Pit slope design process

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Abstract

One of the products of the Large Open Pit project involved the publication of the book Guidelines for Open Pit Slope Design, which presents a description of current methods for the design, implementation and management of pit slopes. The initial chapter of the Guidelines presents the Fundamentals of Slope Design as applied to open pits. It includes a discussion of the current open pit mining environment as it applies to open pit slope designs and a description of the general process in use at the present time for formulating pit slope designs.

This paper presents a summary of the first chapter of the Guidelines and commentary on the design process and its application and the interaction of slope designs in the mine planning process.

INTRODUCTION

In response to the lack of research into the slope design over the previous 15 to 20 years, the Large Open Pit (LOP) project was initiated in 2004 with two basic streams, namely:

- Compilation of a book providing guidelines for the design of slopes in open pit mines.
- Reactivation of research into factors affecting the design and stability of large rock slopes.

The book , which is entitled Guidelines for Open Pit Slope Design (1), describes the current “state of the art” of industry practice and provides a basis for the second stream of the project (research). By agreement amongst the sponsors, the document was framed to provide an overview of the design process and implementation for the “man/woman-on-the-hill”, i.e. the mine geotechnical engineer, who are often working in remote locations and may have only limited previous experience.

This paper is not intended to repeat the details as described in the Guidelines, but rather to provide a commentary on the origin of the pit slope design process and its general application. It also illustrates the interface of slope designs with other aspects of the development of an open pit mine at the various stages, from the conceptual design stage into operation. Other papers presented at the conference address specific technical and slope management aspects as presented in the Guidelines.

OPEN PIT MINING ENVIRONMENT

Although most of the factors that form the environment in which open pit mining occurs have implicitly always existed, in recent years they appear to have become more apparent, making the mining operation itself, and with it the slope design component, both technically and “politically” more complex. Stakeholders involved in the process include not only the owners (shareholders), management and workforce, but also regulators, financial institutions (lenders) and any members of the public who may feel that they are in any way affected.

From the slope designer’s standpoint this means that he must be aware that any uncontrolled slope instability (failure) can have ramifications in safety/social, economic and regulatory/environmental contexts. Specific factors can include:

Safety and social
- loss of life or injury
- loss of worker income
- loss of worker confidence
- loss of corporate credibility, both externally and with shareholders.

Economic:
- disruption of operations
- loss of ore
- loss of equipment

- increased stripping
- cost of cleanup
- loss of markets.

Environmental and regulatory

- environmental impacts
- increased regulation
- closure considerations.

In the last ten years several large failures in open pits in various parts of the world have attracted global attention, following tragic consequences in some cases and major economic consequences in all cases. In the case of some very large open pits, a major slope failure can even impact the world price of the commodity being mined. However, it is generally the bench scale failures and rockfalls that result in the majority of deaths and injuries.

While safety is the paramount consideration, a driving force for the slope designer is the large economic incentives associated with maximum slope angles commensurate with acceptable economic risk tolerance. Particularly in large open pits, steepening a wall by a few degrees can have a significant impact on the economics of the operation through either increased ore recovery and/or reduced stripping, as illustrated in Figure 1.

Regulatory factors influencing slope design are typically related primarily to safety, as discussed above, and to the potential environmental impacts, particularly if the pit is to have other uses after closure such as a recreational lake, or tailings or an urban waste disposal facility. The regulatory codes related to pit slopes vary significantly around the world. In some cases there are general directives, such as for a "Duty of Care" on the part of mine management for all aspects of the operation, including the stability of pit slopes, or a requirement for "clean benches and stable faces" above the mining operation. More defined criteria, include minimum bench widths and maximum operating heights for benches, and even specific design methodologies. The slope designer working on international projects must therefore be cognisant of the regulations under which he is working.

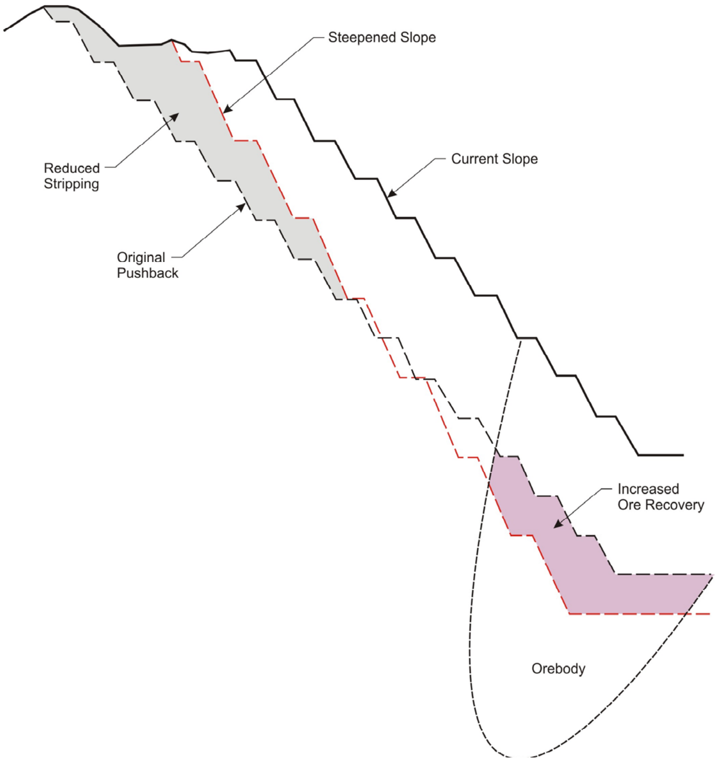


Figure 1 *- Potential Advantages of Slope Steepening. Source, Guidelines for Open Pit Slope Design (1).*

SLOPE DESIGN PROCESS

A Brief History of Open Pit Slope Design

Slope design is an integral part of the engineering of an open pit, regardless of its size. Most cases the slope angles are a key component dictating the economic viability of a proposed or current mining project. This has resulted in open pit mining operating with much lower Factor of Safety tolerances that would be used in civil engineering. However, the failure of a slope can have serious consequences in terms of the safety of personnel working in the open pit, and/or financial implications for the mining operation. These factors place a significant responsibility on the slope designer to produce a reliable design often based upon limited data. This necessitates that the processes that are used to formulate the designs are the best available.

The initial work on the geotechnical design of pit slopes took place in the late 1960's and early 1970's, founded initially on principles of soil mechanics and other materials engineering. At that time, few open pit slopes were higher than 300 m and many had been designed on the "45° suck it and see" principle. Failures were relatively common, resulting in loss of life and injuries to workers, as well as severe economic consequences. Pressure and financial support from industry to establish a better understanding of the factors controlling pit slope stability culminated in the book Rock Slope Engineering (2) and the CANMET Pit Slope Manual (3). With these books providing a technical basis the process of pit slope design was developed.

For slopes of 300 m or less, even in "fair" rock structural factors were typically the main constraint on stability, while for weak rock the technology from soil mechanics provided a reasonable design basis. However, by the early 1980's, with increasing slope heights, rock mass strength , based largely on the empirical Hoek-Brown failure criterion (4), began to be considered as an increasingly important factor in slope design.

With this technology, a general approach to slope design has been developed, based upon a combination of structural analysis, rockmass classification and the Hoek-Brown criterion. This approach is generally still in use today, although the tools being used (e.g. analytical techniques, computing capability) have improved significantly.

From the early 1980's onwards, research into pit slope designs effectively stagnated in favour of underground rock mechanics, reflecting the need to resolve serious issues in that area. That situation remained until the revival of conferences on slope stability in surface mines in 2000 (5) and the initiation of the Large Open Pit Project in 2004.

In the interim, there had been significant advances in the understanding of slope behaviour, at least in part as a result of "hard experience". This has led to the development of slope management practices for dealing with unstable slopes, in large part supported by significant advances in monitoring technology, including equipment types and capabilities, as well as analysis and reporting systems.

- Several factors have led to the recently revived interest in pit slope design including:
- Significant increases in slope heights, with several pits approaching 1,000 m in depth and many over 500 m.
- Several major slope failures that resulted in loss of life and/or significant economic consequences.
- Requirements for slope designs to be technically robust as economic decisions related to large open pits become more significant.

In parallel, changes in the mining industry environment have evolved from several directions, including:

- An increased emphasis on safety, with a requirement for safe operations dictated not only by the regulators, but also by management, who are increasingly being held responsible, the company shareholders and lending institutions, as well as society as a whole. In summary, safety is one of the underpinnings of a mining company's "license to operate".
- A requirement to reduce economic risk, particularly for the larger, more capital intensive projects.
- Regulated requirements that from the early stages of a project there should be "design for closure".

This has led to a requirement for slope designers to emerge from their technical "black box" and become more involved in the overall mine design and implementation (operational) processes.

As part of the response to the lack of research into the slope design over the previous 15 to 20 years, the Large Open Pit (LOP) project was initiated in 2004 with two basic streams, namely:

- Compilation of the Guidelines for Open Pit Design book (1) providing guidelines for the design of slopes in open pit mines.
- Reactivation of research into factors affecting the design and stability of large rock slopes, including:
    - The assessment of rockmass strength
    - The role and modeling of groundwater pressures in slope stability, particularly in fractured rock with low permeability
    - The impact of seismic events on large open pit slopes, which do not seem to be affected in the same way as natural slopes

Several other issues are also being addressed through smaller research initiatives, including methods of assessing blast damage to the rock mass.

The following discussion is intended to provide a brief overview of the slope design process as developed in Guidelines for Open Pit Slope Design and comments on its application, as well as illustrating the interface with other aspects of the open pit mining process. Other papers presented at the conference address specific technical and slope management aspects of the document.

Terminology

Before describing the process as outlined in the Guidelines, a few brief words on terminology are probably in order. The description of slope configurations as presented below is based upon the North American terminology, as illustrated in Figure 2

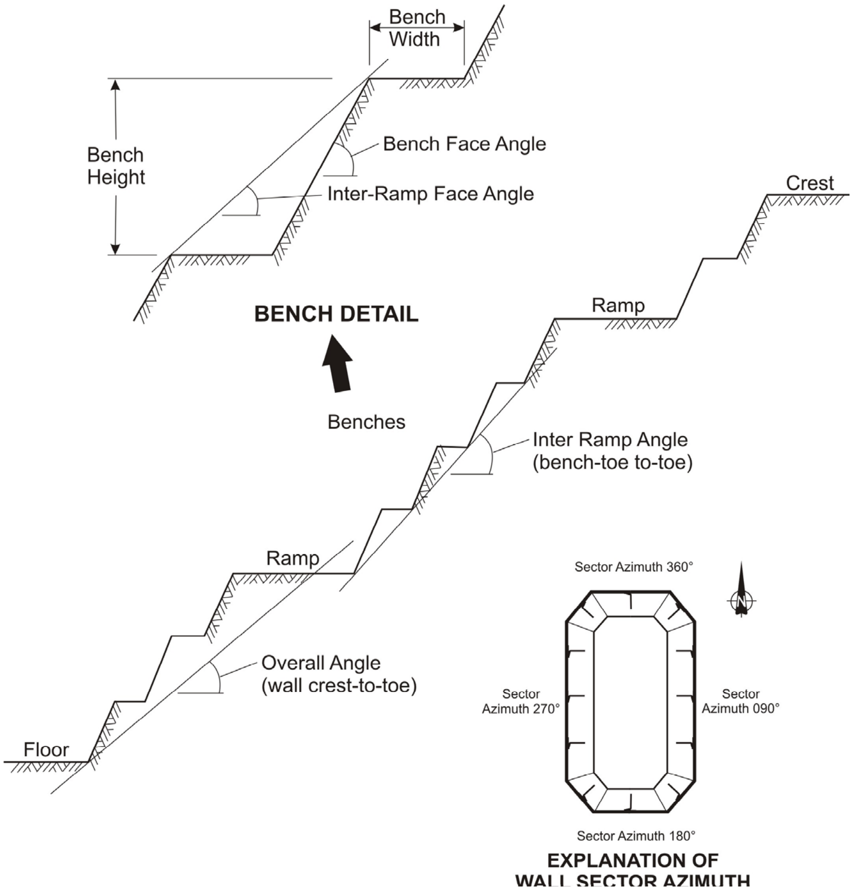


Figure 2 *- Slope Configuration Terminology. Source, Guidelines for Open Pit Slope Design (1)*

Colleagues from Australia and elsewhere use slightly varying terminology, e.g. batter (bench face), while the term "berm" can, confusingly, mean either the flat surface of a bench or the rock pile (windrow, bund) on the outside of a ramp. It is suggested that there needs to be some standardization in the latter case.

With increased involvement of non-practioners, it is suggested that there is a need to better communicate the true status of a slope that is moving. The word "failure" should only be used to describe the complete breakdown of the slope such that its original function is lost. Lesser movement should be clearly defined as either unloading response (relaxation) or, if the movement is clearly beyond that level, "instability", which can often be managed, particularly if it is detected at an early stage.

Formulation of Slope Designs

The Guidelines are based upon the general slope design process illustrated in Figure 3, which is applicable, with modification to local geology and mining requirements, to all open pits.

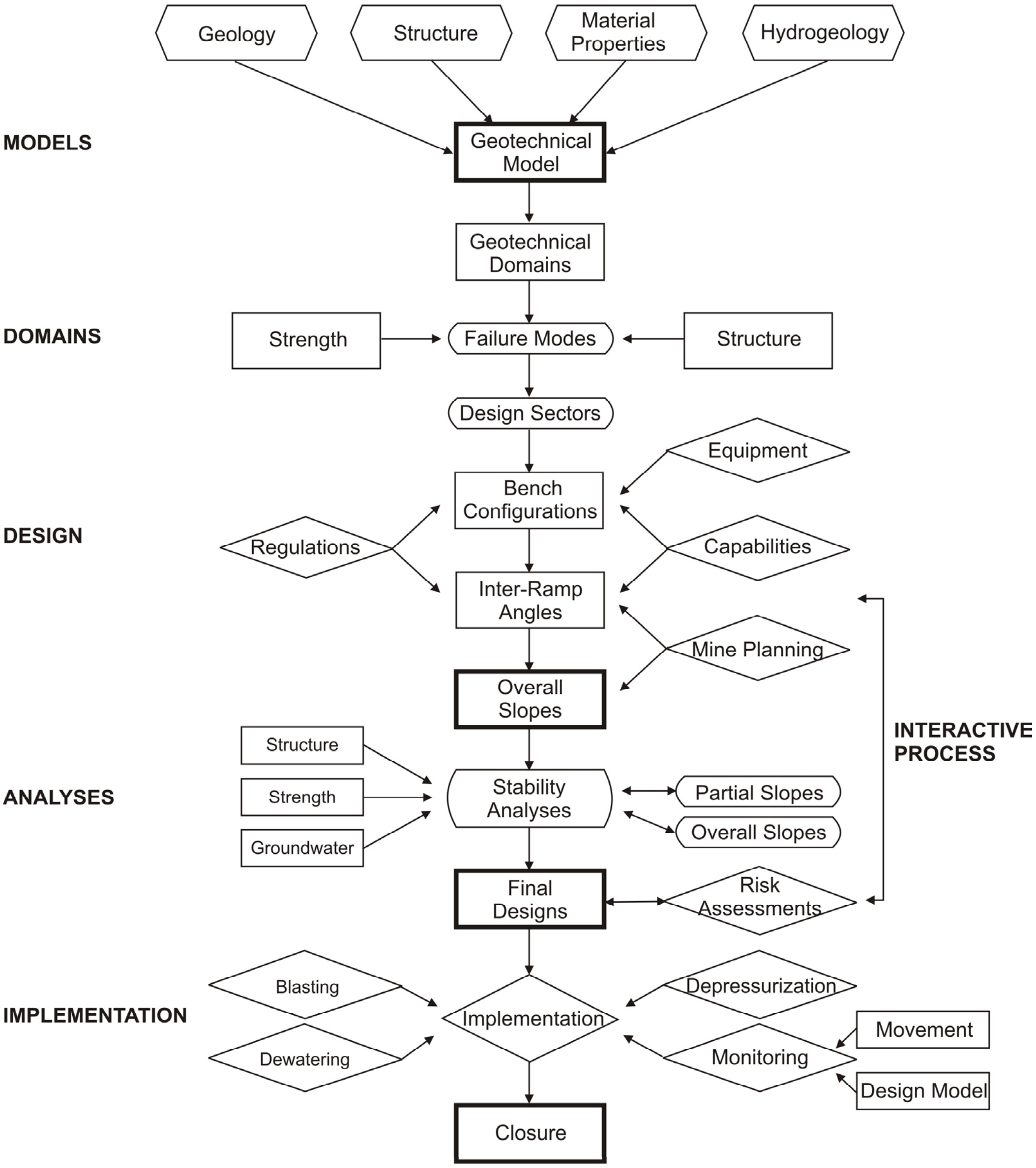


Figure 3 *- Slope Configuration Terminology. Source, Guidelines for Open Pit Slope Design (1)*

The following comments relate to the application of the process, full details of which are presented in the various chapters of the Guidelines.

Geotechnical Model

The fundamental basis of any slope design is the geotechnical model, which is in turn comprised of four models, namely:

- Geological model, which presents rock type and alteration distribution
- Structural model, encompassing both the major structures and fabric (jointing)
- Material properties model, including both basic properties (strength, elastic properties and potential changes on exposure), and rock mass characterization and strengths
- Hydrogeological model, in particular pore pressure distributions and properties that control the drainage and depressurization characteristics

Other papers in this conference deal with the respective components of the Geotechnical Model. The following comments reflect "user experience".

Geological Model

The Geological Model is generally provided by the mine geology staff or regional authorities; the slope design "practioners" must therefore be aware that the geologists may have a somewhat different agenda and view of the materials that will form the slope. Waste is of little interest to the mining geologist and hence rock types, particularly host rocks to mineralization, may be poorly differentiated, even though mechanical properties and structure, particularly fabric, may vary.

Similarly, a geologist's "alteration" does not necessarily reflect significant geotechnical variation. For example, "highly altered" feldspars that comprise less than 10% of a rock may be of significance to the ore genesis, but probably do not significantly impact the rock strength. Further, alteration does not necessarily weaken the rock; silicification can dramatically increase the rock strength.

In summary, the slope designer must be fully aware of the basis and terminology inherent in the Geological Model and, if possible, should discuss it with the geologists involved.

Structural Model

Formulation of the Structural Model component to the geotechnical model is increasingly becoming the role of the specialist structural geologist, who normally takes a much broader view than the ore investigation geologist. Particularly when dealing with major structures such as faults, continuity and patterns, which may indicate undetected structures, are two critical factors.

It is important that there be a clear indication of which structures are confirmed by intercepts and which are projected. The slope designer must question whether a fault detected in surface outcrop can be projected with certainty for the full height of a 600 m slope and should ask for additional confirmation (drilling) if the answer is critical.

The structural geologist should be required to characterize the respective faults in terms of size, nature and infillings, together with variability. These elements can prove invaluable to both the slopes designer, e.g. for assessing probable strength properties, and to the hydrogeologist.

Definition of the structural fabric (joints, minor faults) often falls to the geotechnical engineer as part of the slope investigation process. However, there should be integration with the major structure model; this will require coordination with the structural geologist.

Material Properties

While the procedures for testing small scale samples in the laboratory are well defined and standardized, the extension of the results to slopes several hundred metres high remains problematical. For the past 20 years the main vehicle for assessing the strength of large rock masses has been the empirical Hoek-Brown criterion. This approach has stood up remarkably well, with no record of slopes failing when they have been designed appropriately with this approach in spite of perennial discussions regarding the application of the "D" (disturbance factor) and other aspects.

As part of the LOP studies, significant advances have been made in formulating a more rigorous approach to the determination of rock mass strength through DFN (Discrete Fracture Network) and SRM (Synthetic Rock Mass) models; these are discussed in detail by Lorig (6) in this conference.

Hydrogeology Model

The Hydrogeological Model can be critical to the slope design process, since groundwater is the only element of the geotechnical model that can easily be modified artificially. Therefore a clear understanding of the pore pressure distribution and potential means of modifying (reducing) any pressures is essential.

It is becoming increasingly apparent that, except for rocks with a hydraulic conductivity of approximately 10-8 m/s or greater, the classical approach of establishing a phreatic surface and assigning a hydrostatic pore pressure distribution below this level is incorrect for large open pit slopes. Besides such factors as the downward gradient that is typically present around open pits and the impact of faults acting as flow barriers, it is becoming clear that the pore pressure distribution in larger structures, particularly fracture zones, and the fabric in the rock mass may be significantly different. In consequence, the pore pressure response within the overall rock mass to depressurization measures may also vary significantly over time. This is another area of important research in the LOP project.

In the meantime, as discussed by Lorig (4), the slope designer must be aware of this issue and attempt to take account of potential variations in response in the stability analyses.

Geotechnical Model

In compiling the various elements of the Geotechnical Model, it is important that the slope designer understands the assumptions made in formulating the constituent models, and ensures that these are consistent and carefully balanced before proceeding to the design phases. For example, an argillic alteration zone associated with a major fault is intuitively likely to be:

- continuous over a significant distance
- of low strength, but possibly not as low as any clay (gouge) in the actual fault
- of low permeability and act as a barrier to flow

If these attributes are not included in the fault, then a detailed review of the model should be undertaken.

Geotechnical Domains

The geotechnical model forms the basis for the division of the slopes around a pit into domains, which are fundamentally three-dimensional volumes of material with similar geotechnical properties. The dimensions of the domains can vary, but they should not be reduced to "un-minable" proportions. This translates to at least one to two benches in height, typically in excess of 100 m to 200 m horizontally and/or at least 10° of arc, depending upon the size and shape of the pit. Anything smaller, e.g. a fault zone, must be "merged" into the design for the domain or subject to specific measures. For example, Figure 4 shows a pit wall where units with different strengths and structural fabric (the upper two units), each require different slope configurations.

Where the rocks are strong and structure is likely to have a controlling influence on the slope designs, the geotechnical domains should be sub-divided into Design Sectors based upon wall orientation relative to the structural fabric; this is typically performed for sector arcs of no less than 15°.

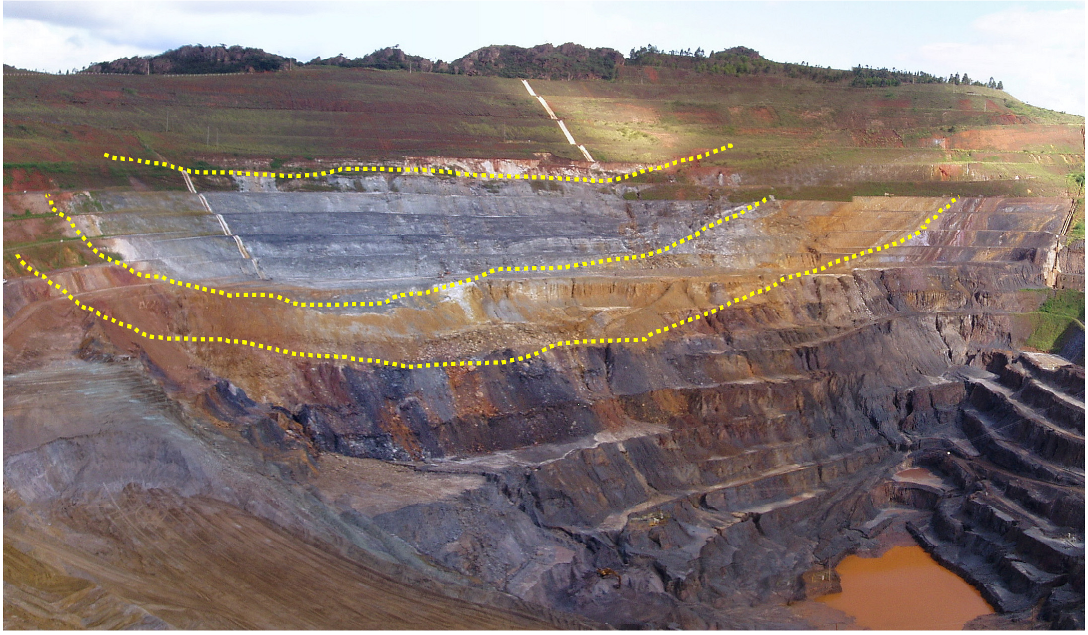
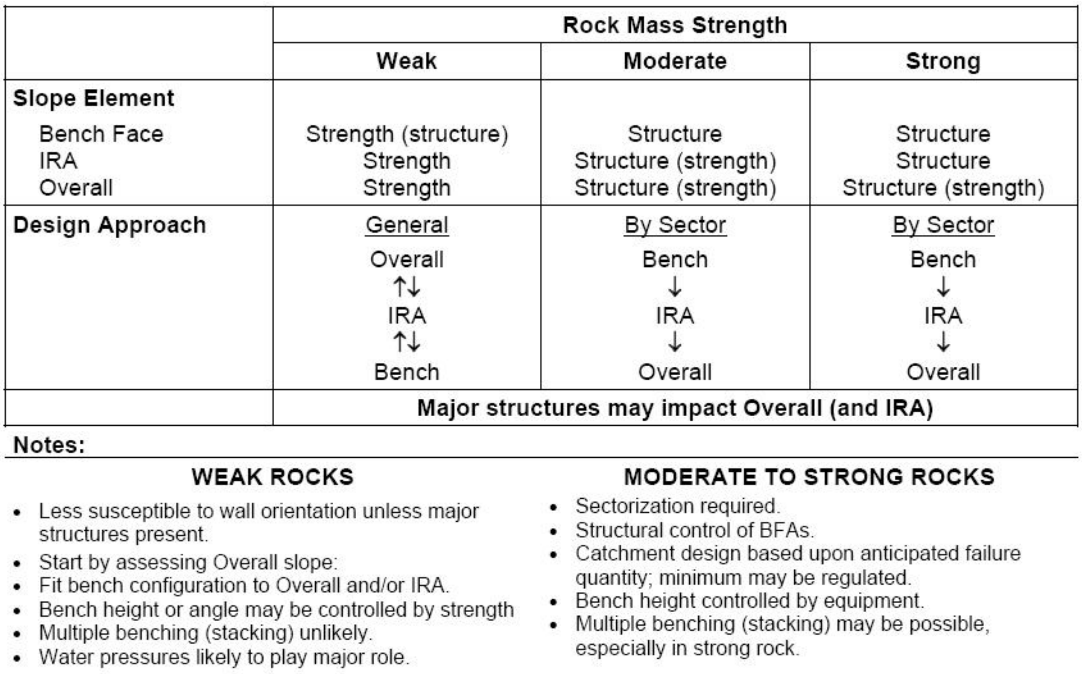


Figure 4 *- Potential Geotechnical Domains based on Rock Types*
(Photo courtesy of Vale)

Design Approach

The approach taken for designing a pit slope initially depends on the strength of the material involved as outlined in Figure 5.



	Rock Mass Strength		
	Weak	**Moderate**	**Strong**
Slope Element Bench Face IRA Overall	 Strength (structure) Strength Strength	 Structure Structure (strength) Structure (strength)	 Structure Structure Structure (strength)
Design Approach	General Overall ↑↓ IRA ↑↓ Bench	By Sector Bench ↓ IRA ↓ Overall	By Sector Bench ↓ IRA ↓ Overall
	Major structures may impact Overall (and IRA)		

Notes:

WEAK ROCKS

- Less susceptible to wall orientation unless major structures present.
- Start by assessing Overall slope:
- Fit bench configuration to Overall and/or IRA.
- Bench height or angle may be controlled by strength
- Multiple benching (stacking) unlikely.
- Water pressures likely to play major role.

MODERATE TO STRONG ROCKS

- Sectorization required.
- Structural control of BFAs.
- Catchment design based upon anticipated failure quantity; minimum may be regulated.
- Bench height controlled by equipment.
- Multiple benching (stacking) may be possible, especially in strong rock.

Figure 5 *- Slope Design Approach by Rock Strength. Source, Guidelines for Open Pit Slope Design (1).*

For weaker rocks and overburden or saprolites, the slope design is typically initiated by determining the overall slope angle that meets the required acceptance criteria (Factor of Safety and/or Probability of Failure). This will involve analyses of conceptual slopes for the relevant domains involving:

- Material properties
- Any structures such as faults, or relict structural fabric
- Water pressures

Initial design recommendations might be supplied to the mine designers in terms of slope height vs. slope angle charts, with the resulting designs being checked for stability of the resulting specific slopes.

For pit slopes in stronger rocks, the design is normally developed from the bench configurations, with the basic elements being:

- Bench face (batter) angle
- Vertical separation between catch benches
- Bench width

Brief comments on each of these aspects are as follows.

Bench face angle

The general procedure for determining the bench face angle revolves around kinematic analyses, as illustrated in Figure 6.

Besides the kinematic analyses using stereographic techniques, many consultants and mining companies have tools for statistically establishing bench face angles based upon acceptance levels for the percentage of bench faces that will fail through undercutting of either planar fabric or wedges. These programs are variously known as Cumulative Frequency Analyses (CFA) or Probability of Undercutting (PoU) analyses. It is stressed that these programs are tools, which require a significant amount of subjective interpretation depending upon the structural fabric input and the strength parameters assigned to the fabric, as well as local experience.

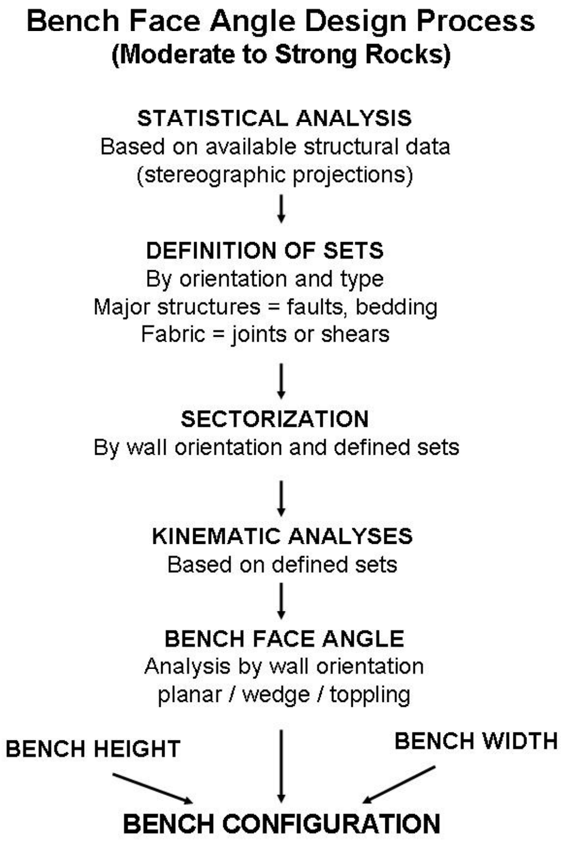


Figure 6 *- Bench Face Angle Determination. Source, Guidelines for Open Pit Slope Design (1).*

Benching

The decision as to whether to introduce catch benches onto a slope and, if so, how frequently depends very much on the dip of the structures that control the bench faces. The main function of the benches is to arrest rockfall material. An exception to the practice of benching a slope is clearly illustrated by a "footwall" mined through an iron mine in Brazil that was mined in a syncline, see Figure 7. In the axis of the fold no benches were left on the wall since the foliation dip is relatively shallow and loose rocks would be likely to slide, rather than roll or fall, down the foliation. Only where the foliation dip increased on the fold limb were catch benches established on the slope.

The vertical separation between catch benches is firstly a function of the excavating equipment. In most mining jurisdictions the operating bench height is restricted to a little above the reach of the equipment. However, stacking of benches is generally permitted provided that the bench faces are clean and therefore that the rockfall hazard to drill and blasting crews is minimal. A typical stacked bench configuration is illustrated in Figure 8 and involves a 30 m vertical separation between catch benches.

Figure 7 *- Application of benches (Photo courtesy of Vale)*

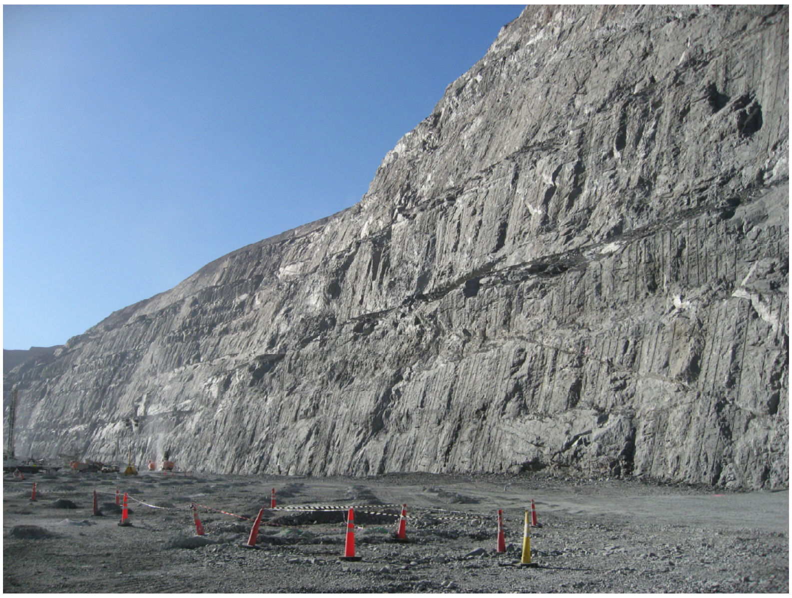


Figure 8 *- Stacked Benches (Photo courtesy of KCGM)*

The main purpose of stacking benches is to increase the inter-ramp angle. However, it should be noted that there is generally little or no advantage in stacking benches where the inter-ramp angle is less than about 45°, since at lower angles sufficient catchment (bench width) can be achieved on the slope and double benching would therefore result in increased waste stripping.

Bench width

The width of catch benches, which are intended to arrest rockfalls and minor failures, depends on the condition of the bench faces and the potential for failure as the slope is mined down. Prior to mining, a number of standard formulae for calculating bench widths can be used. However, once mining commences the success of implementation measures such as controlled blasting and scaling and general slope performance may provide a basis for changes.

Geotechnical benches

It is becoming common practice to leave wider benches at regular intervals on high pit slopes where there are no ramp crossings. The purpose of these benches is to provide:

- decoupling of very high slopes
- catchment for overspill from subsequent pushbacks
- sufficient width for access for clean-up
- a stable location for instrumentation, dewatering wells and other facilities
- flexibility in the slope design

The width of these benches is normally at least twice the width of the normal benches on the slope, but a minimum of 15 m and up to a full ramp width depending upon local conditions, as illustrated in Figure 9.

The typical vertical spacing for geotechnical benches is somewhat subjective, requiring engineering judgement and depending upon the main purpose, but is typically in the range of every five to eight benches, i.e. every 100 m to 200 m vertically on the wall.

The use of geotechnical benches is particularly important where multiple pushbacks are planned to be mined contemporaneously on the same slope, particularly where the inter-ramp angle is greater than about 45°, since it is almost impossible to prevent overspill from the upper cut. This results in a requirement for clean-up access at intervals on the walls to prevent rockfall affecting the lower operation.

Stability Analyses

The slope design process depends heavily on stability analyses of various types, including:

- Stereographic (definition of fracture sets)
- Kinematic (potential structurally controlled failure modes)

Figure 9 *- Geotechnical benches on an open pit slope*
(photograph courtesy of Compañia Minera Antamina S.A.)

- Limit equilibrium (initial stability assessments)
- Numerical modelling (detailed stability analyses and deformation prediction)

The application of each type of analysis is described in detail in the Guidelines and in several papers in this conference, notably those by Hoek (6) and Lorig (7). They will therefore not be discussed further here, except as summarized in Figure 10, which provides a general outline of their application at the various slope scales.

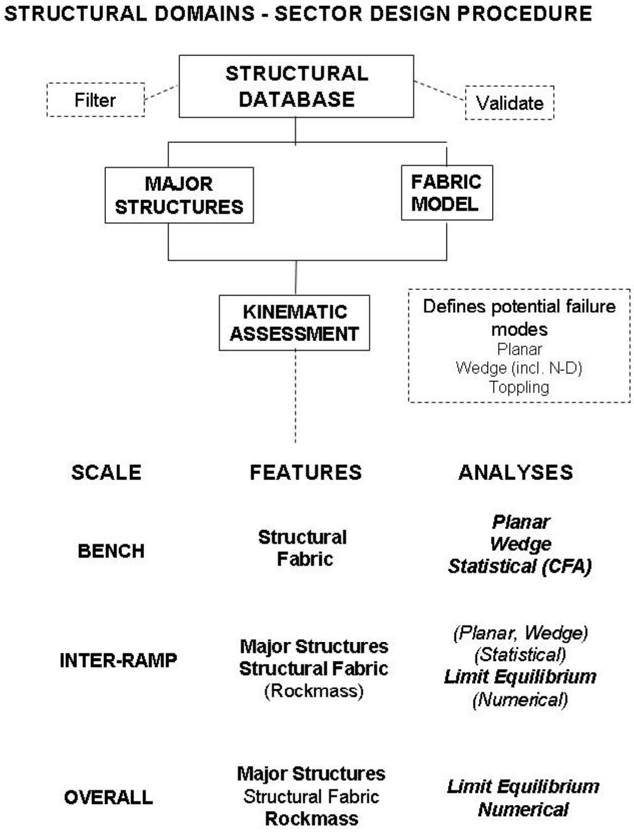


Figure 10 *- Slope Design Procedures for Rocks with Structural Control*

As indicated in Figure 3, where moderately strong and strong rocks are involved, the slope design process commences with the definition of bench configurations and then moves through inter-ramp slopes to the final overall slope design. However, the resulting configurations should not be finalized until the overall stability of a pit design based upon the inter-ramp parameters has been assessed.

It should be emphasized that, before embarking on analyses, the slope designer must be comfortable with the input data. To this end, it is essential to examine the various components of the geotechnical model and assess where uncertainty exists as well as the degree of that uncertainty. This process should be undertaken with the people who generated the component models. Where reasonable certainty does not exist, then the choice is to make allowances in the analyses and interpretation of the results or collect additional data before proceeding. If the sensitivity or probabilistic approach is adopted to address the uncertainties, the wide range of potential results often mandates the collection of additional data.

Once mining has commenced, the opportunity to "calibrate" the stability analyses exists, either through comparison of modelled results with actual field measurements, particularly in the areas of slope deformation or groundwater pressures response, or through slope performance assessments, as discussed by Hawley (8). A detailed monitoring program, including all of these elements, initiated early in the mine life can be invaluable in this regard.

Design Presentation

At the pre-mining stage, it is often appropriate to provide the mine planner with slope configurations for the full 360° of orientations for each domain as a basis for Whittle analyses, as shown in Figure 11. In this example there is thick alluvial overburden that could be expected to exhibit a slope height – slope angle relationship (material strength control), whereas the bedrock is moderately strong and therefore the structural fabric is likely to control the bench face angles and the resulting inter-ramp angles in the various design sectors.

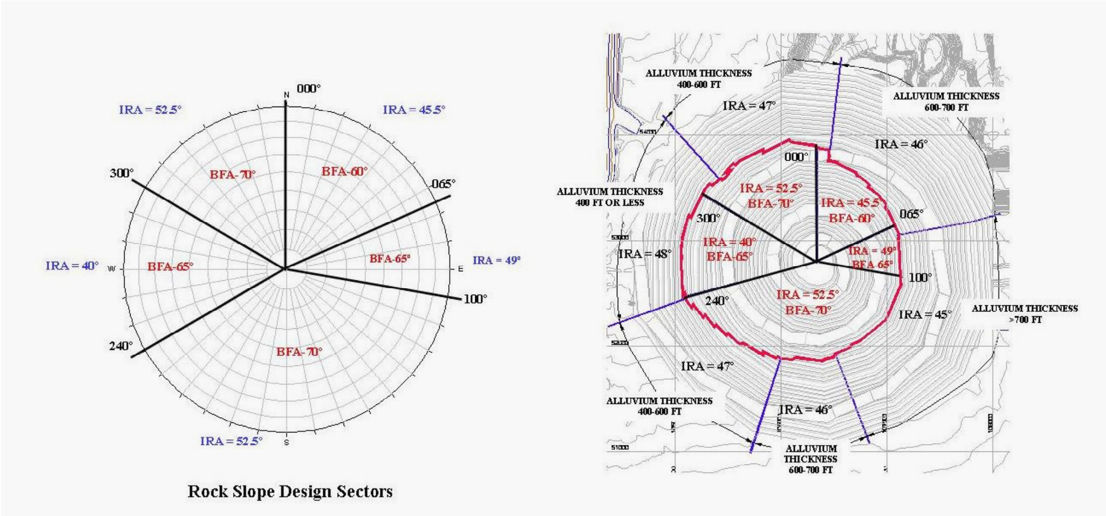


Figure 11 *- Slope design (courtesy of Barrick)*

At later stages in the mine development it is possible to be more specific in the slopes that are addressed, but it is always prudent to extend the limit of the designs beyond the extent (wall orientations) of previous pit design in order to provide the designers with flexibility to modify slope orientations.

Particularly where there are major changes in the recommended slope configuration between adjacent sectors, the question of "transition" exists. A basic rule should be that the transition should generally take place in the sector that has the steepest inter-ramp angle. Where there is a change from a double benched configuration to single benches the intermediate benches can be flared out in much the same way as shown in Figure 7.

Slope Design Interface with Mine Planning

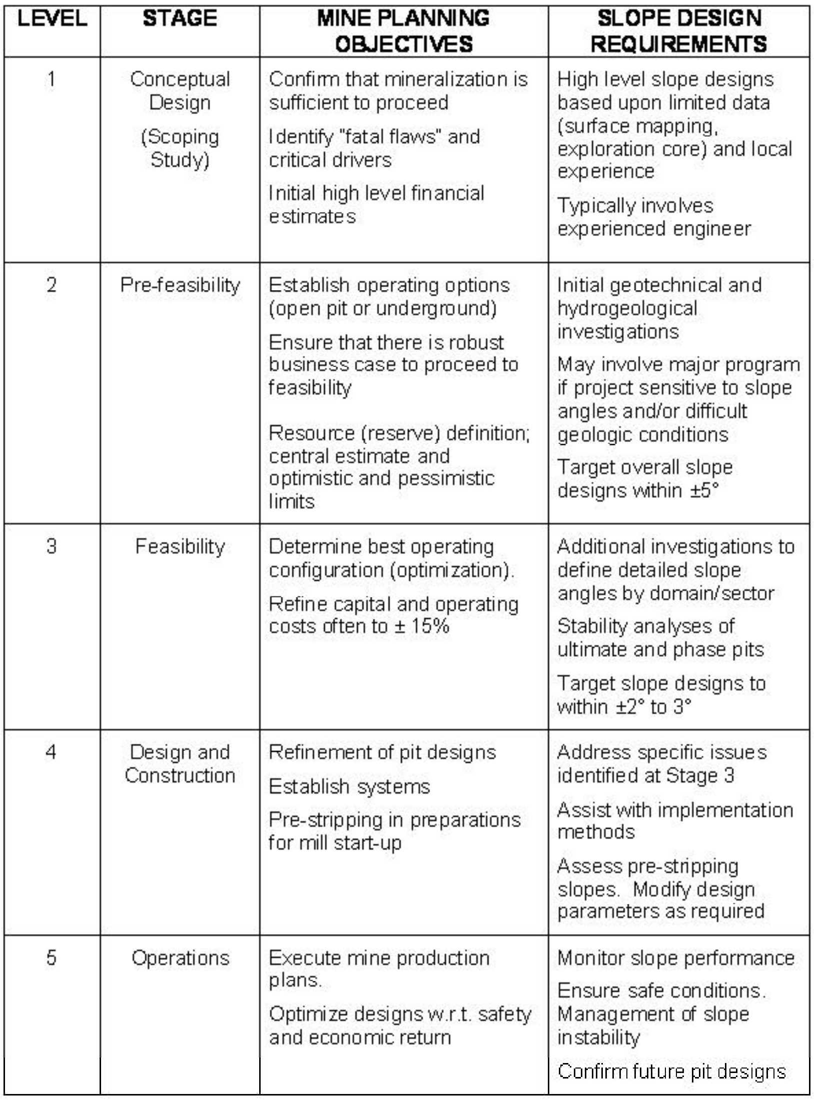
The slope design parameters are a major input to the mine planning process, particularly where significant stripping is involved. In consequence, as a project progresses from conceptual design into an operation and the requirements for the accuracy increase, there must be sufficient data available to support the slope designs. This relationship is summarized in Figure 12.

Throughout the project close interaction between the geotechnical engineers and the mine planners is critical. Any modification of the mine plans should be reviewed by the slope designer, with additional stability assessments as required, depending upon the scale of the change. In short, the slope designer and the mine planners must have a fully interactive relationship throughout the life of the project.

In an attempt to establish the typical cost ranges for slope design programs at the different project stages, mining and consulting companies were asked to provide “approximate estimates” of drilling and engineering costs based upon recent projects of varying sizes. The resulting ranges for medium sized operations (porphyry copper and low grade gold), were as follows (in $US `000):

STAGE	Geotechnical Drilling	Engineering	TOTAL
1 Conceptual	none	25 - 50	25 - 50
2 Pre-feasibility	750 – 4,000	200 – 1,225	1,000 – 4,500
3 Feasibility	1,000 – 10,000	500 – 1,600	1,500 – 11,000
4 Mine Expansion	500	200	~1,000

For very large open pits, the range can increase considerably, with feasibility study slope design costs ranging up to $US 20 Million in the case of a very high, complex slope.



LEVEL	STAGE	MINE PLANNING OBJECTIVES	SLOPE DESIGN REQUIREMENTS
1	Conceptual Design (Scoping Study)	Confirm that mineralization is sufficient to proceed Identify "fatal flaws" and critical drivers Initial high level financial estimates	High level slope designs based upon limited data (surface mapping, exploration core) and local experience Typically involves experienced engineer
2	Pre-feasibility	Establish operating options (open pit or underground) Ensure that there is robust business case to proceed to feasibility Resource (reserve) definition; central estimate and optimistic and pessimistic limits	Initial geotechnical and hydrogeological investigations May involve major program if project sensitive to slope angles and/or difficult geologic conditions Target overall slope designs within ±5°
3	Feasibility	Determine best operating configuration (optimization). Refine capital and operating costs often to ± 15%	Additional investigations to define detailed slope angles by domain/sector Stability analyses of ultimate and phase pits Target slope designs to within ±2° to 3°
4	Design and Construction	Refinement of pit designs Establish systems Pre-stripping in preparations for mill start-up	Address specific issues identified at Stage 3 Assist with implementation methods Assess pre-stripping slopes. Modify design parameters as required
5	Operations	Execute mine production plans. Optimize designs w.r.t. safety and economic return	Monitor slope performance Ensure safe conditions. Management of slope instability Confirm future pit designs

Figure 12 *- Summary of Mine Planning – Slope Design Interaction*

Communication

In the current mining environment, communication between the slope designer and other members of the mining team is essential. As the slope design technology becomes more complex, it is important that the recommendations are presented in a form that is intelligible to all concerned. This is particularly important where the designs are formulated away from the mine.

While slope design parameter recommendations must be fully discussed with, and understood by the mine planners who will use the criteria, as well as the operators who will implement the designs, other lines of communication within the company must include:

- Mine management, who are ultimately responsible for the safety of the operations and the recovery of the design reserves.
- Company executives, who are responsible to the shareholders and regulators, but increasingly come from non-mining backgrounds.
- The site geotechnical staff, who may occupy relatively junior positions and have limited technical and operational experience.
- Permitting and regulatory personnel, who are focussed primarily on the safety and environmental areas.

Where people unfamiliar with the slope design process are involved, the challenge is for the slope designer to present the results of often complex analyses in a clear, intelligible form to those who may have significant responsibilities for decisions related to the project and therefore for the results of the designs. The role of the site geotechnical engineer can be particularly important in this regard, since he/she may be required to make rapid decisions in the event that unexpected instability develops. It is therefore essential that the slope designer also provides a clear explanation of the various design assumptions to these technical staff, and is available to provide support where required.

Review

In recent years it has become increasingly common for slope designs to be the subject of independent reviews undertaken on behalf of various stakeholders, including corporate executives, financial institutions and management. The main purpose of these reviews, which may be undertaken by in-house specialists or external specialists, often acting as a “Board”, is to provide additional confidence in the designs and implementation procedures.

It should be emphasized that the role of the reviewer(s) is not to provide the design services that should be provided by in-house staff or consultants, but rather to provide an objective evaluation of the overall activities associated with the pit slopes, as outlined by Hoek and Imrie (9). To meet these requirements, an internationally recognized authority in pit slope engineering, and often a similarly experienced mine hydrogeologist form the team.

DESIGN IMPLEMENTATION

The factors associated with the implementation of the slope designs as well as slope monitoring are beyond the scope of this paper. However, a few guidelines related to the interaction between the slope design and its implementation are offered, including:

It is critical that the constraints associated with the recommended slope configurations are within the capabilities of the operating team who will implement the designs.

The mine operators who will implement the designs must fully understand these constraints and be willing to accept them. This also means that there must be sufficient allowance in the operating budget to perform the necessary controlled blasting, horizontal drain hole drilling and other measures that are required to ensure safe operating conditions and achievement of design targets.

The mine operators must be involved in the slope monitoring and slope assessment process, from the perspectives both of safety and of slope performance. In this regard it is suggested that the mine geotechnical engineer should tour the pit with the mine superintendent on a regular basis.

Where instability develops or serious rockfall conditions exist, the design of remedial measures should involve a team consisting of the geotechnical engineer, the operations supervisor and the mine planner.

In summary, to be successful, a slope design must be understood and accepted by the mine operators, who must be involved at least from the feasibility study level onwards.

SUMMARY

Part of the Large Open Pit project has involved the development of Guidelines for the design and implementation of slope designs that apply to every scale of surface mining operation. The key to this process is a reliable geotechnical model that forms the basis for a carefully engineered approach to the slope design at all stages of an open pit mining project.

The formulation and implementation of pit slope designs requires interaction with all members of the mining team. This team includes the company executives and management, who must establish the acceptance criteria on which the slope designs are based, the mine planners, who are the immediate clients, and the operators who are responsible for the implementation of the designs. It is therefore essential that the slope designer communicates the results of the process in a form that can be understood and endorsed by all stakeholders in the mining project.

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