MANAGING THE GEOTECHNICAL RISK ASSOCIATED WITH HIGH AND LOW WALLS AT ANGLO COAL'S OPEN PIT MINES.

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SYNOPSIS

Anglo Coal South Africa mines coal for both the domestic and export market using open cast and strip mining methods.
To establish a mine, a process is set in place to gather ever increasing amounts of geological and metallurgical data to confirm a proven reserve. Increasingly, geotechnical data are also included in this process to confirm that reserve is easily and safely mineable.

The mine design process is an iterative one using a combination of numerical modelling and empirical data to arrive at a mining layout that is both, practical, productive and safe.

In South Africa it is a legal requirement to compile a code of practice to combat rock fall and slope instability accidents and these have to be revised annually, reinforcing the iterative process of continual improvement.

To ensure best practise occurs, all Anglo Coal operations are subjected to annual 2nd party audits and ad hoc 3rd party audit by independent consultants.

This paper attempts to explain the process described above in a concise, but understandable manner.

1.0 GEOLOGICAL SETTING

The Ecca sediments date from the Permian period and the coal deposits were formed in glaciated valleys on a basement of Dolomite, Ryolite or Granophyre rock types.

The sediments overlying the coal deposits are typically flat lying and multiple bedded. The sediments consist of mudstones, shales and sandstones and are generally capable of forming stable highwalls given the time that they must stand up for.

Anglo Coal extracts coal from the Witbank, Highveld and Vereeniging coalfields. The Witbank coalfields contain five seams numbered from the base upwards, 1 to 5 Seam; Highveld coalfield the 2 and 4 Seam and the Vereening area the seams are described as Top, Middle and Bottom seams.

Coal deposited over the basement Dolomite formation display very erratic dips, as contemporaneous subsidence occurred in some instances over sinkholes that were forming, resulting in local thickening of the coal deposit and resulting in strata that dips toward the centre of the sinkhole.

Most of the seams have been affected by Dolerite intrusions in the form of dykes and sills, resulting in local burning and devolatilisation.

2. STRIP MINING

An ideal strip mine has a cut length from 2.0km to 5.0km and is easily identified by the type of mining equipment employed when compared to conventionally known open pit mining methods. The definition of strip mining used by Anglo Coal is *a mining method characterised by a moving void with continuous backfilling.*

The stability benches are by definition short life, typically between six to twelve months. The intact side of the void is termed to the *highwall* and the disturbed dumped material is termed the *lowwall*, both wall types have their unique stability problems. At the extremities of the cuts or mines, an end wall is often created which could have a life of many years.

Access into the cuts is via ramps from the haul roads and may be positioned in the high wall or the low wall, both of which present unique stability problems.

To further complicate the issue of strip mining, Anglo Coal has pioneered the open cast mining of previously mined areas by the bord and pillar mining method. This type of mining usually results in spontaneous combustion and as a result has to be treated in a certain way to minimise the associated risks.

3. MINING METHODS AND EQUIPMENT

As mentioned above in the definition, the mining method results in continuous backfilling of the mined void, which also facilitates the continuous rehabilitation of the mined area and the placing of top soil onto levelled spoils.
Once a steady state of mining is established the mining can typically follow the following steps:

- Pre-strip top soil (remove by truck and shovel);
- Strip overburden to base of soft weathering (remove by truck and shovel or dragline);
- Drill and blast highwall pre-split;
- Drill and blast hard interburden (remove by dragline) exposing coal;
- Drill and blast coal (remove by truck and shovel);

Where mining is taking place over previously mined bord and pillar workings, the highwall is blasted in two cuts ahead of where mining is taking place, this is termed *buffer blasting*. The Anglo Coal definition of “buffer blasting” for stability requirements is *to affect a controlled collapse of the underground workings thus creating a stable pad for mining equipment and a stable highwall face where the risk of uncontrolled failure is minimised or eliminated. In addition the spontaneous combustion risk is reduced by minimising airflow into the old underground workings.*

4. GEOTECHNICAL DATA REQUIREMENTS

Anglo Coal South Africa has over the years implemented various controls to ensure the likelihood of surprises is minimised, to this end the following compliance guidelines has been formulated.

The guideline draws heavily on a paper "A Reporting Framework for Geotechnical Classification of Mining Projects" published by Snowdens (Australia) in 2004; but makes cross references to the SAMREC code and the AAC Plc project code comparisons.

Comparison between definitions based on the SAMREC and AAC Plc. Codes and suggested Geotechnical Framework after Haile et al 2004.

SAMREC CODE, boreholes required.	Inferred <1/100 Ha.	Indicated >4/100 Ha.	Measured >8/100 Ha.	Proven Reserve
AAC Plc	Class 0	Class 1	Class 2	Class 3 + Optimisation
Geotechnical Data Type	Implied	Qualified	Justified	Verified
Suggested % of Boreholes logged/tested	100%	25%	12.5%	Infill as required.
General requirements and geotechnical model reliability.	No site specific geotechnical data necessary	Project specific data are broadly representative of the main geotechnical domains, although local variability or continuity cannot be reliably accounted for	Project-specific data are of sufficient spatial distribution (density) to identify geotechnical domains and to demonstrate continuity and variability of geotechnical properties within each domain	Site-specific data are derived from local in-situ rock mass
Geological Model				
Stratigraphic boundaries	Inferred from regional geology	Reasonable knowledge of major units and	Well constrained in the vicinity of	Mapped in the field

		geometry	the mine excavations and infrastructure	
Weathering/alteration boundaries	Inferred from regional geology	Based on Geology model	Well defined grading of weathering and local variability	Mapped in the field
Major structural features	Inferred from regional geology	Major 'dislocations' interpreted	Drilling sufficient to be well constrained in continuity, dip and dip direction	Mapped in the field
Defect data				
Orientation	Inferred from regional geology	Orientation inferred from geological model	Dip and dip direction statistical data from drill holes	In-situ measurement of dip and dip direction from excavation mapping
Surface characteristics	Estimated on precedent experience	Estimated on precedent experience	Statistical estimates from core logging from all defect sets. Laboratory shear strength testing of critical defects	Statistical estimates from in-situ measurements laboratory sheer strength testing of critical defects
Volumetric distribution (continuity and spacing)	Estimated on precedent experience	Estimated on precedent experience	Estimated on precedent experience	Persistence and spacing measurements
Stress regime				
Principal stress field	Estimated on precedent experience	Mean regional trend	Local magnitude and orientation based on local experience or modelling	Measured or inferred from in-situ performance

Seismicity/earthquake	Based on general experience	Based on general experience	Based on general experience	In-situ experience
Geotechnical model/ Domains	Based on geology model	Based on geology model	Based on geotechnical data	Based on in-situ data, sonic probe etc
Hydrogeological model	Based on general experience	Based on general experience	Hydro geological study	Local observations

DEFINITIONS

- **Implied –** Design recommendations are typically based on broad industry experience.
- **Qualified –** Design recommendations are typically based on a combination of empirical guidelines and broad industry experience.
- **Justified –** Design recommendations are justified by rigorous analyses, which account for the measured intrinsic and/or extrinsic variability in the geotechnical characteristics.
- **Verified –** Design recommendations are based on site-specific experience and analysis of *in situ* characteristics which are probably derived by back analysis of local excavation performance.

	Opencast	**High Extraction**	**Bord & Pillar**
Concept/Scoping		Implied	Implied
Pre-feasibility	Implied	Qualified	Implied
Feasibility	Implied/Qualified	Justified	Qualified/Justified
Operating Mine	Justified	Verified	

Table above indicates a comparison various mining methods, the progress status of the project/mine, and the required confidence and implies that the risks associated with a strip mine are lower than for other mining methods.

5. GEOTECHNICAL DATABASE

As indicated above, selected geological bore holes are geotechnically logged and representative samples taken for testing. Typical tests are unconfined compressive , tensile and shear strength properties are determined. This information is often of more use for blast design than for slope stability design.

Typical values collected to date are listed in the table below:

Material	**Range of values determined**			
	UCS Mpa	Tangent E@50%	Possion Ratio	Remarks
Sandstone	38 – 123	7.1 – 34.1	0.27 – 0.78	Easy to collect undisturbed

				samples.
Shale	36 -83	6.3 -13.3	0.25 – 0.26	Difficult to collect in the field from exploration holes.
Mudstone	35 -46	8.3 – 10.6	0.2 – 0.22	: :
Soil	Na	Na	Na	Very difficult to collect undisturbed samples in the field.

No failures through intact material have ever been observed in the South African strip mines although large failures have been observed and reported along bedding that dips into the face on angles as low as 7 degrees.
The full implication of variation in rock strengths to the design of walls and slopes is not yet fully understood, but the role of weak materials always appear to dominate observed instabilities.

6. DESIGN METHODS

Design of strip mines revolves around the suit of equipment used in the mining process, of which the dragline dominates the whole process as it is the unique piece of equipment in the mining fleet.

Key characteristics of a dragline are its mass, the reach of the boom, its ability to "chop down", its slow speed of movement (walking) and its ability to move, on average, 42000 tonnes per day, depending on bucket and machine size.

Although the dragline prefers to walk in long straight lines, it is also versatile in forming its own extended bench and re-positioning itself in a more productive position. Currently in the South African operations of Anglo Coal there is a desire to construct low wall benches such that productivity can be further enhanced.

Once a cut direction is established, it is very difficult to change it. Vertical surface exploration boreholes yield minimum geotechnical detail other than lithological rock type and bedding intensity. The mining lease boundaries are usually controlled by the position of a farm boundary fence, which subsequently controls the position and direction of the initial box cut, and all subsequent mining cuts.

6.1 Numerical modelling

Anglo Coal South Africa has recently developed design charts for all its open pit operations after T.Ranganasamy which are the process of incorporation into the Codes of Practice.

6.1.1 Choice of modelling suite

The FLAC Slope programme (FSP) was chosen for the analysis of FOS due to its ability:

- To adequately represent both rock and soil materials
- Easily set-up models and incorporate parametric studies
- To be driven by Windows drop down menus rather than command driven
- To naturally define failure surfaces
- To be kinematically feasible

6.1.2 Model set-up

Models were set-up to examine the influence of changing batters, soil thickness, surcharge-loading (spoil loading), coal dip angles and faulting on strip mine stability using the FOS as a measure of stability (Figure 1). Due to the limitations of FLAC/Slope in representing multiple discontinuities, 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.

The inherent stability of spoil piles was examined with FSP as a separate exercise using variations in material types and angles of repose.

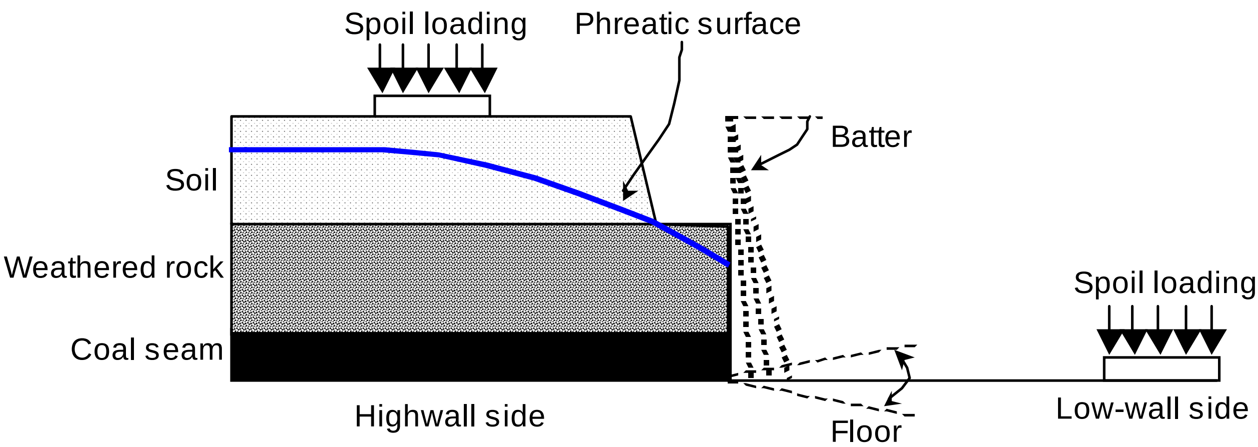


Figure 1 ***Schematic representation of aspects modelled***

6.1.3 Modelling methodology

Figure 2 shows the modelling process divided into primary investigative parameters, modelled ranges and variables that influence the resulting FOS.

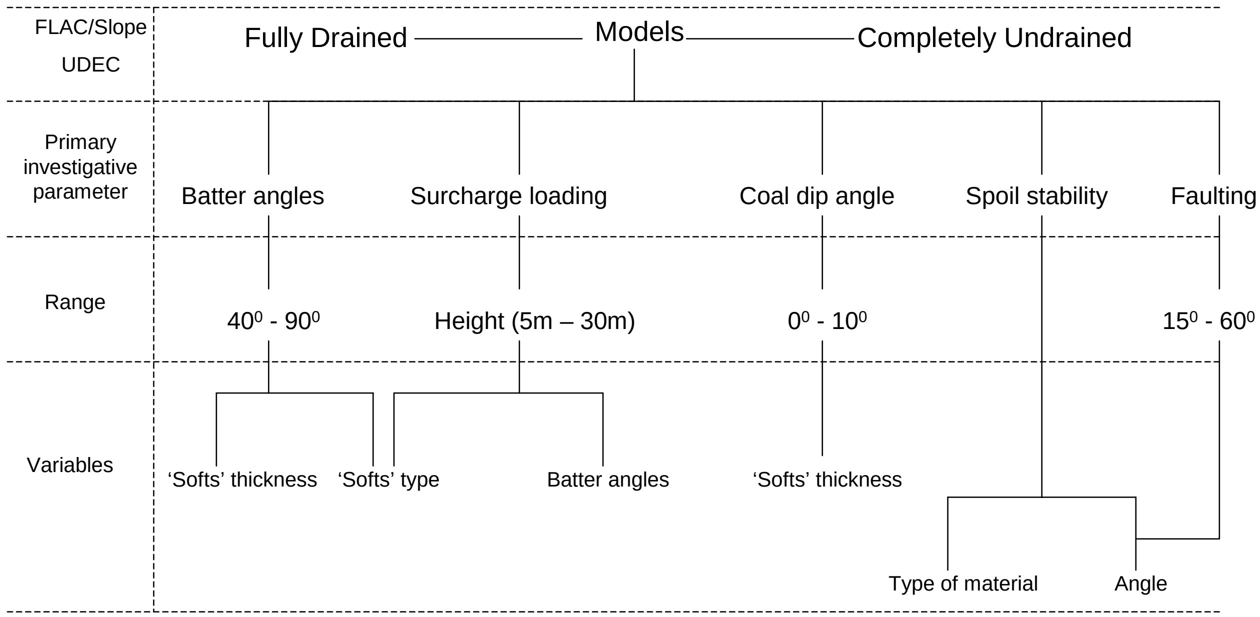


Figure 2 Process flow chart of parameterised study

An interface (slip surface) was used to define the top contact of the coal seam with either weathered rock or thick soil. The interface was assigned a cohesion value of 10 kPa and a friction angle of 30^0.

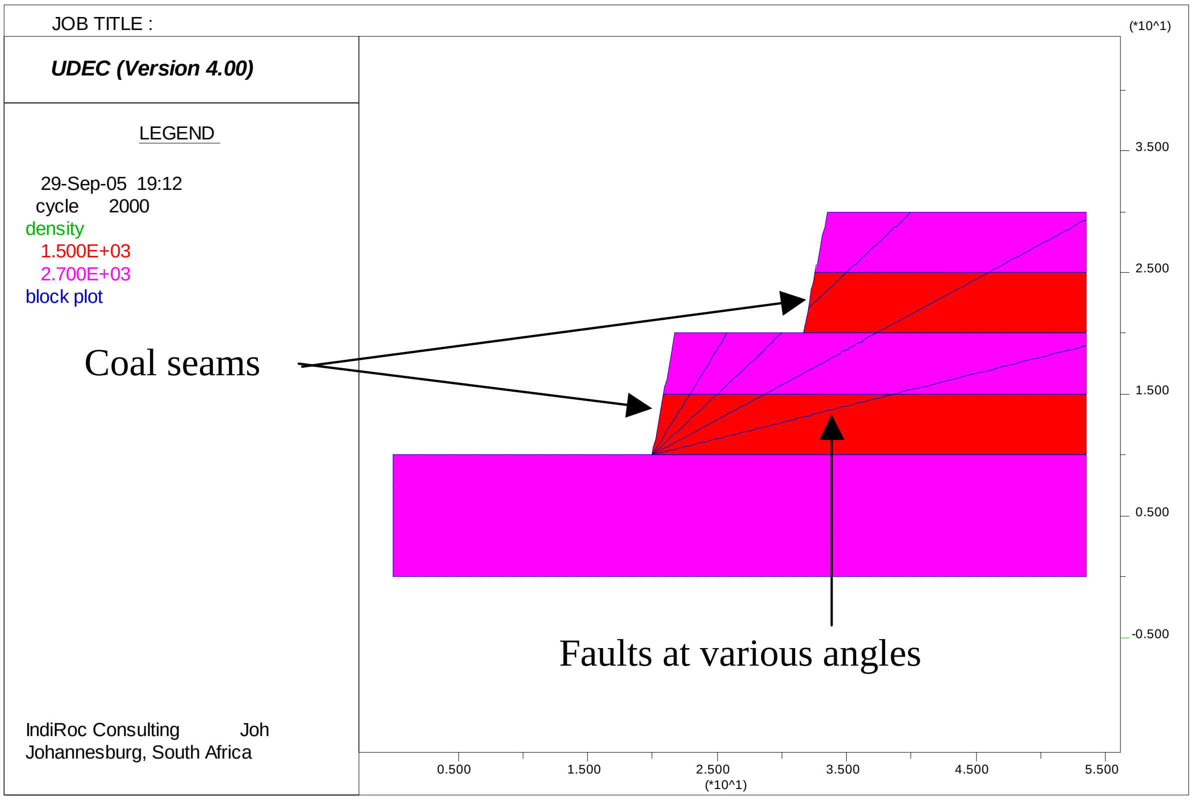


Figure 3 Modelled fault geometries in a double bench slope

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:

$$\tau = c + \sigma_n \tan\phi ,$$

Where c is the cohesion σ_n the normal stress acting on the plane and ϕ the friction angle of the plane.

The FOS was calculated using the following equation:

$$FOS = \frac{\tau_{strength}}{\tau_{stress}} ,$$

Where the shear stress acting along the plane was taken as the maximum and the shear strength, the minimum.

6.1.4 Spoil stability

The stability of spoils was assessed using the FOS resulting from changes to the angle and material that constitutes the spoils (Figure 4). The thin outer edges of the spoils were excluded from the calculations to focus the analysis on the potential for large scale rather than small scale spoil collapses.

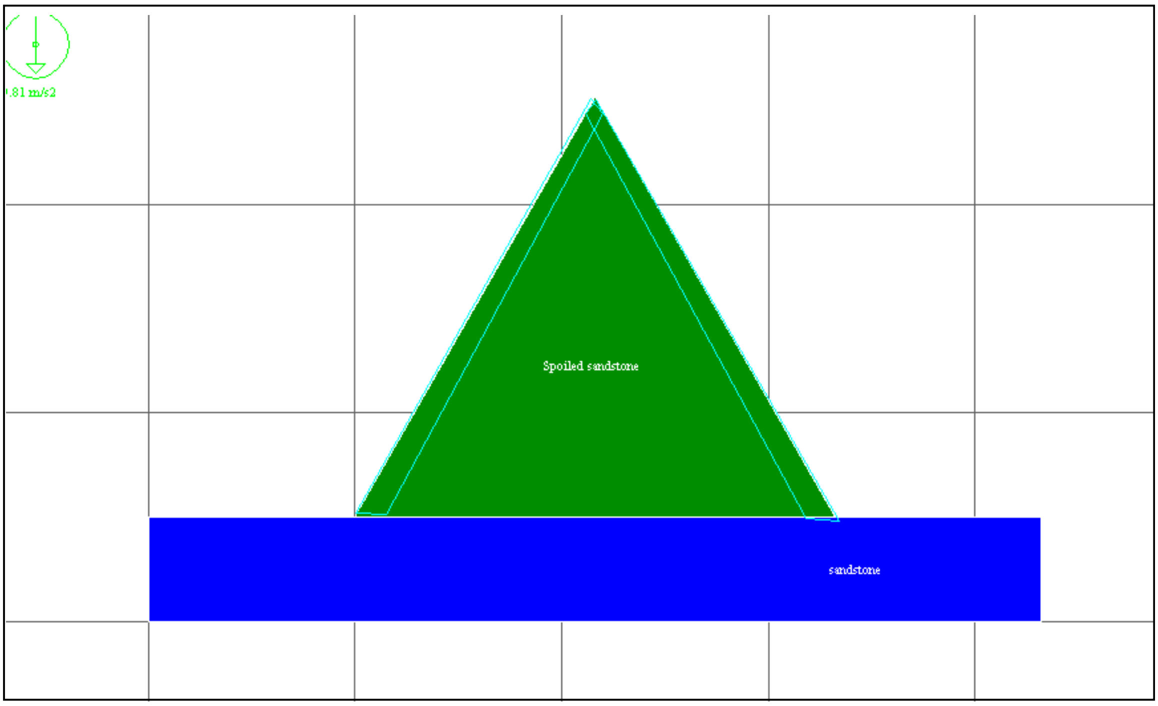


Figure 4 Simulation of spoils

6.1.5 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:

$$C^{trial} = \frac{1}{F^{trial}} c$$

$$\phi^{trial} = \arctan\left(\frac{1}{F^{trail}} \tan\phi \right)$$

A series of simulations are made using trail values of the factor F^{trail} to reduce the cohesion, c, and friction angle, , 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.

6.2 Operating the design charts

6.2.1 Primary functions and selection of FOS

The charts have been designed to enable the user(s) to select appropriate:

- Batter angles or pushback angles when dealing primarily with thick soft material of variable types
- Stopping distances for highwalls so that spoil piles or topographical highs do not influence the stability of strip slopes
- Thickness of soft unconsolidated overburden to be stripped prior to establishing bench faces in more competent material
- FOS based on the top coal contact dip angle
- Support and management measures should adversely orientated geological features daylight in the strip slopes
- Spoil pile angles based on the predominant material that constitutes the pile

The target audience for the design charts are:

- Rock Engineers
- Geologists
- Pit foremen and overseers
- Geotechnical Engineers
- Senior colliery managers

6.2.2 Guide to using the charts

The user upfront will have to make the following decisions prior to using the charts:

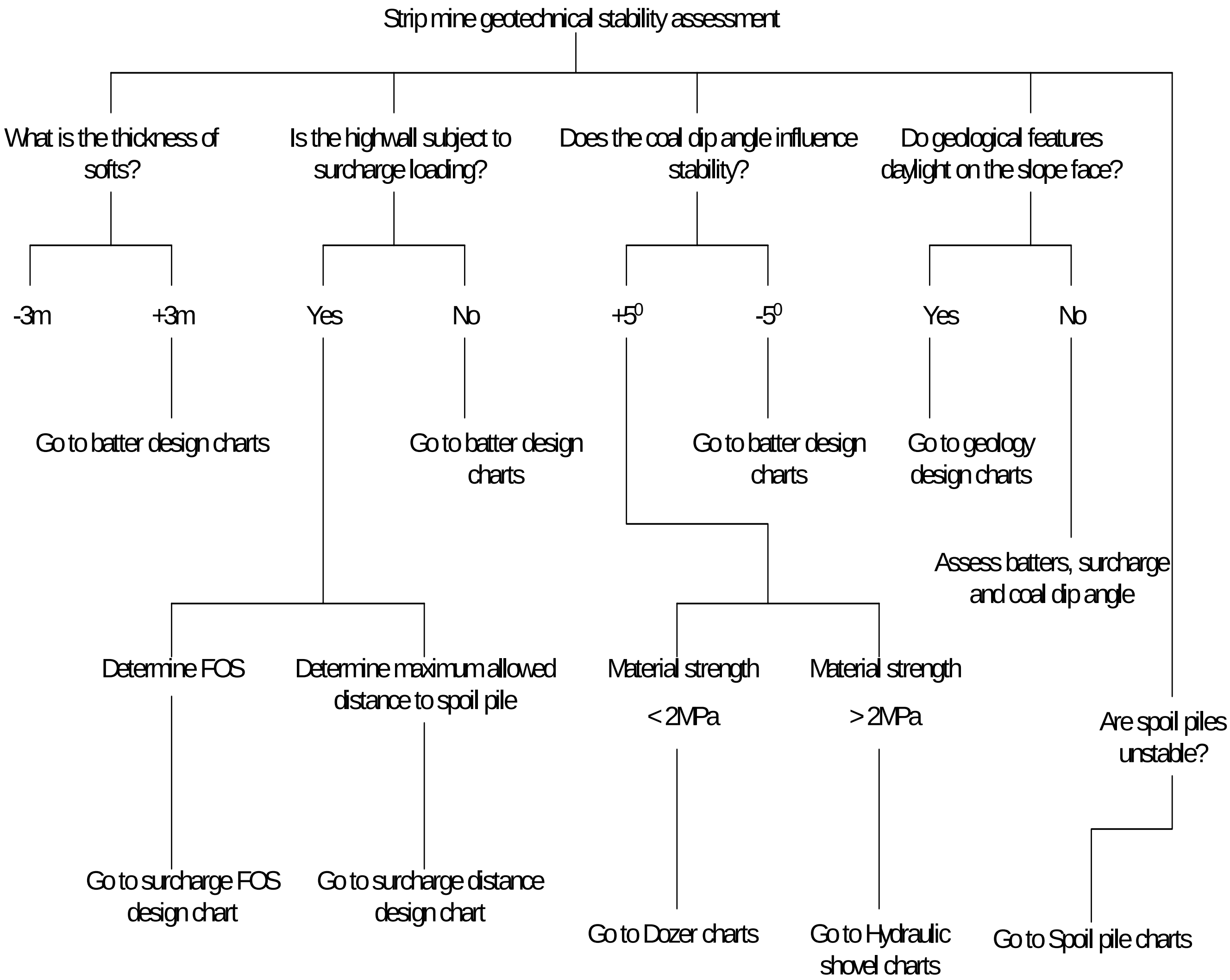
What aspect of strip mine stability is to be resolved?

  - Batter or pushback angles
  - Surcharge loading
  - Variable coal dip angles
  - Problems related with geological features daylighting in the slope
  - Spoil pile stability

- The water infiltration into the slope must be assessed and either of the following batch of charts related to the aspect being assessed should be used:
  - Fully drained (dry slopes)
  - Completely un-drained (saturated slopes)
- If the FOS determined for the aspect being analysed is within tolerable code of practice levels, then the existing slope rock-related management strategies should be maintained or adopted

- If the FOS determined for the aspect being analysed is outside tolerable code of practice levels, then the slope rock-related management strategies should be reviewed

Figure 5 Guide to using the design charts



6.3 Example applications

6.3.1 Example 1 – Appropriate batter angle for thick softs

The average 5 year annual rainfall for a strip mine exploiting coal was recorded as 50 mm. A 15 m thick layer of hard-silt-clay material directly overlies the 5m thick coal seam for a 25 m section of the highwall face. The remaining 300 m of the highwall face is characterised by relatively thin softs of 5 m thickness overlaying a 10 m thick competent sandstone. The Pit Foreman is uncertain whether the 80^0 batter angle (measured from the horizontal) used for the 300 m section is still appropriate for the 25 m section of face. Is the Pit Foreman's uncertainty justified? What would be appropriate recommendations apart from pre-stripping?

Route to solution

- What aspect of stability is to be resolved? Batter angle (Figure 6)
- What route should be followed on design guide? +3 m (since softs are greater than 5 m for both cases) and Appendix D2 (Dry charts)

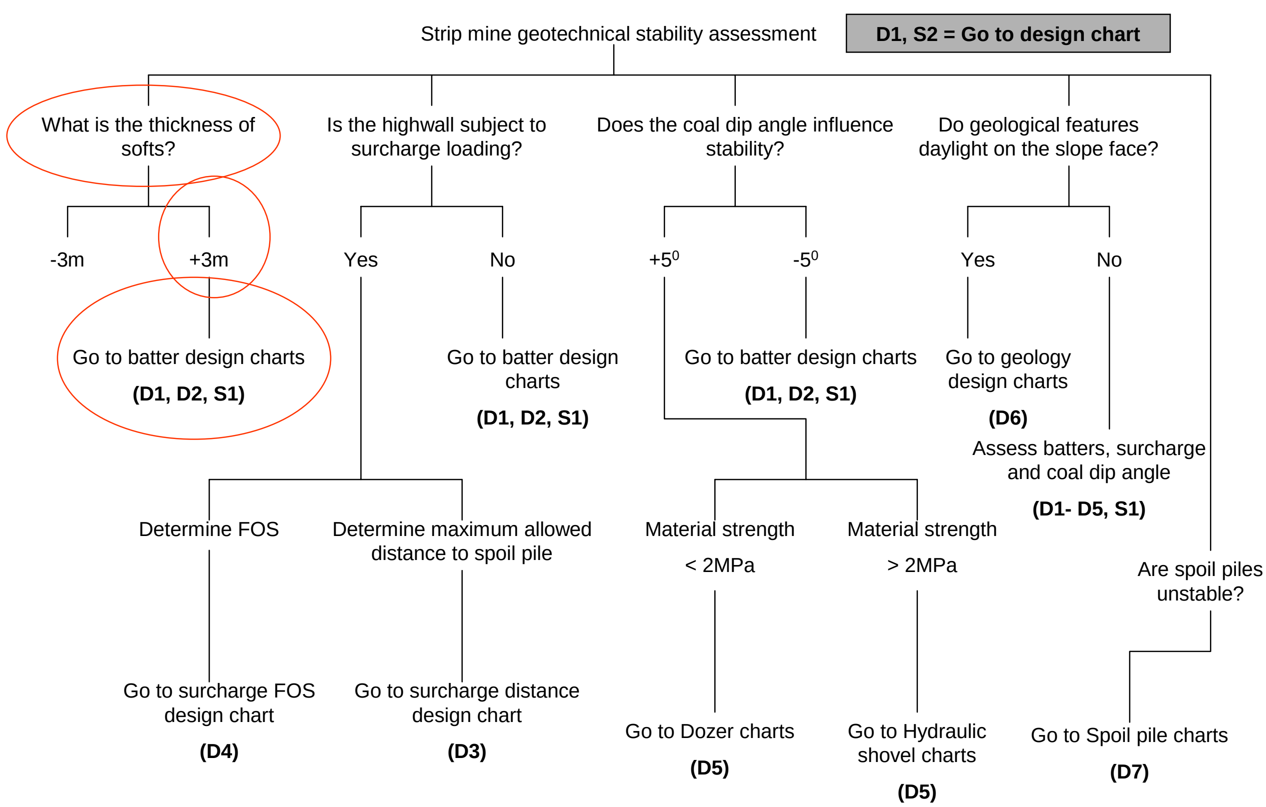


Figure 6 Example 1, design guide

- What type of softs are we dealing with? Hard silty clayey
- What is the acceptable FOS? 1.2 (assumed)

- What is the FOS for the 300 m section with thin softs? 1.3 (Figure 7)
- What is the corresponding FOS for 15 m thick softs? 0.6 (Figure 7)

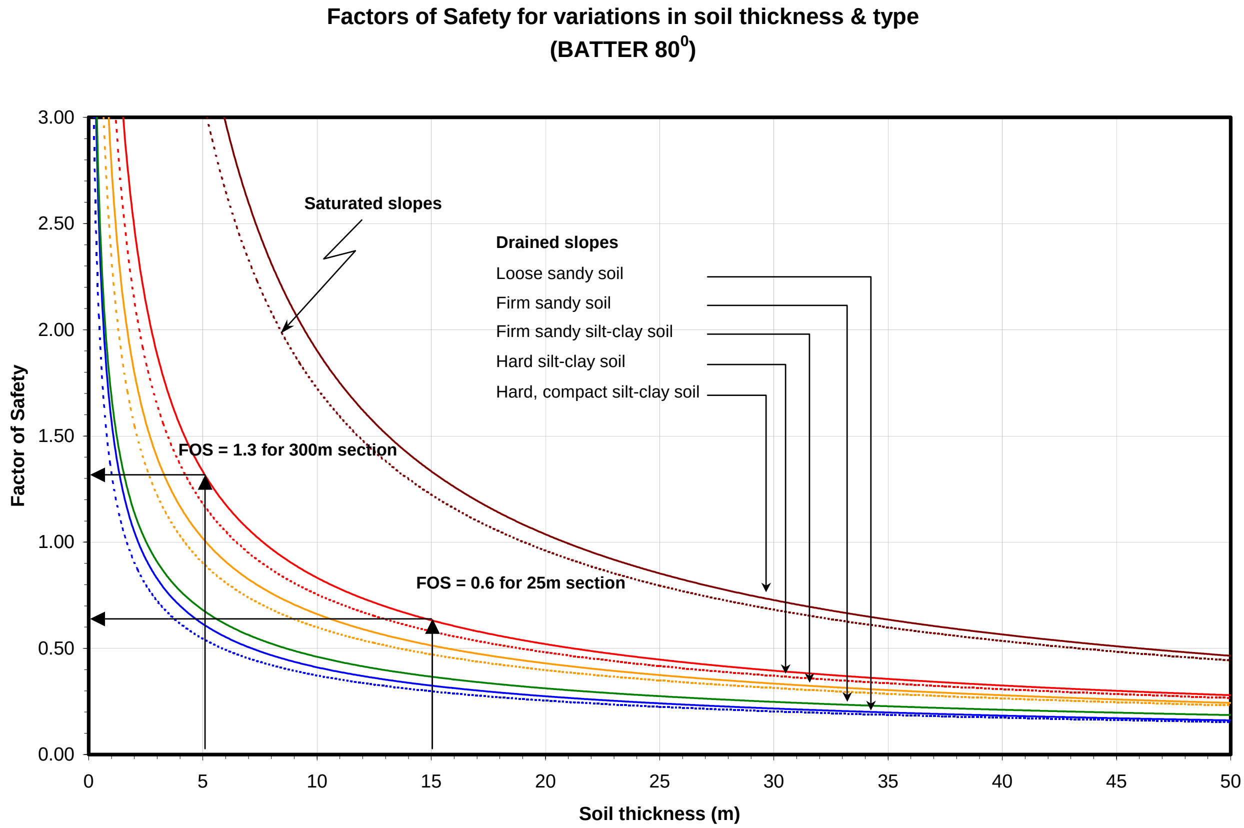


Figure 7 Example 1, FOS for 300 m and 25 m sections

- To maintain a FOS of 1.3, the batter angle for the soft material must be reduced to 40^0 (Figure 8)

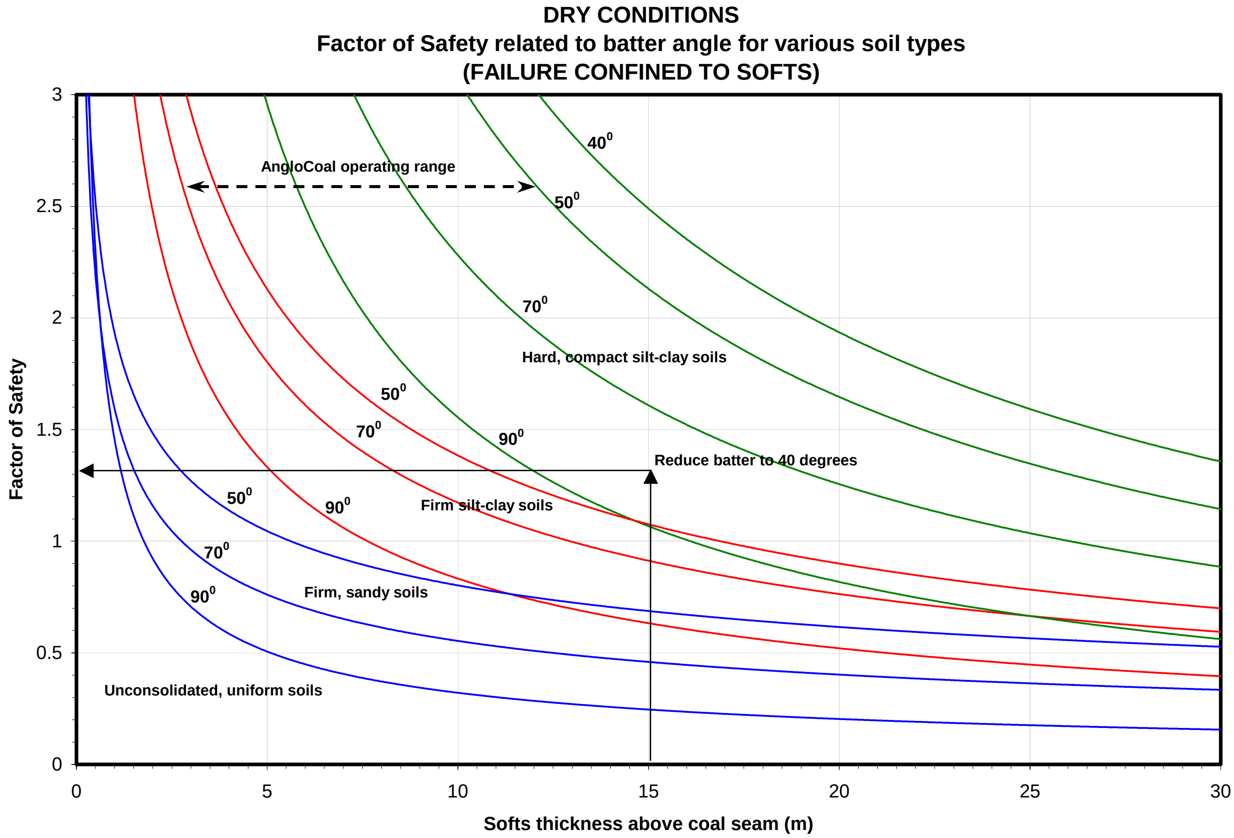


Figure 8 Example 1, Selecting appropriate batter angle for the 25 m sections

6.3.2 Example 2 – Surcharge loading

A strip colliery is mining towards the lease area boundary of another mine. The other mine has been dormant for 15 years and a 20 m high laterally extensive spoil pile has been left just within their boundary. Economics does not favour moving the spoil pile and mine drainage is expected to be poor. The stratigraphy of the advancing strip colliery is on average a 10 m thick firm sandy soil that overlies the 5 m thick competent sandstone that rests on the coal seam. Batters are variable and lie between 60^0 and 90^0. What would you recommend as the appropriate stopping distance for the advancing face before the spoil pile has any influence on stability?

- What aspect of stability is to be resolved? Appropriate stopping distance from a spoil pile
- What route should be followed on design guide? Surcharge loading and maximum distance to spoil piles for wet conditions

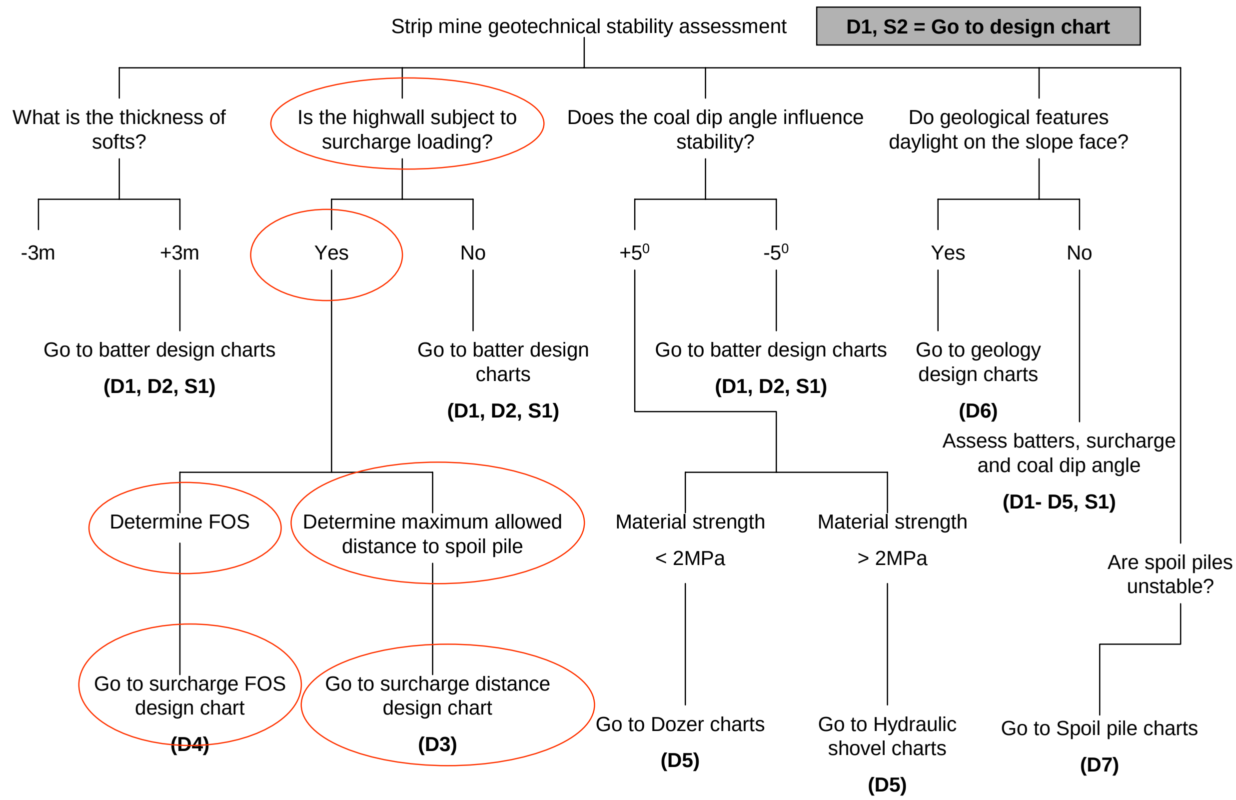


Figure 9 Example 2, design guide

What batter angle should be used for projections in the design charts? Most conservative, 90^0

What would be the stopping distance? 18.5m

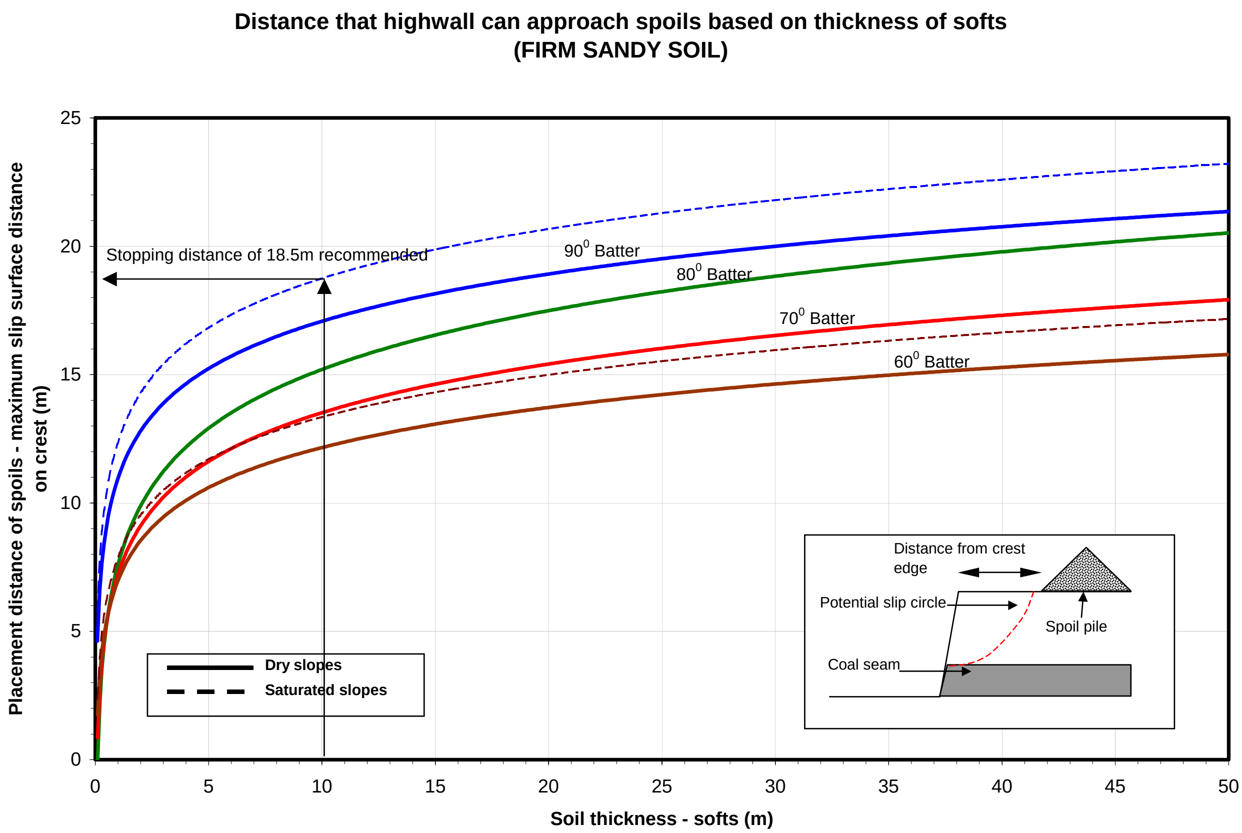


Figure 10 Example 2, calculating the stopping distance

7. RISK REDUCTION METHODS

The UK Engineering Council defines the risk assessment process "*Structured process which identifies both the likelihood and extent of adverse consequences arising from a given activity*".

Highwall and lowwall design and creation are subject to many uncertainties, the manifestation of which can result in a failure causing disruption and loss. These uncertainties may be considered to fall into the following categories: (After Summers).

- What we should know, but do not know, parameter uncertainty, and
- What we should do, but do not do; behaviour uncertainty.

In South Africa, the Department of Mineral and Energy issues a guideline for drafting a Code of Practice (CoP) to prevent rock related incidents from occurring.

In the CoP generic or base line risk assessment has to be performed, where all actual and conceptually possible risks are listed and the controls to ameliorate the identified risk are stated.

The table below lists a sample of risks currently listed in the CoP's of South African operations.

Risk	**Control**	**Remarks**
Highwall instability, structurally controlled	Pre-split blasting, spotting, floor hazard plan	Pre-split blasting may induce spontaneous combustion where previously mined seams are to be opencast mined
Highwall instability; water driven	Cut off drains or channels	
Highwall instability Old Bord and Pillar workings	Confirm layout from old plans and buffer blast	Workings older than 50 years are problematical from a survey perspective.
Lowwall instability, high void water pressure	No spoiling into water tolerated	Pumping and training required
Lowwall instability, poor quality material	Mixing of mud and clay material with fresh overburden/interburden material	Requires re-handling which impacts on mining efficiency.
Inexperienced operators, maintenance and repairs of machinery at inappropriate positions	Training given to all personnel work categories that have access to the pit.	Refresher training given on an annual basis to leave returnees.

8. OPERATIONAL CONTROLS

Many of the operational controls emanate from the CoP, but they only mean something if they are recognised and adhered to. To achieve this, trained and motivated personnel are required. In these operations beside the production personnel, the geologists in charge of in pit quality control are often the first to recognise a non standard or unusual situation.

The easiest control for an impending highwall or lowwall failure is to leave a coal berm, which stabilises the potential failure but may result in a coal loss if not extracted at the end of the coaling process. The imminent introduction of radar technology will allow many of these coal berms to be recovered safely.

Where instabilities are identified and are accessible, extensometers are installed across an identified failure trace (crack) and measurements recorded. Depending upon the risk associated with a possible failure, the instrumentation may be automated to indicate an accelerating rate of deformation which would trigger an evacuation or reduced intensity of mining. As the mines are very large and spread out, communication from the instability source to the control room is always problematical.

9. 2ND AND 3RD PARTY AUDITS

Anglo Coal South Africa, being a wholly owned subsidiary of Anglo American Plc; is listed on both the London and Johannesburg stock exchanges and has to demonstrate duty of care in all its operations, and one of these mechanisms is the 2nd and 3rd party audit.

Currently all operations are subjected to a 2nd party audit at least once a year and operations with an identified risk are audited at closer intervals. This service is provided by the Technical Division of Anglo American.

The graphic below depicts the current risk rating of all the Anglo Coal South Africa at the end of 2005.

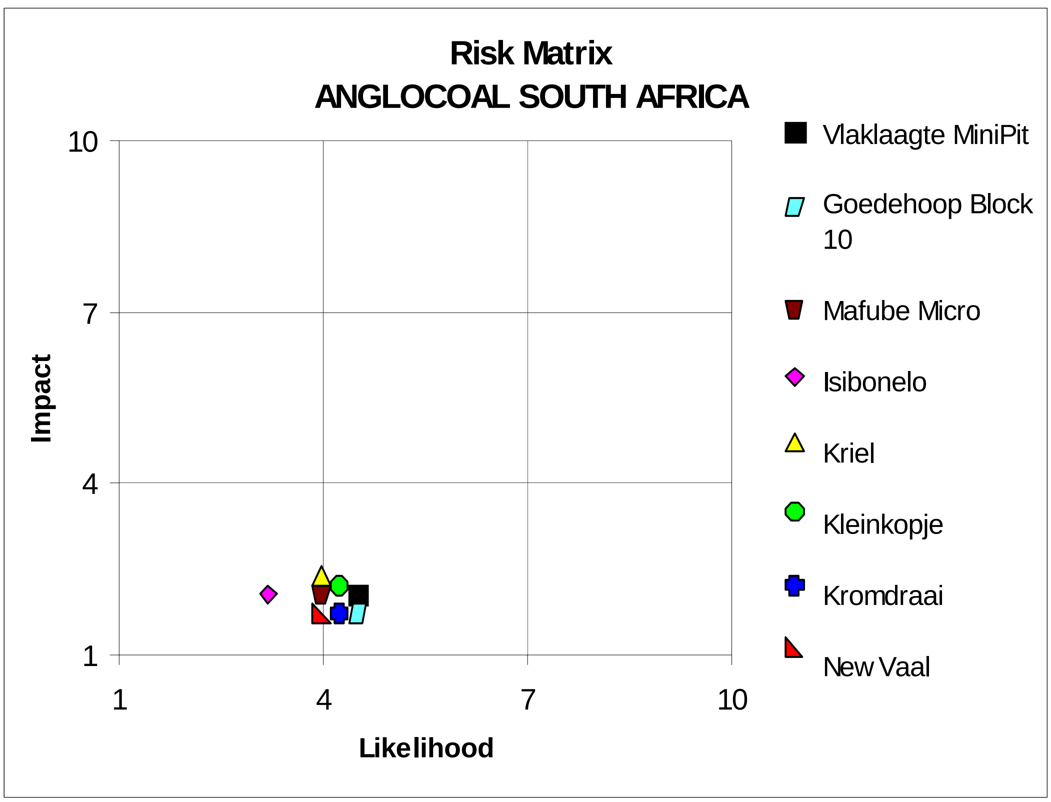


Fig 11 The status of the Anglo Coal South Africa operations at the end of 2005. The objective is to have all operations sitting within the first box on the likelihood/impact axes. (After Munsamy, 2005)

3rd party audits are performed on an ad hoc basis and involve internationally recognised experts that have no affiliation to Anglo Coal

10. CONCLUSION

Anglo Coal South Africa will mine approximately 48million tonnes of saleable coal by open cast mining methods in 2006. To achieve this some 84million bulk cubic metres of overburden will be removed to expose this amount of coal and represents the most tonnes ever moved by the company in South Africa in one year. In the coming years it may well increase as the demand for energy continues to grow.

Therefore the challenge to the geotechnical engineers is to ensure quality information is available in a timeous manner to the mining engineers, thus ensuring the rock related risk is identified and managed and the personnel are well trained to understand the consequences of the identified risks.

ACKNOWLEDGEMENTS:

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