SLOPE MONITORING

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the reasons for monitoring rockmass movement and slope stability in surface mining operations;
- Sketch, describe, explain and discuss the techniques used to measure deformations in surface mining excavations;
- Describe, explain and discuss the equipment used to measure deformations in surface mining excavations;
- Describe, explain and discuss how displacements in the rock-mass are determined;
- Describe, explain and discuss how the components of ground movement may be derived from these determinations;
- Calculate components of ground movement from given sets of monitoring data;
- Interpret given ground movement data and determine the effect on slope stability;
- Describe, explain and discuss the use of piezometers to measure and monitor groundwater levels and pore water pressures in surface mining excavations;
- Interpret given groundwater data and determine the effect on slope stability;
- For given sets of surface mining conditions:
 - state, describe, explain and discuss what types of measurements need to be made and monitored,
 - describe, explain and discuss required monitoring station

layouts,

- describe, explain and discuss appropriate monitoring programmes,
- interpret practical monitoring data and determine slope failure modes and the behaviour of slopes with time.

6.5. MODELLING

6.5.1. NUMERICAL MODELLING

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the selection of appropriate codes to tackle various problems;
- Describe, explain and discuss the application of the following codes to tackle various problems:
 - Flac,
 - Udec and
 - dips
- Describe, explain and discuss the input of appropriate parameters to investigate various problems; and
- Describe, explain and discuss the interpretation of output in the investigation of various problems.

6.6. RISK MANAGEMENT

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the various elements of a comprehensive risk management strategy for an open pit mine; Describe, explain, discuss and generate information for the following elements of a risk assessment and hazard control programme:
 - Hazard maps,
 - ground control management plans,
 - evacuation procedures and
 - engineering interventions
- Describe, explain, discuss and generate information on acceptable limits on surface mine slope design.

6.7. AUDITING FOR BEST PRACTICE

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the concept of monitoring for understanding, prediction and design.

6. INVESTIGATION TECHNIQUES

6.1. SITE INVESTIGATION

LEARNING OUTCOME 6.1.1

CONNECTION 1

Refer to [Paper 2](#)
Outcome 3.1.1

DESCRIBE, EXPLAIN, DISCUSS AND APPLY SITE INVESTIGATION TECHNIQUES, PROCEDURES AND ASSESSMENTS COVERING THE FOLLOWING ASPECTS:

- Drilling,
 - logging,
 - mapping,
 - sampling,
 - measuring,
 - testing.
- Page 15, Read and Stacey, Guidelines for open pit slope design, 2009



LEARNING OUTCOME 6.1.2

DESCRIBE, EXPLAIN AND DISCUSS THE APPLICATION OF SUCH SITE INVESTIGATION TECHNIQUES AND PROCEDURES TO THE CHARACTERISATION AND ASSESSMENT OF THE FOLLOWING ASPECTS:

- Geology,
- rockmass,
- groundwater,
- slope stability.

The fundamental approach to slope design is based on the creation of a geotechnical model as a first step towards the design of stable slopes. The geotechnical model is a description of the rockmass within which the pit walls will be created and therefore incorporates all the data gathered in the investigation process, and will comprise the following models:

- Geological model;
- Structural model;
- Rock mass model; and
- Hydrogeological model.

Geological model

This model includes a complete look at the geology in terms of rock types, thickness, dips, and alteration (state of weathering) of materials. The regional geological setting its mineralisation genesis is often valuable to understand as it can assist in providing some engineering judgement of the material, even at this early stage of investigation.



- Page 6, 53, Read and Stacey, Guidelines to open pit slope design, 2009

Structural model

Knowledge of major (folds, faults), as well as minor structures (joints, bench scale faults), in terms of their position, orientation and surface properties (persistence, infilling, etc.) is critical for future stability analysis and should be presented in the model.



Major structures may impact on stack and slope stability, while minor structures will most likely impact on bench stability only.



- Page 7, 69, Read and Stacey, Guidelines to open pit slope design, 2009

Rockmass model

The rockmass properties that will define the stability or performance of the slope must be determined and described in this model. This will include rock strengths, rockmass strengths, rockmass quality, etc. At the same time, this model should consider the impact of time on strengths, appropriate blast designs and the impact of the data gathered in the geological and structural models on the rockmass behaviour.



Back analysis of slope behaviours in similar materials will provide valuable insight into and additional information to assist in future designs.



- Page 8, 83, Read and Stacey, Guidelines to open pit slope design, 2009

Hydrogeological model

Both groundwater pressures and surface water flow have the potential to impact on the stability of a slope and should be investigated and described in this model, as well as the need for measures to address any significant water concern such as de-watering and depressurisation measures.



- Page 8, 141, Read and Stacey, Guidelines to open pit slope design, 2009

LEARNING OUTCOME 6.1.3

CONNECTION 2

Refer to
"LEARNING OUTCOME
2.2.2.1" on page 39 and
Paper 2 Outcome 3.1.1

DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE FOLLOWING SITE INVESTIGATION TECHNIQUES AND PROCEDURES TO CLASSIFY, CHARACTERISE AND ASSESS ROCKMASS CONDITIONS:

- Scanline mapping,
- cell mapping,
- window mapping,
- photogrammetric mapping,
- stereographic projection.



- [Role and mitigation of groundwater on slope stability](#)
- Page 15, Read and Stacey, Guidelines to open pit slope design, 2009

6.2. SLOPE STABILITY ANALYSIS

LEARNING OUTCOME 6.2.1

CONNECTION 3

Refer to
“[LEARNING OUTCOME 3.1.6](#)” on page 62

DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE FOLLOWING SLOPE STABILITY EVALUATION TECHNIQUES AND PROCEDURES:

- Empirical analyses,
- Kinematic analyses,
- Limit equilibrium analyses,
- Numerical analyses,
- Finite element analyses,
- Finite difference analyses.



- Page 237, Read and Stacey, Guidelines to open pit slope design, 2009

LEARNING OUTCOME 6.2.2

CONNECTION 4

Refer to
[Paper 2](#) Outcome 3.1.1

DESCRIBE, EXPLAIN, DISCUSS AND APPLY THE STEREOGRAPHIC PROJECTION TECHNIQUES TO ANALYSE AND EVALUATE SLOPE STABILITY



- Page 77, Read and Stacey, Guidelines to open pit slope design, 2009

LEARNING OUTCOME 6.2.3

DESCRIBE, EXPLAIN, DISCUSS AND APPLY TECHNIQUES AND PROCEDURES FOR DEALING WITH ISOLATED ROCKFALLS.

Isolated rockfalls are normally not catered for in the slope design in terms of stable slope angles, but are the result of the loosening of isolated pieces of rock due to blasting/seismic vibrations or time-related deterioration. These isolated falls are addressed through:

- Making safe of the wall or
- Support installation.

Making safe practices

In the project report on GEN703 (SIMRAC – Making safe highwalls) it is concluded that highwall cleaning is internationally considered as a reactive strategy and is generally conducted by:

- scratching of the highwall face carried out by a dragline or excavator buckets;
- pulling a chain across the highwall face with a bulldozer (however, rarely done);
- dozing of loose material over the edge.



Figure 1: Making safe with chains

GEN703 is a SIMRAC initiated research report that addresses the making safe of highwalls, focusing on coal mines. This research project investigated and reported on:

- Methods for making highwalls safe.
- Methods to clean highwalls.
- A geotechnical database relevant to highwall planning in South Africa.
- A highwall risk assessment procedure.
- An international benchmarking study on monitoring and cleaning procedures for highwalls.

The study showed that:

- highwall rockfall hazards were reduced by the implementation of good smooth wall blasting practices or by mechanical cleaning (bulldozers and chains);
- international operators considered that inclined highwalls and the limitation of highwall heights were effective in rockfall control.

At the same time, the following were recommended to address the potential for rock related hazards:

- The execution of a geotechnical assessment of the ground conditions requires the collection of information on the strength characteristics of both the soft and hard overburden and should be carried out;
- The creation of a geotechnical domain model of the ground conditions through which the strip mine will advance, i.e. an analysis of the geotechnical information gathered;
- The execution of standard geotechnical analyses to determine highwall heights as well as overall geometries and orientations. In this respect, empirical, deterministic, probabilistic and numerical methods of slope analysis should be used. Kinematic techniques should also be used to analyse stability with regard to highwall orientation;
- Highwalls should, where possible, be orientated at right angles to major geological structures and changing to smooth wall blasting strategies or inclined highwalls may be beneficial.

From accident data, the following:

- A correlation exists between highwall failures and the height of the overburden being mined where the majority of failures occurred within the upper 30m of overburden;
- Failures were correlated to the presence of geological structures with trace lengths greater than 5m;
- Most fatal accidents occurred during the night shift where truck and shovel methods are being used;
- Mining personnel do not understand the importance of the structural geological regime on highwall stability.

From the blasting analyses:

- The influence of rockmass structure on highwall blasting quality is critical;
- The need for the evaluation of geotechnical data in the blast design is important;
- The need to develop effective smooth wall blasting techniques in weathered and highly jointed rockmasses was seen as important in order to improve highwall conditions.

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PAPER 3.4: CHAPTER 6



CONNECTION 5

Refer to
[Paper 2](#) Outcome 3.1.1



- [GEN 703 Making safe highwalls](#)

Support practices

Refer to
Outcome 5 (The whole chapter 5???)

- Page 310, Read and Stacey, Guidelines to open pit slope design, 2009

6.3. ROCK TESTING

LEARNING OUTCOME 6.3.1

CONNECTION 6

Refer to
[Paper 2](#) Outcome 6.1.1

**DESCRIBE, EXPLAIN AND DISCUSS VARIOUS ROCK TESTING PROCEDURES.**

Refer to
Paper 2 Outcome 6.1.1

- Page 83, Read and Stacey, Guidelines to open pit slope design, 2009

LEARNING OUTCOME 6.3.2

CONNECTION 7

Refer to
[Paper 2](#) Outcome 6.1.1
and
[Paper 1](#) Outcome 4.1.11

**INTERPRET AND INCORPORATE TEST RESULTS IN ANALYSIS AND DESIGN.**

Rock strength testing forms part of the data gathered to complete the geotechnical model, leading into the slope design process. Since the rockmass strength is a critical part of the slope design, rock testing is an important input into the defining of the rockmass in terms of its strength properties, which can include reference to its Mohr-Coulomb (Friction angle and cohesion) or Hoek-Brown (m_i , m , s) properties.

There are a number of ways to determine these strength properties and the selection of the process is probably based on the type and level of data available to the user.

EXAMPLE

A number of examples are provided below to indicate possible ways of determining the relevant rockmass strength properties.

1. Waste material characterisation

The waste material will consist of an assortment of rocks belonging to the Kalahari Formation, Mooidraai Formation and Hotazel Formation. Unsorted dumping of material is assumed. The properties of the different types of waste material (Table 1 and Figure 32) were derived using statistical methods that incorporate the following parameters into the accompanying set of equations to determine the waste secant friction angle.

back

- Angularity measured on a scale of 1 to 8 with 8 being extreme angularity and 1 low angularity
- Fines – percentage of fines passing 0.075mm (%)
- Coefficient of curvature
- UCS – Unconfined compressive strength of the rock (MPa)

$$\Phi = a + b\sigma_n$$

$$\Phi' = \text{secant friction angle}$$

$$a = 36.43 - 2.067\text{ANG} + 0.594\text{FINES} - 5.105(\text{C}-2) - 0.408(\text{UCS}-150) - 0.408c$$

$$= -0.3974$$

WASTE TYPE	ANG	FINES	CC	UCS (MPa)	Density (kg/m ³)	Normal stress (kPa)	a	b	c	f
Soft calcrete	3	30	0	5.13	2190	1289.95	22.31	185.70	-0.40	33.09
Hard calcrete	5	30	0	19.65	2190	1289.95	22.44	200.31	-0.40	34.07
Gravel	4	40	0	12.56	2190	1289.95	20.66	198.43	-0.40	32.18
Clay	1	60	0	2.95	1900	1119.14	17.58	182.52	-0.40	28.79
Dolomite	6	20	0	156.04	2717	1600.37	30.15	149.45	-0.40	38.12
Banded ironstone	7	10	0	295.56	3156	1858.95	38.01	97.30	-0.40	42.90

Table 1: Properties for waste material

EXAMPLE

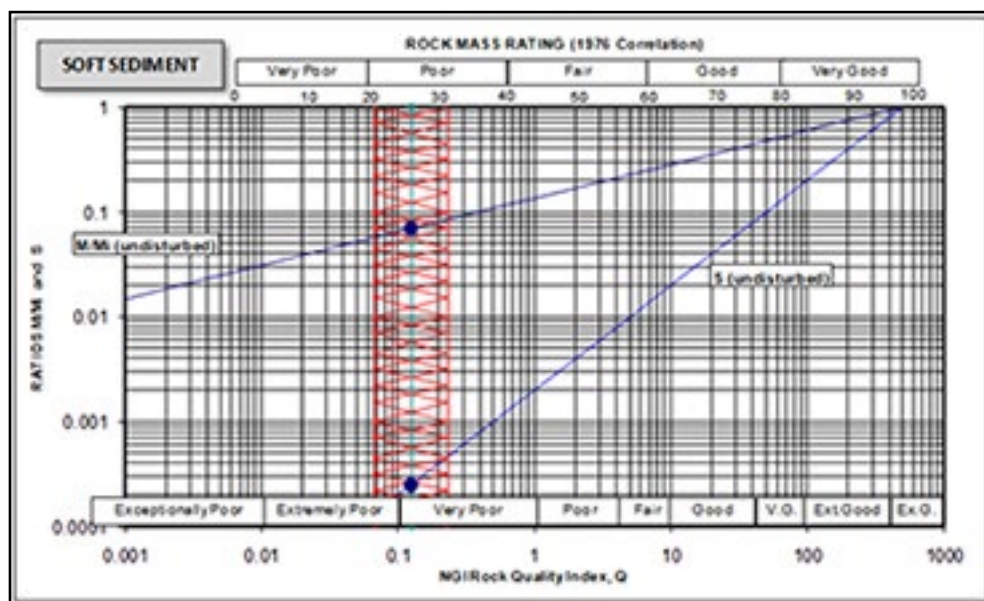
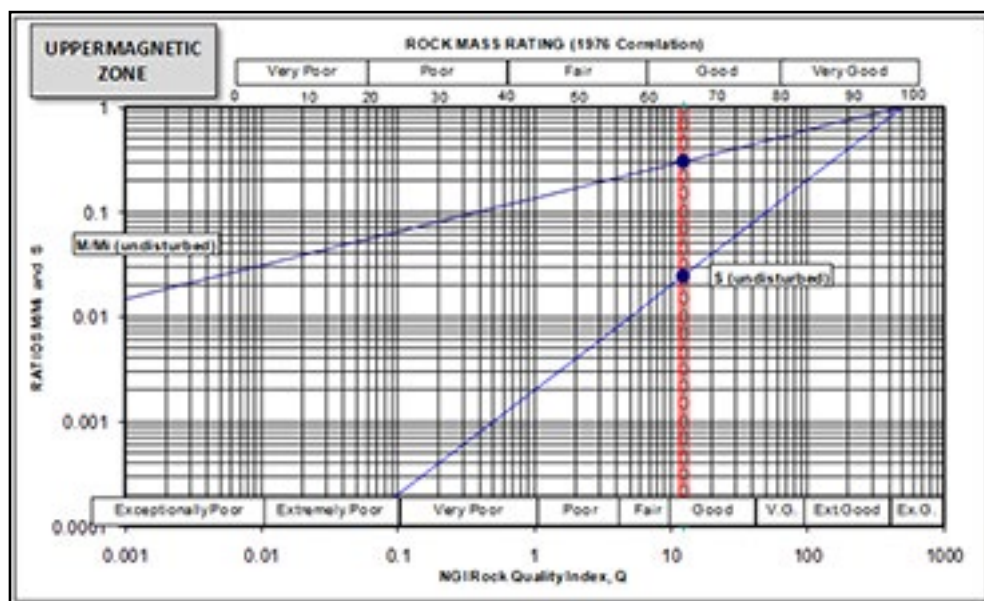
A catalogue of typical rock properties has been derived and is presented in Table 2. These properties were used as input parameters to estimate the rockmass ratings of the lithological units that host and constitute the deposit.

Geological Unit	Max thickness (m)	Description	Rock types	Strength (MPa)	Mean strength (MPa)	Density (kg/m ³)	Mean density (kg/m ³)	Assumed geotechnical characteristics
Sediment	10	Weathered mudstones, siltstones and wackes, with intercalated sandstones	Mudstone	54.14	73.16	2340.00	2467.50	Single weathered grade upto 10 m. Water table expected to lie between 10-15m below surface. Can be treated as single domain
			Siltstone	79.01		2570.00		
			Wackes	79.75		2400.00		
			Sandstone	79.75		2480.00		
Upper Magnetic Zone	20	Moderately magnetic mudstone with minor layers of siltstone and chert	Magnetic mudstone	54.14	108.18	2340.00	2536.67	Laminated body. Strength reduction of 30% expected due to proximity to surface. Could be within
			Siltstone	79.01		2570.00		
			Wackes	79.75		2480.00		
			Sandstone	79.75		2480.00		
Sediment	30	Fresh mudstones, siltstones and wackes, with intercalated sandstones	Mudstone	54.14	73.16	2340.00	2467.50	Defects dominated by beds and laminae. Defect dip between 7-25 degrees expected i.e. with lie of strata
			Siltstone	79.01		2570.00		
			Wackes	79.75		2480.00		
			Sandstone	79.75		2480.00		
Middle Magnetic Zone 3	12	Magnetic mudstone interlayered with magnetite and haematite	Magnetic mudstone	54.14	96.38	2340.00	3513.33	Normally, horizontally inclined defects with sporadic vertical joints that are tightly healed
			Magnetite	175.00		4000.00		
			Haematite	60.00		4200.00		
			Haematite	60.00		4200.00		
Middle Magnetic Zone 2	8	Haematite and magnetite layers with minor chert & Jasper	Magnetite	175.00	142.13	4000.00	3633.33	Defects dominated by beds and laminae. Defect dip between 7-25 degrees expected i.e. with lie of strata
			Chert	191.40		2700.00		
			Magnetic mudstone	54.14		2340.00		
			Magnetite	175.00		4000.00		
Middle Magnetic Zone 1	10	Magnetic mudstone interlayered with magnetite and haematite	Magnetic mudstone	54.14	146.71	2340.00	3513.33	Defects dominated by beds and laminae. Defect dip between 7-25 degrees expected i.e. with lie of strata
			Magnetite	175.00		4000.00		
			Haematite	211.00		4200.00		
			Magnetite	175.00		4000.00		
Sediment	15	Fresh mudstones, siltstones and wackes, with intercalated sandstones	Mudstone	54.14	73.16	2340.00	2467.50	Strong, possibly massive layer with well healed beds and laminae
			Siltstone	79.01		2570.00		
			Wackes	79.75		2480.00		
			Sandstone	79.75		2480.00		
Lower Magnetic Zone 2	20	Massive magnetite and haematite with chert banded	Magnetite	175.00	193.00	4000.00	4100.00	Standard Penetration tests will be required to test bearing capacity
			Haematite	211.00		4200.00		
			Magnetic mudstone	54.14		2340.00		
			Magnetite	175.00		4000.00		
Lower Magnetic Zone 1	15	Magnetic mudstone interlayered with magnetite and haematite	Magnetic mudstone	54.14	146.71	2340.00	3513.33	Standard Penetration tests will be required to test bearing capacity
			Magnetite	175.00		4000.00		
			Haematite	211.00		4200.00		
			Magnetite	175.00		4000.00		
Sediment	Floor	Fresh mudstones, siltstones and wackes, with intercalated sandstones	Mudstone	54.14	73.16	2340.00	2467.50	Standard Penetration tests will be required to test bearing capacity
			Siltstone	79.01		2570.00		
			Wackes	79.75		2480.00		
			Sandstone	79.75		2480.00		

Table 2: Typical rock properties and geotechnical descriptions of the deposit

The RMR_{76} and Q classification of the different rock units were obtained by assuming likely conditions of the rockmass. These conditions were based on engineering judgement rather than a set of identifiable parameters. The RMR_{76} values were, in turn, adjusted to provide an $MRMR$ rating of the rock units. A summary of the ratings is shown in Table 3 and the graphical representation of the ratings in Figure 2 and Figure 3.

Geological Unit	RMR_{76}	Q
Weathered sediment	31.00	0.07
Upper magnetic zone	66.00	13.20

Table 3: Likely rockmass ratings**Figure 2: Rockmass ratings for weathered material****Figure 3: Rockmass ratings for upper magnetic zone**

Geological unit	M/mi	s
Weathered sediment	0.07	0.0025
Upper magnetic zone	0.3	0.025

Table 4: Hoek-Brown properties

EXAMPLE

In order to carry out analysis on failure modes, the following need to be determined:

- Rockmass rating (RMR) (After Bieniawski 1989),
- Q value (After Barton 1974),
- The UCS of the intact rock,
- The value of the geological strength index (GSI) for the rockmass.
- The value of the Hoek-Brown constants of m_i , m_b , s and a for the intact pieces,
- Rock density,
- Values of cohesion and friction.

The RocScience program RocData was used to determine the m_b , s , a , cohesion and friction angles with the UCS, GSI, m_i and D properties as the input parameters. The properties determined for each rock type are as follows:

Rock properties	Units	Highly weathered	BIF
Mean RMR89	N/A	Not recorded	67.29
Mean Q	N/A	Not recorded	12.51
GSI	N/A	30.00	52.29
UCS (Mean)	MPa	44.25 (estimated)	119.38
m_i	N/A	5.21	17.88
D	N/A	0.80	0.80
m_b	N/A	0.081	1.045
s	N/A	0.000002	0.0007
a	N/A	0.5220	0.505
ρ	kg/m ³	3090.0	4010.0
c	kPa	101.0	2009.0
f	degrees	27.63	38.05

Table 5: Summary of fresh rock properties and weathered materials

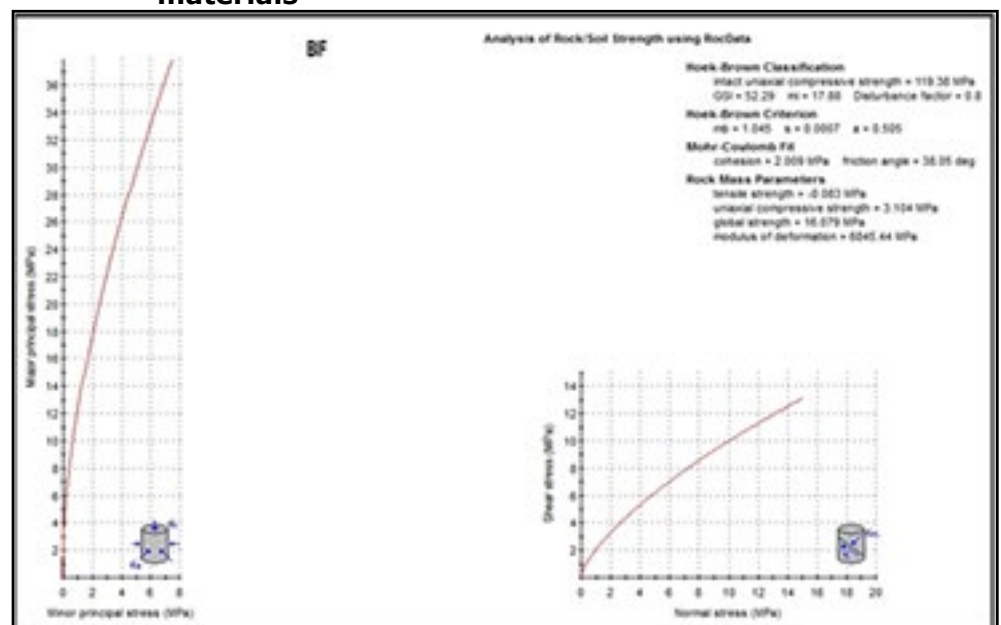


Figure 4: RocData results for BIF

[back](#)

PAPER 3.4: CHAPTER 6

INTERESTING INFO

RocScience has developed software to assist in the derivation of rockmass strength properties from rockmass quality and intact rock strength test results (RocData).

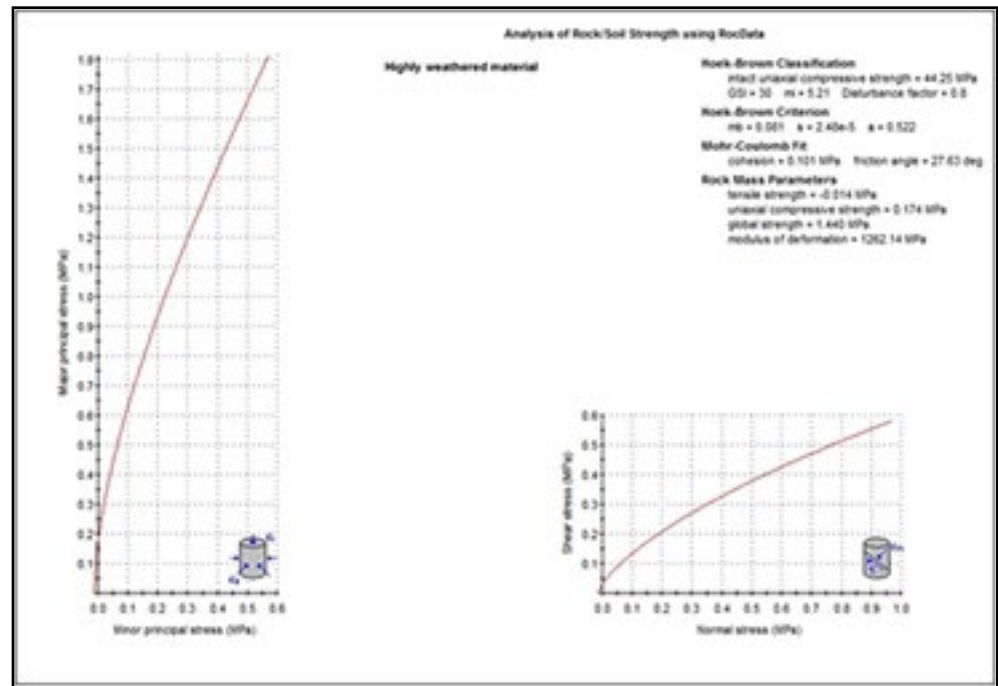


Figure 5: RocData results for highly weathered material



www.rocscience.com/products/4/rocddata



The following must be kept in mind when this software is used to determine rockmass properties:

1. The program is used to derive principally the shear parameters of a jointed rockmass as opposed to an intact rock. It bases its derivation on a set of UCS and tri-axial test results. The equivalent Mohr-Coulomb parameters are simply derived by fitting a straight line to the estimated Hoek-Brown curve;
 - The program results are undefined when the σ_3 is less than (σ_c/m_i) value. This must be checked (quite easily) when tri-axial results are obtained;
 - Inserting a 0 for σ_3 and the UCS (obtained from either UCM or Tri-axial tests) as the first entry into the data used from tri-axial tests, derivation of m_i values works very well as opposed to starting the analysis with say 5, 10 or 15MPa confining stress. This is in keeping with the ranges dictated by Hoek of 0 to $(0.5 \times \sigma_c)$ for tri-axial calculators for m_i built into the program;
 - The program uses the tri-axial results to estimate the cohesion and friction angle, BUT, since this is laboratory scale, the user now only has a base to work from to downgrade these values using Hoek-Brown;
 - The tri-axial calculators for m_i derivation use three curve fitting methods. Base all derivation on linear regression first, since this is the foundation of the Hoek-Brown system. Other methods can be used if the user is comfortable with the processes referred to;
 - In all tabled outputs, state what excavation method was selected for the Hoek-Brown derivation, i.e. custom, slopes, tunnels or general (this is important if one has to recreate the data);

[back](#)

2. M_i values:

- The m_i values for all rocks should show scatter since it is based on mineralogy, grain size and composition. The user should therefore have some understanding of these factors when determining the appropriate m_i values. For example:
 - A porous sandstone that hosts copper mineralisation should have an m_i in the region of 8-12;
 - A capping sandstone with very low permeability ($k = 1 \times 10^{-6}$) should have an m_i in the region of 22-30;
 - A typical Witbank sandstone that falls between the two mentioned above should have an m_i of 12-22;
- The point here is that they are all sandstones, but their sedimentary disposition determines their m_i value. If the user simply uses the tables provided, it is probable to allocate a low m_i for one requiring something higher;
- The UCS of the rock should give an indication of the m_i ;

3. GSI:

- GSI is equal to RMR_{76} or $(RMR_{89} - 5)$;
- The RMR basic value is the RMR_{76} and RMR_{89} rating when dry conditions are assumed and no adjustments for joint orientations are made;
- Note: RMR_{76} must be greater than 18 and RMR_{89} must be greater than 23 when using the program. If GSI is derived from any of the two RMR systems and produces a value less than 25, then the GSI tables must be used and not the derivation based on RMR;
- Note: If the rock is highly altered and disturbed, then use the Flysch GSI tables. This should apply to weathered materials;

4. Benchmarking:

- Some level of benchmarking must be done on the relevance of cohesion and friction angles;
- Always check the m_i value derived through tri-axial tests against the default value obtained from the Hoek-Brown tables as a form of benchmarking.

5. Important:

- It is important not to mix deriving JOINT friction and cohesion with ROCK friction and cohesion;
- The Barton Bandis model must be used for joints and the Hoek-Brown for jointed rockmasses.
- Rock can degrade to the strength of joints eventually, but this is only when the rock fabric has been completely distorted and altered. Folded and contorted rock is a good example in soft meta-sediments.



- Page 127, Read and Stacey, Guidelines to open pit slope design, 2009

6.4. MONITORING**6.4.1. ROCK SLOPE MONITORING****LEARNING OUTCOME 6.4.1.1****CONNECTION 8**

Refer to
Paper 2 Outcome
6.2.1, 6.2.2, 6.2.3

DESCRIBE, EXPLAIN AND DISCUSS THE REASONS FOR MONITORING ROCKMASS MOVEMENT AND SLOPE STABILITY IN SURFACE MINING OPERATIONS

Due to the difficulty to accurately predict slope behaviour, even though data on the rockmass is gathered and analysed, the monitoring of slopes forms an important part of pit management. Monitoring can perform the following functions:

- Indicate the performance of the design implemented;
- Confirm adequacy or inadequacy of the design;
- Reduce risk due to warning against failure and potential to remove personnel and equipment from harm;
- Provides data to assist in forward prediction of expected behaviours and therefore allowing the determination of remedial actions before actual failure occurs.

The instruments should therefore be installed as soon as possible to:

- Detect and record any slope movements;
 - Ensure safe mining environment;
 - Assist in establishing the reasons for the displacements recorded;
 - Manage instabilities that might occur;
- Assist with an investigation into slope failures that have occurred;
 - Assist in identifying failure mechanisms;
 - Assist in back analyses;
 - Assist in determining appropriate remedial actions;
- Provide a base to evaluate or modify the designs;
- Ensure that design criteria are achieved.



- Page 342, Read and Stacey, Guidelines to open pit slope design, 2009
- Open pit failure:
http://www.youtube.com/watch?v=qkxBb7rp7_w&feature=player_embedded
- World's largest landslides:
http://www.youtube.com/watch?v=0Vf7P-hKDpM&feature=player_embedded
- Landslides: How do they occur?
http://www.youtube.com/watch?v=JrV4uCVwmfk&feature=player_embedded

LEARNING OUTCOME 6.4.1.2

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE TECHNIQUES USED TO MEASURE DEFORMATIONS IN SURFACE MINING EXCAVATIONS.

Stability assessments usually consist of qualitative and quantitative methods where qualitative assessments are usually performed by on-site personnel as part of their legal responsibility inspections, while quantitative assessments include instrumentation.

In most cases, large failures are preceded by smaller failures or movements that can be detected using appropriate instruments. This is much easier to detect in soft material, in low stress environments close to surface, as in deeper, high stress conditions in hard brittle material, movements can be very small and very difficult to detect. For this reason, instruments are classified as surface or subsurface instruments, each appropriate for specific environments.

Surface displacement instruments may include:

- Visual inspections
- Cross-crack measurements;
- Survey monitoring;
- GPS;
- Photogrammetry;
- Laser scanning;
- Radar;
- Tiltmeters and electrolevels.

Subsurface instruments include:

- Inclinometers;
- Shear strips and time domain reflectometer cables;
- Extensometers;
- Micro-seismic.



- Page 343, Read and Stacey, Guidelines to open pit slope design, 2009
- Page 323, Hoek and Bray, Rock slope engineering, 1981



- Instrumentation
http://www.youtube.com/watch?v=sST--HfxRw8&feature=player_embedded

LEARNING OUTCOME 6.4.1.3

DESCRIBE, EXPLAIN AND DISCUSS THE EQUIPMENT USED TO MEASURE DEFORMATIONS IN SURFACE MINING EXCAVATIONS.

Instruments normally consist of the following components:

- A sensor or transducer to measure the property of interest;
- A transmitting system to send information to another location;
- A read out unit to display the measured quantity.

The following instrumentation units have been recorded by Read and Stacey (2009) and are summarised in Table 6.

Type of assessment	Information	Image	Reference
Visual inspection	Record of observed crack patterns. Spray paint on cracks show movements. 'Tell-tale' glass slides across fine cracks will break.		Read/Stacey Page 345
Cross-crack instruments	Thin coating of concrete over crack to make measurements easier. Embedded anchors in material on both sides of cracks. Tapes / tape extensometers. Portable clinometer to assist with differential movements.		Hoek/Bray Page 152 Read/Stacey Page 345
Crack measuring pins	Steel pins or pegs fixed on both sides of a crack. Tape, Vernier calliper or micrometre is used to measure distance between pins. Automated crack meters measure displacements and can be connected to a warning device.		Read/Stacey Page 345
Wireline extensometers	Wire is fixed on one side of a crack and passed over a pulley on a tripod on other side and tensioned using a weight. This system can also be automated and connected to a warning device.		Read/Stacey Page 346
Survey monitoring	Theodolites, total stations, GPS receivers, photogrammetric cameras. Conventional survey techniques are used.		Read/Stacey Page 348

Type of assessment	Information	Image	Reference
GPS systems	GPS receivers and satellites. GPS receiver requires a view of four satellites for accurate 3D (depth) positioning and 3 for accurate horizontal (2D) positioning.		Read/Stacey Page 348
Photogrammetry	Photo-theodolites take a series of photos from a fixed point and along a fixed baseline. A stereo compactor identified movements between photos. All is not digital and much faster to produce results using computers and software.		Read/Stacey Page 349
Laser scanning	LiDAR (light detection and ranging) technology using terrestrial laser scanning. Note: Not accurate enough for slope monitoring (cm range), but surface definition before and after failures finds application.		Read/Stacey Page 350
Radar scanning	Radar unit scans the pit and transfers data to computers with relevant software. Note: Accurate (mm range)		Read/Stacey Page 351
Tiltmeters and electrolevels	Tiltmeters with electrolytic level transducers. Several types of tilt meters are available		Read/Stacey Page 353

Table 6: Instruments specific to sements

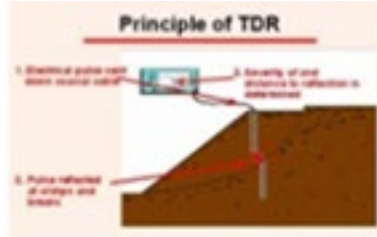
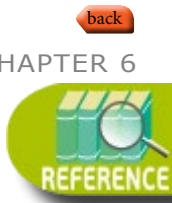
Type of assessment	Equipment / record information	Image	Reference
Inclinometers	Portable probe lowered into drill hole that measures relative to the bottom of the hole and takes a reading every time it is lowered. Several probes left in place that record lateral displacement to a remote sensor and provide real-time readings.		Read/Stacey Page 354
Shear strips and time domain reflectrometers (TDR)	Detect location of deformation, but not magnitude. Shear strip is string of electrical resistors connected in parallel along the length of a circuit conductor and is grouted into the hole. Local movement breaks the strip and the change in resistance indicates where it has been broken. TDR is coaxial cable installed in a drill hole so that displacement will pinch or break the cable. The position of this break is determined by transmitting pulses from a cable tester.		Hoek/Bray Page 152 Read/Stacey Page 354
Extensometers	Extensometers are installed in drill holes to measure movement along the hole. Single or multiple position extensometers are used. Anchors are grouted in position and cables are used to indicate displacement. Rod or wire extensometers are available. Electronic extensometers are used more often and allow partly remote reading.		Read/Stacey Page 356
Micro-seismic	Real-time monitoring of seismic waves initiated by rock failure processes. Sensors are installed that record wave forms and transmit it to computers where software is used to locate the source of the wave, indicating where the failure had taken place.		Read/Stacey Page 357

Table 7: Instruments specific to subsurface measurements

- [Slope stability prism monitoring](#)
- [Slope monitoring with total station Cawood](#)



- Page 343, Read and Stacey, Guidelines to open pit slope design, 2009
- Page 323, Hoek and Bray, Rock slope engineering, 1981

Interesting information (Courtesy of Mining Magazine)

INTERESTING INFO

Radar

Radar is a relatively recent introduction to the market, but is now widely used and accepted by the majority of open-pit mines. Lower-cost monitoring methods such as prisms and extensometers are used for background monitoring of general wall areas, but once instability has been detected, radar is often the best monitoring method. These systems consist of a dish that scans horizontally and vertically, usually mounted on a mobile trailer.

There are two basic types of slope-monitoring radar commercially available: real-beam radar such as GroundProbe's Slope Stability Radar (SSR) and synthetic aperture radar.

Both types are similar in the way that they measure displacement in a mine wall, but differ in the way in which they locate and map the measured displacements.

A real-beam, slope-monitoring radar offers a more precise instrument for monitoring rock wall movements that are the precursor to a fall. It provides full coverage of the slope, and independent measurements in horizontal and vertical dimensions, near real-time measurements, sub-millimetre accuracy and it can detect rapidly developing failures. However, it is heavy to move around and may be affected by atmospheric changes.

Synthetic aperture radar gives scope for high azimuthal resolution at long range, but vertical resolution depends on converting range information into elevation using a digital terrain model. It gives full coverage, but only in its deployment area, and offers near real-time measurement and sub-millimetre accuracy. However, it requires a fixed installation and is not mobile.

The main advantages of radar systems are that they can penetrate dust and fog while optical devices cannot.

Companies

- Reutech

Reutech Mining, a division of Reutech, makes three different slope-stability radar systems for the mining industry. The range includes: the MSR 200, which can detect slope failures at an operational range of 1,200m; and the MSR 300, with an operational range of 2,500m. Both are fully autonomous systems that generate their own electrical power. The newest member of the MSR family is the MSR 060 V, which is a fully fledged MSR system, mounted on a standard pick-up vehicle and capable of operating at distances of up to 600m.

Reutech's MSR systems are used in 14 countries and range in altitude from sea level to 4,800m elevation. The standard MSR can operate in temperatures ranging from -30°C to +55°C; however, a special configuration was provided to a client in the Arctic Circle where the system was modified to operate at -50°C.

- **GroundProbe**

GroundProbe first introduced the SSR in 2003. This system remotely measures the movement of wall surfaces, and uses visual images to confirm and display the results. The dual-measurement system enables geotechnical engineers and mine personnel to track slope movements confidently, and set alarms to improve safety and optimise productivity.

The Work Area Monitor (WAM), launched in 2011, was developed for operation by a mine production crew with no specific technical skills. The system comprises sensitive, fast-scanning radar, coupled with a high-resolution camera, all built into a mine-standard, light vehicle.

The primary function of the WAM is to sound a local area alarm to warn workers of slope movement in their vicinity, as opposed to the broader pit-monitoring and long-term deformation measurements of the known slope-stability radars.

GroundProbe also offers GeoSeer, a software application that provides secure local and remote access to geotechnical information from the SSR.

GroundProbe equipment is operating successfully in mines in a range of climates and conditions, including Rio Tinto's Diavik diamond mine in northwestern Canada, the Collahuasi copper mine (owned by Xstrata and Anglo American) at an altitude 4,000m in Chile and at Tarong Energy's Meandu mine in Australia.

- **IDS Australasia**

IDS manufactures two products for slope stability monitoring: IBIS-L, which was designed specifically for landslide monitoring; and IBIS-M, which is used for monitoring walls in open-pit mines.

IBIS-L uses microwave interferometry to offer real-time, 2D mapping of simultaneous displacements over large areas, with an accuracy of up to 1/10mm. It operates autonomously, samples movements every five minutes, and is suitable for use by day or night in any weather.

IBIS-M is based on small, horn antennas that are moved along a linear scanner, making the product more flexible than parabolic dish antennas, which have to be moved mechanically. IDS says this allows it to achieve higher performance in terms of accuracy, resolution, scan time, reliability, capital and operational costs.

IBIS-M uses advanced processing techniques derived from satellite radar interferometry technology, along with a software suite that was developed specifically for the mining industry.

IBIS-M has had over 40 installations since its introduction in early 2010, in mines in North America, South America, Europe, Africa, Oceania and Asia. These installations have been commissioned by prominent mining groups for a range of geotechnical conditions, including massive hard rock, intensely fractured rock and soft material, coal and metal mines. Working distances range from a few hundred metres to more than 3.5km from the slope.

Laser

Laser scanning is a remote sensing technique that involves sweeping a narrow laser-beam pulse along a direction characterised by lateral and vertical angles relative to the scanned slope. The method gives accurate discontinuity measurements by generating a 'point cloud' or 3D representation of each reflecting point of the target slope.

James Howarth, I-Site research and development manager at Maptek, says: "Laser scanners are ideal for capturing baseline data and for visualising changes in surfaces. Apart from the obvious benefit of being able to capture accurate survey data from a safe distance, laser scanning creates an immediate record of structures such as undercuts."

Laser-based techniques are popular for larger mines as they do not have the same distance limitations of other techniques such as radar. However, Mr Howarth adds: "A large, detailed point-cloud assessment is only as useful as the specialised tools available to interpret and analyse the data."

Modelling and analysis software enables geotechnical and engineering teams to interpret the data. Some advantages of laser surveying include full coverage of the target area, near real-time results and no need to physically access the slope.

Disadvantages include less accuracy than other methods, a fixed installation and the fact that systems need to be protected from environmental conditions.

Companies

- 3D Laser Mapping

3D Laser Mapping provides SiteMonitor Slopes; a monitoring system that uses advanced laser-scanning technology with powerful, simple-to-use software. SiteMonitor is a flexible, modular system that can be tailored to suit clients' needs.

The data generated by SiteMonitor Slopes is high resolution and takes advantage of waveform analysis. Jon Chicken, sales director at 3D Laser Mapping, says: "This is a complex feature, but in essence provides the facility to 'see more'; for example, through vegetation or protective wire meshes. In competing systems, both of these factors can have a significant impact on the measurements taken, whereas SiteMonitor allows the user to ignore the presence of such 'noise'."

3D Laser Mapping's systems have been installed in a diverse range of major open-pit mines, from Anglo Platinum's PPL mine in South Africa to Newmont Mining's Yanacocha gold mine in Peru.

- Maptek

Maptek's I-Site laser-scanning technology collects and models detailed survey data. Maptek makes the I-Site 8800 and 8400 scanners. Mr Howarth says: "Users can survey a scene, recording all structures and faces in true 3D, and quickly build a full, digital elevation surface model. Cut and fill volumes can be calculated, and the model can be used to model slope stability over time. I-Site point data can also be imported into hydro-dynamic models and used to estimate shear stresses on slopes."

The new geotechnical module, released alongside I-Site Studio

3.5, includes extensive software tools for users to monitor changes in surfaces such as walls, batters and faces. Stereonet plots, rose diagrams, the addition of contours and colouring surfaces by the dip and strike values are some of the options available to users. Overlapping surfaces from different scans can be compared to track movement.

The Vulcan modelling and mine-planning software includes a geotechnical module that contains tools to help users analyse the data collected and distinguish zones of weakness in a 3D graphical environment.

A specialised monitoring module contains options for viewing, plotting and manipulating data obtained from monitors periodically as time series data. Models can be built to demonstrate change over time.

Prism-based systems

The nature and function of a total station is well described in a paper by one of the market leaders, Leica Geosystems: "Automatic prism-monitoring systems using motorised total stations have been used in mines since the early 1990s. Prisms are mounted on each of the points to be monitored, together with one or more stable reference points, with their observation controlled by a software application.

"The total station measures horizontal and vertical angles and slope distances to each prism, from which easting, northing and height values and, subsequently, displacements are computed.

"Usually, the total stations are installed at a permanent location and levelled to align their main axis with the direction of local gravity. Attention is paid to select only very stable sites to ensure the co-ordinates computed from the station will remain in a consistent reference frame to simplify the detection of movement in the monitoring points.

"In mines, the total stations are usually placed at the top of the pit. At least one stable point is needed to orientate the total station, and account for rotations due to uneven heating and cooling of the monument and instrument. If the instrument cannot be located on a stable pillar then a free-station calculation, using measurements to multiple stable control points, can be used to account for movements of the total station."

Total stations are often referred to as robotic because once the station and prisms are installed in the mine, no manual input is needed as the instrument movements are managed by software.

Advantages of prism-based systems include sub-millimetre accuracy, measurement in real-time, the ability to measure long-term deformation changes, 3D co-ordinates and a long measurement range. Compared with radar, the initial cost is low. However, it is restricted to localised measurement only, requires a fixed installation and can be affected by atmospheric changes.

Technological advances in total stations include faster speeds and the ability to find and lock on to targets over long distances. Improvements in communications technology, such as wireless mesh radio networks, also allow remote placement and control of total stations and global navigation satellite systems (GNSS) receivers.

Companies

- Leica Geosystems

Leica Geosystems provides a wide range of products for slope stability monitoring, including sensors, software and communications systems that can be integrated modularly and seamlessly into an automatic geodetic deformation monitoring system.

Its high-precision total stations are the most commonly used sensor for slope stability. The latest is the Leica TM30/TS30 series, which is designed especially for monitoring applications, and provides high-accuracy angular measurements of 13mm and 25mm, and sub-millimetre accuracy on prism distances. Other sensors in the range include the GMX902 GNSS monitoring receivers, the GMX901 smart antenna and the high-precision Nivel210/220 tilt sensor.

The Leica GeoMoS software provides a highly flexible, automatic deformation monitoring system, which can combine geodetic, geotechnical and meteorological sensors to match the needs of a monitoring project. The software distributes data in real-time and provides professional management based on a SQL Server database.

It comprises two main applications called Monitor and Analyzer. GeoMoS Adjustment is add-on software that allows users to make decisions based on statistically optimised and validated data. Leica GeoMoS Web is a web-based service for the visualisation and analysis of monitoring data collected by the GeoMoS software.

Other software tools that can be integrated include: Leica GeoMoS HiSpeed, which analyses fast movements and deformations in real-time; Leica GNSS Spider, a professional business solution for GNSS networks; and Leica CrossCheck, a GPS/GNSS deformation monitoring service.

The firm also provides the Leica M-Com series, which are compact plug-and-play solutions for monitoring communication that increase the mobility of periodic or short-term monitoring systems.

Leica GeoMoS is used at the Centerra Gold Kumtor mine in Kyrgyzstan, while GeoMoS and GNSS Spider are used at Marmor Sežana's Lipica II quarry in Slovenia.

- Trimble

Trimble makes the high-precision Trimble S8 Total Stations and Trimble Net R9 GNSS receivers for monitoring slope stability. Its instruments allow users to combine both GNSS and optical data on a single project for slope stability monitoring. The GNSS technology provides long-range accuracy and rapid update rates, and can be used to verify the stability of station control points.

The firm also offers Trimble 4D Control; scalable monitoring software that provides analysis and management tools for the monitored data. It has three options to easily expand from post-processed deformation monitoring campaigns to a real-time system where data from total stations, GNSS receivers and geotechnical sensors can be processed simultaneously and in real time.

Trimble monitoring solutions have been installed in mines in Australia, Asia, Europe, North America and South America.

Extensometers

A wire extensometer or crack monitor is basically a metal rod that is inserted into the ground on the unstable side of a crack, with the monitor and pulley station located on a stable portion of the ground behind the last tension crack. The wire runs over the top of a pulley and is tensioned by a weight suspended from the other end. As the unstable portion of the ground moves away from the pulley stand, the weight will move. The displacements can be recorded and automatically transmitted back to the geotechnical office or noted manually. Wire extensometers are mainly aimed at monitoring small movements in particular areas.

For subsurface, another type of extensometer can be used – a borehole variant. Changes in the distance between the anchor and the rod head provide the displacement information for the rock mass. Key manufacturers of these products include RocTest, Geokon, Slope Indicator and RST Instruments.

Advantages of extensometers include real-time measurement and sub-millimetre accuracy. However, they only give localised measurements and require a fixed installation.

Borehole survey

In addition to wire extensometers, borehole extensometers consist of tensioned rods anchored at different points in a borehole. Changes in the distance between the anchor and the rod head provide the displacement information for the rock mass.

Inclinometers are also used. These consist of a special, grooved casing, which is cemented into place, with the grooves serving as tracks for the sensing unit. The sensor is pulled up through the casing and measures any deflection, which corresponds to deflection in the surrounding rock mass.

Piezometers are used to measure pore pressure. They measure groundwater levels and can give advance warning of zones of bench-scale failure, as well as measuring whether dewatering activities are working.

Finally, time domain reflectometry (TDR) is a technique in which electronic pulses are sent down a length of coaxial cable. When deformation, pinching or a break in the cable is encountered, a signal is reflected, giving information on the subsurface rock-mass deformation.

Bingham Canyon mine, for example, has TDRs at four specific locations of concern, which are checked weekly.

Micro-seismic survey

Slope monitoring is normally carried out using surface-deformation measurements of either points along the surface or the entire surface. However it can be difficult to identify potential failure mechanisms in advance from the 1D or 2D surface data, no matter how accurately it is obtained.

Since slope angles are critical to the economics of open-pit mining, micro-seismic monitoring of fracturing within a slope using geophones can add significant value. Recent technological advances have enabled the routine use of this technique, yielding quantitative 3D data about the state of the slope. The seismic events are very small, relative to

earthquake events, but can still be accurately recorded.

Olaf Goldbach, business development manager at the Institute of Mine Seismology (IMS), says: "Routine micro-seismic monitoring in the open-pit environment enables the collection of 3D data from where brittle fracturing is occurring within the wall. The aim is to monitor subsurface fracturing at depth to assess the slope stability before the surface expression of the movement is detected in the pit. To do this, the seismic sensors are installed in inclined boreholes, often drilled from outside the pit."

This generates a 3D picture of rock mass instabilities, unlike the 2D picture obtained with conventional surface monitoring. Rock movement associated with deep-seated deformations can be detected weeks before the conventional scanning techniques detect the surface expression on the exposed pit wall. This allows long-term indications of where significant surface movements can be expected to be made.

Mr Goldbach adds: "Comparison between surface and seismic measurements have shown that seismic data may be able to indicate regions of surface movement some 30-45 days before these movements are seen on the surface."

Micro-seismic techniques enable far-field monitoring of the zone in and around the seismic sensor array, rather than being limited to monitoring the point where the instrument is installed; this means it can potentially collect information from areas that were not originally intended for monitoring. Recording micro-seismic activity can also act as an early warning system by detecting instability weeks before the failure is apparent on the surface, especially as open-pit mines get deeper and increase stress levels, resulting in more seismic activity behind the slopes. Micro-seismic systems are quite robust and, once installed, require very little maintenance.

Dr Trifu says: "Some of our equipment, including sensors, were installed in mining environments more than 15 years ago and continue to function well."

Companies

- **IMS**

In 2009, IMS bought the businesses and assets of ISS International, an Anglo American subsidiary. IMS offers micro-seismic monitoring technology for slope stability monitoring; however, non-seismic sensors such as extensometers can be connected to its seismic stations, allowing simultaneous recording of seismic and non-seismic data.

IMS offers a digital, high-resolution seismic monitoring and control system, featuring online seismological processing, analysis and visualisation.

The hardware of an IMS seismic network is divided into three major constituents: sensors that convert ground motion into a measurable electronic signal; digital acquisition devices that convert analogue signals from sensors into a digital format; and various means of data communication for transmitting seismic data to a central computer for storage and processing, or to a local disk in the case of a stand-alone system.

Mr Goldbach says: "Adaptive spectral triggering is a novel technique that filters out the noise associated with drilling,

vehicles and pumps, allowing for better detection of actual seismic events. False triggers associated with cultural noise are greatly reduced. The technique has improved the sensitivity of IMS's micro-seismic monitoring systems."

The IMS has installed micro-seismic monitoring equipment to assess slope stability in open-pit mines in Australia, Russia, Namibia, Chile, the US and South Africa, including at Codelco's Chuquicamata copper mine in Chile, the Kovdor-sky apatite-magnetite mine in Russia and Xstrata's Black Star zinc-lead mine in Australia.

- **ESG Solutions**

ESG makes seismic sensors (geophones and accelerometers), the Paladin data acquisition unit and associated timing equipment to ensure data collected from different sensors around a mine site are all synchronised.

ESG's Hyperion Seismic Software (HSS) suite is a proprietary set of Windows-based modules, which enable the real-time automatic/manual acquisition and processing of micro-seismic data. The software is also used to visualise results with respect to slope geometry for a greater understanding of rock mass behaviour behind the slope wall.

In addition to its passive micro-seismic technology, ESG offers in-place inclinometers as part of a comprehensive slope monitoring solution. Inclinometers monitor tilt variations and movements, providing a better understanding of the behaviour of the slope movement.

Improvements to ESG's hardware components, including signal amplification and on-board digital signal processing, have contributed to improved signal quality. Reductions in the power requirements of ESG's data-acquisition hardware have enabled the prolonged deployment of remote monitoring stations to increase the field of coverage.

ESG's equipment has been used at Anglo Gold's Cripple Creek and Victor mine in Colorado, US, and BHP Billiton's Mount Keith mine in Western Australia.

LEARNING OUTCOME 6.4.1.4

CONNECTION 9

Refer to
"LEARNING OUTCOME
6.4.1.3" on page 173

Refer to
Paper 2 Outcome 6.2.3

Refer to
"LEARNING OUTCOME
6.4.1.7" on page 185

DESCRIBE, EXPLAIN AND DISCUSS HOW DISPLACEMENTS IN THE ROCKMASS ARE DETERMINED.

Displacements are measured using the devices discussed in the outcomes above.



LEARNING OUTCOME 6.4.1.5

CONNECTION 10

Refer to
"LEARNING OUTCOME
6.4.1.3" on page 173

Refer to
Paper 2 Outcome 6.2.3

Refer to
"LEARNING OUTCOME
6.4.1.7" on page 185

DESCRIBE, EXPLAIN AND DISCUSS HOW THE COMPONENTS OF GROUND MOVEMENT MAY BE DERIVED FROM THESE DETERMINATIONS.



Most instruments used in slope monitoring will provide the displacement results without the need for any manipulation. Where manipulation is required, refer to the specific instrument's user manual.

LEARNING OUTCOME 6.4.1.6

CALCULATE COMPONENTS OF GROUND MOVEMENT FROM GIVEN SETS OF MONITORING DATA.



Calculation of displacements are only required when using instruments such as extensometers or survey theodolites, where the data is provided relative to a certain point. Most of the other instruments will be able to provide the displacements (as stipulated in each unit's user manual) in single or multiple co-ordinates.

INTERESTING INFO

Calculate the total displacement between two points, where their positions have been determined in three co-ordinates.

Calculate the positive difference between each of the coordinates X, Y and Z. For example, suppose two points in three-dimensional space have coordinates (-3, 7, 10) and (1, 2, 0). The actual differences in each coordinate direction are $X = 4$, $Y = 5$ and $Z = 10$.

Use the formula $D^2 = X^2 + Y^2 + Z^2$ to find the squared distance between two points in three-dimensional space.

Example:

If $X = 4$, $Y = 5$, and $Z = 10$,
then $D^2 = X^2 + Y^2 + Z^2 = 141$.

Therefore, the square of the distance between the coordinates is 141.

Take the square root of D^2 to find D , the actual distance between the two points.

Example:

If $D^2 = 141$, then $D = 11.874$,
and so the distance between (-3, 7, 10) and (1, 2, 0)
is 11.874 (unit depends on the measurement units).



If displacements in three co-ordinate directions are required separately, equipment that will be able to provide this must be used.

CONNECTION 11

Refer to
[Paper 2](#) Outcome 6.2.3

Refer to
"LEARNING OUTCOME
6.4.1.7" on page 185

LEARNING OUTCOME 6.4.1.7

INTERPRET GIVEN GROUND MOVEMENT DATA AND DETERMINE THE EFFECT ON SLOPE STABILITY.

The following examples are provided to indicate possible uses of the data gathered via different instrument types to evaluate slope behaviours.

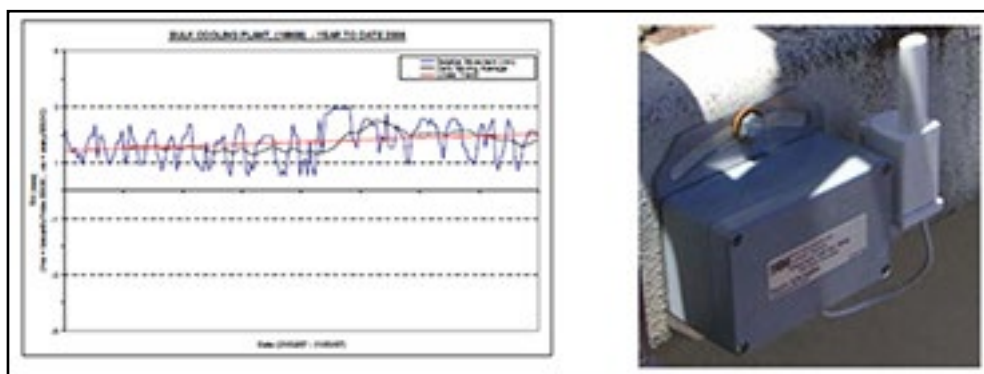


This list of examples should not be seen as exhaustive, but should be used to lead the user into finding ways to maximise the use of the data gathered in each case.

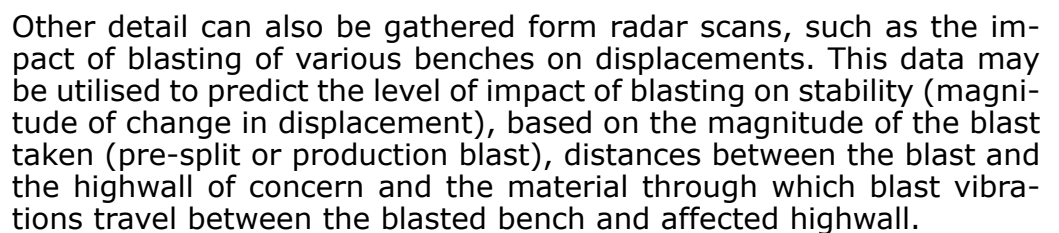
It is important to note that the example given below has been analysed without in-depth knowledge of the reasons or positions for instrumentation. The example analyses of the data given below should therefore be viewed in this light and should not be seen as absolute. The user is simply sensitised by the examples to look for signs in the readings that would indicate changes in rockmass behaviour.

Examples given below are courtesy of Xstrata (zinc and copper divisions) presentations (internet).

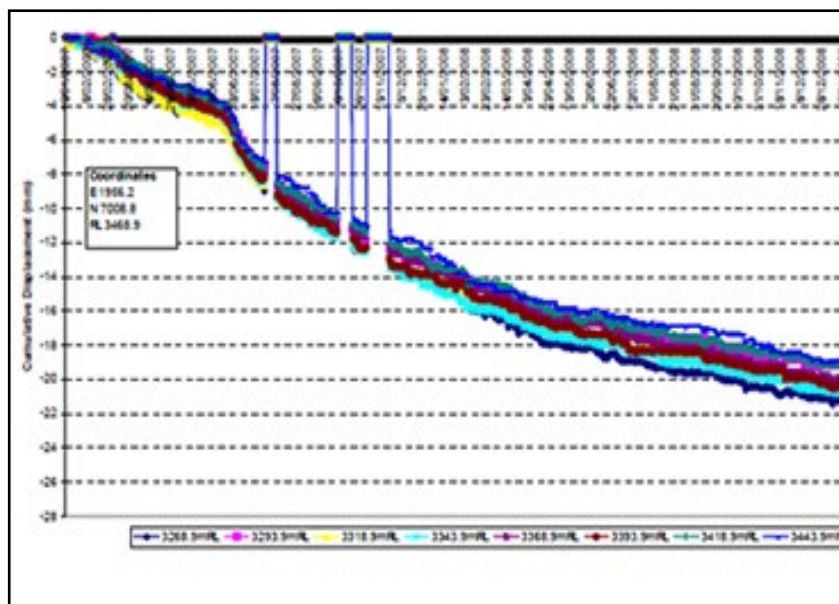
EXAMPLE

Tilt meter

A change in the daily average reading occurs in the middle of the monitoring period and indicates a change in behaviour or tilt towards one side of the instrument. Since this reading remained at this new level for approximately $\frac{1}{2}$ month, the change appears real and suggests that the structure to which the instrument has been attached may be tilting slightly towards one side. This change should now be viewed in conjunction with the position of the structure and mining activities in close proximity to the structure. Correlation of these measurements with other instrument readings such as radar could indicate the impact/extent of slope displacement.

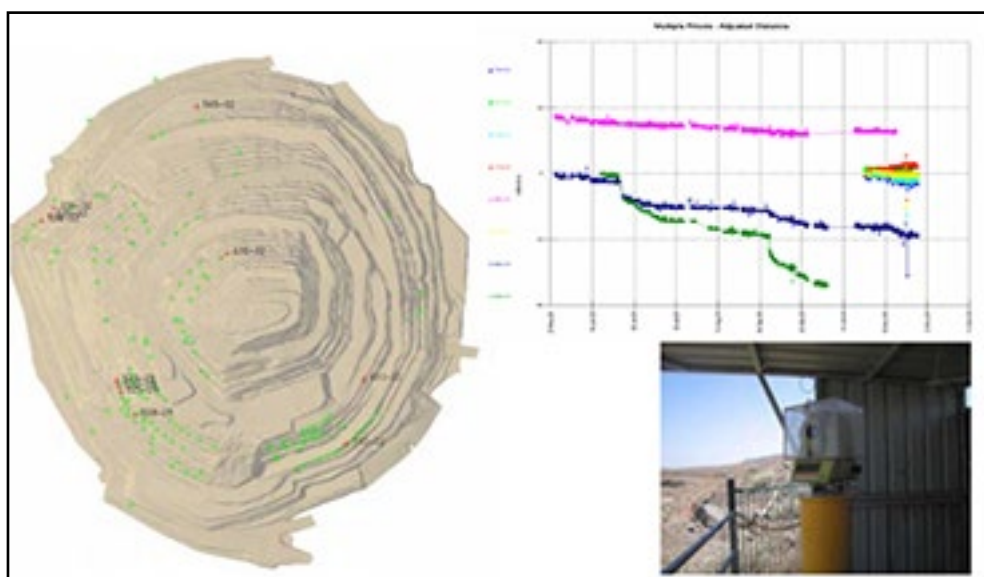


Extensometer



Extensometer readings near a plant indicate changes in the slope of the cumulative displacement, suggesting an increase in rate of displacement, which then tapers off towards the last readings, suggesting a slow-down in displacement (see dotted lines indicating slope of the graph over different stages). Since this trend seems to be reflected at all the measuring points, this behaviour seems to suggest that the whole extensometer station is moving at the same rate. However, since the data points also appear to be moving apart in the latter portions of the results, the measuring points within this extensometer installation are moving away from each other, suggesting that some parts of the rockmass are moving slightly more than the rest.

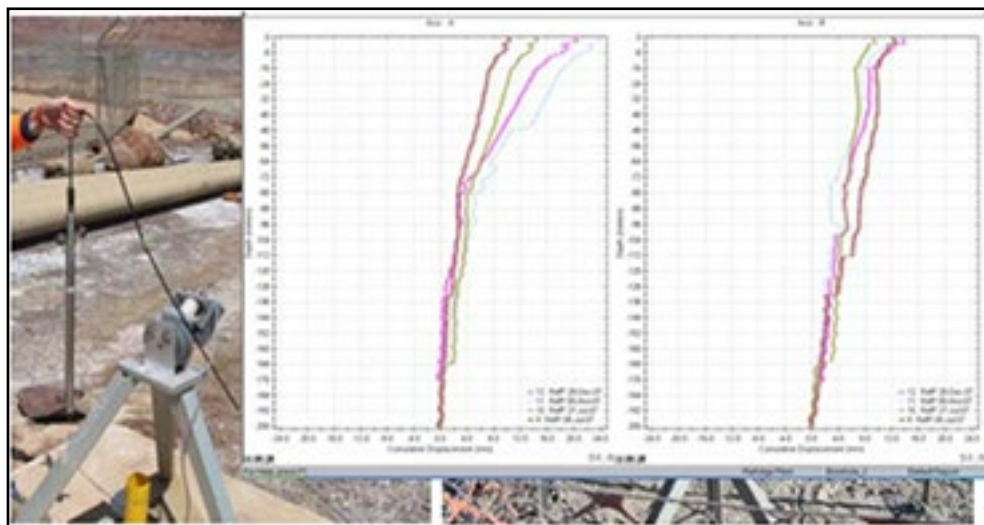
Prism



Prism stations are installed at specific points of interest and results can therefore be applied to specific areas. The results for a number of stations given above indicate readings from three stations over a long period, followed by readings from stations installed at a later stage and in a particular area. The different results obtained from the readings at the various positions indicate high levels of displacement

in some areas (red, dark blue) with very little in others (light blue). Depending on where these prisms were placed, remedial action or increased level of monitoring can now be determined.

Inclinometer



The readings indicate changes in borehole positions with time, measured relative to the bottom of the hole. The readings suggest that the tops of the holes are displacing in some direction with time at what appears to be a constant rate of displacement. These results indicate that the tops of the holes are moving in some direction and that the hole, if positioned close to a pit wall, may indicate rockmass displacement towards the pit. The results between readings from two different holes indicate that the depth at which the largest displacement occurs is greater in the second hole, even though the amount and rate of change is less in the second hole, but that the depth at which the displacement commences (towards the bottom of the holes) is the same. The fact that the displacement onset point is the same between the holes may indicate that the holes are the same distance away from a highwall, while the differences in the shallower portions may indicate greater, but shallower displacement at the first hole. This could be due to the position of the hole with regard to a potentially unstable structure, which has been intersected by both holes, but at a shallower depth at the first hole.



- [Lessons in open pit monitoring Cawood](#)

LEARNING OUTCOME 6.4.1.8

CONNECTION 12

Refer to
[Paper 2](#) Outcome 6.2.3

DESCRIBE, EXPLAIN AND DISCUSS THE USE OF PIEZOMETERS TO MEASURE AND MONITOR GROUNDWATER LEVELS AND PORE WATER PRESSURES IN SURFACE MINING EXCAVATIONS.



- Page 419, Read and Stacey, Guidelines for open pit slope design, 2009.

LEARNING OUTCOME 6.4.1.9

INTERPRET GIVEN GROUNDWATER DATA AND DETERMINE THE EFFECT ON SLOPE STABILITY.

Groundwater data can be gathered from piezometers, horizontal drain flows and dewatering well dischargers and related to slope conditions or behaviour. The following data can be gathered:

1. Piezometers:
 - Water levels;
 - Pore pressure;
 - Presentation of data:
 - Hydrographs showing total head against time;
 - Water level maps showing total head or pore pressure at any given moment of time or time period;
2. Horizontal drain flows:
 - Flow rate from each horizontal drain hole;
 - Presentation of data:
 - Flow rate against time;
3. Dewatering well dischargers:
 - Discharge rate;
 - Presentation of data:
 - Flow rate against time;
 - Maps showing distributions of well flows across the mine.

The interpretation of this data in terms of slope stability is well indicated in Figure 6, where the horizontal drain flow results are correlated with slope displacements. The creation of the graph that shows both parameters against time, allows for making conclusions with regard to the impact that the water flow programme has had on slope behaviour. It is clear from Figure 6 that the rate of slope displacements reduced drastically after the horizontal drain flow programme was completed, indicating the large impact that groundwater has on slope displacement in this environment.

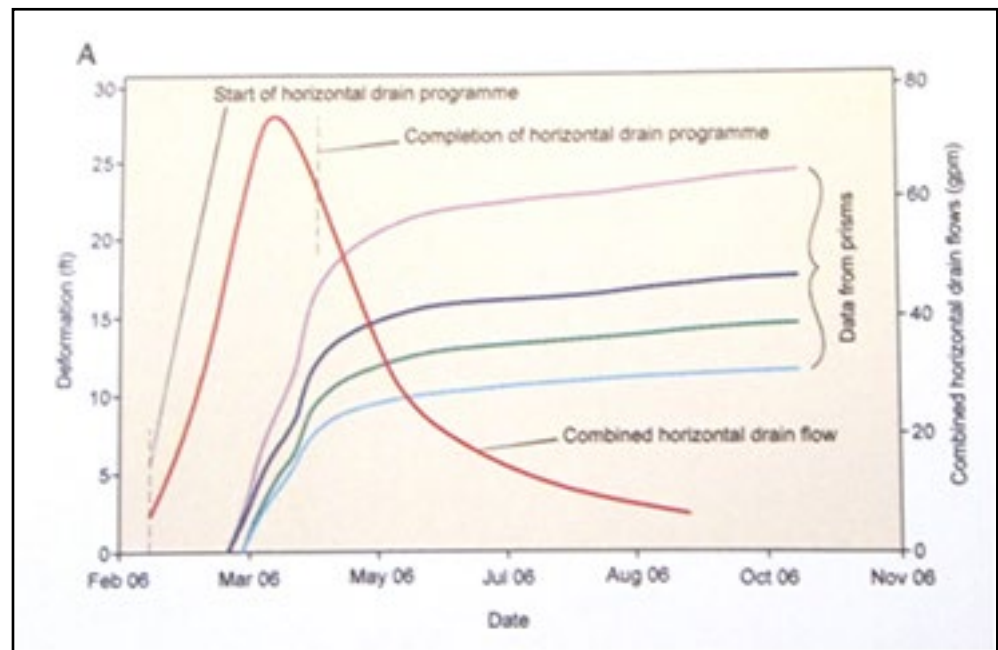


Figure 6: Horizontal drain flow and slope displacement correlated (Read & Stacey, 2009)



- [Geotechnical consideration in slope stability Potch \(Courtesy Dr K Morton, KLM Consulting services\)](#)
- Page 360, Read and Stacey, Guidelines for open pit slope design, 2009.

LEARNING OUTCOME 6.4.1.10

CONNECTION 13

Refer to
[Paper 2](#) Outcome 6.2.1,
6.2.2 and 6.2.3
Also refer to Outcome 6.4.7

FOR GIVEN SETS OF SURFACE MINING CONDITIONS:

- State, describe, explain and discuss what types of measurements need to be made and monitored,
- Describe, explain and discuss required monitoring station layouts,
- Describe, explain and discuss appropriate monitoring programmes,
- Interpret practical monitoring data and determine slope failure modes and the behaviour of slopes with time.

A monitoring programme should take on the following process:

1. Preparation:

- Monitoring should be executed from the onset of the creation of an open pit as later information may be worthwhile from a safety point of view, but the loss in the initial data may limit the correlation with designs.
- Implementation of monitoring should be considered in the planning phases already.

2. Programme selection:

- The type of monitoring programme must be decided on early in the life of the mine and the mix of instruments or methods selected (Table 8 and Table 9);

3. Collecting data:

- The geotechnical engineer should be responsible for gathering this information as he is also the end user and will be required to know and understand limitations, concerns etc. around the monitoring that could affect its interpretation;
- The regularity at which the readings are taken is decided on by the geotechnical engineer who will use engineering judgement or previous readings in the decision-making process;

4. Processing and interpretation of data

- Processing is normally executed with computers and software specific to each instrument;
- The need for a rapid turn-around time between readings and analysis is important and indicates the need for real-time or at least fast computer and software-based systems;
- Processing should also be governed by the geotechnical engineer so that the need for the instrumentation installation can be ensured in the presentation method used for the data;

5. Reporting conclusions:

- Data, its presentation, analyses, conclusions and remedial action should all form part of the monitoring report and should be made available on a regular basis.



- Pages 364-370, Read and Stacey, Guidelines for open pit slope design, 2009



From Read and Stacey (2009), summaries of monitoring procedures are shown below, but the reader is referred to Read and Stacey for detail.

Procedure	Areas	Frequency	Activities	Personnel	Reporting and actions
Daily inspections	All current active mining areas, high risk areas	Daily	Visual checks for crack-ing, dilation and scaling requirements	Geotechnical geologist	Wall inspection book, discussed at daily meeting, geotech superintendent and operations superintendent (if problems exist). Batter and berm inspection forms to be completed and signed off at daily production meeting as required.
Periodic visual inspections of perimeter and berms	Pit perimeter and all accessible berms	Weekly to fortnightly and after heavy rainfall	Visual checks for tension cracks, other signs of slope movement and rockfalls	Geotechnical geologist, technician	Berm walk over inspection form, slopes and berms overlay to pit plan, cracks to be painted and surveyed. Advise operations superintendent, production meetings. Issue hazard alert as appropriate.

Procedure	Areas	Frequency	Activities	Personnel	Reporting and actions
Tension crack monitoring	Cracked areas on pit perimeter and berms	Initially daily and after heavy rainfall. Frequency to be adjusted depending on rates of opening	Measurements of crack widths and visual checks of other signs of slope movement and rockfalls.	Technician	Spreadsheets. Geotechnical geologist to be notified if acceleration noted in opening. Production meetings. Hazard alert to be issued as appropriate.
EDM monitoring	Cracked areas around perimeter and on berms and other designated areas	ATS and semi-automatic. Frequency to be adjusted depending on rates of prism movement	Survey of changes in prism northings, eastings and elevations	Surveyor	Quickslope database and graphs. Autoslope alarm system. Geotechnical geologist and operations superintendent to be notified of acceleration in movement. Hazard alert to be issued as appropriate. Prepare monthly report.
Slope stability radar, ground probe	High risk rockfall hazards	Ongoing, continuous	Daily checks of data and instrument status	Technician, geotechnical geologist	Dispatcher to notify the E Zone controller, geotechnical geologist if alarm is triggered. EW zone evacuation initiated for all alarms.
Slope photography	All portions of walls	Ongoing over pit life	Monthly to quarterly	Geotechnical geologist	Geotechnical superintendent, file.
Slope failure records (hazard alert and incident reports)	Any portion of walls where a rockfall has occurred into a working area.	As required	Complete hazard alert and incident report for the rockfall or failure	Geotechnical geologist	Management and senior mine operations personnel.

Table 8: Pit wall stability monitoring procedures (source Geita Gold Mine)

Block size m ³	Speed of failure	Implications	Monitoring for detection	Typical remedial
1-10	Immediate	Rockfall - Safety	Visual	Catchment
10-1000	Very rapid to rapid	Safety	Visual - radar	Cathment
1000 -100 000	Rapid to slow	Operational	Visual Surveying Radar Seismic	Manage / Modify slope (step-out)
100 000 - 1 000 000	Moderate to slow	Operational - financial	Surveying Radar TDR / inclinometer Seismic	Modify slope (step-out) Recut?
> 1 000 000	Slow to moderate	Force majour	Surveying Radar TDR / inclinometer Seismic	Modify slope (recut) Mine closure >10m ³ Manage

Table 9: Monitoring methods based on failure size



- Page 363, Read and Stacey, Guidelines for open pit slope design, 2009

6.5. MODELLING

6.5.1. NUMERICAL MODELLING

LEARNING OUTCOME 6.5.1.1

DESCRIBE, EXPLAIN AND DISCUSS THE SELECTION OF APPROPRIATE CODES TO TACKLE VARIOUS PROBLEMS.

CONNECTION 14

Refer to
[Paper 2](#) Outcome 6.4

Numerical models have made it possible to model complex conditions such as non-linear stress-strain behaviour, anisotropy and geometry changes/variations. Models applied fall broadly into continuum or discontinuum categories.

Continuum models assume that the rockmass is continuous, and joints are represented in a reduction in the rockmass strengths applied. The rockmass strength is in its simplest form represented by the shear strength that the material can sustain and therefore requires the Mohr-Coulomb strength properties to describe the rockmass strength, namely cohesion and friction angle. However, the Hoek-Brown failure criterion has found large support in the industry, leading to the determination of 'equivalent Mohr-Coulomb' parameters. These 'equivalent' parameters are derived from the Hoek-Brown failure curve by estimating the cohesion and friction angle for a failure surface that is tangent to the Hoek-Brown curve, at any specific range of confinement stress.



Continuum software codes generally used for slope designs include Phase2, Flac.

Discontinuum models can model faults and joints and allow contacts to separate, based on given contact conditions. The description of the joints within the models is critical to the results as it defines the shape and extent of the blocks in the model that will behave in certain ways, depending on the shapes, extent and contact conditions of each block.



Continuum software codes generally used for slope designs include UDEC.



- Page 253, Read and Stacey, Guidelines for open pit slope design, 2009

Advanced numerical models include Elfen and PFC (particle flow code). Elfen is a 2D package that includes finite element and discrete element (continuum and discontinuum) analysis and has the ability to develop fracture patterns. PFC includes 2D and 3D versions and these are essentially distinct element codes that represent the rockmass in terms of bonded particles that can separate and 'flow' in the model based on the contact laws set, allowing the simulation of displacements in faults/joints.



- Page 259, Read and Stacey, Guidelines for open pit slope design, 2009

LEARNING OUTCOME 6.5.1.2

CONNECTION 15

Refer to
Paper 2 Outcome 6.4

DESCRIBE, EXPLAIN AND DISCUSS THE APPLICATION OF THE FOLLOWING CODES TO TACKLE VARIOUS PROBLEMS:

- Flac,
- Udec,
- dips.

Examples of application are provided for the user but applications are not limited to those shown below.

Flac

The FLAC/Slope (FSP) programme was used for the analysis of FOS due to its ability:

- To adequately represent both rock and soil materials
- To naturally define failure surfaces
- To be kinematically feasible.

Models were set-up to examine the influence of changing batters, soil thickness, surcharge-loading (spoil loading) and coal dip angles on strip mine stability using the FOS as a measure of stability (Fig 1). The inherent stability of spoil piles was examined with FSP as a separate exercise using variations in material types and angles of repose.

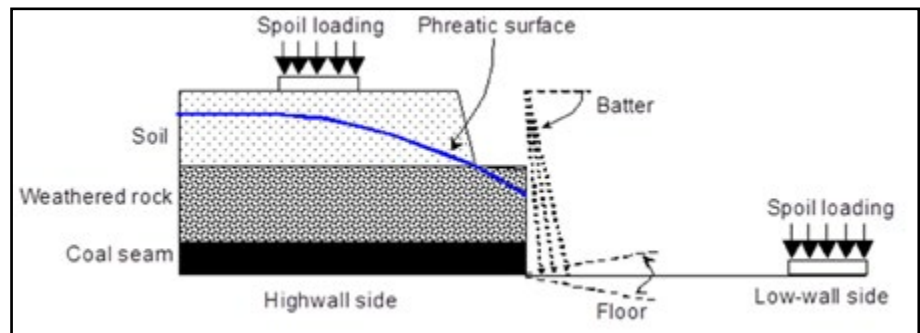


Figure 7: Schematic representation of aspects modelled

The models were set-up using four stages i.e. parametric model stage, build stage, solve stage and plot stage

Parametric model stage

Each model in a project (e.g., batter simulations) was named and listed in a tabbed bar that allowed easy access to any model results thus enabling efficient comparative analysis (fig 2). New models were added to the project by cloning previous models. Models for the different aspects investigated were grouped into projects.

20m/fs	2m/fc	5m/fc	10m/fc	15m/fc	20m/fc	2m/hc	5m/hc	10m/hc	15m/hc	20m/hc
2m,ls	5m,ls	10m,ls	15m,ls	20m,ls	2m,rs	5m,rs	10m,rs	15m,rs	20m,rs	

Figure 8: Individual models within a project

Build stage

The slope conditions were defined in the build stage which, included changes to the geometry (Fig 3,4), addition of layers, specification of materials, application of surface loading and positioning of the water table.

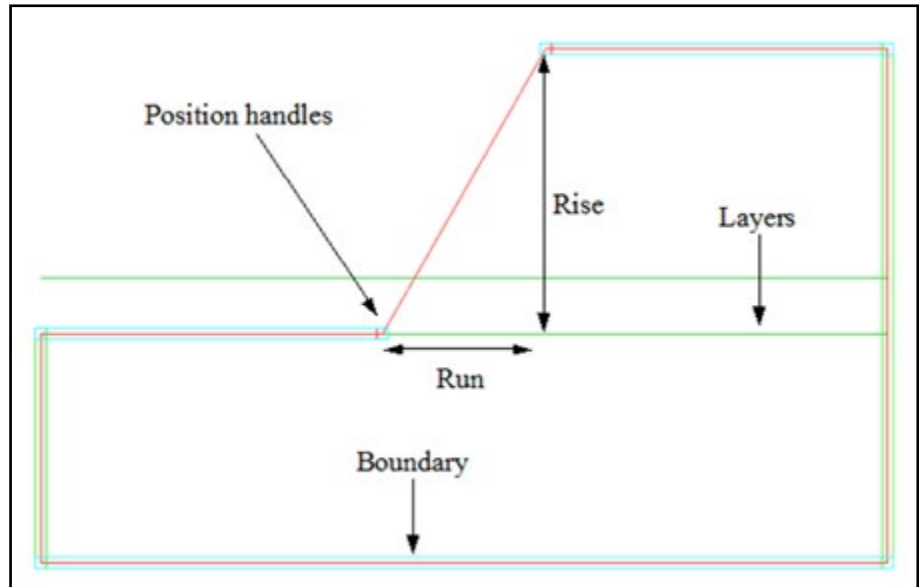


Figure 9: Geometrical changes to the model

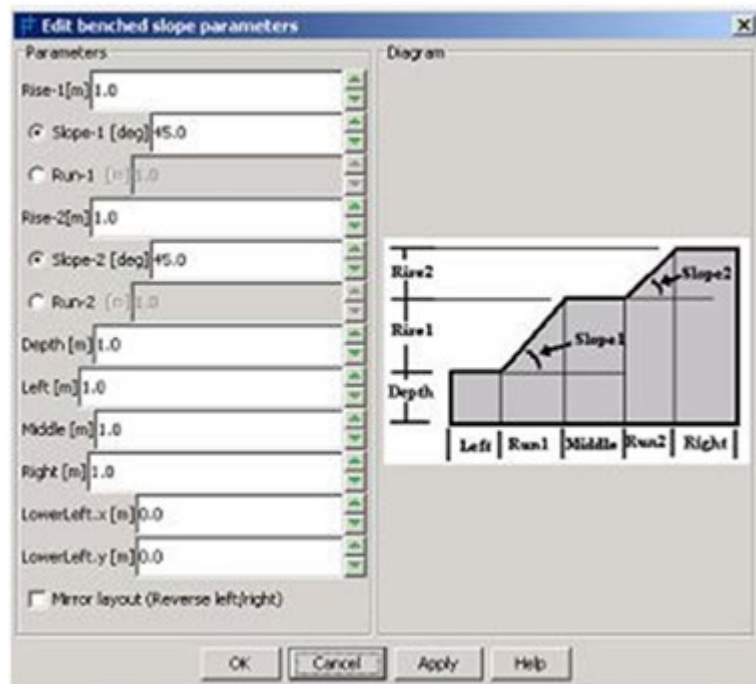


Figure 10: Input menu to define slope geometry

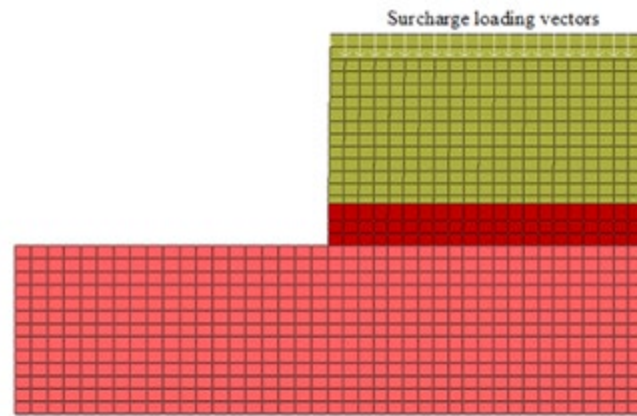


Figure 11: Surcharge applied over entire slope crest (indicated by vectors)

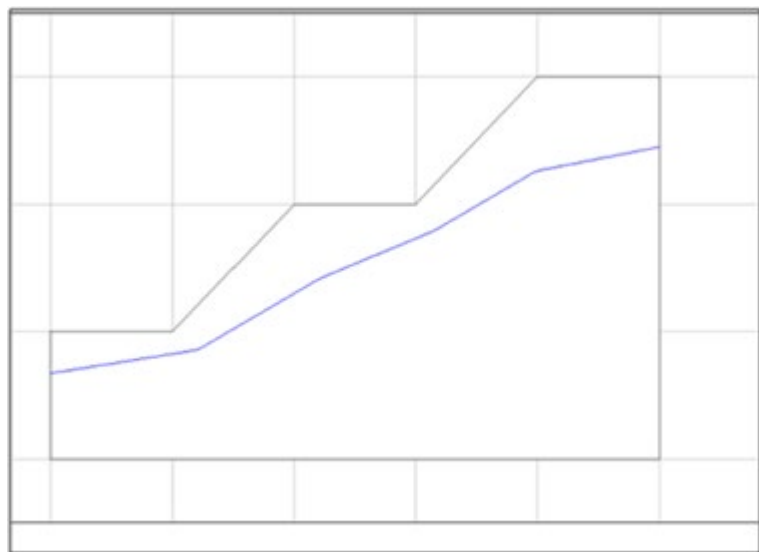


Figure 12: Double bench slope with the position of the water table indicated in blue

Solve Stage

The FOS is calculated in the solve stage with either a coarse, medium, fine or customised grid selected. Different strength parameters can be selected for inclusion in the strength reduction approach to calculate the FOS.

Plot stage

After the solution is complete, several output selections (Figure 15) are available for displaying the failure surface(s) and recording the results.

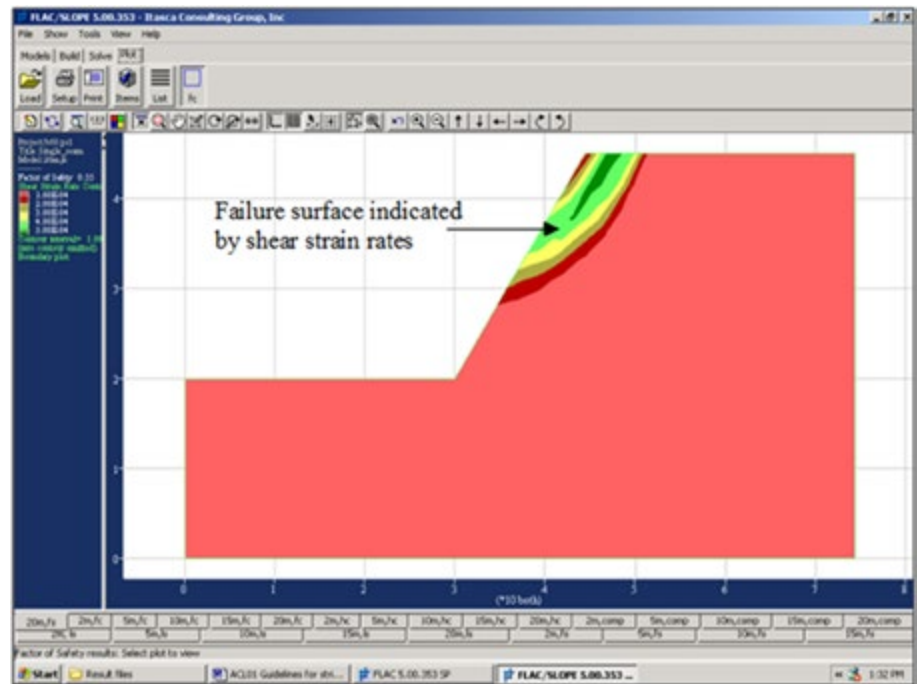


Figure 13: Failure plot indicating the likely slip surface using shear strain rates

UDEC

The Universal Distinct Element Programme (UDEC) was used to determine the factor of safety of slopes for variations in both fault properties and dip angles. UDEC was used to assess the stability of a range in angles of faults that traverse the highwall, perpendicularly. Smooth, undulating planar and rough cohesive and frictional properties for the fault planes were assigned.

The modelled geometry for fault simulation is shown in Fig 8.

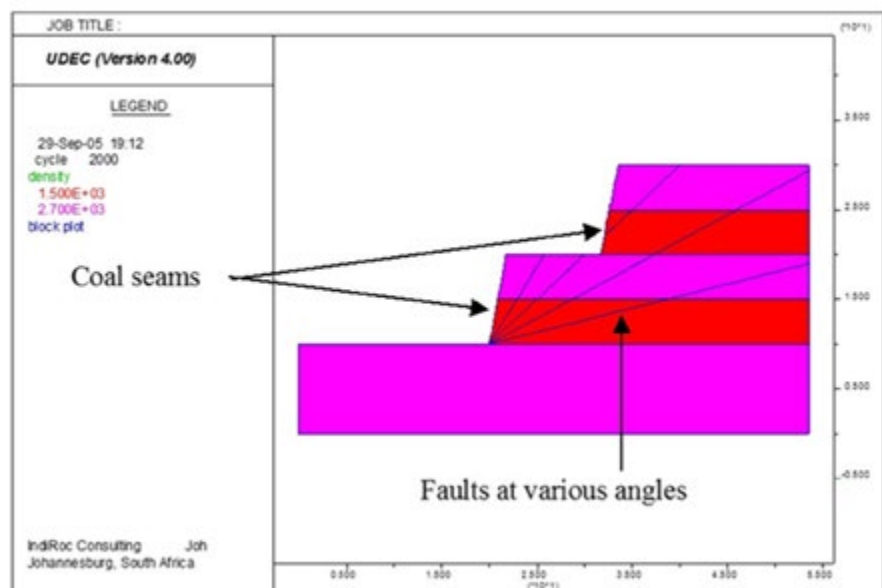


Figure 14: Modelled fault geometries in a double bench slope

The FOS was calculated by equating the shear strength on the fault plane to the shear stress acting along the plane. The Mohr-Coulomb criterion was assumed to govern the shear strength along the fault plane whilst the FOS was calculated using the following equation:

$$FOS = \tau_{\text{strength}} / \tau_{\text{stress}}$$

Where the shear stress acting along the plane was taken as the maximum and the shear strength, the minimum.

DIPS

The stability of surface excavation in hard rock is frequently controlled by the orientation of discontinuities within the rockmass. Structurally controlled failure in rock usually occurs as a result of slip or failure along (or from) pre-existing geological discontinuities. Three basic failure mechanisms are studied for rock slopes; these being plane failure, wedge failure and toppling failure.

The magnitude and frequency of structurally controlled failures are directly related to the continuity and spacing of the structures along which sliding can occur. Rockmass structures that exhibit limited continuity, such as minor joints, are more often associated with small-scale failures that are rarely of consequence to overall slope stability, but may adversely affect access ramps or equipment installations.

The relevant discontinuity data is analysed using stereographic projections within the RocScience geotechnical software package *Dips* and allows for derivation of the type of failure mode. Examples of this analysis are provided in Figure 7 and Figure 8, where the blue circle represents the friction angle of the material.

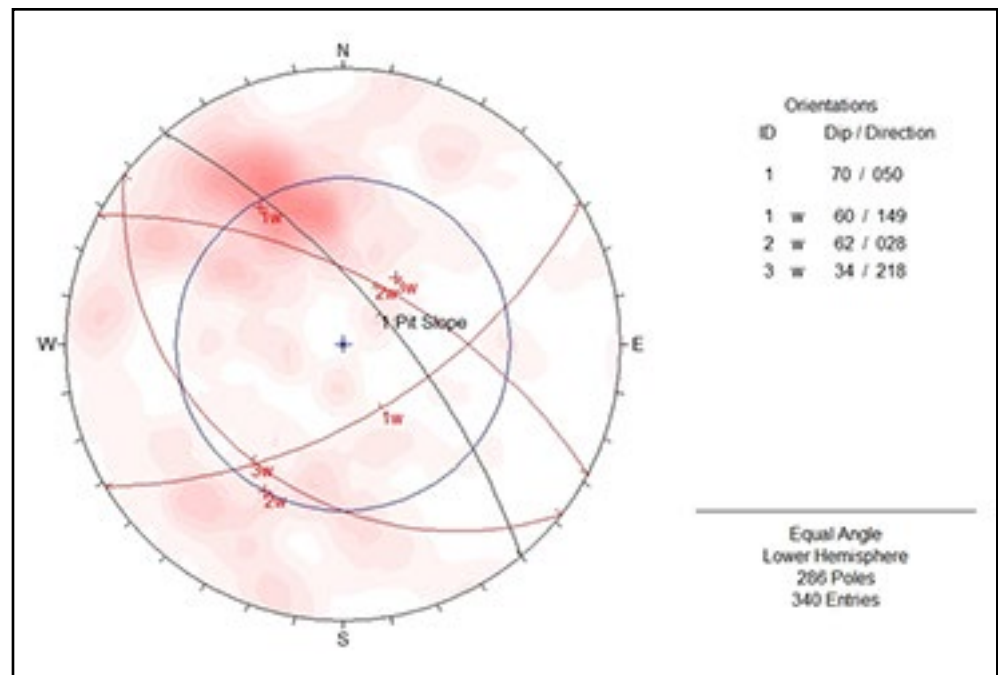


Figure 15: Example of kinematic analysis for wedge failure

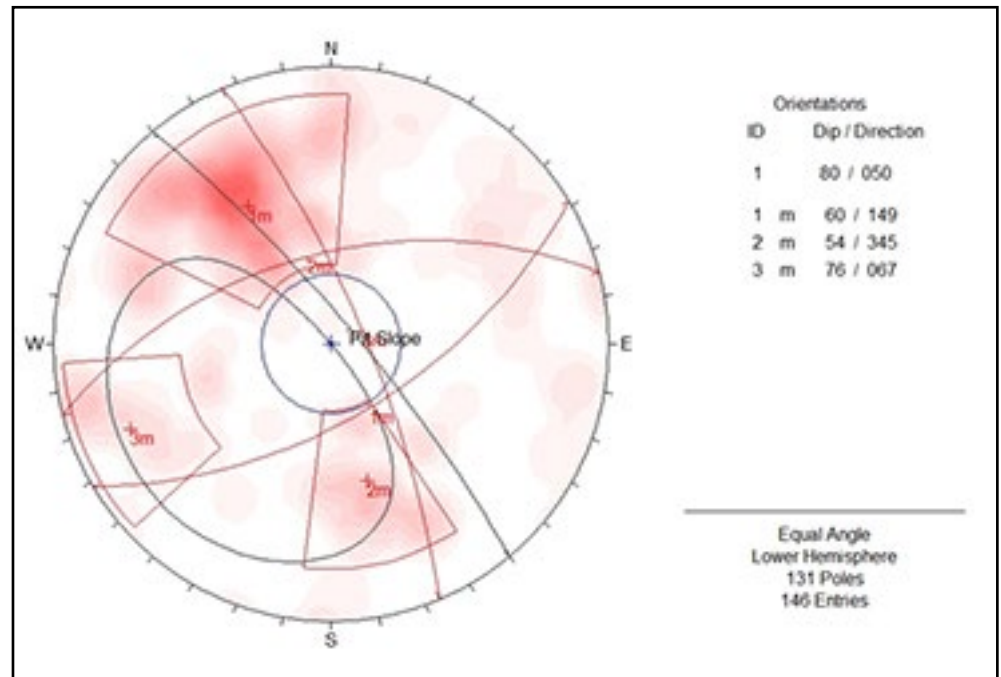


Figure 16: Plane failure analysis: Sector 1, 25m-35m, for 80 degree bench face



- DIPS tutorial

DIPS toppling, wedge, plane, sliding (Courtesy of RocScience)
http://www.rocsience.com/help/dips/webhelp/tutorials/Dips_Tutorials.htm

LEARNING OUTCOME 6.5.1.3

CONNECTION 16

Refer to
[Paper 2](#) Outcome 6.4

Refer to
["LEARNING OUTCOME 6.5.1.1"](#) on page 193
["LEARNING OUTCOME 6.3.2"](#) on page 164

DESCRIBE, EXPLAIN AND DISCUSS THE INPUT OF APPROPRIATE PARAMETERS TO INVESTIGATE VARIOUS PROBLEMS.

LEARNING OUTCOME 6.5.1.4

CONNECTION 17

Refer to
[Paper 2](#) Outcome 6.4

DESCRIBE, EXPLAIN AND DISCUSS THE INTERPRETATION OF OUTPUT IN THE INVESTIGATION OF VARIOUS PROBLEMS.

This example shows the use of a number of numerical models to facilitate the design of an open pit highwall and is provided only to indicate the possible use of the programmes.

Weathered material:

The slide analysis was carried out on the highly weathered and transitional material and yielded safety factors 1.36 and 2.88 for the highly weathered material and transitional material respectively (Table 10,

Figure 16 and Figure 17).

Design sector	Material	Maximum bench height (m)	Berm width (m)	Bench number	Bench face angle	Factor of safety
Throughout	Highly weathered material 5		5.5	2.0	60	1.36
Throughout	Highly weathered material	10	6.5			
Throughout	Transitional	10	7.0	1.0	70	2.88

Table 10: Summary of weathered and transitional material analysis

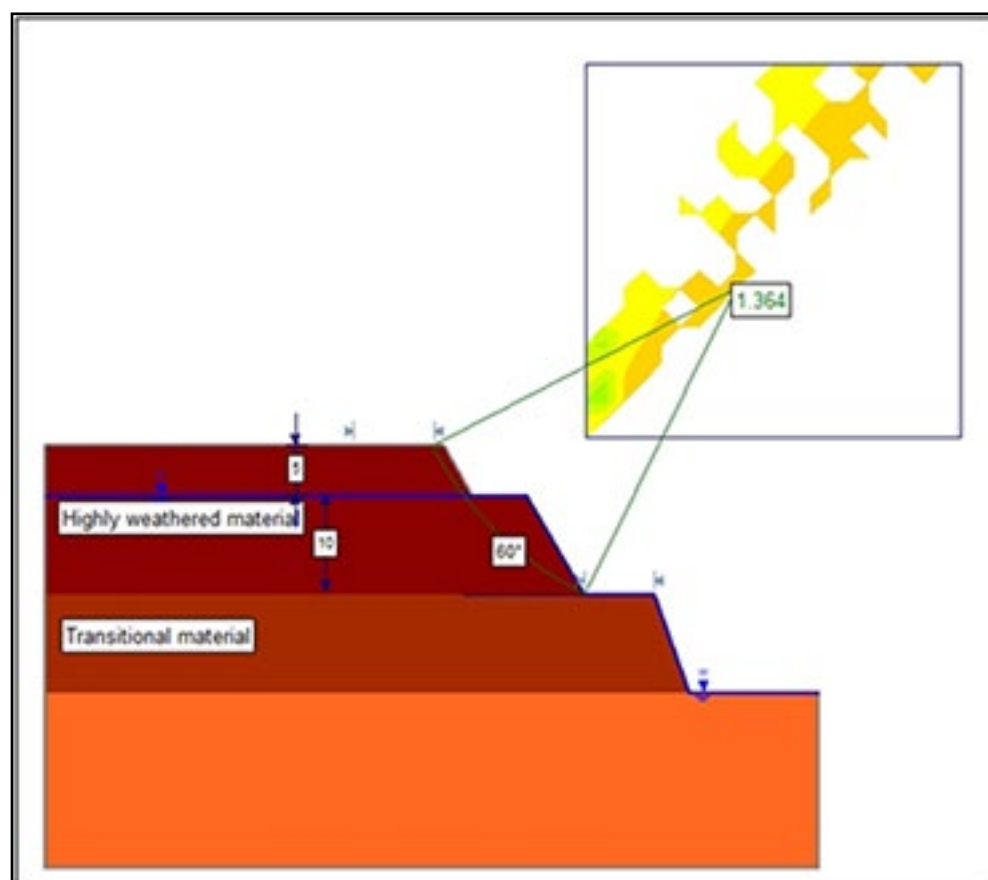


Figure 17: Slide results for highly weathered material

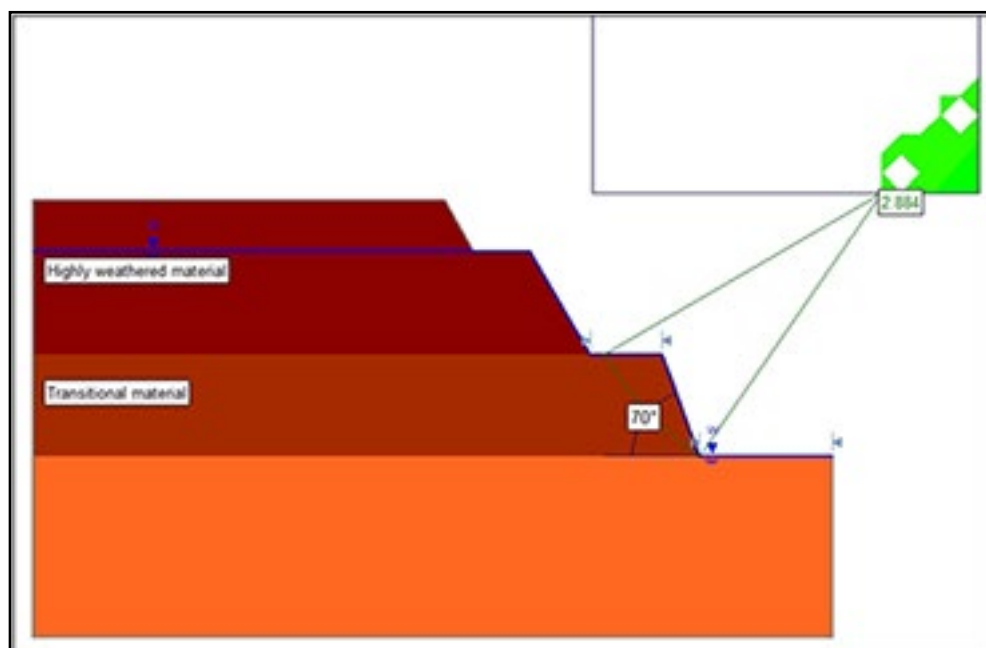


Figure 18: Slide results for transitional material

Fresh material:

The kinematic analysis was carried out on the RocScience software program *DIPS* for each of a number of depth domains where joints with similar dip and dip directions were grouped. These plots were then analysed for probability of wedge and planar failure.

Depth sector 25-35m		Depth sector 100-135m		Depth sector 135-150m	
Joint set	Orientation	Joint set	Orientation	Joint set	Orientation
JS 1	62°/146	JS 1	65°/094	JS 1	59°/095
JS 2	66°/305	JS 2	60°/130	JS 2	57°/059
		JS 3	66°/051		
Depth sector 35-70m		Depth sector 70-100m		Depth sector 150-250m	
Joint set	Orientation	Joint set	Orientation	Joint set	Orientation
JS 1	60°/164	JS 1	58°/156	JS 1	62°/329
JS 2	66°/121	JS 2	67°/091	JS 2	73°/008
JS 3	61°/086	JS 3	46°/238	JS 3	71°/275
JS 4	46°/297	JS 4	60°/290		

Table 11: Summary of major joint orientations for each depth domain

The probability of wedge failure occurrence was tested in DIPS. Different bench face angles of 60, 70, 75 and 80 degrees were modelled for each depth sector and each pit wall sector. The joint properties that were used to model the joints for this analysis and all other kinematic analysis were that of amphibole schist test results. These were the weakest joint properties and will therefore include a degree of conservatism in the wedge failure analysis by assessing the worst case scenario.

An example of the DIPS wedge failure probability analysis is shown in Figure 11. The blue circle represents the plane friction cone of the amphibole schist. Joint sets 2 and 3 intersect each other in the circle, behind the wall direction, which indicates potential wedge failure.

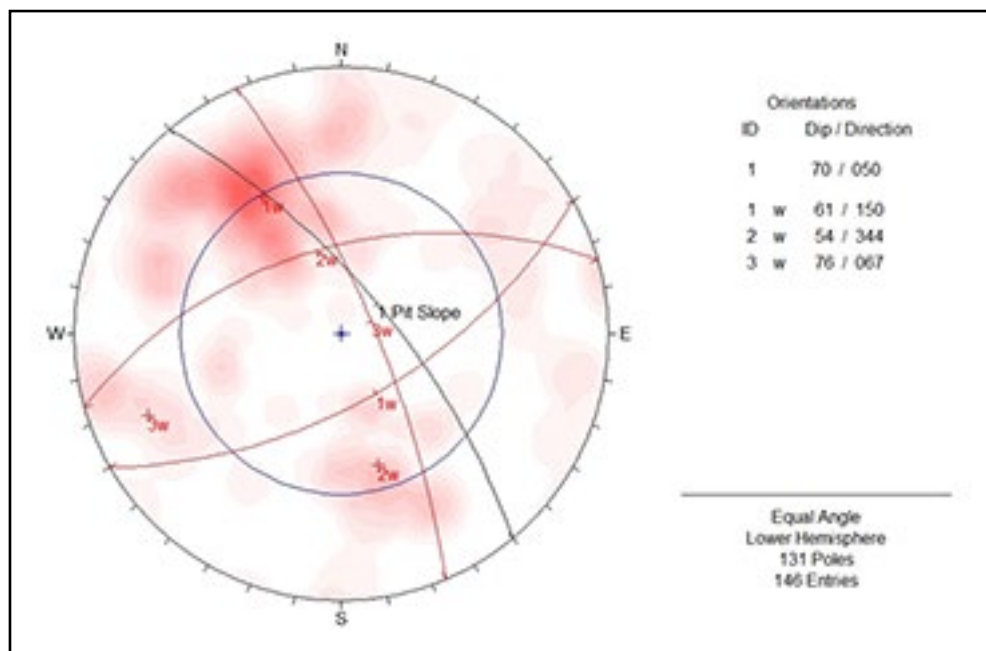


Figure 19: Example of wedge analysis for pit wall sector 1 for depth sector 25-35m

The analysis on DIPS is only a probabilistic method to determine the likelihood of failure. The plots that indicated failure were further analysed in the RocScience program SWEDGE. The joint sets that indicated failure were analysed in SWEDGE to determine a safety factor (Figure 12). Each pit wall sector and depth sector was tested and is presented in Table 12. Each red block indicates an SF of lower than 1.3. Possible wedge failure is prevalent in pit wall sectors 1, 4 and 5. In pit wall sectors 2 and 3, wedges are either not formed, or have acceptable SFs when there are wedges present.

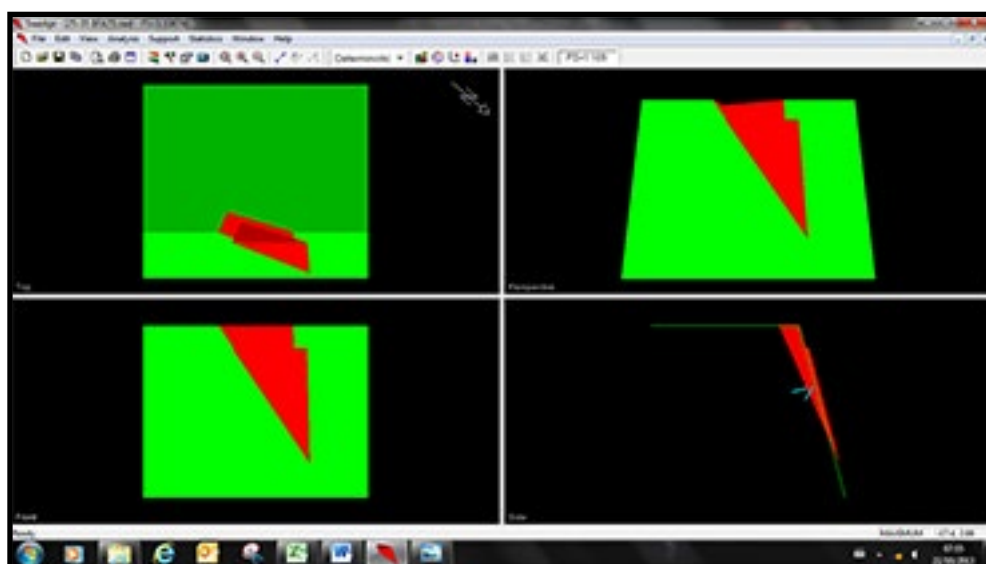


Figure 20: Example of SWEDGE analysis for pit sector 1, depth sector 25-35m

Safety factor for wedge failure at different bench face angles								
Depth sector	Sector 1 (050)				Sector 2 (310)			
	60° BFA	70° BFA	75° BFA	80° BFA	60° BFA	70° BFA	75° BFA	80° BFA
25-5m	N/A	1.20	1.11	0.97	N/A	N/A	N/A	2.05
35-70m	N/A	N/A	N/A	N/A	3.10	2.35	2.13	1.96
70-100m	1.67	3.45	3.05	2.76	N/A	N/A	N/A	N/A
100-135m	N/A	2.53	2.14	1.89	N/A	N/A	N/A	N/A
135-150m	3.92	3.17	2.95	2.79	N/A	N/A	N/A	N/A
150-250m	N/A	0.81	0.75	0.66	N/A	N/A	N/A	N/A
Depth sector	Sector 3 (220)				Sector 4 (130)			
	60° BFA	70° BFA	75° BFA	80° BFA	60° BFA	70° BFA	75° BFA	80° BFA
25-5m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
35-70m	N/A	2.84	2.38	2.08	1.53	3.03	2.59	2.29
70-100m	N/A	N/A	N/A	N/A	4.61	3.37	3.06	2.83
100-135m	N/A	N/A	N/A	N/A	N/A	1.49	1.23	2.05
135-150m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
150-250m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Depth sector	Sector 5 (080)							
	60° BFA	70° BFA	75° BFA	80° BFA				
25-35m	N/A	N/A	0.83	0.76		* Limiting safety factor = 1.3		
35-70m	2.15	1.55	1.40	1.30		* N/A = No wedge formed		
70-100m	N/A	N/A	1.34	1.11				
100-135m	N/A	0.78	0.69	0.63				
135-150m	N/A	0.76	0.68	0.62				
150-250m	N/A	N/A	N/A	N/A				

Table 12: Summary of SWEDGE analysis for wedge failure for all depth and pit wall sectors

The probability of plane failure occurrence was also tested in *DIPS*. Different bench face angles of 60, 70, 75 and 80 degrees were modelled for each depth sector and each pit wall sector. An example of the *DIPS* planar failure probability analysis is shown in Figure 13. The blue circle represents the pole friction cone of the amphibole schist. The circle beside the pole friction angle is the daylight envelope. The crescent-shaped area highlighted in red is where plane failure will occur. Joint sets 2 and 3 intersect within this area, which indicates potential planar failure.

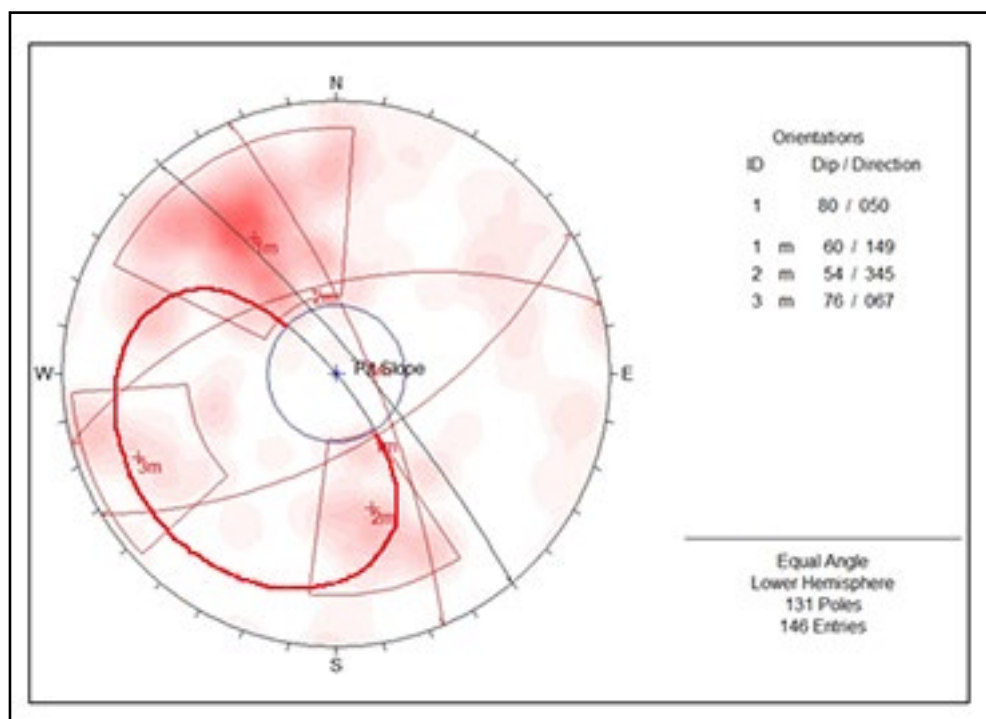


Figure 21: Example of planar analysis for pit wall sector 1 for depth sector 25-35m

The analysis on DIPS is only a probabilistic method to determine the likelihood of failure. The plots that indicated failure were further analysed in the RocScience program ROCPLANE. The joint sets that indicated failure were analysed in ROCPLANE to determine a safety factor. An example of the ROCPLANE results is shown in Figure 14. Each pit wall sector and depth sector was tested and is presented in Table 13. Each red block indicates an SF of lower than 1.3, where failure will potentially occur. Planar failure is prevalent in all pit wall sectors, but only when the bench face angle is 80 degrees or more.

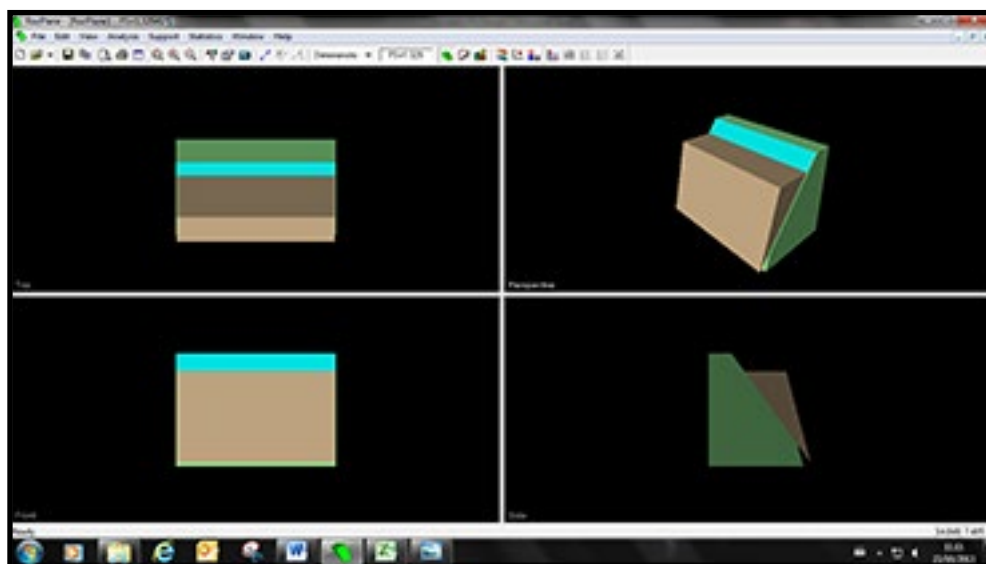


Figure 22: Example of ROCPLANE analysis for pit sector 1, depth sector 25-35m

Safety factor for planar failure at different bench face angles								
Depth sector	Sector 1 (050)				Sector 2 (310)			
	60° BFA	70° BFA	75° BFA	80° BFA	60° BFA	70° BFA	75° BFA	80° BFA
25-5m	N/A	1.58	1.33	1.17	N/A	N/A	N/A	N/A
35-70m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.25
70-100m	N/A	N/A	N/A	1.25	N/A	N/A	N/A	1.27
100-135m	N/A	N/A	1.44	1.21	N/A	N/A	1.37	1.19
135-150m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.20
150-250m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Depth sector	Sector 3 (220)				Sector 4 (130)			
	60° BFA	70° BFA	75° BFA	80° BFA	60° BFA	70° BFA	75° BFA	80° BFA
25-35m	N/A	N/A	N/A	1.27	N/A	N/A	N/A	N/A
35-70m	N/A	N/A	N/A	1.25	N/A	N/A	N/A	1.27
70-100m	N/A	N/A	N/A	1.25	N/A	N/A	1.44	1.21
100-135m	N/A	N/A	1.44	1.21	N/A	N/A	1.44	1.21
135-150m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.23
150-250m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Depth sector	Sector 5 (080)							
	60° BFA	70° BFA	75° BFA	80° BFA				
25-35m	N/A	N/A	N/A	1.27				
35-70m	N/A	N/A	N/A	1.25		* Limiting safety factor = 1.3		
70-100m	N/A	N/A	N/A	1.23		* N/A = No plane formed		
100-135m	N/A	N/A	N/A	1.20				
135-150m	N/A	N/A	N/A	1.20				
150-250m	N/A	N/A	N/A	N/A				

Table 13: Summary of ROCPLANE analysis for planar failure for all depth and pit wall sectors

6.6. RISK MANAGEMENT

LEARNING OUTCOME 6.6.1

CONNECTION 18

Refer to
Paper 2 Outcome
8.1, 8.2 and 8.3

DESCRIBE, EXPLAIN AND DISCUSS THE VARIOUS ELEMENTS OF A COMPREHENSIVE RISK MANAGEMENT STRATEGY FOR AN OPEN PIT MINE.

A risk management strategy related to geotechnical issues should be developed by following the steps below (Read and Stacey, 2009):

1. Establish the content:
 - Risk management context defined;
 - Criteria against which risk will be determined to be established;
2. Identify risks:
 - When, where, how and why risks could affect stability, safety, etc.
3. Analyse the risks:

- Identify and evaluate existing controls;
 - Determine consequences and likelihoods of particular occurrences;
 - Determine the risk levels;
4. Evaluate the risks:
 - Compare risks against criteria;
 5. Treat the risks:
 - Develop remedial action plans to reduce risk levels to acceptable levels;
 6. Monitor:
 - Monitor effectiveness of remedial action plans;
 7. Review:
 - Review effectiveness of implementation of plans;
 - Review action plans based on monitoring.



- Page 381, Read and Stacey, Guidelines for open pit slope design, 2009

LEARNING OUTCOME 6.6.2

DESCRIBE, EXPLAIN, DISCUSS AND GENERATE INFORMATION FOR THE FOLLOWING ELEMENTS OF A RISK ASSESSMENT AND HAZARD CONTROL PROGRAMME:

- Hazard maps,
- ground control management plans,
- evacuation procedures.

Hazards maps

Hazard maps are used to present risks on a plan of the mine so that all personnel are aware of the specific hazard and the position on the mine where it is present. At the same time, the hazard plan allows the plotting of remedial action such as prevention of access via berms, support installation etc. to address the hazard.

Ground control management plans



Ground control management plans are a concept very similar to the Code of Practice, as applied to the South African mining industry.



- [Paper 2](#) Outcome 8.2.4

Evacuation procedures

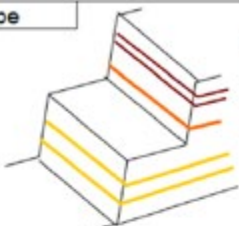
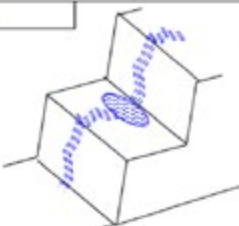
Evacuation procedures are derived to ensure that actions are known in case of a high risk event occurring. This could potentially include slope failures at bench, stack or overall slope scale. The TARP can be in the form of a checklist where the potential for a certain event occurring is established and the risk level will indicate a certain response, of which evacuation may be one action.

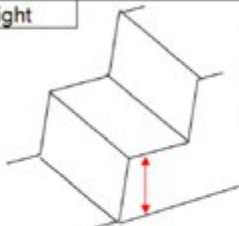
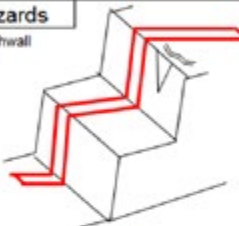
EXAMPLE

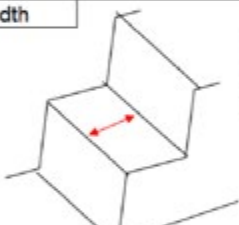
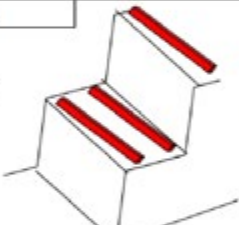
Geotechnical Post-Blast Report				Workplace	
Date				Block nr	
Unconformity Condition	Absent	Present	Prominent		
Blast induced cracks-H wall (damage)	1	2	3		
Layering / jointing opening up	1	2	3		
Loose, broken rock present in high wall	1	2	3		
				/ 9	
Back-break Condition	Absent	Present	Prominent		
Back-break thickness > 0.5m	1	2	3		
Back-break crack opening > 0.3m	1	2	3		
Back-break opening - continuous / random	1	2	3		
				/ 9	
Bench Geometry	Absent	Present	Prominent		
Bench angle 72° - 80°	3	2	1		
Crest overhang	1	2	3		
Straight face shape	3	2	1		
				/ 9	
Blasting Indicators	Absent	Present	Prominent		
Blast hole barrels present	3	2	1		
Black color at top of blasted hole	3	2	1		
				/ 6	
Muckpile / Fragmentation Observation	Absent	Present	Prominent		
Oversize boulders	1	2	3		
Intact crest heaved not broken	1	2	3		
Fragmentation: Upper muckpile	3	2	1		
Fragmentation: Lower muckpile	3	2	1		
				/ 12	
Total					
Poor Blast	27-45	NOTE: When a blast bench is classified as a Poor Blast special instructions must be provided.			
Average Blast	22-26				
Good Blast	0-21				
Comment: _____ _____ _____					
Checklist usage guide Ensure to score all lines in the 5 sections. Add up per section, add up all 5 sections. Rate total score with color rating.					

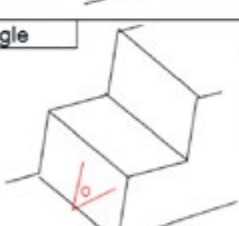
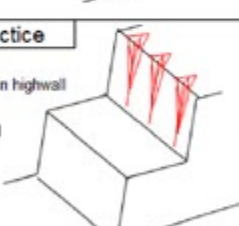
PAPER 3.4: CHAPTER 6

Geotechnical Checklist		Workplace	
Date		Block nr	

Rock Type Clay & Gravel Clay Calcrete BIS / Mn	Water Flowing Wet Damp Dry
	
4 3 2 1	4 3 2 1

Bench Height > 30 m 20 - 29 m 15 - 19 m < 15m	Geology Hazards Wedge present in highwall Overhang created Opening cavities None
	
4 3 2 1	4 4 4 1

Bench Width < 10 m 10 - 19 m 20 - 30 m > 30 m	Berms No berm Sub std berm Loose rocks in berm Berm to std
	
4 3 2 1	4 3 2 1

Bench Angle > 90° 80 - 90° 70 - 80° 70°	Blasting Practice Back-break created Severe - loose rocks in highwall Irregular faceshape Solid straight highwall
	
4 3 2 1	4 3 2 1

HIGH RISK
MEDIUM RISK
LOW RISK

32 to 21
 20 to 18
 17 to 8

NOTE: When a workplace is classified as a High Risk area immediately inform your Shift Supervisor.

Comment _____

GPS Mining _____

Production Supervisor _____

Miner _____



TARPs or Trigger Action Response Plans are in essence remedial procedures based on some trigger that sets the process in motion. This trigger can be certain conditions, slope displacements, seismic activity, rain levels, etc.

LEARNING OUTCOME 6.6.3

CONNECTION 19

Refer to
[“LEARNING OUTCOME 3.1.6”](#) on page 62,
 and [“4.2.1. SLOPE STABILITY”](#) on page 119

DESCRIBE, EXPLAIN, DISCUSS AND GENERATE INFORMATION ON ACCEPTABLE LIMITS ON SURFACE MINE SLOPE DESIGN.

Acceptable factors of safety for slope design have been suggested in previous sections.



Due to the inability of industry to derive limits that are acceptable to all environments and companies, the acceptable limits in terms of slope displacements, blasting and/or seismic vibrations etc., appropriate to a specific operation, should be contained in its specific code of practice or ground control management plan.

6.7. AUDITING FOR BEST PRACTICE

LEARNING OUTCOME 6.7.1

CONNECTION 20

Refer to
[Paper 2](#) Outcome 4.4
 and to
[“6.4.1. ROCK SLOPE MONITORING”](#) on page 171

DESCRIBE, EXPLAIN AND DISCUSS THE CONCEPT OF MONITORING FOR UNDERSTANDING, PREDICTION AND DESIGN.

PAPER 3.4: SURFACE MINING (HARD AND SOFT ROCK)

LEARNING OUTCOMES

7. ROCKBREAKING IN SURFACE MINING

7.1. CUTTING TECHNIQUES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss geotechnical aspects associated with various non-explosive rock breaking procedures used in surface mining operations
- Describe, explain and discuss the methodologies and applications of these techniques.

7.2. DRILLING TECHNIQUES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Sketch, describe, explain and discuss the different blast hole layouts used in surface mining operations;
- Describe, explain and discuss the spacing of blast holes in surface mining operations;
- Describe, explain and discuss the direction of drilling of blast holes in surface mining operations;
- Describe, explain and discuss the drilling of long holes in surface mining operations;
- Describe, explain and discuss the types of initiation used in the above layouts;
- Describe, explain and discuss the sequence of initiation of blast holes in surface mining operations;
- Describe, explain and discuss the importance of blast-hole drilling accuracy in the following applications:
 - Temporary walls, moving walls, final walls,
 - Back damage,
 - Trim blasting, buffer blasting,
 - Cushion blasting, smooth blasting, pre-split blasting,
 - Long-hole drilling.

7.3. BLASTING PRACTICES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the effect of the following parameters on blast damage:
 - Explosive type, initiation method,
 - Initiation sequence, hole orientation
- Describe, explain and discuss the objectives and effects of decoupling explosives;
- Describe, explain and discuss the methods by which decoupling of explosives is achieved;
- Describe, explain and discuss the following excavation cushion blasting and smooth blasting techniques:
 - Pre-splitting, angled pre-splitting,
 - Concurrent smooth blasting,
 - Post-splitting
- Describe, explain and discuss the methodologies and typical applications of each technique;
- List and discuss the advantages and disadvantages of these techniques;
- Evaluate and determine blasting requirements for the variety of surface mining applications making use of knowledge of explosives;
- Evaluate and determine appropriate blasting rounds to suit given conditions in surface mining operations;
- Evaluate and determine appropriate explosive types to suit given conditions in surface mining operations;
- Evaluate and determine appropriate initiation techniques to suit given conditions in surface mining operations;
- Evaluate and determine appropriate detonating techniques to suit given conditions in surface mining operations;
- Evaluate and determine appropriate blasting techniques to suit given conditions in surface mining operations; and
- Evaluate and determine appropriate slope geometries and dimensions to achieve optimum blasting efficiency

7. ROCK BREAKING IN SURFACE MINING

7.1. CUTTING TECHNIQUES

LEARNING OUTCOME 7.1.1

CONNECTION 1

Refer to
[Paper 2](#) Outcome 7
[Paper 3.1](#) Outcome 7

DESCRIBE, EXPLAIN AND DISCUSS GEOTECHNICAL ASPECTS ASSOCIATED WITH VARIOUS NON-EXPLOSIVE ROCK BREAKING PROCEDURES USED IN SURFACE MINING OPERATIONS.

Free digging of soft materials is possible close to the surface and may not require the use of explosives to break or move the material. Normally, material that does not require explosives to break is either dug or ripped using appropriate equipment. Ripping is typically performed by tractor-mounted equipment. The size of the tractor (dozer) is determined by the ripping assessment of the rock. The hardness and competency of each individual material will determine the ease of rippability. Rock that is too hard to be ripped is fragmented with explosives.



The ability to be able to indicate the diggability or rippability of rocks assists in successful excavation of these materials.
Rippability

Rippability is the ease with which soil or rock can be mechanically excavated. Rocks can be classified into igneous, sedimentary, and metamorphic with igneous rocks the most difficult to rip. This is partly because they lack planes of weakness such as bedding or cleavage planes. Metamorphic rocks vary in rippability, depending on their degree of stratification or foliation and sedimentary rocks are generally the most rippable.

Any highly stratified or laminated rocks, and rocks with extensive fracturing, are usually rippable.

The physical characteristics that are favourable for ripping are given below:

1. Frequent planes of weakness such as fractures, faults and laminations
2. Weathered rocks
3. Rocks with moisture permeating the formations
4. Highly stratified rocks
5. Brittle rocks
6. Rocks with low 'shear strength'

Conditions that make ripping difficult are as follows:

1. Massive rocks
2. Rocks with no planes of weakness
3. Crystalline rocks
4. Non-brittle energy absorbing rock fabrics
5. Rocks with high 'shear strengths'
6. Rocks with a high seismic velocity



(Courtesy of Handbook of Ripping, The Caterpillar Company).
 The rippability of rock can be assessed by evaluating numerous parameters including uni-axial strength, degree of weathering, abrasiveness, and spacing of discontinuities, but seismic refraction has historically been the geophysical method utilised to indirectly predetermine the degree of rippability.

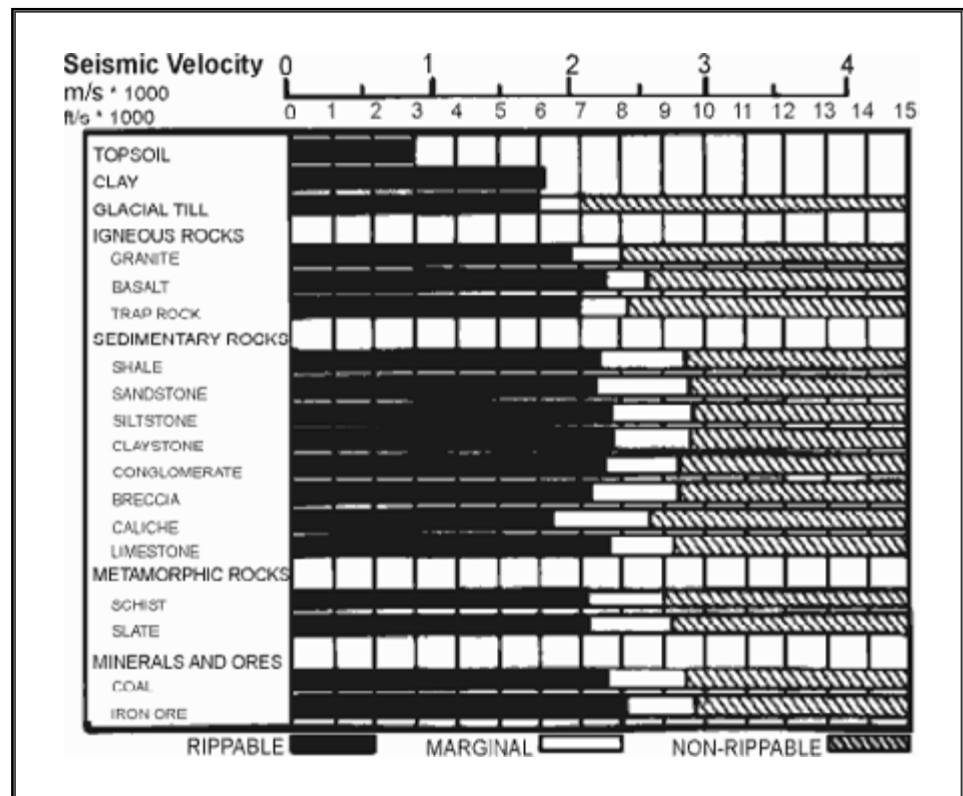


Figure 1: Rippability versus seismic velocity (Caterpillar. Handbook of Ripping, 8th Edition)

Figure 1 shows the rippability of various rock types for different seismic velocities using a D9 Caterpillar tractor. When the seismic velocity is more than 2 000m/s, the D9 tractor is insufficient, and a larger tractor will be required. A D11 tractor can rip some rocks with velocities of almost 3 000m/s.

EXAMPLE

The properties of the target conglomerates that influence the seismic velocity are:

- The mass density of the rock (kg/m^3)
- The elastic and deformation modulus (GPa)
- The Poisson's ratio

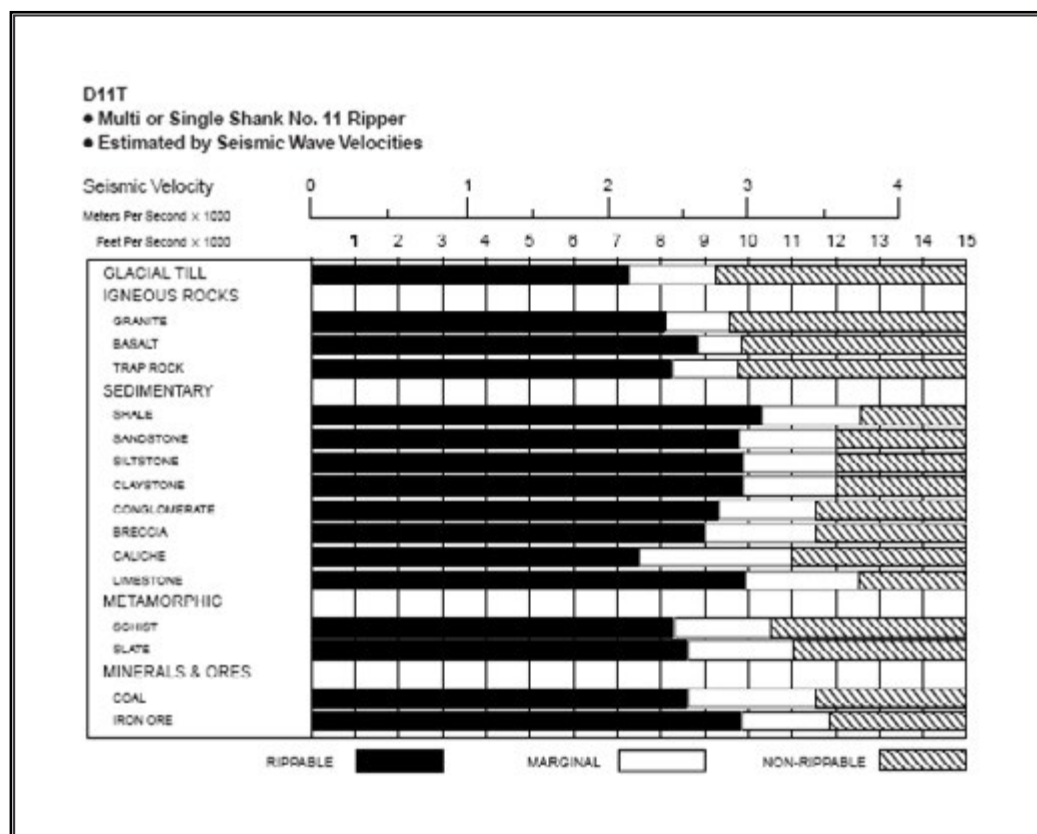


Figure 2: Rippability chart for a D11 ripper

The properties influencing the derivation of the seismic velocity are dependent on the rockmass rating (RMR) of the outcrops. It is reasonable to assume that fresh outcrop would have comparatively higher RMR values than deeply/highly weathered outcrop. In turn, it follows that outcrops with lower RMR values will have comparatively lower elastic moduli and global strengths.

Seismic velocities are directly proportional to the rockmass moduli, i.e. the higher the moduli, the higher the velocity. Since seismic velocities are directly related to rippability, it follows that establishing the rockmass moduli for different degrees of weathering will provide an indication of the rippability.

Reef environment	UCS (MPa)	RMR	Density (kg/m ³)	Poisson's ratio	Studio modulus
Main reef	162	49°	2800	0.18	20.23
Bird reef	162	49.6°	2800	0.18	

Table 1: Rock sample results

Ryder and Jager (2002) define the velocity of propagation of the P and S waves, respectively, as:

$$P_w = \sqrt{\frac{E(1-\nu)}{(1+\nu)(1-2\nu)\rho}}$$

where E = dynamic elastic modulus, ν = Poisson's ratio and ρ = mass density

$$S_w = \sqrt{\frac{E}{2(1+\nu)\rho}}$$

Using the above equations and the input parameters derived and shown above, the seismic velocities for the different reef environments were derived below.



For calculation of the seismic velocities, the dynamic modulus was used. The dynamic modulus is normally 35% higher than the static modulus.

Reef environment	Primary wave (m/s)	Secondary wave (m/s)
Main reef	3254.33	2032.96
Bird reef		

Table 2: P- & S-wave velocities

The rippability of the outcrop is marginal. The upper bound limit for seismic velocity has been selected at 3 500m/s, which relates to rock conglomerates. The preliminary assessment indicates that direct free digging may be possible for the outcrop, but may also require alternative methods to reduce the rock quality and allow ripping.

Diggability index (DI)

This index makes use of a state of weathering, strength (UCS or PLI), joint spacing and bedding spacing rating system (Table 3) to determine the relative ease with which the material can be dug out using the appropriate equipment.

Parameter	Symbol	Ranking				
Weathering	W rating	Complete 0	High 5	Moderately 15	Slight 20	Fresh 25
Strenght (MPa) UCS	S rating	<20 <0.5 0	20-50 0.5-1.5 5	40-60 1.5-2 15	60-100 2-3.5 20	>100 <3.5 25
Joint spacing (m)	J rating	<0.3 5	0.3-0.6 15	0.6-1.5 30	1.5-2 45	>2 50
Bedding spacing (m)	P rating	<0.1 0	0.1-0.3 5	0.3-0.6 10	0.6-1.5 20	>1.5 30

Table 3: Rating table for diggability index (Scoble et al., 1984)

The input parameters for the calculations performed below were sourced:

- The state of weathering, joint spacings and bedding spacings were taken from the log sheets;
- The strength ratings were taken from point load index tests and UCS test results. The results (Table 4) indicate that 'easy' to 'very difficult' digging zones exist within the material in both the data available prior to sinking and that gathered during sinking.

Diggability Index (Scoble et al , 1984)								
Source	Rock type		W	S	J	B	DI	Classification
Itasca data during sinking	94m	Calcretised gravel and clay	5	5	15	5	30	Very easy
			5	0	15	5	25	Very easy
	114m	Thinly bedded and folded siltstone/ shale	5	5	15	5	30	Very easy
			5	0	15	5	25	Very easy
	122.5m	Folded interbedded chert and shale	5	20	15	10	50	Moderately
			5	5	15	10	35	Very easy
MDI data presented in geotechnical reports	120m - 140m	Transition Kalahari - Lucknow quartzite	5	20	15	10	50	Moderately
			20	25	15	10	70	Very difficult
	130m - 140m	Silty shale transitions	20	0	15	10	45	Easy

Table 4: Diggability results (DI)

12.7 Diggability classification

- The Diggability in terms of the type of plant required uses the Index obtained from the previous table.

Table 12.7 Diggability classification for excavators (adapted from, Scoble and Muftuoglu, 1984).

Class	Ease of digging	Index (W + S + J + B)	Typical plant which may be used without blasting	
			Type	Example
I	Very Easy	<40	Hydraulic backhoe < 3 m ³	CAT 235D
II	Easy	40–50	Hydraulic shovel or backhoe < 3 m ³	CAT 235FS, 235 ME
III	Moderately	50–60	Hydraulic shovel or backhoe > 3 m ³	CAT 245FS, 245 ME
IV	Difficult	60–70	Hydraulic shovel or backhoe > 3 m ³ : Short boom of a backhoe	CAT 245, O&K RH 40
V	Very difficult	70–95	Hydraulic shovel or backhoe > 4 m ³	Hitachi EX 100
VI	Extremely difficult	95–100	Hydraulic shovel or backhoe > 7 m ³	Hitachi EX 1800, O&K RH 75

Table 5: Diggability categories (Scoble et al., 1984)

INTERESTING INFO

A number of empirical graphs to estimate diggability or the need to blast rocks were sourced and are shown below for interest sake. More detail on each method, if required, should be sourced by the user.

[back](#)

PAPER 3.4: CHAPTER 7

Empirical graphs

A

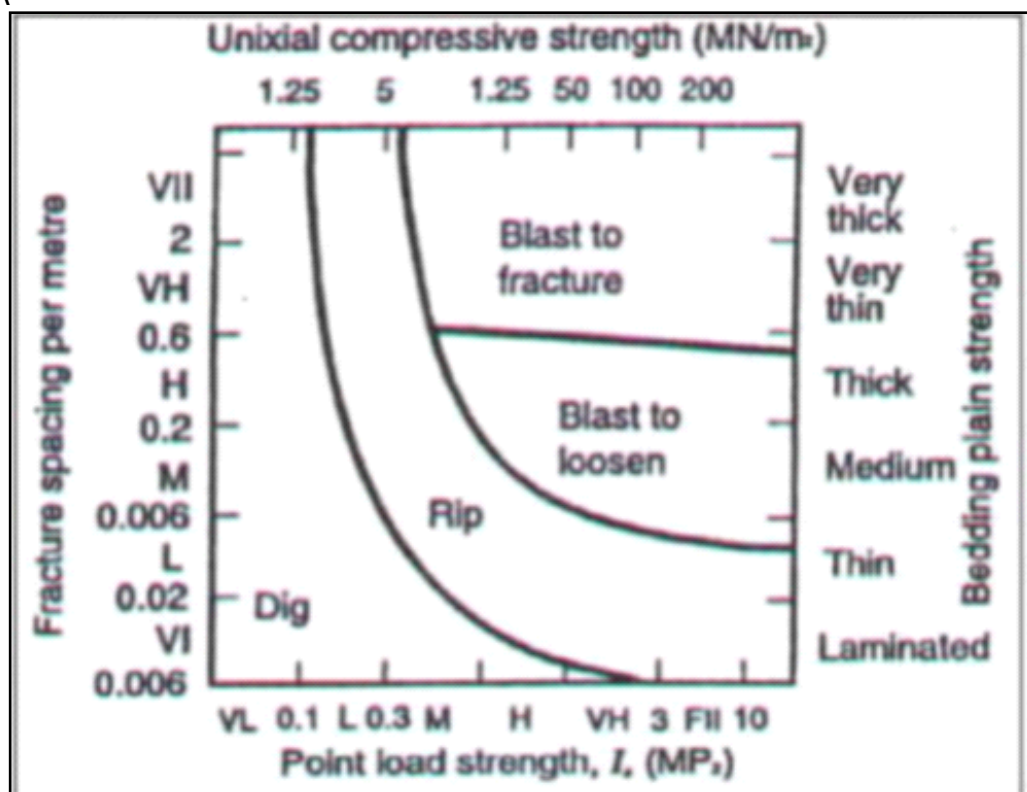


Figure 3: Diggability, rippability and the need to blast
please note: POOR QUALITY SCAN SUPPLIED. SHOULD WE LEAVE AS IS?

[back](#)

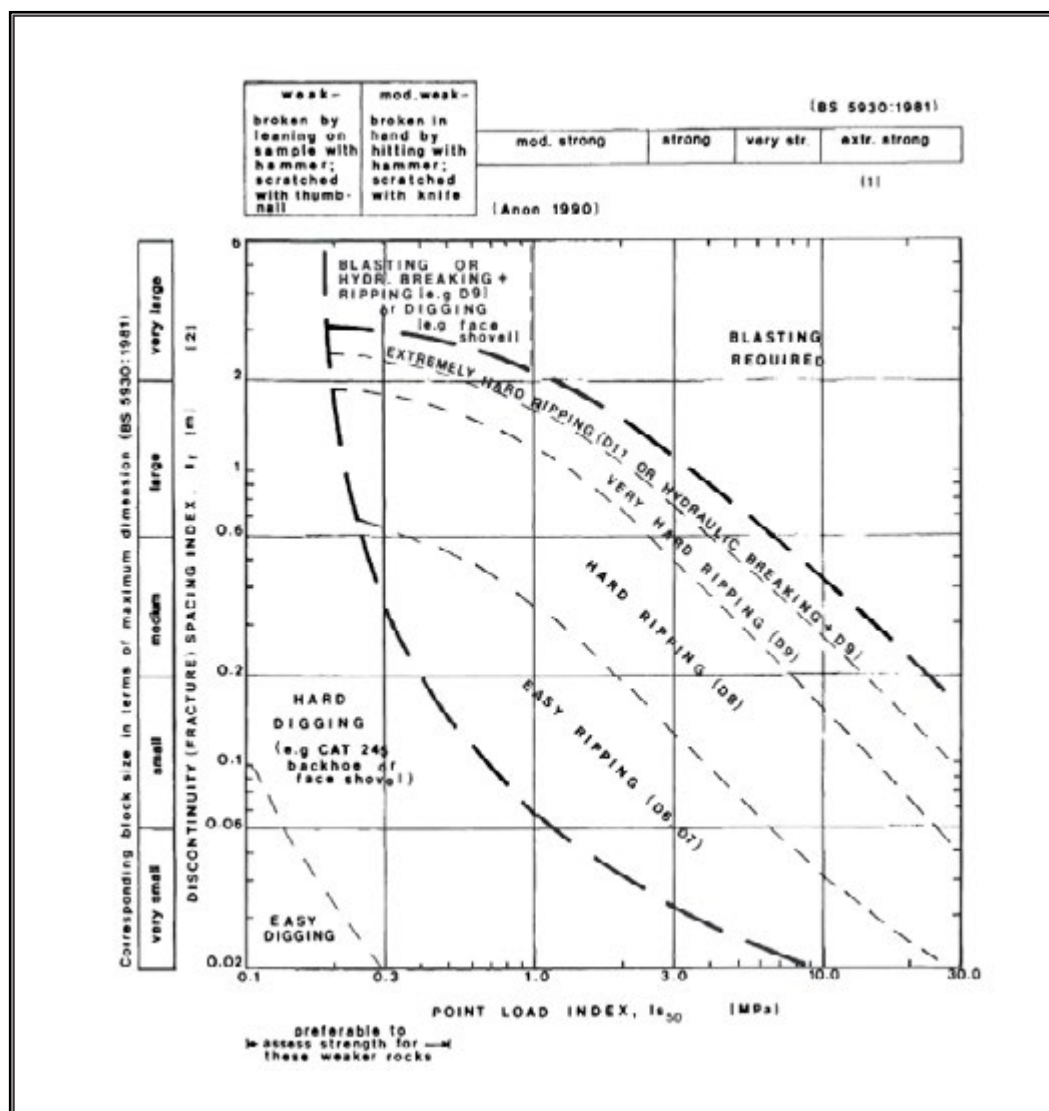
[back](#)


Figure 4: Excavatability based on PLI and fracture spacing



- [Graphical method to assess excavatability](#)
- [Predicting cuttability with surface miners](#)
- [Rippability assessment of rock based on specific](#)

LEARNING OUTCOME 7.1.2

CONNECTION 2

Refer to
"LEARNING OUTCOME
7.1.1" on page 212

DESCRIBE, EXPLAIN AND DISCUSS THE METHODOLOGIES AND APPLICATIONS OF THESE TECHNIQUES.

[back](#)

7.2. DRILLING TECHNIQUES

INTERESTING INFO

The importance of production blasting of the highwall on the operation's economic status is reflected in the cost implications of incorrect fragmentation, which have significant impacts on drilling, loading, hauling and crushing costs. Hoek and Bray (1981) suggested that fragmentation, i.e. how fine or coarse the material created by the blast is, has increased cost implications when fragmentation is too fine and too coarse (Figure 5), indicating that there is a range of fragmentation that will be optimum to the operation and that should be considered in the design.

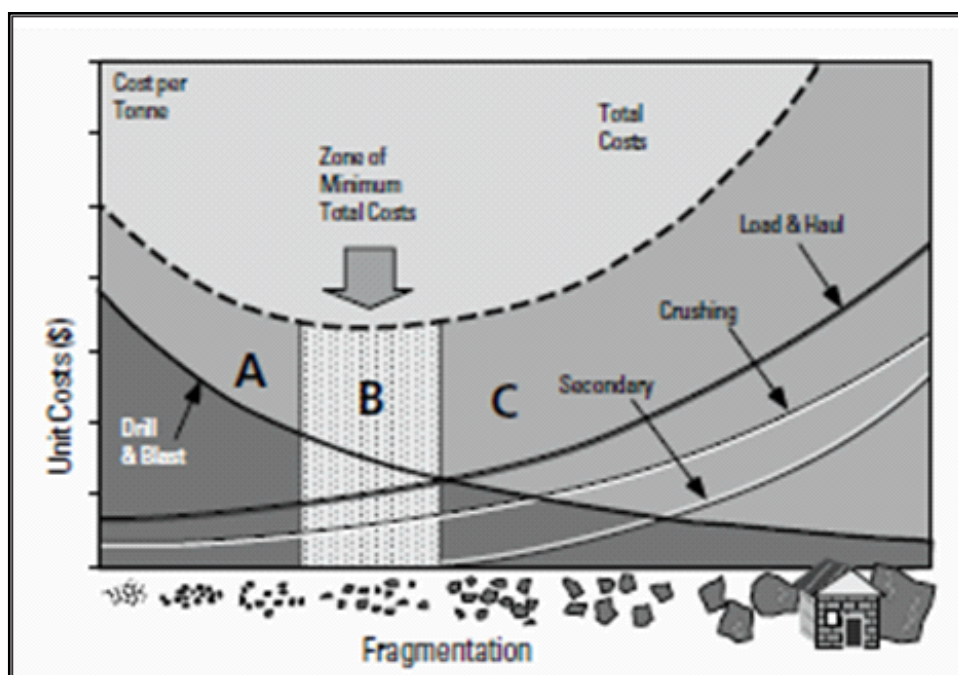


Figure 5: Fragmentation impact on costs (Atlas Copco)



From Hoek and Bray (1981), the following (refer to Figure 6):

- Burden: Spacing between blast holes towards the highwall, i.e. spacing between rows;
- Spacing: Spacing between blast holes along the highwall, i.e. spacing between holes in a row;
- Sub-drill: Drill distance below the planned bench floor level;
- Stemming: Closing of the hole with non-explosive material to confine the gas created by explosives, allowing it to break and throw the rock material.

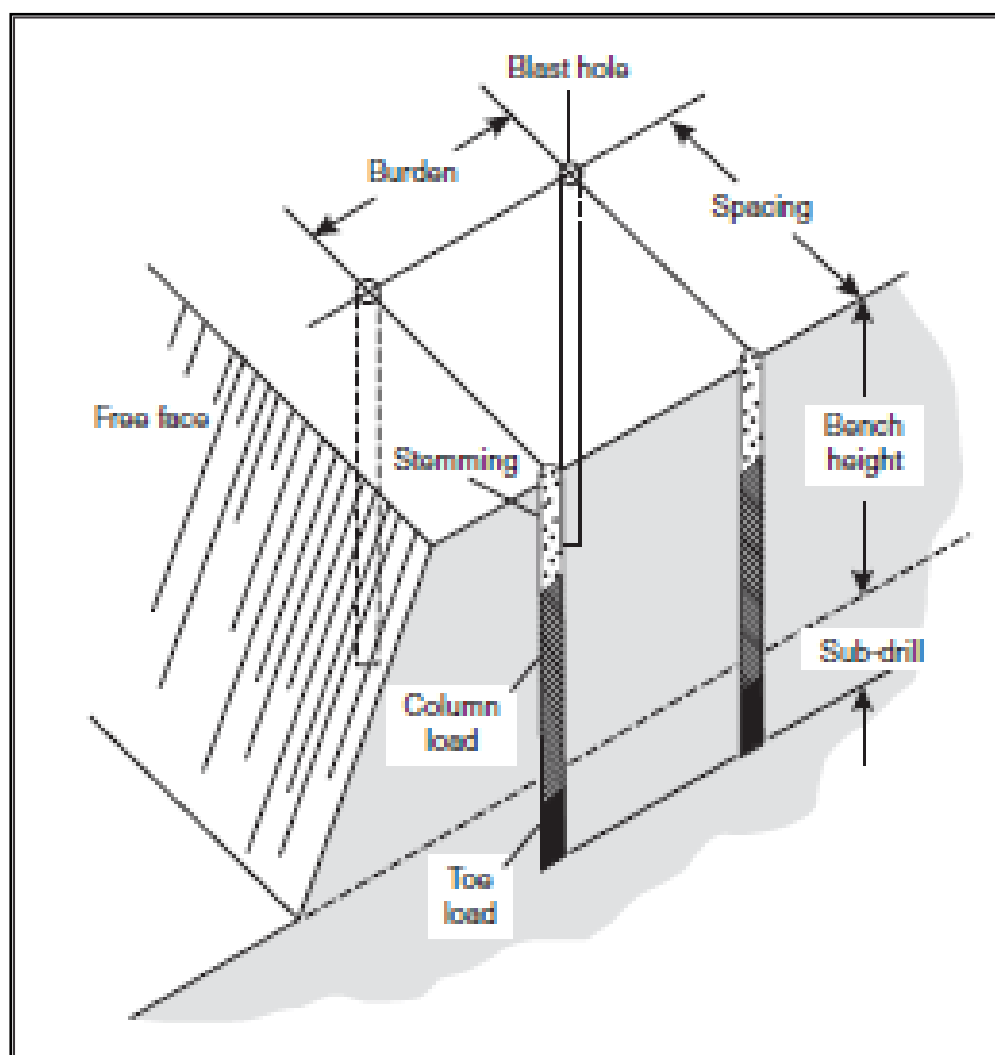


Figure 6: Definitions (Hoek & Bray, 1981)

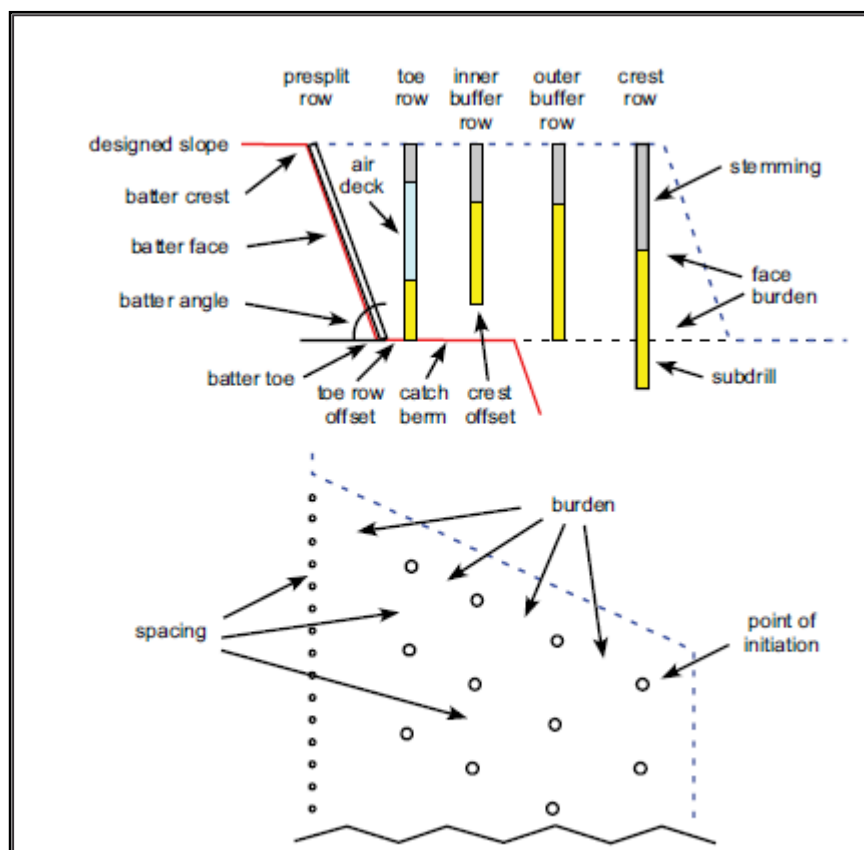


Figure 7: Definitions (Read & Stacey, 2009)



From Read and Stacey (2009), the following (refer to Figure 7):

- Pre-split row: Row along the next bench (slope) face position, drilled at the planned face/batter angle;
- Crest row: Row along the current bench crest;
- Toe row: Row along the toe of the next bench face, i.e. first row from the pre-split row;
- Toe row offset (also called toe stand-off): Distance between the planned toe position and the toe row holes;
- Crest offset: Distance between the bottom of the holes and the planned bench level;
- Face burden: Distance between the first row of holes and the current bench face, taking cognisance of the bench face angle;
- Inner and outer buffer rows: Rows drilled between the crest and toe rows, where the outer row is towards the current bench face and the inner towards the solid wall.



- Page 271,273 Hoek and Bray, Rock slope engineering, 1981
- Page 274,278, Read and Stacey, Guidelines to open pit slope design, 2009

LEARNING OUTCOME 7.2.1

SKETCH, DESCRIBE, EXPLAIN AND DISCUSS THE DIFFERENT BLAST HOLE LAYOUTS USED IN SURFACE MINING OPERATIONS.

The following layouts are typical layouts, but variations of these layouts are possible. The ratios between the burden and spacing distances have been reported to vary anything from 1 (Figure 8) to as much as 8 in some layouts.



The blast must be effective in fragmenting and throwing the rock as designed and the appropriate burdens and spacings must be derived for each specific bench design and material to be blasted.

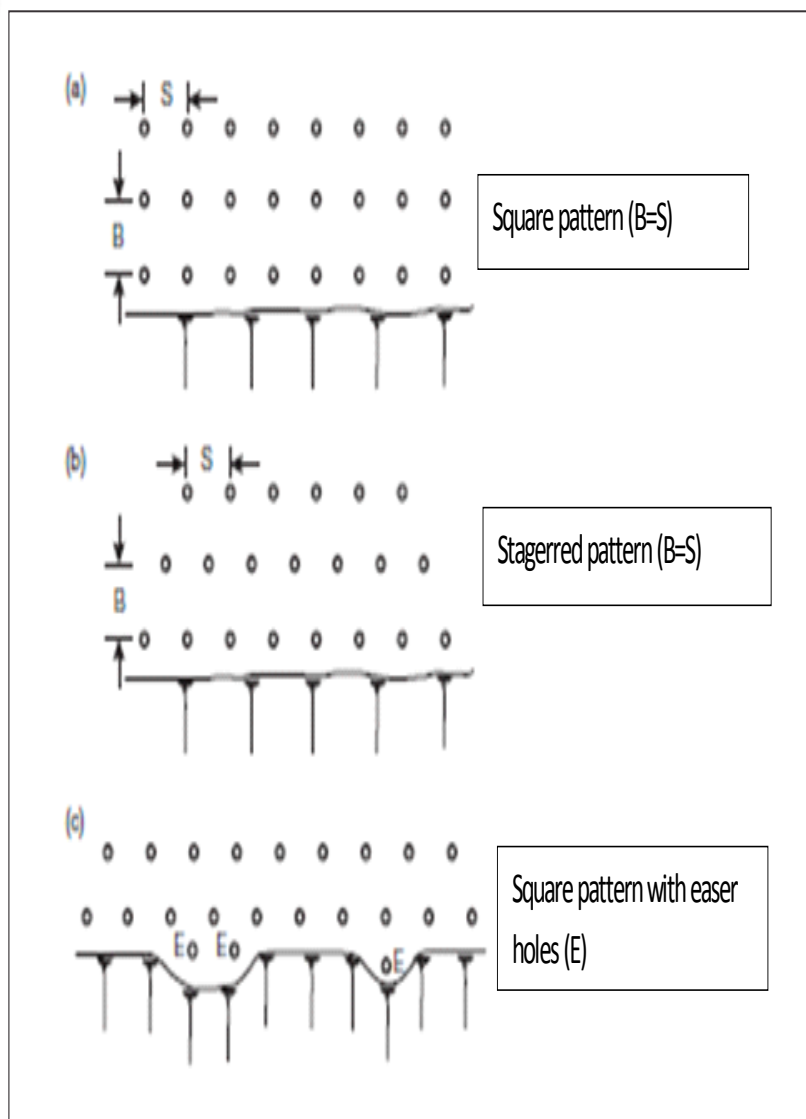


Figure 8: Drill hole patterns (Hoek & Bray, 1981)

- Page 278, Hoek and Bray, Rock slope engineering, 1981



LEARNING OUTCOME 7.2.2

CONNECTION 3

Refer to
"7.2. DRILLING TECH-
NIQUES" on page 219

DESCRIBE, EXPLAIN AND DISCUSS THE SPACING OF BLAST HOLES IN SURFACE MINING OPERATIONS.

Spacing of blast holes are defined by the 'burden' and 'spacing' of the holes.

Effective burdens create distances where the blast is effective in that it breaks and throws the blasted rock towards the free face. If burdens are too small, blast-induced fractures will extend to the free face and allow the release of the explosive gas to surface before it can break the rock, extend the fractures and throw the rock. If burdens are too large, the blast will be 'choked', i.e. the gas pressure is insufficient to break rock, extend fractures and throw the amount of rock between the holes and the previous row of holes. This will create large rocks (gas pressure insufficient to adequately fracture rock and extend cracks), poor throw (fractures not adequately extended parallel to the free face and gas pressure insufficient to move the rock) and therefore an ineffective blast.

Effective spacings ensure that the holes are close enough to each other to allow the creation of a crack between the holes, parallel to the free face by the gas pressure and tensile wave (shock wave) and still ensure that the pressures are high enough to throw the rock towards the free face.

- Page 276, Hoek and Bray, Rock slope engineering, 1981



LEARNING OUTCOME 7.2.3

DESCRIBE, EXPLAIN AND DISCUSS THE DIRECTION OF DRILLING OF BLAST HOLES IN SURFACE MINING OPERATIONS.

INTERESTING INFO

Drilling of the blast holes at between 10 and 30° from the vertical has been reported to provide better fragmentation and throw, as well as reduced damage to the highwalls.

When bench faces are inclined ($<90^\circ$ batter angle/bench face angle), Figure 7 shows that the 'face burden' is variable, i.e. the burden between the first row of holes and the free face varies from the top of the hole to the bottom of the hole.



Some drill rigs can only drill vertical holes, but if rigs can drill at an inclination, it has been shown that it is advantageous to drill the holes parallel to the inclination of the bench face.

In cases where only vertical holes can be drilled, while the bench face is inclined, the explosive placement (charging up) must take notice of this increasing burden towards the end of the hole and change the charges appropriately.

- Page 279, Hoek and Bray, Rock slope engineering, 1981



Inclined drilling, as well as vertical drilling could result in problematic blast results if the charging up/explosive placement process does not take account of the actual burdens created by the free face the drilled holes (Figure 9).

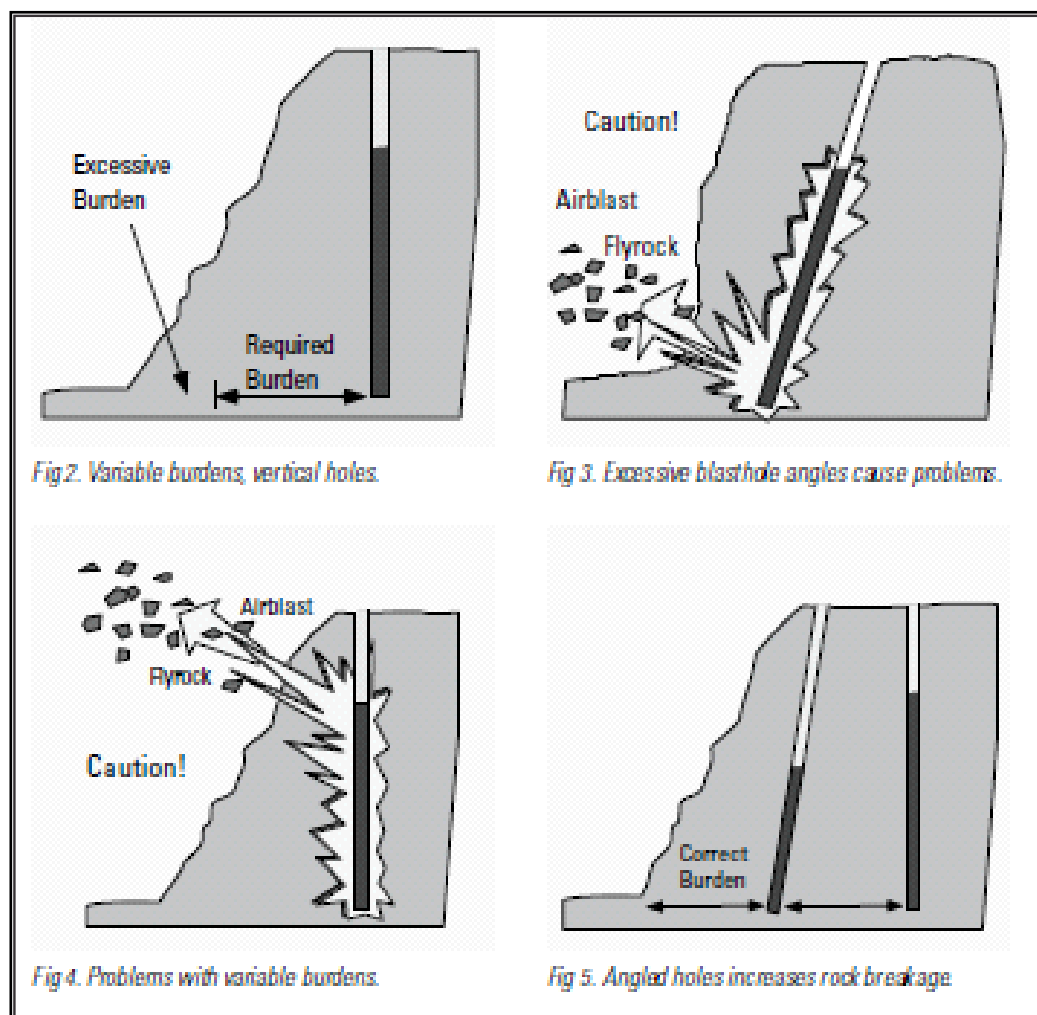


Figure 9: Blasting concerns (Atlas Copco)

LEARNING OUTCOME 7.2.4

DESCRIBE, EXPLAIN AND DISCUSS THE DRILLING OF LONG HOLES IN SURFACE MINING OPERATIONS.



Drilling methods and drill machines (rigs) vary across the many open pit mines in the industry.

Courtesy of Atlas Copco, a reference book is linked to these guidelines, which contains significant data on rigs and applications. The user is advised to read the appropriate sections in this guide.

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Talking technically	
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11	Ergonomics and safety
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29	Automated surface blasthole drilling
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For latest updates contact your local Atlas Copco Customer Center or refer to www.atascopco.com/blastholedrills	

Figure 10: Index to the Atlas Copco blast-hole guide



- [Blast-hole reference book 3rd Edition](#) (Courtesy of Atlas Copco)

Courtesy of Atlas Copco, the following six drilling methods are briefly shown:

1. Tophammer (Figure 10):
 - Impact energy is generated when the piston strikes the shank adapter. This energy is transmitted from the rock drill via the shank adapter, drill steel and drill bit to the rock, where it is used to crush the rock. Primarily used for drilling in hard rock for hole diameters up to 140mm, and the main advantage is the high penetration rate in good solid rock conditions.
2. COPROD system (Figure 10):
 - Combines the speed of tophammer drilling with the precision and long service life of the down-the-hole method. Inside each rigid, threaded pipe section is an impact rod, and the COPROD sections are joined together via the drill pipes. Since the drill pipes transmit rotation force only, stress to the threads is minimal and their service life very long. All negative effects of the transmission of impact energy through the threads are eliminated entirely. The result is high impact power with minimal wear. The method gives good overall economy, particularly in large-scale production drilling and when drilling in demanding rock conditions.
3. Down-the-hole (Figure 10):

- Reliable way to drill in various formations, from hard to soft, competent to broken or abrasive to non-abrasive rock. The rock drill piston strikes the drill bit directly, while the hammer casing gives straight and stable guidance of the drill bit. This results in minimal deviation and greater hole wall stability, even in demanding rock. Good hole quality enables the burden and spacing to be increased, while straight holes make charging easier and enable the amount of explosive to be reduced.

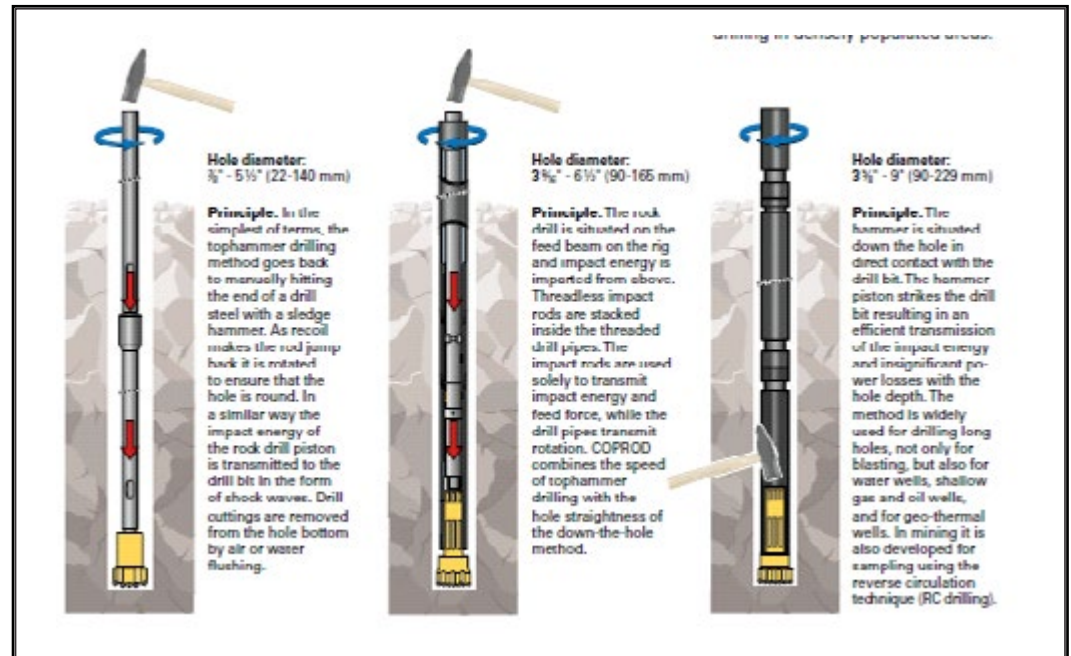


Figure 11: Top Hammer, COPROD and down-the-hole methods (Atlas Copco)

- Reverse circulation (Figure 11):
 - Used to collect rock chips to the surface for subsequent analysis. The air and rock chips are blown past the bit and up through the centre of the drill string to the surface. The RC method is used for mineral exploration as an alternative to diamond core drilling. With the RC hammer, the cost of drilling is much less than diamond drilling and the penetration rates are an order of magnitude greater than diamond drills.
- Rotary drilling (Figure 11):
 - The prime difference from other drilling methods is the absence of percussion. Rotary cutting is mainly used for soft rock that is cut by shearing. Rotary crushing bits rely on crushing and spalling the rock. This is accomplished by transferring down force to the bit while rotating in order to drive the teeth into the hole. The softer the rock the higher the rotation speed. The drill rigs need to be heavy to provide sufficient weight on the bit. Generally, drilling below 152mm is best accomplished by percussive drilling unless prevailing rock conditions are suited for rotary cutting. Rotary crushing is the prime choice for large diameter holes, above 254mm in open pit mining.
- PARD (Figure 11):
 - Combines percussive power and rotational force. The high frequency impacts provide significant increases in the rate of penetration when drilling in medium to hard rock. The Secoroc PARD system consists of a high frequency, low impact energy hammer and a specially designed drill bit that is mounted onto a standard rotary drill and drill string.

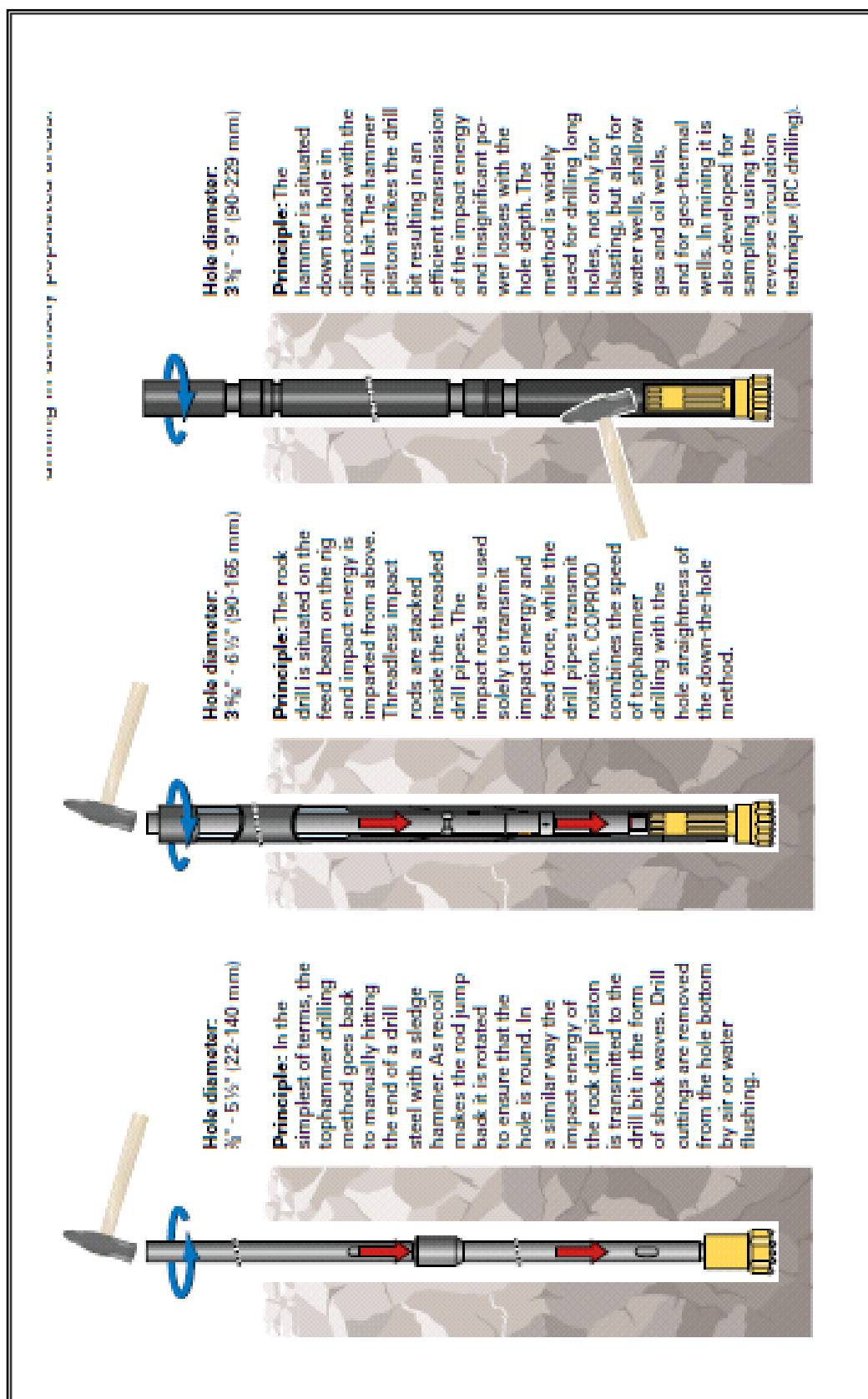


Figure 12: Reverse circulation, rotary and PARD methods (Atlas Copco)

- Page 176, Blast hole reference book, Atlas Copco





- Video on Atlas Copco Viper pit drill rigs <http://www.atlascopco.com/videogallery/detail/28348541-c852-4148-a274-df044f3eaf37>

LEARNING OUTCOME 7.2.5

CONNECTION 3

Refer to
[Paper 2](#) Outcome 7
[Paper 3.1](#) Outcome 7

DESCRIBE, EXPLAIN AND DISCUSS THE TYPES OF INITIATION USED IN THE ABOVE LAYOUTS.

LEARNING OUTCOME 7.2.6

DESCRIBE, EXPLAIN AND DISCUSS THE SEQUENCE OF INITIATION OF BLAST HOLES IN SURFACE MINING OPERATIONS.

To prevent excessive vibrations caused by a blast where all holes are initiated at the same time, it is advantageous to divide the blast into several detonations and in a specific firing/detonation sequence. As material is moved away from the bench by the blast, the free face position shifts and allows the next set of holes to detonate and break towards this new free surface (Figure 13a). If the detonation sequence does not allow for sufficient 'relief' by creating a free surface, the next holes that detonate will still be partly confined by the previous blast, and a poor blast will result (Figure 13b).

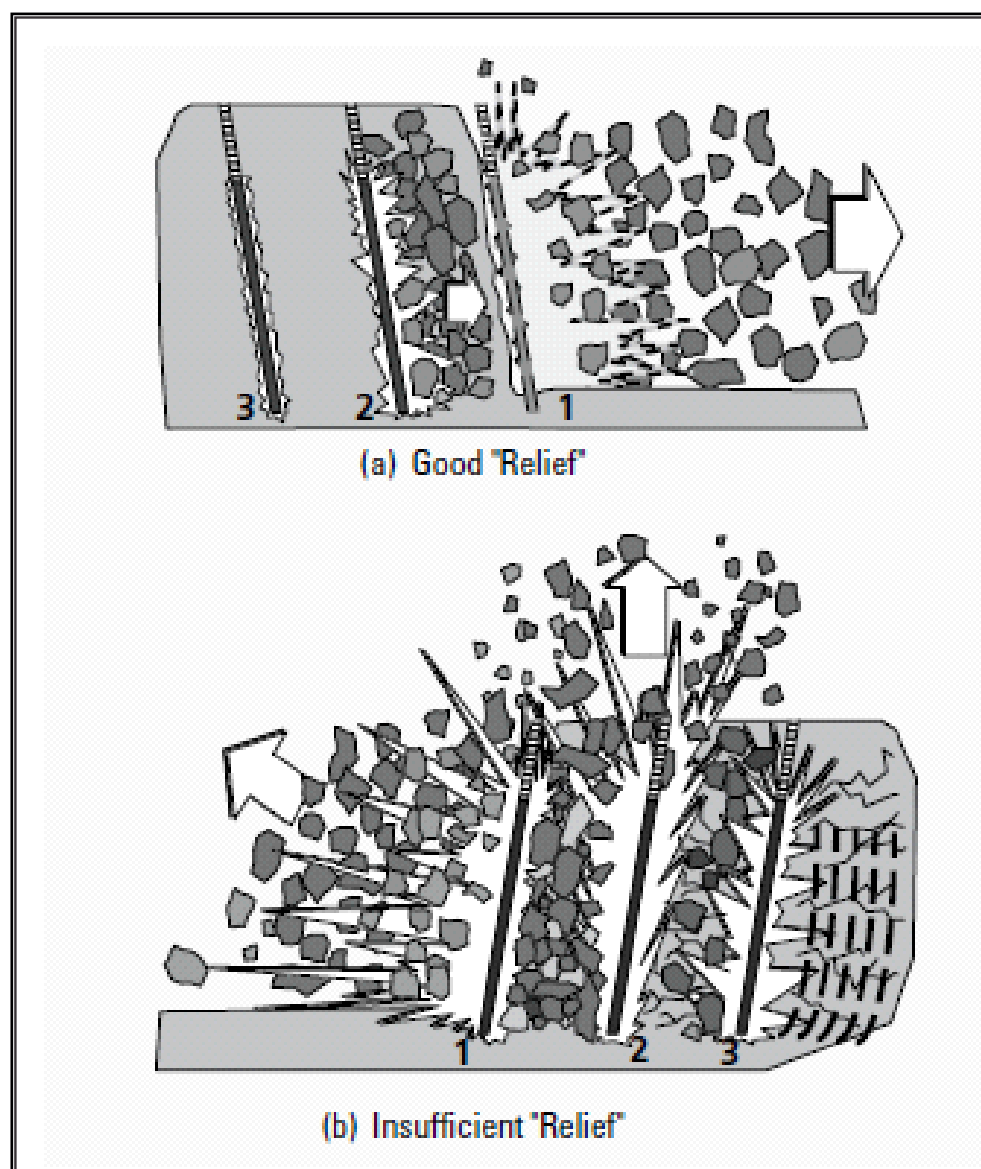


Figure 13: 'Relief' created/prevented by detonation sequence (Atlas Copco)

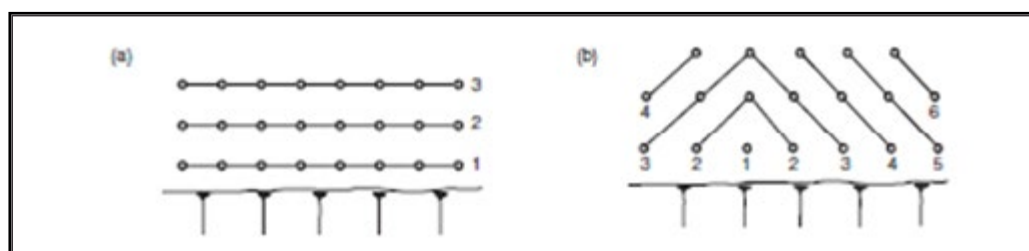


Figure 14: Detonation sequence (a) square 'row by row', (b) square 'V' (Hoek & Bray, 1981)

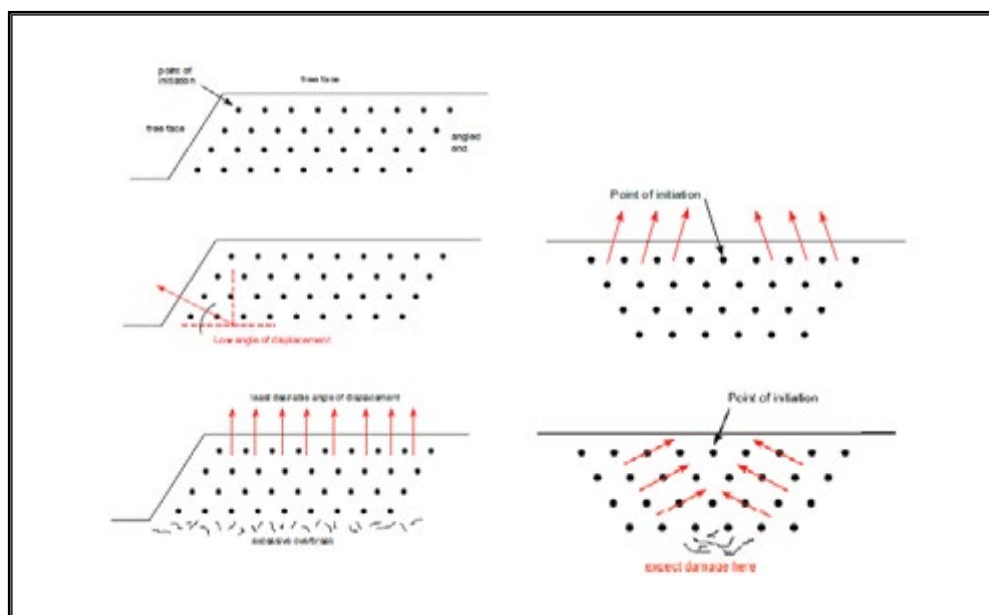


Figure 15: Initiation points and rock movement for various detonating sequences (Read & Stacey, 2009)

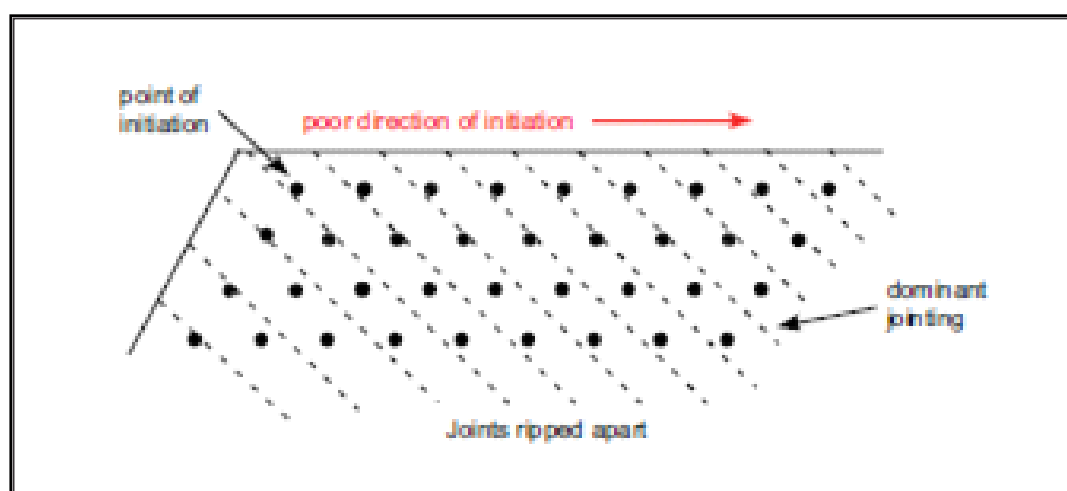
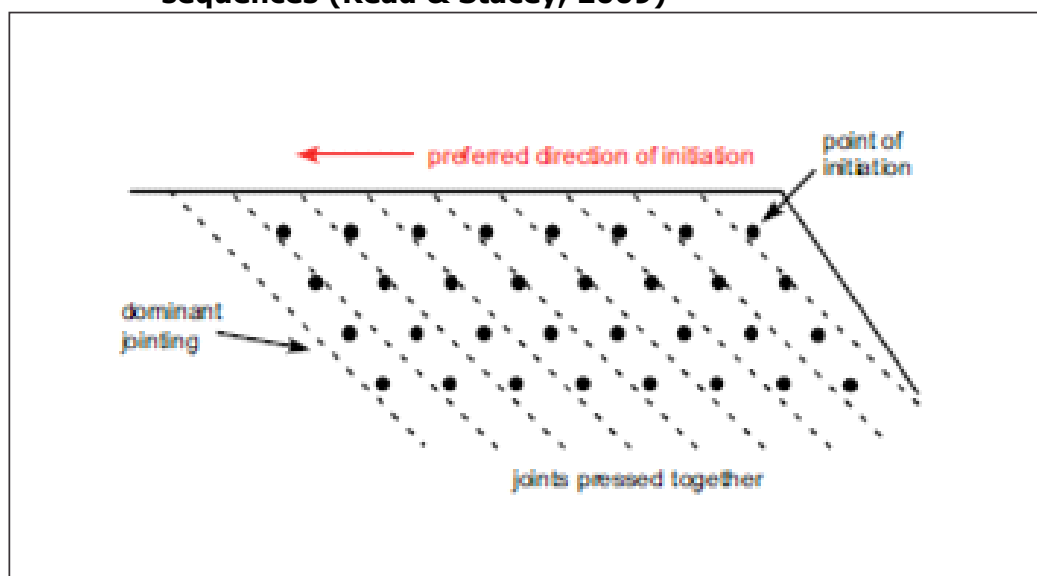


Figure 16: Detonating sequences that (a) protect or (b) cause damage (Read & Stacey, 2009)

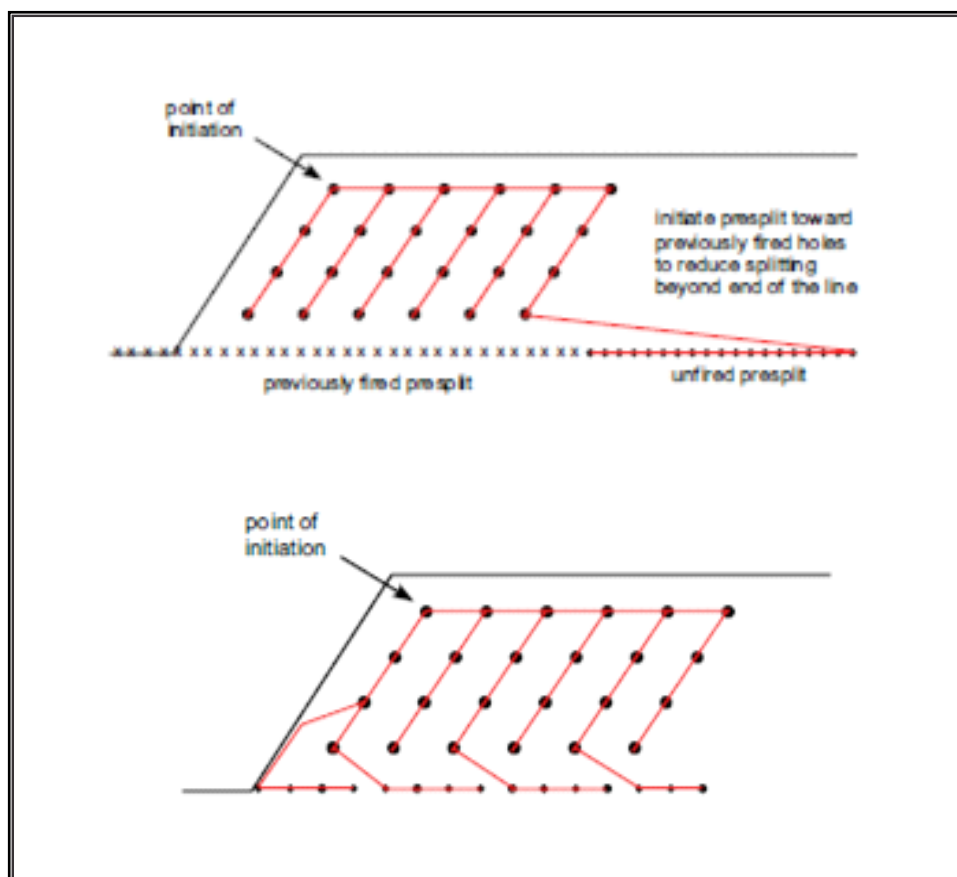


Figure 17: Trim blast and mid-split detonating sequences (Read & Stacey, 2009)

The following general rules can be applied:

- Trim and cushion blasting should be laid out on a staggered pattern and shot to free faces (Figure 15);
- When blasting to one free face, a flat chevron or 'V' configuration should be used (Figure 15);
- Pre-split holes are fired simultaneously if vibration control is not an issue, or else groups of 25 holes should be fired or post-splitting techniques should be considered;
- Pre-split holes should be fired before adjacent holes are drilled;
- To reduce the impact of production, the trim blast and next pre-split should be fired together (Figure 17a);



Correct timing can result in a good blast design performing better, but cannot make a poor design perform better.



- Page 292, Read and Stacey, Guidelines to open pit slope design, 2009
- Page 280, Hoek and Bray, Rock slope engineering, 1981

LEARNING OUTCOME 7.2.7

CONNECTION 4

Refer to
"LEARNING OUTCOME
7.3.4" on page 233
[Paper 2](#) Outcome 7
[Paper 3.1](#) Outcome 7

DESCRIBE, EXPLAIN AND DISCUSS THE IMPORTANCE OF BLAST-HOLE DRILLING ACCURACY IN THE FOLLOWING APPLICATIONS:

- Temporary walls,
- moving walls,
- final walls,
- back damage,
- trim blasting,
- buffer blasting,
- cushion blasting,
- smooth blasting,
- pre-split blasting,
- long-hole drilling.
-

Drilling accuracy is critical to any blasting process, whether it be to ensure the correct fragmentation or the creation of stable walls, since the drilling accuracy determines the final hole burden and spacing, which are critical to the outcome of a blast.

Drilling accuracy decreases with:

- increasing hole length or bench height;
- decreasing hole diameter;
- inclined holes.

7.3. BLASTING PRACTICES

LEARNING OUTCOME 7.3.1

CONNECTION 5

Refer to
[Paper 2](#) Outcome 7
[Paper 3.1](#) Outcome 7

DESCRIBE, EXPLAIN AND DISCUSS THE EFFECT OF THE FOLLOWING PARAMETERS ON BLAST DAMAGE:

- Explosive type, initiation method,
- Initiation sequence, hole orientation

LEARNING OUTCOME 7.3.2

CONNECTION 6

Refer to
[Paper 2](#) Outcome 7
[Paper 3.1](#) Outcome 7

DESCRIBE, EXPLAIN AND DISCUSS THE OBJECTIVES AND EFFECTS OF DE-COUPLING EXPLOSIVES.

LEARNING OUTCOME 7.3.3

CONNECTION 7

Refer to

[Paper 2](#) Outcome 7

[Paper 3.1](#) Outcome 7

DESCRIBE, EXPLAIN AND DISCUSS THE METHODS BY WHICH DE-COUPLING OF EXPLOSIVES IS ACHIEVED.

LEARNING OUTCOME 7.3.4

DESCRIBE, EXPLAIN AND DISCUSS THE FOLLOWING EXCAVATION CUSHION BLASTING AND SMOOTH BLASTING TECHNIQUES:

- Pre-splitting, angled pre-splitting
- Concurrent smooth blasting
- Post-splitting



The following methods are also discussed in this section:

- Trim blasting,
- Buffer blasting/cushion blasting;
- Line drilling.

Pre-splitting

A row of closely spaced holes is drilled along the line of the final face, usually consisting of small diameter holes. These holes are lightly charged and decoupled. The row is fired before the main charge and results in the creation of a fracture running between holes. A good pre-split usually shows a clean face with a clear fracture running between the blast hole barrels.

Pre-split holes are usually drilled at 70°, but can be vertical, and should then be placed along the planned toe of the bench. They are successful in conditions that include:

- Massive rock;
- Tightly jointed rockmass;
- A dominant joint set that strikes > 30° to the designed face;
- Absence of weak structures that create a wedge along the bench face.



Mid-split blasting is when a pre-split is blasted a short time before the adjacent holes, i.e. in the middle of the timing sequence for the main blast instead of before the main blast.

INTERESTING INFO

The pre-split fracture does not prevent the wall behind from blasting vibrations, but allows the venting of explosive gases along the fracture, preventing the extension of blast fractures into the rock wall.

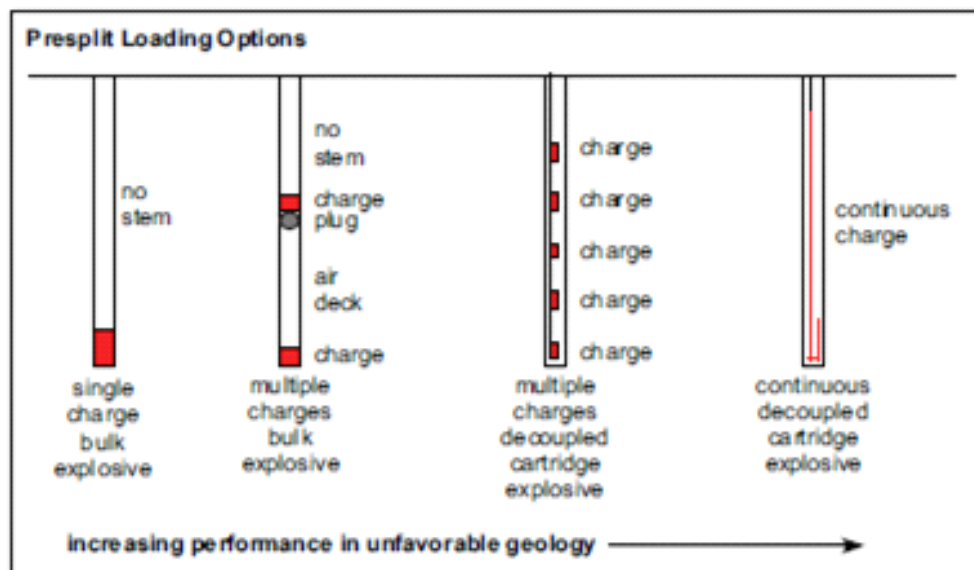


Figure 18: Pre-split loading options (Read & Stacey, 2009)



- [Large diameter pre-splitting](#)

Smooth wall / Post-splitting

This is similar to pre-split, except that the line of holes is fired after the main charge. This means that the free face exists close to the line of holes and therefore at a small burden. This method is often used as a clean-up blast to minimise rockfall potential.

Trim blasting

This method is normally applied to harder rock materials and is a very common practice. Trim blasts are typically three to five rows deep and are shot to a free face at a constant burden. Batter angles are typically 60 to 75°, but in many cases, the bench face angle is controlled by inherent jointing.



In adverse geological conditions extra rows can be added to prevent damage to the walls.

The purpose of the toe row is to define the toe of the bench and not the crest, and the burdens and spacings, as well as charge, are reduced. The burden is greater than the spacing to promote breaking along the toe holes with spacings of approximately 50% of the normal spacings. Decoupling is also applied to reduce blast hole pressures and improve wall conditions.

The inner buffer row is designed to define the crest of the bench.



This blasting requires the increase in distance between the last row and the final face position, applying a 'stand-off' distance from the bench toe. This distance is critical in creating the better angle and preventing damage to the bench.

- Pattern width is reduced to three to six rows deep;
- Delay sequence is changed to control vibration and displacement levels;
- Sub-drilling is reduced above the catch berm.

This method is typically used for weaker rocks and for batter angles less than 60°.

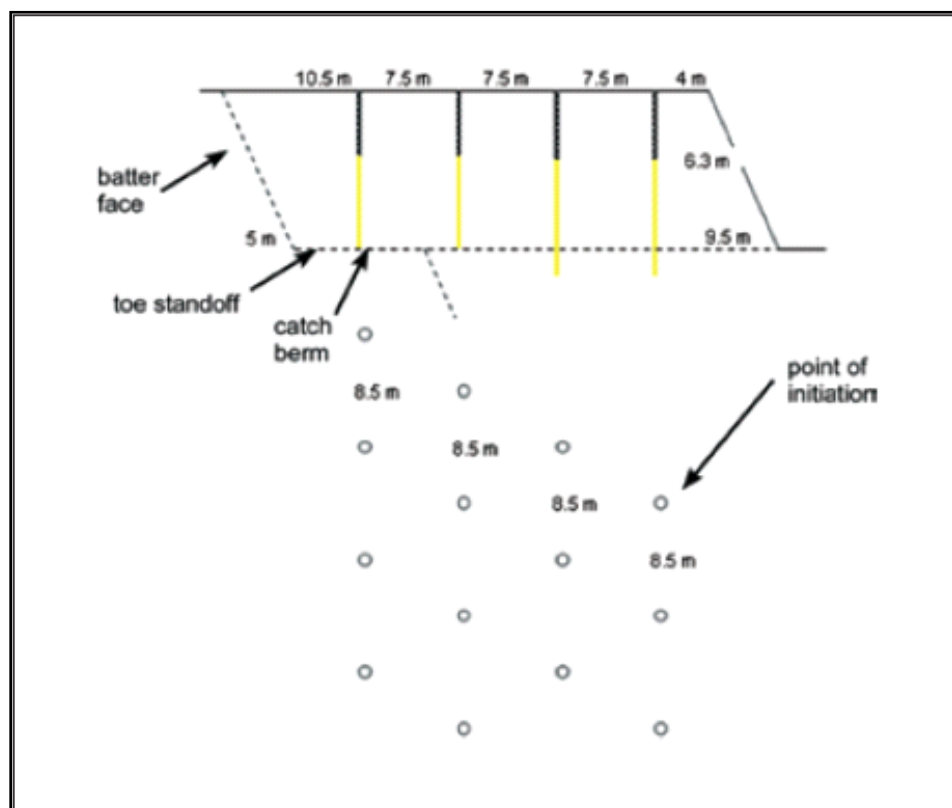


Figure 20: Buffer blasting (Read & Stacey, 2009)

Line drilling

This consists of a line of unloaded holes drilled along the final limit and creates a fracture between the holes when the material is placed in tension during the adjacent blast. In weak material, holes are typically spaced at around 12x hole diameter and in hard rock, 3 to 6x hole diameters. Buffer rows should be drilled at a reduced burden.



- [Blast designs to protect walls](#)



- Page 282, Read and Stacey, Guidelines to open pit slope design, 2009
- Page 302, Hoek and Bray, Rock slope engineering, 1981

LEARNING OUTCOME 7.3.5

CONNECTION 8

Refer to
["LEARNING OUTCOME 7.3.4"](#) on page 233
[Paper 2 Outcome 7](#)
[Paper 3.1 Outcome 7](#)

DESCRIBE, EXPLAIN AND DISCUSS THE METHODOLOGIES AND TYPICAL APPLICATIONS OF EACH TECHNIQUE.



- Page 282, Read and Stacey, Guidelines to open pit slope design, 2009
- Page 302, Hoek and Bray, Rock slope engineering, 1981

LEARNING OUTCOME 7.3.6

CONNECTION 9

Refer to
["LEARNING OUTCOME 7.3.4"](#) on page 233
[Paper 2 Outcome 7](#)
[Paper 3.1 Outcome 7](#)



LIST AND DISCUSS THE ADVANTAGES AND DISADVANTAGES OF THESE TECHNIQUES.

- Page 282, Read and Stacey, Guidelines to open pit slope design, 2009
- Page 302, Hoek and Bray, Rock slope engineering, 1981

LEARNING OUTCOME 7.3.7

CONNECTION 9

Refer to
["LEARNING OUTCOME 7.3.4"](#) on page 233
["DRILLING TECHNIQUES"](#) on page 219



EVALUATE AND DETERMINE BLASTING REQUIREMENTS FOR THE VARIETY OF SURFACE MINING APPLICATIONS MAKING USE OF KNOWLEDGE OF EXPLOSIVES.

- Page 282, Read and Stacey, Guidelines to open pit slope design, 2009
- Page 302, Hoek and Bray, Rock slope engineering, 1981

LEARNING OUTCOME 7.3.8

CONNECTION 9

Refer to
["LEARNING OUTCOME 7.3.4"](#) on page 233
["BLASTING PRACTICES"](#) on page 232

EVALUATE AND DETERMINE APPROPRIATE BLASTING ROUNDS TO SUIT GIVEN CONDITIONS IN SURFACE MINING OPERATIONS.

LEARNING OUTCOME 7.3.9

CONNECTION 10

Refer to
["LEARNING OUTCOME 7.3.4"](#) on page 233
["BLASTING PRACTICES"](#) on page 232

EVALUATE AND DETERMINE APPROPRIATE EXPLOSIVE TYPES TO SUIT GIVEN CONDITIONS IN SURFACE MINING OPERATIONS.

LEARNING OUTCOME 7.3.10

CONNECTION 11

Refer to
["LEARNING OUTCOME 7.3.4"](#) on page 233
["BLASTING PRACTICES"](#) on page 232

EVALUATE AND DETERMINE APPROPRIATE INITIATION TECHNIQUES TO SUIT GIVEN CONDITIONS IN SURFACE MINING OPERATIONS.

CONNECTION 12

Refer to
["LEARNING OUTCOME 7.3.4"](#) on page 233
["BLASTING PRACTICES"](#) on page 232

LEARNING OUTCOME 7.3.11

EVALUATE AND DETERMINE APPROPRIATE DETONATING TECHNIQUES TO SUIT GIVEN CONDITIONS IN SURFACE MINING OPERATIONS.

LEARNING OUTCOME 7.3.12**CONNECTION 13**

Refer to
["LEARNING OUTCOME 7.3.4"](#) on page 233
["BLASTING PRACTICES"](#) on page 232

EVALUATE AND DETERMINE APPROPRIATE BLASTING TECHNIQUES TO SUIT GIVEN CONDITIONS IN SURFACE MINING OPERATIONS.

LEARNING OUTCOME 7.3.13**CONNECTION 14**

Refer to
["LEARNING OUTCOME 7.3.4"](#) on page 233
["BLASTING PRACTICES"](#) on page 232

EVALUATE AND DETERMINE APPROPRIATE SLOPE GEOMETRIES AND DIMENSIONS TO ACHIEVE OPTIMUM BLASTING EFFICIENCIES.

PAPER 3.4: SURFACE MINING (HARD AND SOFT ROCK)

LEARNING OUTCOMES

8. ENVIRONMENTAL EFFECTS

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the possible effects and consequences of given surface mining methods on the following issues:
 - Blast vibration damage to buildings and structures
- Describe, explain and discuss techniques and design tools to limit potential blast vibration damage;
- Describe, explain and discuss the concept of peak particle velocity in this regard;
- Describe, explain and discuss techniques and design tools to limit the effects of air blasts;
- Describe, explain and discuss techniques and design tools to limit the effects of mining on groundwater; and
- Describe, explain and discuss techniques and design tools for:
 - Spoil heaps,
 - Tailings dumps,
 - Long-term rehabilitation of the ground surface,
 - Ultimate closure of the mine.

8. ENVIRONMENTAL EFFECTS

LEARNING OUTCOME 8.1

DESCRIBE, EXPLAIN AND DISCUSS THE POSSIBLE EFFECTS AND CONSEQUENCES OF GIVEN SURFACE MINING METHODS ON THE FOLLOWING ISSUES:

1. Blast vibration damage to buildings and structures.

Explosives are used to break rock through the shockwaves and gases yielded from the explosion. Ground vibration is a natural result from blasting activities. The far field vibrations are inevitable, but undesirable by-products of blasting operations. The shockwave energy that travels beyond the zone of rock breakage is wasted and could cause damage and annoyance. The level or intensity of these far field vibrations is dependent on various factors.



Some of these factors can be controlled to yield desired levels of ground vibration and still produce enough rock breakage energy. Factors influencing ground vibration are:

- the charge mass per delay,
- the delay period, distance from the blast,
- rockmass and
- the geometry of the blast.

These factors are controlled by planned design and proper blast preparation.

- The larger the **charge mass per delay** – not the total mass of the blast – the greater the vibration energy yielded. A certain quantity of holes will detonate within the same time frame or delay and it is the maximum total explosive mass per such delay that will have the greatest influence. All calculations are based on the maximum charge detonating on a specific delay.
- The **distance between the blast and the point of interest**. Ground vibrations attenuate over distance at a rate determined by the mass per delay, timing and geology. Each geological interface that a shockwave encounters will reduce the vibration energy due to reflections of the shockwave. Closer to the blast will yield high levels and further from the blast will yield lower levels.
- The **geology** of the blast medium and surroundings also has influences. High density materials have high shockwave transferability where low density materials have low transferability of the shockwaves. Solid rock, i.e. granite, will yield higher levels of ground vibration than sand for the same distance and charge mass. The precise geology in the path of a shockwave cannot be observed easily, but can be tested for if necessary in typical signature trace studies.

Prediction of ground vibration

When predicting ground vibration and possible decay, a standard accepted mathematical process of scaled distance is used:

$$y = a(D/\sqrt{E})^b$$

Where:

a = Site constant

b = Site constant

D = Distance

E = Explosive mass

In the absence of tested values for a and b, the following factors are normally used and applied for the prediction of ground vibration:

Factors:

a = 1143

b = -1.65

The equation uses the charge mass and distance with two site constants. The site constants are specific to a site where blasting is to be done.



In new opencast operations, a process of testing for the constants is normally done using a signature trace study in order to predict ground vibrations accurately and safely. This is done by firing single holes at the site in question and monitoring the ground vibrations at various distances. The peak particle velocity (PPV) or ground vibration in mm/s is plotted against the scaled distance ($D/\sqrt{E}$) on a log/log graph. From this graph, the slope and y-intercept for the trend line through the points are determined. The site constants a and b are the y-intercept and slope of the trend line, respectively. The analysis of the data will also give an indication of frequency decay over distance.

In the absence of a signature trace study, there are, however, constants used prior to actual tests that will take most of the factors into account. The signature trace process can be applied and will be useful in long-term mining on surface and in sensitive blasting areas.

Limitations on structures

Limitations on ground vibration are in the form of maximum allowable levels for different installations and structures. These levels are normally quoted in millimetres per second, i.e. velocity of the particles.

There are fixed South African criteria for safe ground vibration levels:

- Early day recommendations were as follows:
 - 25 mm/s maximum at private structures if frequency of ground vibration is greater than 10 Hz and
 - 12.5 mm/s where frequency of ground vibration is less than 10 Hz.
- Currently, the United States Bureau of Mines (USBM) criterion for safe blasting is applied where private structures are of concern.
 - This is a process of evaluating the vibration amplitudes and frequency of the vibrations according to set rules for preventing damage.
 - The vibration amplitudes and frequency are then plotted on a graph.
 - The graph indicates two main areas,
 - a. The safe blasting criteria area and
 - b. The unsafe blasting criteria area.
 - When ground vibration is recorded and the amplitude in mm/s is analysed for frequency, it plots this relationship on the USBM graph. If data falls in the lower part of the graph, then the blast was done safely. If the data falls in the upper part of the graph, then the probability of inducing damage to mortar and brick structures increases significantly.

- There is a relationship between amplitude and frequency due to the natural frequencies of structures. This is normally low – below 10 Hz – and therefore the lower the frequency, the lower the allowable amplitude. Higher frequencies allow for higher amplitudes.
- The extra lines on the graph are more detailed for specific types of walls and structure configurations.
- Locally, we are only concerned with the lowest line on the graph. This is a pre-blast analysis, but predictions help us determine expected amplitudes and experience has taught us what frequencies could be expected.
- The USBM graph for safe blasting was developed by the United States Bureau of Mines through research and data accumulated from sources other than their own research.

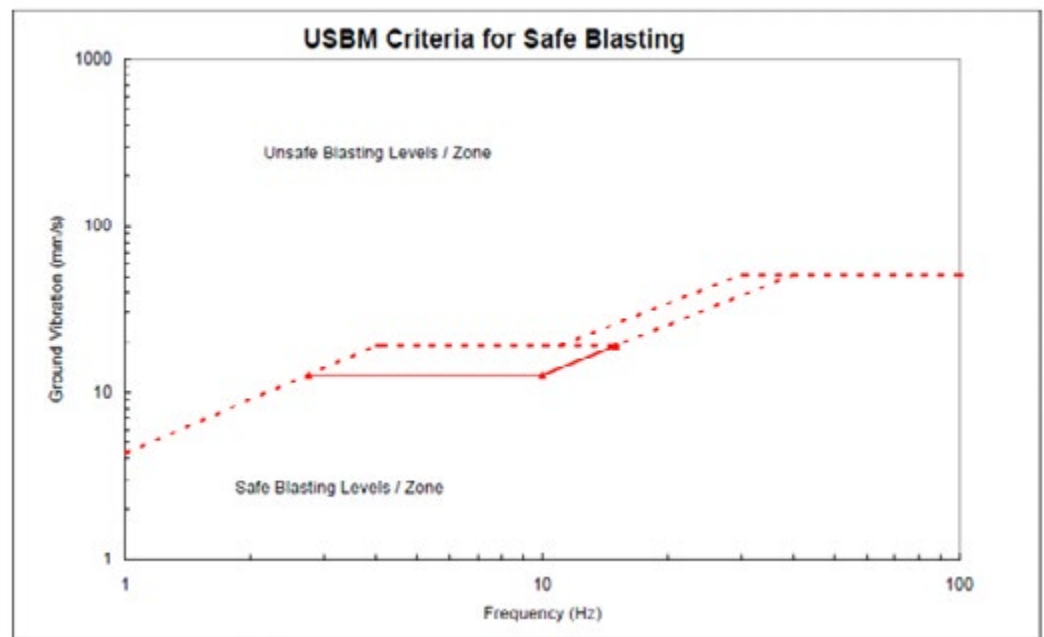


Figure 1: USBM criteria for safe blasting vibrations

Additional limitations that should be considered are as follows. These were determined through research and various institutions:

- National Roads/Tar Roads: 150 mm/s
- Steel pipelines: 50 mm/s
- Electrical Lines: 75 mm/s
- Railway: ~ 150 mm/s
- Concrete aged less than 3 days: 5mm/s
- Concrete after 10 days: 200 mm/s
- Sensitive plant equipment: 12 or 25 mm/s depending on type – some switches could trip at levels less than 25 mm/s

Limitations with regard to human perceptions

A further aspect of ground vibration and frequency of vibration is the human perception.



The legal limit for structures is significantly greater than the comfort zones for people.

Humans and animals are sensitive to ground vibration and the vibration

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PAPER 3.4: CHAPTER 8

of the structures. Research has shown that humans will respond to different levels of ground vibration and at different frequencies. Ground vibration is experienced as "perceptible", "unpleasant" and "intolerable" (only to name three of the five levels tested) at different vibration levels for different frequencies. This is indicative of the human's perceptions of ground vibration and clearly indicates that humans are sensitive to ground vibration. This 'tool' is only a guideline and helps to manage ground vibration and the respective complaints that people could have due to blast-induced ground vibrations.



Humans already perceive ground vibration levels of 4.5 mm/s as unpleasant.

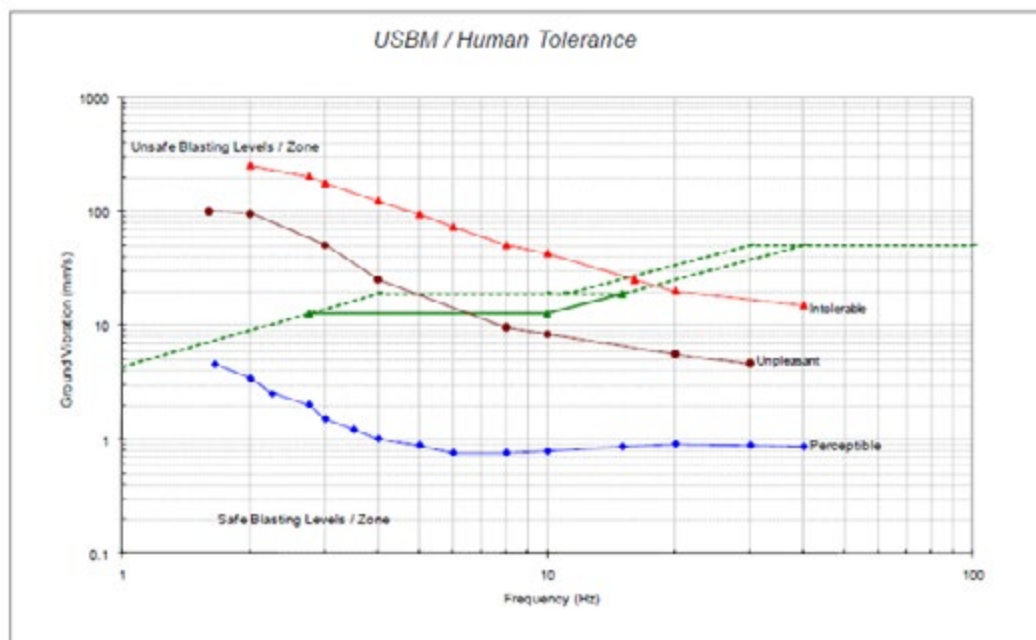


Figure 2: Human perception with regard to vibration levels



- Understanding blast vibrations (presentation courtesy of Ken Eltschlager)
- Measurement of ground vibrations
- Assessment of blasting vibrations
- ISRM Blast vibration monitoring

LEARNING OUTCOME 8.2

CONNECTION 1

Refer to
"LEARNING OUTCOME
8.1" on page 240

DESCRIBE, EXPLAIN AND DISCUSS TECHNIQUES AND DESIGN TOOLS TO LIMIT POTENTIAL BLAST VIBRATION DAMAGE.

LEARNING OUTCOME 8.3

CONNECTION 2

Refer to
"LEARNING OUTCOME
8.1" on page 240

DESCRIBE, EXPLAIN AND DISCUSS THE CONCEPT OF PEAK PARTICLE VELOCITY IN THIS REGARD.

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LEARNING OUTCOME 8.4

CONNECTION 3

Refer to
"LEARNING OUTCOME
8.1" on page 240

DESCRIBE, EXPLAIN AND DISCUSS TECHNIQUES AND DESIGN TOOLS TO LIMIT THE EFFECTS OF AIR BLASTS.

Air blast and prediction

Air blast or air-overpressure is pressure acting and should not be confused with sound that is within audible range (detected by the human ear). Sound is also a build-up from pressure, but is at a completely different frequency to air blast.

Air blast is normally associated with frequency levels less than 20Hz, which is the threshold for hearing. Air blast is the direct result from the blast process although influenced by the final blast layout, timing, stemming, accessories used, covered or not covered etc. all have an influence on the outcome of the result.

The three main causes of air blasts can be observed as:

- Direct rock displacement at the blast; the air pressure pulse (APP),
- Vibrating ground some distance away from the blast; rock pressure pulse (RPP),
- Venting of blast holes or blowouts; the gas release pulse (GRP).

Limitations with regard to air blast

The recommended limit for air blast currently applied in South Africa is 134dB.

This is specifically pertaining to air blast or otherwise known as air-overpressure. This takes into consideration where the public is of concern. However, all attempts should be made to keep air blast levels generated from blasting operations below 120dB, as this will ensure that the minimum amount of disturbance is generated towards the critical areas surrounding the mining area.

Monitored air blast amplitudes up to 135dB are safe for structures, provided the monitoring instrument is sensitive to low frequencies (down to 1Hz).

Level	Description
120dB	Threshold of pain for continuous sound
>130dB	Resonant response of large surfaces (roofs, ceilings). Complaints start
150dB	Some windows break
170dB	Most windows break
180dB	Structural damage

Table 1: Air blast limits (measured at point of interest)

LEARNING OUTCOME 8.5

DESCRIBE, EXPLAIN AND DISCUSS TECHNIQUES AND DESIGN TOOLS TO LIMIT THE EFFECTS OF MINING ON GROUNDWATER.



- Nitrate pollution Bosman
- Groundwater impact risk assessment
- IMWA proceedings – International Mine Water Association
<http://www.proceedings.com/7782.html>
<http://www.imwa.info/imwa-meetings/proceedings/264-proceedings-2012.html>

LEARNING OUTCOME 8.6

DESCRIBE, EXPLAIN AND DISCUSS TECHNIQUES AND DESIGN TOOLS FOR:

- Spoil heaps,
- Tailings dumps,
- Long-term rehabilitation of the ground surface,
- Ultimate closure of the mine.

Spoil heaps and tailings dumps

EXAMPLE

Sub-surface conditions

The sub-surface characteristics described below have been derived from the geological and geotechnical databases in the surrounding area. The immediate soil layer is on average 8.53m thick, with areas where the thickness can be substantial and in the region of 16m. Consequently, it was assumed for the dump design that the soil would be removed and that dump construction would occur with the Calcrete material as foundation.



Detailed descriptions of the type and foundation indicators (bearing capacity and Atterberg Limits) are outside the scope of this exercise.

Rock/Soil	Mean	Std dev	Min	Max
Kalahari Sand	4.72	2.03	1.00	13.00
Soft calcrete	14.57	5.22	2.00	25.00
Hard calcrete	7.88	5.50	0.70	26.00

Table 2: Material thickness

Waste material Properties

The Mohr-Coulomb properties for the waste material are listed below.

Properties	Units	Kalahari sand	Soft Calcrete	Hard Calcrete
ρ	kg/m ³	1900	2190.00	2190.00
c	kPa	0	180.34	492.12
Φ	degrees	34	32.95	43.01

Table 3: Sub-surface rock and soil geotechnical properties

Characterisation

The waste material will consist of an assortment of rocks belonging to the Kalahari and Hotazel Formation. The properties of the different types of waste material were derived using a method that incorporates the following parameters into the accompanying set of equations to determine the waste secant friction angle:

- Angularity measured on a scale of 1-8 with 8 being extreme angularity and 1 low angularity;
- Fines – percentage of fines passing 0.075mm (%);
- UCS – Unconfined compressive strength of the rock (MPa).

Utilising this method, the secant friction angle of the waste material can be derived from

$$\Phi' = a + b\sigma_n^c$$

Where

$$a = 36.43 - 0.267.ANG - 0.172.FINES + 0.756.(C-2) + 0.0459.(UCS-150)$$

$$b = 69.51 + 10.27.ANG + 0.549.FINES - 5.105.(C-2) - 0.408.(UCS-150) - 0.408$$

and

$$c = -0.3974$$

Waste type	ANG	FINES	UCS (MPa)	Density (kg/m ³)	Normal stress (kPa)	a	b	c	Secant friction angle
Hard caltrate	2	30	19.65	2190	1289.034	22.9405	171.5335	-0.3974	32.9
Gravel	4	40	12.56	2190	1289.034	20.36107	200.4562	-0.3974	32.0
Clay	1	60	2.95	1900	1118.34	17.28097	184.5471	-0.3974	28.6
Manganese	7	10	201.44	3729	2194.889	33.38966	137.7332	-0.3974	39.9
Banded Iron-stone	7	10	295.56	3156	1857.622	37.70977	99.22335	-0.3974	42.7

Table 4: Properties for waste material

Selection of the ratings for angularity and fines has been done subjectively.



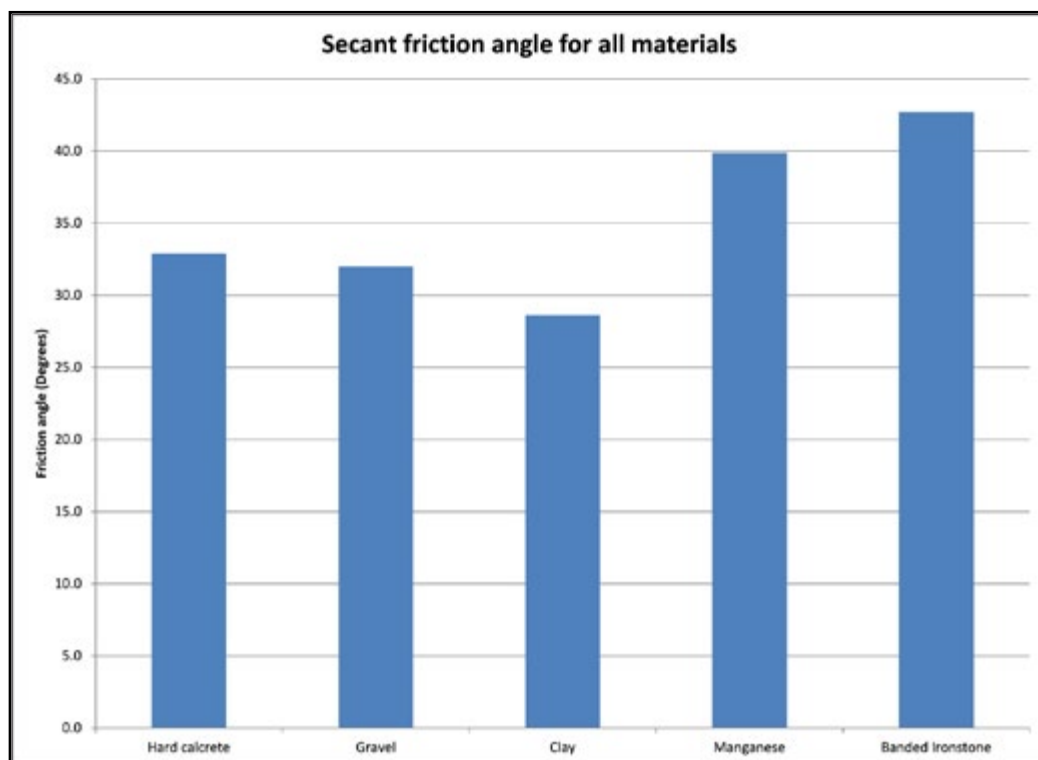


Figure 3: Graphical representation of waste rock friction angles

Validation of slope angles for WRDs

Phase 2

The Rocscience Phase2 software was used to validate slope angles used for the bankable design of the WRDs. The output of software is a stress reduction factor that equates to the slope safety factor (SF), as determined in the shear strength reduction approach applied by this software. The limiting or threshold safety factor used for the WRDs is 1.3 (Table 24), as suggested by Stacey (2002).

Consequences of failure	Examples	Minimum FOS
Not serious	No person-entry	1.2
	Individual benches, small temporary slopes not adjacent to haul roads	1.3
Moderately serious	Any slope of a permanent or semi-permanent nature	1.6
Very serious	Medium-sized and high slopes carrying major haulage roads or underlying permanent mine installations	2.0

Table 5: Threshold Safety Factors for WRDs

Assumptions

The following assumptions have been included into this design process:

- Since a mix of waste material types (BIS and Calcrete) will be provided to the dumps, unsorted dumping of material is assumed during the placement (i.e. placement of a well-mixed waste product).
- Even though all material properties were determined, it was recorded for future use and only Calcrete and BIS were utilised in this design.
- Based on the inclusion of different materials within the dumps and the difficulty of determining a material friction angle for a mix of materials, it was assumed that stability would be governed by the lowest shear strength material, namely Calcrete.

- Due to the aseismic signature of the area, no seismic coefficient was applied to the design, while it was also assumed that the dumps would be remote from the pit and that blast vibrations due to blasting would be negligible.
- At the same time, it was assumed that good water controls will be in place and that saturation of the material will not occur.
- If any other material is added to the waste dumps, this design will be revisited.

Models created

A large number of models were created to test various combinations for stability in terms of FOS, using the material properties as noted in the above sections of this report. The options included the following:

1. To determine the optimum bench face angle:
 - Bench height variations between 10m and 60m (examples are shown in Figure 22 and Figure 23);
 - Bench face angles between 20 and 40° (examples are shown in Figure 22 and Figure 23);
 - Different material types (only Calcrete reported in this document);
2. To determine the optimum dump geometry, 60m final dump heights were simulated with:
 - Constant bench face angles;
 - Bench/lift heights that vary between 10 and 20m and
 - Bench widths/step distances that vary between 3 and 15m.



The maximum dump height of 60m was taken from designs performed on foundation material in this area and was shown to indicate a maximum height at which foundation deformation is seen to increase substantially.

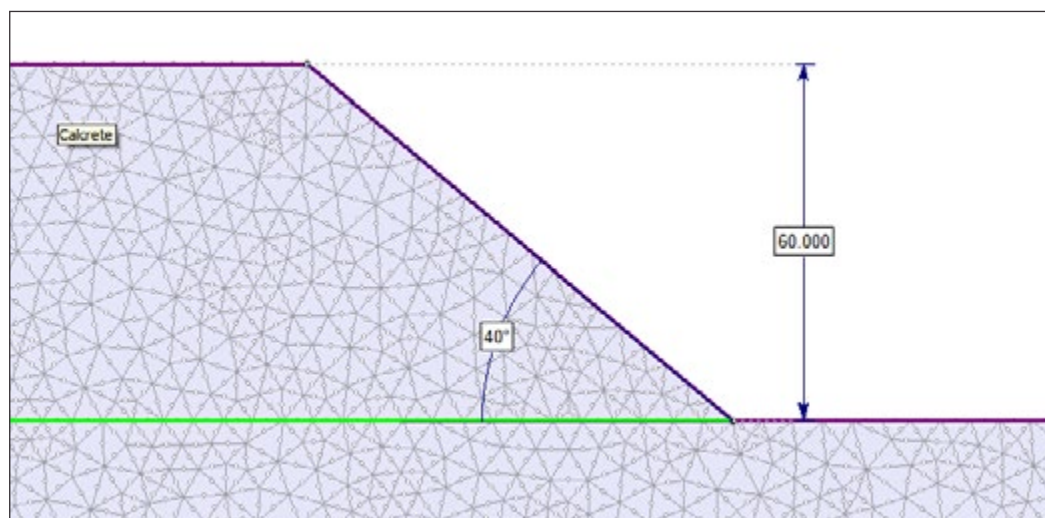


Figure 4: Single bench 60m high at 40° face angle

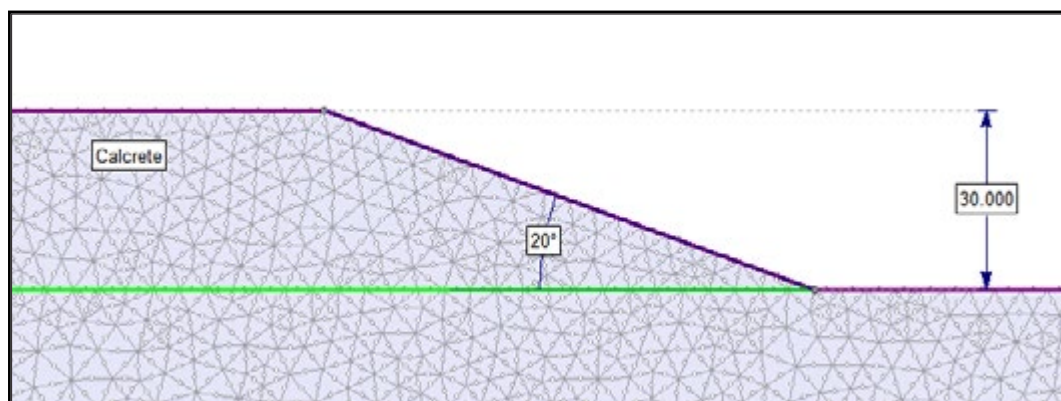


Figure 5: Single bench 30m high at 20° face angle

Results

The results of the investigation are given for:

1. Bench face angle determination:
 - All resulting factors of safety are given in Table 25 with those below the threshold of 1.3, indicated in grey shading;
 - FOS for Calcrete material only are provided for the different bench face angles and lift heights simulated in Figure 24 and Figure 25
2. Dump geometry determination:
 - All resulting factors of safety are provided in Table 25, with those below the threshold of 1.3 indicated in grey shading;
 - FOS for Calcrete material only is provided for the different dump geometries simulated, in Figure 31.

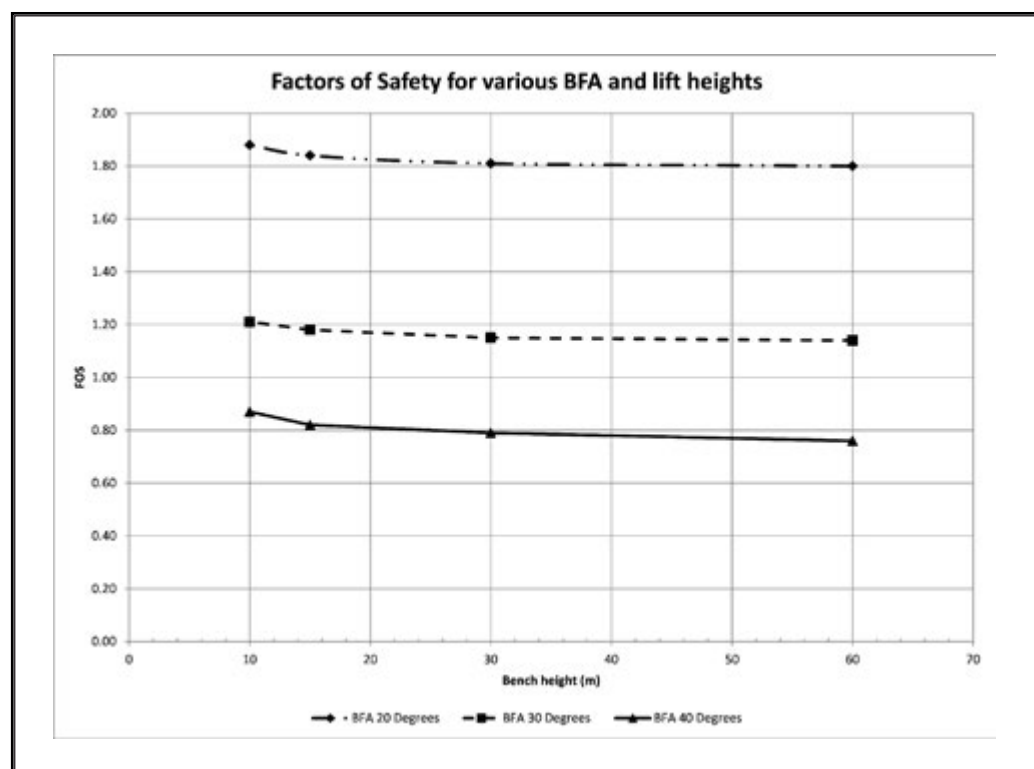
Model			Factor of safety	
Benches	BFA	Height	Calcrete	BIS
1	20°	60	1.80	2.72
		30	1.81	2.79
		15	1.84	3.00
		10	1.88	3.11
Model			Factor of safety	
Benches	BFA	Height	Calcrete	BIS
1	30°	60	1.14	1.70
		30	1.15	1.79
		15	1.18	2.01
		10	1.21	2.10
Model			Factor of safety	
Benches	BFA	Height	Calcrete	BIS
1	40°	60	0.76	1.18
		30	0.79	1.25
		15	0.82	1.42
		10	0.87	1.51

Model		Factor of safety		
Bench	BFA	Height (m)	Calcrete	BIS
1	20°	60	1.80	2.72
		30	1.81	2.79
		15	1.84	3.00
		10	1.88	3.11

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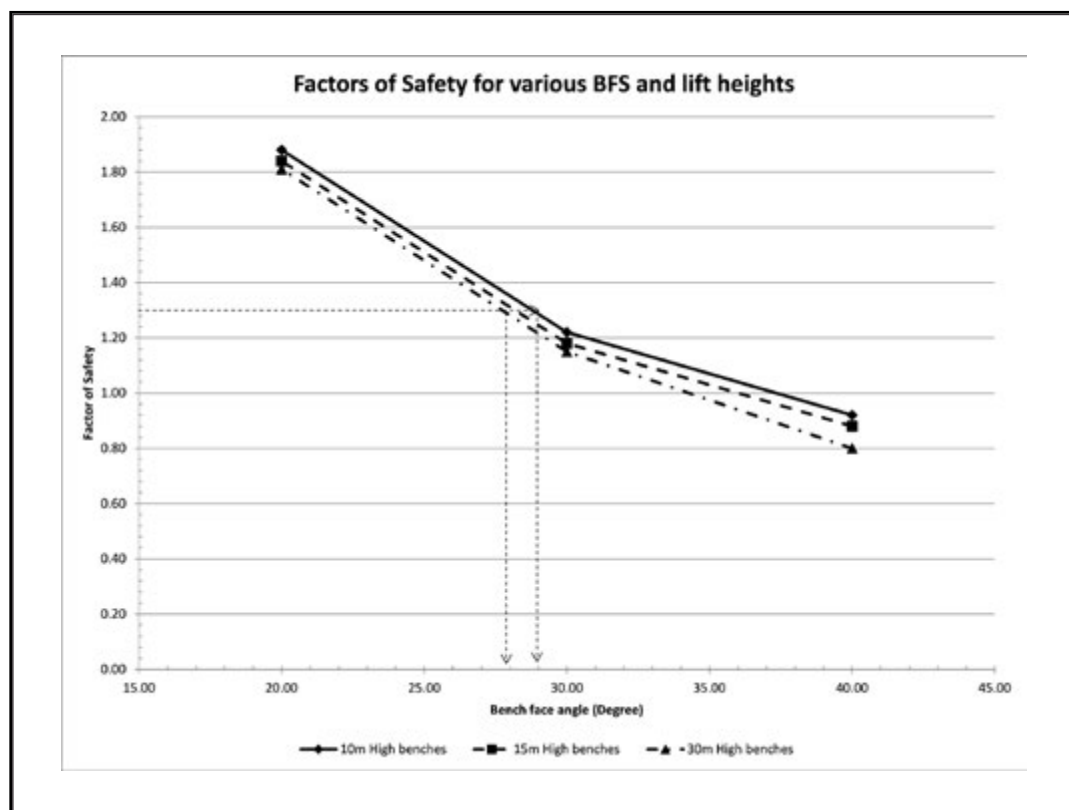
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Model		Factor of safety		
1	30°	60	1.14	1.70
		30	1.15	1.79
		15	1.18	2.01
		10	1.21	2.10
1	40°	60	0.76	1.18
		30	0.79	1.25
		15	0.82	1.42
		10	0.87	1.51

Table 6: Results for bench face angle determination**Figure 6: BFA for different bench heights in Calcrete**
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**Figure 7: Bench face angles at FOS 1.3**

Multiple benches / lifts			
Bench / step width	Bench / lift heights		
	10m Bench height	15m Bench height	20m Bench height
3	1.33	1.32	1.29
5	1.4	1.36	1.31
10	1.47	1.38	1.32
15	1.5	1.39	1.33

Table 7: Results for determination for the dump geometry
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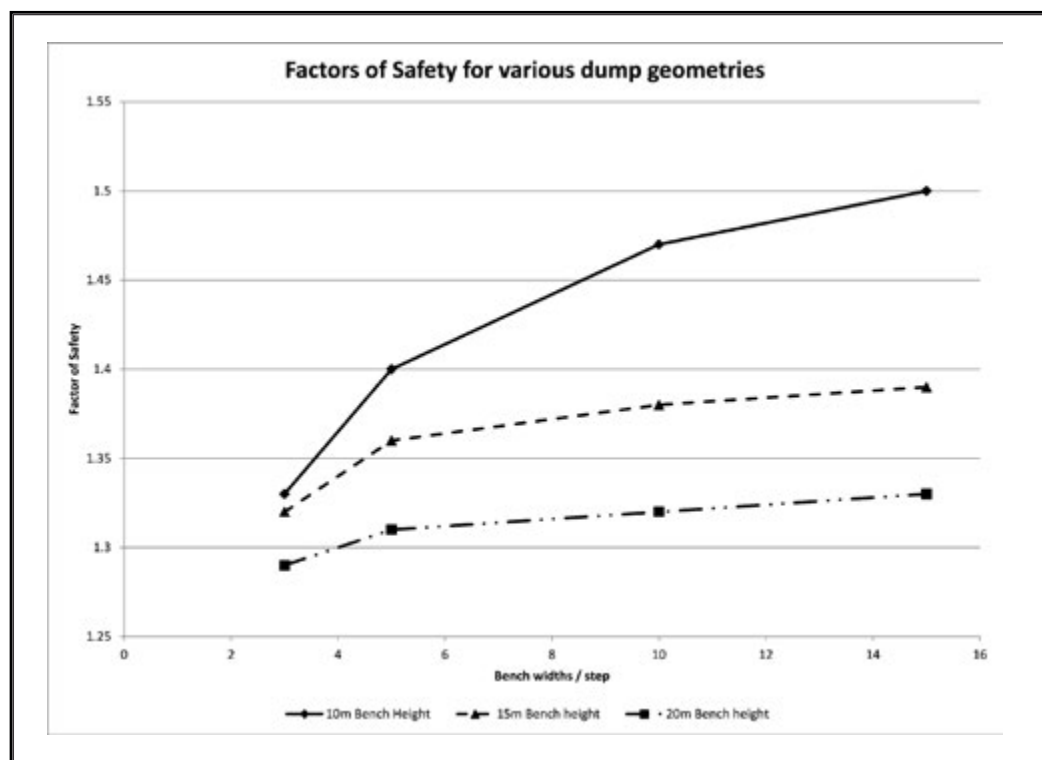


Figure 8: Waste dump stack geometry

Analysis

The results provided above indicate:

- From Figure 24, it is clear that the optimum bench face angles would fall between 20 and 30° as the FOS for 40° bench face angles is well below the acceptable limit of 1.3;
- Figure 25 indicates that for an acceptable FOS of 1.3, the bench face angle for Calcrete waste material should be between 27 and 29°, depending on the acceptable lift height and that at a lift height of 20m, 28° is the maximum bench face angle to be allowed;
- The optimum geometry for a 60m maximum high dump is given in Figure 26, from which it is clear that any lift height beyond the 20m will result in FOS below the limit, while bench widths of 10m provide sufficient flexibility for any placement inaccuracies in final bench heights that may occur.

The final geometry can be given by Figure 9.

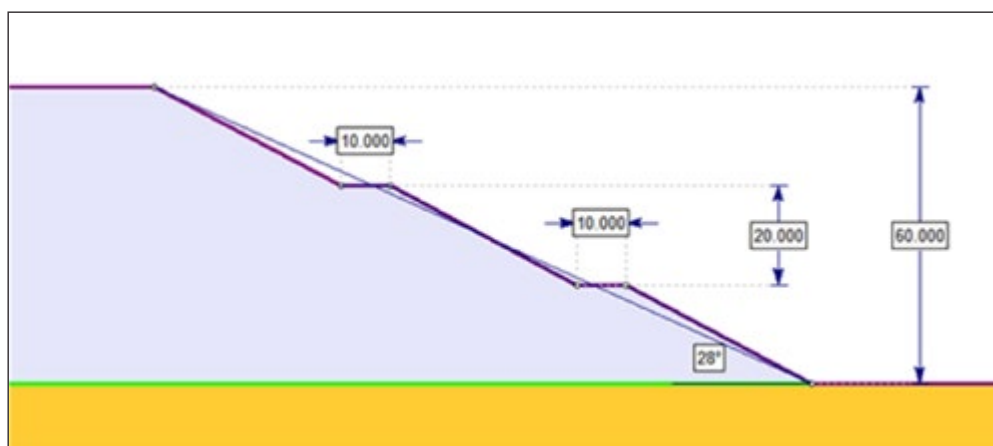


Figure 9: Waste dump geometry

The following water control operating practices are suggested to prevent saturation of the waste dumps:

- Toe drains must be constructed at the bottom of each lift bench and the water directed to appropriate disposal or treatment facilities; and
- Dump surfaces must be developed to provide positive drainage to prevent ponding and infiltration. This is accomplished by maintaining a drainage gradient on the platform so that water drains away from the crest.

It is further required that:

- No travelling is allowed along the toe of the bottom bench;
- No travelling is allowed on any of the berms;
- Monitoring is regularly performed, especially after significant rains;
- Dumping on the top of the waste dumps must be managed such that all materials are well mixed into the waste dump;
- A safety berm (windrow) is to be used as a back stop at all times at the platform crest. The minimum berm height should be one half the height of the highest haul truck tyre.
- Dumping on top of the waste dumps is not allowed within 5m of the crest to protect vehicles from possible failures.
- Waste dumps must not be placed within 30m of surface structures such as buildings, roads, power lines, etc.
- Mining faces must not approach within 50m of spoil dumps

An appropriate monitoring strategy must be developed and implemented for the dumps.

- The most effective being formalised observations of:
 - Excessive surface cracking;
 - Safety berms not in place;
 - Bulging of the dump face;
 - Toe or foundation creep and bulging.
- Survey monitoring of bench levels and bench face angles.

The main purposes of the surveillance of the waste dumps will be:

- To protect the personnel and equipment working on and below the dumps;
- To minimise the risk to infrastructure located below the dumps during the life of the mine;
- To provide early warning of impending failure so that personnel and equipment can be removed from the area at risk; and
- To collect and assess data that will confirm or negate the assumptions made during the design process and allow the design of the dump to be modified during the life of the mine to improve the performance of the dump.



- Stability analysis waste rock dump in high seismic area
- Steepened spoil slopes

Long-term rehabilitation of the ground surface



- [Guidelines for the rehabilitation of mines land \(Coaltech\)](#)

Ultimate closure of the mine



Closure planning should commence during the design phases of the mine to limit the work that must be done at the end of the pit's life and should include the derivation of a closure plan (which could be updated during the mining of the pit).



Mine closure: Includes the whole mine site and refers to removal of buildings and infrastructure, management of remaining fluids (tailings supernatant and heap leach effluent) and reclamation of disturbed land.

Reclamation: Regrading, topsoil replacement and vegetation.

Mine closure is a complex process and should involve a multidisciplinary team to ensure that all facets are evaluated and remedial actions derived. The process should include:

- Site characterisation;
- Geochemical evaluations;
- Surface and groundwater hydrological considerations;
- Access to the pit and
- Pit wall stability.

The process also includes:

- Stakeholder involvement: Mine employees and community;
- Detail planning: Ongoing process of refinement;
- Financial provision: Requires an accurate estimation of mine closure costs;
- Implementation: Identifies accountability;
- Standards: Reaching of targets set;
- Relinquishment: Agreement that the closure has been successful.



- [Strategic framework for Mine Closure \(ANZMEC\)](#)

Pit wall stability is the main focus of the geotechnical engineer and wall stability after mining operations have been ceased can be affected by issues such as dewatering processes that are stopped, increasing pore pressure and decreasing joint shear strengths, unravelling that will occur over time, etc.

The geotechnical stability is therefore influenced by:

- Hydrological changes;
- Weathering and slaking;
- Debris flow;
- Filling in of benches;
- Loss of access into the pit due to instability;
- Loss of surface water controls;

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- Increasing rockfall hazard;
- Stress relief or relaxation;
- Seismicity; and
- Shear strength changes of pit wall materials.



- Page 401,459, Read and Stacey, Guidelines to open pit design, 2009

PAPER 3.4: SURFACE MINING (HARD AND SOFT ROCK)

LEARNING OUTCOMES

9. MINING STRATEGIES IN DIFFICULT CIRCUMSTANCES

The candidate must be able to demonstrate knowledge and understanding of the above subject area by being able to:

- Describe, explain and discuss the geotechnical aspects of dealing with the following difficult circumstances:
 - Mining in major geological structures or disturbances,
 - Mining in localised disturbed, weak or poor ground conditions,
 - Mining in highly weathered conditions,
 - Mining in localised high or anomalous stress situations,
 - Dealing with excessive over break situations,
 - Dealing with excessive back damage situations.

LEARNING OUTCOME 9.1

DESCRIBE, EXPLAIN AND DISCUSS THE GEOTECHNICAL ASPECTS OF DEALING WITH THE FOLLOWING DIFFICULT CIRCUMSTANCES:

- Mining in major geological structures or disturbances,
- Mining in localised disturbed, weak or poor ground conditions,
- Mining in highly weathered conditions,
- Mining in localised high or anomalous stress situations,
- Dealing with excessive over break situations,
- Dealing with excessive back damage situations.

Mining in major geological structures or disturbances

Major geological structures or disturbances such as shear zones normally provide continuous (persistent) and relatively smooth contact planes into the slope walls, along which shear failure could occur. Since the scale of failure on these structures is potentially larger than bench scale, failure analyses should take special notice of the presence of these structures. The same methods discussed in the design chapters of this guideline apply and should be used to estimate the stability of these structures in different stack/slope geometries and layouts.

Mining practices should install monitoring devices around major structures identified within the pit walls, so that displacements can be identified timeously and the necessary precautionary actions taken. It is also prudent to consider the installation of support to stabilise specific structures when potential failure is identified during the design stage.



- Page 313, 237, Read and Stacey, Guidelines for open pit slope design, 2009

Mining in localised disturbed, weak or poor ground conditions

It must be acknowledged that adequate excavation and scaling of batter faces (and selection of the mining equipment to be used to achieve the desired standards) are critical elements for the achievement and maintenance of safe slopes in all open pit mines. 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 surfaces so that scaling is not generally required.

In strong rocks, drilling and blasting are required to fragment the rock-mass prior to the final preparation of the slope. Again, care should be exercised to prevent over digging of the batter face, particularly where there is blast damage or fractured rock. Large equipment, primarily meant for loading blasted rock, should not be used for slope construction because such equipment could cause excessive damage to the batter face. Scaling of the batter crest and face following the excavation is an important component of the implementation of the design. Scaling is intended to remove loose blocks and slabs that may form rockfalls or small failures. Scaling also helps preserve the catch capacity of berms required to retain loose rock material drilling from above.

The debris accumulated at the toe of the batter after the scaling should be removed before the access to the toe is lost. This is necessary to maintain adequate catchment volume on the safety berm.

Open pit mining through underground workings presents a number of potential hazards that must be accounted for in the mine design and during mining. The steps involved in the mitigation of relevant potential safety hazards include:

- Review of available plans, sections and other documentation showing the existing underground mine voids.
- Confirmation of the extent of the voids identified from the existing records, and if no records exist, definition of the extent of the mine voids using probe drilling and/or remote sensing techniques.
- Determination of the status of mine voids, i.e. whether they are open, backfilled or partially collapsed, or water filled.
- Establishing a suite of operating procedures for mining near and through underground voids that matches with production requirements, covering safe approach and access for personnel and equipment, blasting strategies, infill/backfill of voids, barricading procedures, and general reporting procedures for all possible safety issues.
- Definition of the minimum pit floor pillar thickness, for a given void span, such that mining equipment and personnel can safely traverse during normal mining operations.
- Determination of the likely stability of ground at the edges of underground voids and derive the positioning of safety barricades to minimise the risk to personnel or equipment working near mine voids – particularly near unfilled stopes
- Determination of the safe thickness of 'rib' pillars left between open pit walls and underground workings to ensure continued stability of the pit walls.
- Signoff procedures to ensure all aspects of void and safe access assessment have been followed and match well with existing data/assumptions.

It is the responsibility of the mine operator to ensure that safe working procedures, which address each of these issues, are appropriate for the risks at each mine site, and are implemented rigorously.



- Page 279, Read and Stacey, Guidelines for open pit slope design, 2009

Mining in highly weathered conditions

Weathered rock material, taken to its extreme, approaches the characteristics of soil. Failure under these conditions would therefore be governed by the shear strength of the 'soil-like' material and circular failure mechanisms should be investigated as indicated in the design sectors of this guideline.

Generally, weathered material is mined at lower bench face angles, with sufficient berms widths to act as 'catch berms' should limited failures occur and to prevent the collapse of material to lower benches. The presence and control of water are critical as it significantly reduces the shear strength of this material, resulting in failures at relatively low slope angles.

Mining in localised high or anomalous stress situations

It is known that convex shaped walls (rock 'noses') are potentially unstable due to the lack of confinement within this convex shape and that straight or concave shaped walls are more stable based on the lateral confinement that exists in the walls. In most cases, the existence of the actual state of stress is ignored in pit wall design, especially also since limited equilibrium models are based on gravity loading only and exclude the impact of lateral stresses. Even when using numerical models, the lateral (horizontal) stress is mostly determined as a factor of the vertical stress. The exclusion of a detailed look at the impact of a large horizontal stress on slope stability appears acceptable in smaller slopes, but when slopes become large, this impact should be quantified.

Two- and three-dimensional numerical modelling (Read & Stacey, 2009) indicated the impact of a changing stress field on stress levels and displacement in pit walls and indicated the following:

- Stress levels can be raised in certain areas of a pit, as a result of the stress field and pit geometry, causing increased displacements in the same areas;
- A decrease in the k-ratio (results in:
 - a decrease in horizontal stress levels along pit bottom;
- An increase in k-ratio:
 - increases potential for increased displacements along the pit bottom due to high 'abutment' stress levels caused by the high horizontal stress component;
 - shows substantial larger areas of 'failure' in pit walls;
- It should be noted that:
 - material strengths must be low enough to be affected by the stress levels encountered around the pit, for stress changes to effect the conditions/stability of the pit walls;
 - only at k-ratios exceeding 2 does the impact appear to be significant and at a level where the impact of other factors on stability is outweighed by the *in situ* stress field;
- Methods such as SSR (shear strength reduction) incorporates the horizontal stress field directly and could indicate larger failed volumes than other methods due to this fact.



- Page 437, Read and Stacey, Guidelines for open pit slope design, 2009

Dealing with excessive over break situations/excessive back damage situations

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

- Loose rock on slope faces and batter crests.
- 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, which can destroy safety berms leading to a reduction in their effectiveness as a means of retention of loose rock pieces falling from above.
- A cumulative reduction in the strength of rockmass in which the

slope is developed. In particular, the shear strength of the structural defects will be reduced.

Consequently, the mine operator must develop and implement standardised drilling and blasting practices that have been based on well-founded and recognised blast design procedures, and that are appropriate to the ground conditions at the mine site.

When developing standardised drilling and blasting practices, the mine operator must take into account all factors that control the level of slope damage caused by blasting; including:

- Geotechnical characteristics of the rockmass: dynamic compressive and tensile strength and elastic properties of rock material, structural defect properties such as orientation, persistence, spacing, roughness, aperture size, infilling material and shear strength. Variations of these characteristics significantly influence the effectiveness of the blast as well as the extent of unnecessary damage to the slope.
- The presence of groundwater in the rockmass: water saturated rockmasses transmit shock energy more efficiently than dry rockmasses do. The vibration and pressure levels do not attenuate as quickly as in dry rockmass and the damage envelop is likely to be greater. Therefore, there is greater susceptibility to slope damage.
- Blast pattern parameters: amount of blast energy and rate of release. These depend on the type and mass of explosives, blast hole diameter, burden, spacing, sub-grade depth, blast hole orientation, stemming, initiation sequence and delay times.
- Static stability of the pit slopes: the level of static stability of the slope. The less stable a slope under static loading conditions, the more prone it will be to failure under dynamic loading during blasting.

Examples of measures commonly used to control blast-induced slope damage include:

- Buffer blasting.
- Trim blasting.
- Pre-split or mid-split blasting.
- Post-split blasting.
- Line drilling.
- Air decking.
- Electronic delays.

It is essential, when designing site-specific controlled blasting techniques, to understand that each of these techniques has advantages and disadvantages depending on the site-specific rockmass conditions and the slope design.



- Page 282, Hoek and Bray, Rock slope engineering, 1981