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STEPS FOR DETERMINING THE SLOPE ANGLE OF AN OPEN MINE

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Abstract

Open pit mining is defined as the method of extracting any near surface ore deposit using one or more horizontal benches to extract the ore while dumping overburden and tailings (waste) at a specified disposal site outside the final pit boundary. Open pit mining is used for the extraction of both metallic and nonmetallic ores. Open pit mining is considered different from quarrying in the sense that it selectively extracts ore rather than an aggregate or a dimensional stone product. A new Mine Slope Instability Index (MSII) to assess the (in)stability conditions of slopes in open-pitmining is presented. Eighteen parameters that can be easily obtained and rated in the field, and that areimportant for open-pit slope stability, are employed for the MSII definition. Their corresponding ratings are also proposed, so that the MSII can be computed as a simple weighted sum of ratings for all parameters considered; to minimize subjectivity the weights are computed, in the context of the Rock Engineering Systems paradigm, using an optimized Back-Propagation Artificial Neural Network that has been trained with an extensive database of worldwide open-pit slope stability case histories. Results show that the ANN provides a highly reliable RES interaction matrix, and also that the selected parameters are important for open-pit slope stability. Slope (in)stability hazard levels are defined based on MSII values and the predictions of the newly proposed MSII are validated by comparing our predictions with the actual (i.e. observed) behaviour corresponding to 12 independent case histories that were not used for the ANN training. An excellent agreement between predictions and observations has been found, with only one (out of 12) cases providing an incorrect prediction.

Keywords: Open-pit mining,slope instability potential,rock engineering systems, mining technology,artificial neural networks.

Introduction

For an open pit mine, the design of the slopes is one of the major challenges at every stage of planning and operation. It requires specialised knowledge of the geology, which is often complex in the vicinity of orebodies where structure and/or alteration may be key factors, and of the material properties, which are frequently highly variable. It also requires an understanding of the practical aspects of design implementation. This chapter discusses the fundamentals of creating slope designs in terms of the expectations of the various stakeholders in the mining operation, which includes the owners, management, the workforce and the regulators. It is intended to provide a framework for the detailed chapters that follow. It sets out the elements of slope design, the terminology in common usage, and the typical approaches and levels of effort to support the design requirements at different stages in the development of an open pit. Most of these elements are common to any open pit mining operation, regardless of the material to be recovered or the size of the open pit slopes.

Pit Slope Designs

The aim of any open pit mine design is to provide an optimal excavation configuration in the context of safety, ore recovery and financial return. Investors and operators expect the slope design to establish walls that will be stable for the life of the open pit, which may extend beyond closure. At the very least, any instability must be manageable. This applies at every scale of the walls, from the individual benches to the overall slopes. It is essential that a degree of stability is ensured for the slopes in large open pit mines to ecogniz the risks related to the safety of operating personnel and equipment, and economic risks to the reserves. At the same time, to address the economic needs of the owners ore recovery must be ecognize and waste stripping kept to a minimum throughout the mine life. The resulting compromise is typically a balance between formulating designs that can be safely and practicably implemented in the operating environment and establishing slope angles that are as steep as possible. As outlined in Figure 1, the slope designs form an essential input in the design of an open pit at every stage of the evaluation of a mineral deposit, from the initial conceptual designs that assess the value of further work on an exploration discovery through to the short- and long-term designs for an operating pit. At each project level through this process other key components include the requirements of all stakeholders. Unlike civil slopes, where the emphasis is on reliability and the performance of the design and cost/benefit is less of an issue, open pit slopes are normally constructed to lower levels of stability, ecognized the shorter operating life spans involved and the high level of monitoring, both in terms of accuracy and frequency, that is typically available in the mine. Although this approach is fully ecognized both by the mining industry and by the regulatory authorities, risk tolerance may vary between companies and between mining jurisdictions. Uncontrolled instability, in effect failure of a slope, can have many ramifications including:

Safety/social factors

*loss of life or injury;
*loss of worker income;
* loss of worker confidence;
*loss of corporate credibility, both externally and with shareholders.

Economic factors

#disruption of operations;
loss of ore;
loss of equipment;
increased stripping;

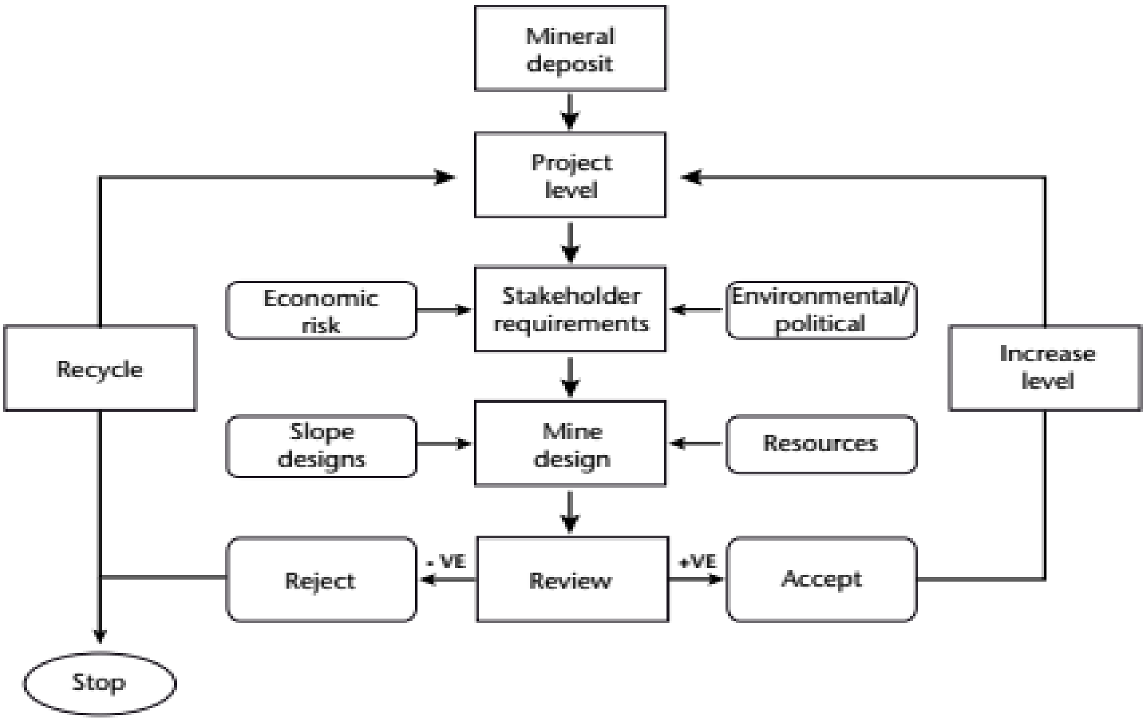

Figure 1.Project development flowchart

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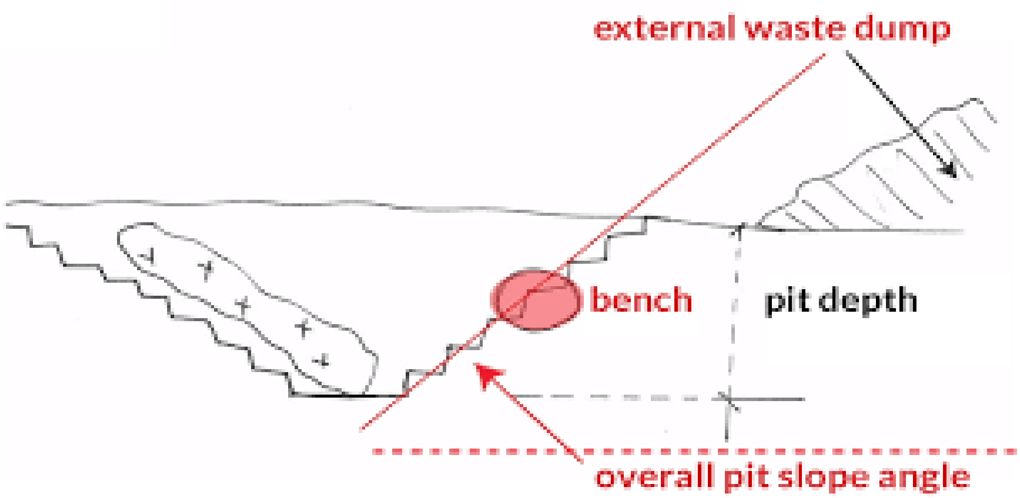
Safety/Social Factors

Safe operating conditions that protect against the danger of death or injury to personnel working in the open pit are fundamental moral and legal requirements. While open pits have always been prone to wall instability due to the complexity of mining environments, since the adoption of formal slope design methodology in the early 1970s the number of failures has generally decreased. Even so, in recent years there have been several large failures in open pits around the world. Tragically, some of these have resulted in loss of life; most have had severe economic consequences for the operation. These failures have attracted the attention of regulators and the public. Consequently, it is becoming increasingly common for management (including executives) and technical staff to face criminal proceedings when mining codes are violated, in either the design or the operation of a mine. While the major failures attract wide attention, it is the smaller failures, often rockfall at a bench scale, that typically result in the majority of deaths and injuries. For the mining industry to be sustainable, safety is a prime objective and must therefore be addressed at all scales of slope stability.



Economic Factors

The main economic incentive in most open pits is to achieve the maximum slope angle commensurate with the accepted level of stability. In a large open pit, steepening a wall by only a few degrees can have a major impact on the return of the operation through increased ore recovery and/or reduced stripping (Figure 2). In some instances, 'operating slopes' in initial expansion cuts may be flatter than the optimum, either to provide additional operating width or to ensure stability where data to support the designs are limited. However, this flexibility, which must be adopted with the understanding and consent of all stakeholders, almost always has negative economic consequences. The impact of slope steepening will vary depending on the mine but, for example, it has been shown that an increase in slope angle of 1° in a 50° wall 500 m high results in a reduction of approximately 3600 m3 (9000 t) of stripping per metre length of face. Increasing the slope angle will generally reduce the level of stability of the slope, assuming that other factors remain constant. The degree to which steepening can be accomplished without compromising corporate and regulatory acceptance criteria, which usually reflect the safety requirements for both personnel and ore reserves, must be the subject of stability analyses and ultimately risk assessments.

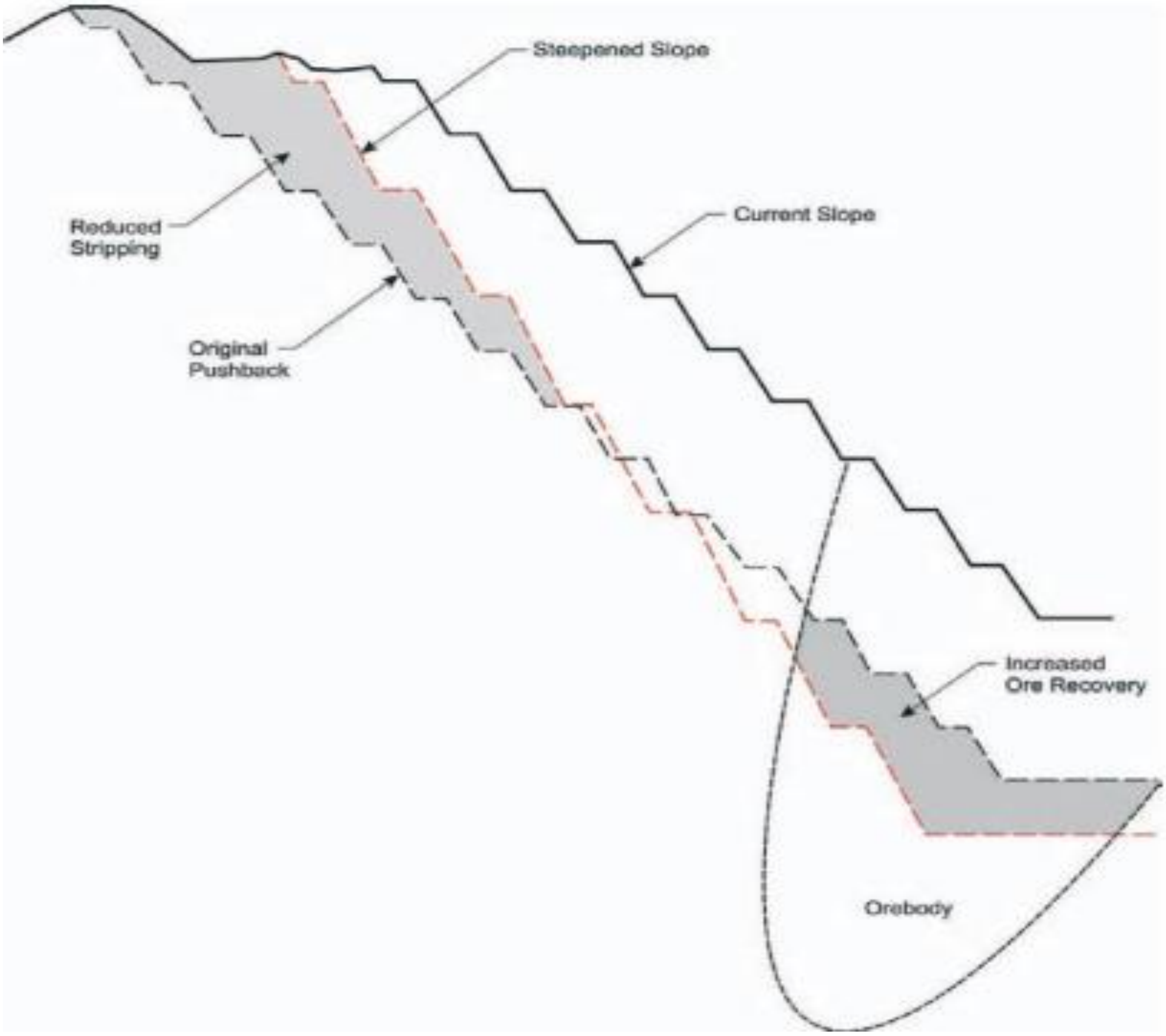


Figure 2: Potential impacts of slope steepening

Obtaining the dimensions of the slope of the open pit

The standard terminology used to describe the geometric arrangement of the benches and haul road ramps on the pit wall is illustrated in Figure 3. The terms relevant to open pit slope design as used in the manual are given in the Glossary. It should be noted that terminology related to the slope elements varies by geographic regions. Some important examples include the following. Another aspect of terminology that can cause confusion is the definition of slope orientations. Slope designers usually work on the basis of the direction that the slope faces (dip direction), as this is the basis of kinematic analyses. On the other hand, mine planning programs usually require input in terms of the wall sector azimuth, which is at 180° to the direction that the slope

faces, i.e. a slope facing/dipping toward 270° has an azimuth of 090° (inset, Figure 3). It is important that the convention adopted is clearly understood by all users and is applied consistently. Note that the bench face angles are defined between the toe and crest of each bench, whereas the inter-ramp slope angles between the haul roads/ramps are defined by the line of the bench toes. The overall slope angle is always measured from the toe of the slope to the topmost crest (Figure 3).

The part of the field where permanent work is carried out in the mine

Increased ability to detect small movements in slopes and manage instability gives rise to a need for greater precision in terminology. Previously, significant movement in a slope was frequently referred to in somewhat alarmist terms as 'failure', e.g. failure mode, even if the movement could be managed. It is now appropriate to be more specific about the level of movement and instability, using the definitions that recognise progression of slope movement in the following order of severity.

Unloading response

Initial movements in the slope are often associated with stress relaxation of the slope as it is excavated and the confinement provided by the rock has been lifted. This type of movement is linear elastic deformation. It occurs in every excavated slope and is not necessarily symptomatic of instability. It is typically small relative to the size of the slope and, although it can be detected by instruments, does not necessarily exhibit surface cracking. The deformation is generally responsive to mining, slowing or stopping when mining is suspended. In itself, unloading response does not lead to instability or largescale movement.

Movement or dilation

This is considered to be the first clear evidence of instability, with associated formation of cracks and other visible signs, e.g. heaving at the toe (base) of the slope. In stronger rock, the movement generally results from sliding along a surface or surfaces, which may be formed by geological structures (e.g. bedding plane, fault), or a combination of these with a zone of weakness in the material forming the slope.

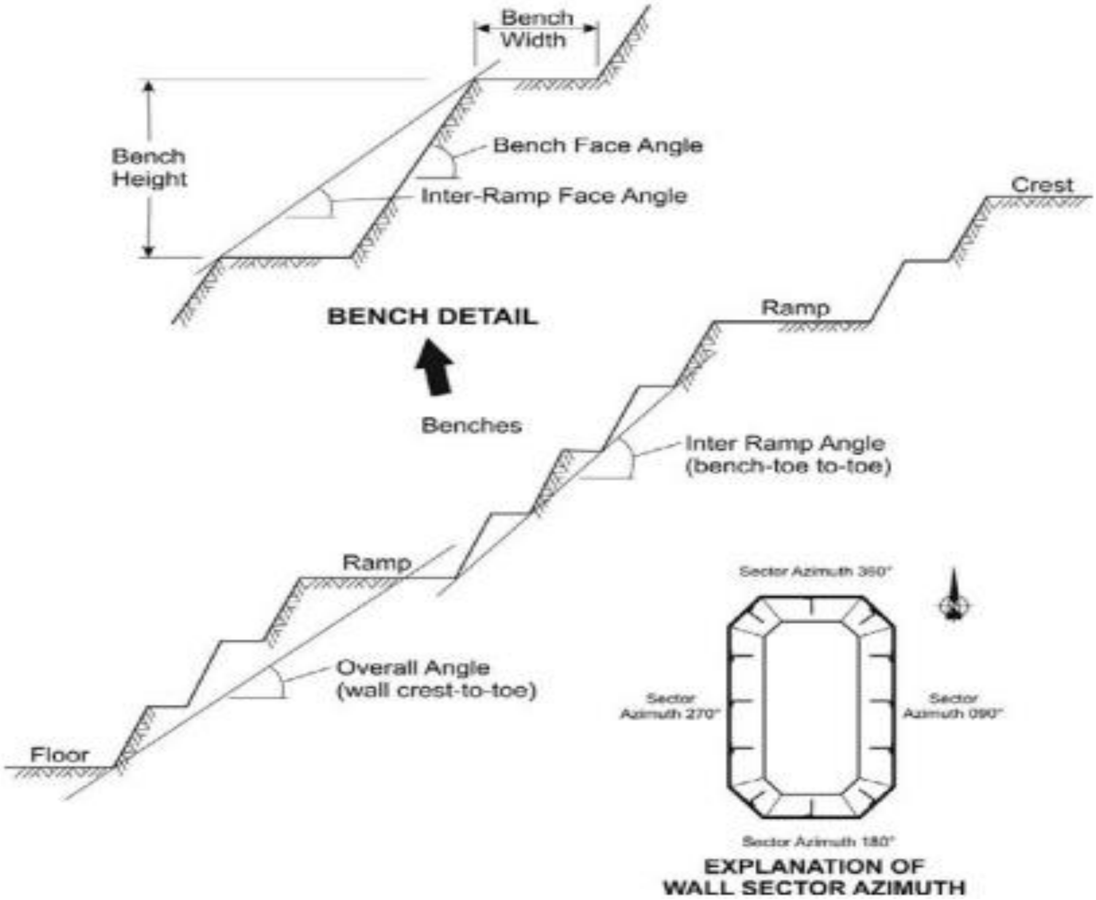


Figure 3. Pit wall terminology

Slope dilation may take the form of a constant creep I which the rate of displacement is slow and constant. Mor frequently, there can be acceleration as the strength on the sliding surface is reduced. In certain cases th displacement may decrease with time as influencing factors (slope configuration, groundwater pressures) change. Even though it is moving, the slope retains its general original configuration, although there may be varying degrees of cracking. Mining can often continue safely if a detailed monitoring program is established to manage the slope performance, particularly if the movement rates are low and the causes of instability can be clearly defined. However, if there is no intervention, such as depressurisation of the slope, modification of the slope configuration or cessation of mining, the movement can lead to eventual failure. This could occur as strengths along the sliding surface reduce to residual levels or if additional external factors, such as rainfall, negatively affect the stress distribution in the slope.

Conclusions\Failure

The following chapters expand on the design of large open pit slopes within the general framework outlined above. It must be a basic design premise that a slope design addresses the requirements of all stakeholders, from the owners through the operators to the regulators. In delivering a design, technical soundness is the foundation. The slope designer must build on this, responding to the varying conditions in each phase of the mine's life. The safety of personnel and equipment is of paramount importance in all phases, and acceptable risk levels must be carefully assessed and incorporated into the designs. By presenting the slope designs in a manner that enables mine personnel, from executives to operators, to fully understand the basis and shortcomings of the designs, practitioners provide the means of discerning the risks associated with deviation from those designs. With greater understanding, better and safer decisions can be made. A slope can be considered to have failed when displacement has reached a level where it is no longer safe to operate or the intended function cannot be met, e.g. when ramp access across the slope is no longer possible. The terms 'failure' and 'collapse' have been used synonymously when referring to open pit slopes, particularly when the failure occurs rapidly. In the case of a 'progressive failure' model, failure of a pit slope occurs when 'the displacement will continue to accelerate to a point of collapse (or greatly accelerated movement). During and after failure or collapse of the slope, the original design configuration is normally completely destroyed. Continued mining almost always involves modification of the slope configuration, either through flattening of the wall from the crest or by stepping out at the toe. This typically results in increased stripping (removal) of waste and/or loss of ore, with significant financial repercussions. The application of a consistent terminology such as that outlined above will also help to establish a more precise explanation of the condition of a slope for nonpractitioners such as management and other stakeholders. verall') failures tend to occur for MSII values greater than 60.The newly proposed MSII has been validated by comparing our MSII-based predictions with the actual (i.e. observed) behavior corresponding to 12 independent case histories of the 'validation' dataset. An excellent agreement between predictions and observations has been found, with only one (out of 12) case providing an incorrect prediction (it predicted 'set of benches failure' vs. the observation of 'overall failure'), hence confirming the validity of the proposed approach. However, the MSII does not aim to substitute the traditional engineering approach to solving slope stability problems (i.e. assessing rock mass conditions, determining probably failure modes, conducting stability analysis, interpreting the results) but, rather, it aims to serve as a fast and simple field method that provides 'adequate' approximations to reality using only easily available input data. In this context, note that—despite the 'complex' mathematics behind the ANN-based calibration of the RES interaction matrix—the actual use of the MSII in the field is very simple, since it is just a simple sum of weighted parameter ratings, with weights provided herein (they are constant as long as the training database is not extended or modified), and with parameter ratings that can be easily rated in the field (they are specific for a given open-pit) following the procedures discussed. Finally, being an empirical method, the reliability of (in)stability predictions based on MSII could be improved as the database of the open-pit cases is extended, and as engineers and geologists become more acquainted with its use. (For instance, this may lead to future improvements in the definition of parameters or in the numerical evaluation of their categories.) In that sense, although the MSII has been proven to work well in a number of validation case histories, further validation case histories are welcome, since they will allow users to define better weighting factors and threshold values between hazard levels. (Note that, for large projects with plenty of data, they may even define site-specific values.) It is therefore important that users contribute to the maintenance and extension of the database, sharing their experiences with MSII in open-pit mines worldwide.

Earthquakes and landslides, rock falls

The term ‘rockfall’ is typically used for loose material that either falls or rolls from the faces. As such it is primarily a safety issue, although it could possibly be a precursor to larger-scale instability. Rockfall can be a symptom of poor design implementation, i.e. poor blasting and/or scaling practices. However, it may also result from degradation of the slope as a result of weathering or from freeze–thaw action. constraints defined by the designer. In this context, a key element in the designs is the acceptance criteria against which the designs are formulated. These must be clearly defined by management working in consultation with the slope designers and mine planners. As discussed in the following section, the available data and hence the level of confidence in the resulting designs generally improve with each successive stage in the development of an open pit mining project. However, the basic design procedures are essentially the same for all projects, with minor modification depending upon such factors as geology, groundwater conditions and proposed mine life. The following points describe the basic elements of each step. They are discussed in following chapters, cited in parentheses.

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