Rock engineering challenges

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Synopsis

Rock engineering is concerned with the design of rock structures generated by mining activities. Therefore, rock engineering designs have major implications for the safe recovery of mineral deposits and operating costs. The paper deals with a few challenges facing rock mechanics engineers operating in the hard rock underground mining environment in South Africa. Finally, examples are included, which may assist rock mechanics engineers in providing better designs, which could ultimately lead to further improvement in safety and lower operating costs.

Introduction

Engineering is defined as the application of scientific principles to such ends as the design, construction, and operation of efficient and economic structures, equipment and systems (Wagner, 1991). Satisfactory engineering design involves a design process. According to Hill (1983), the design process is a sequence of events within which the design develops logically.

The term 'engineer' is derived from the French word genie meaning 'ingenious'. Hence, ingenuity, creativity and innovation should be the aspiration of all engineers. The engineer's creative ability manifests itself in design. (Wagner, 1991)

In accordance with the above definition, the mission of rock mechanics engineers could be defined as follows: 'Our mission is to work in close collaboration with mine management and production personnel on the solution of rock stability and support problems which could affect the short- medium-and long-term profitability of the mining operation and the safety of the mineworkers through the development and application of rock mechanics and support principles and technology.'

Consequently, the goal of rock engineering should be to maximize utilization of the mineral resources, to minimize rock-related production losses and to reduce rock-related accidents. Therefore, the main rock engineering challenge should be to achieve this goal by considering all the relevant rock engineering design principles.

Rock engineering design

Design is the goal of rock engineering activity. Although impressive progress has been made in the field of underground mining, the knowledge accumulated has not been fully utilized in rock engineering design. While this situation may have been justified in the past, unacceptable safety records and low profit margins dictate an improved design philosophy for rock engineering. This situation can be improved by a better understanding of the design process.

Bieniawski (1988) discusses the design process in mining and concludes that mine design is a process based on empiricism and practical experience that does not qualify as engineering design in terms of the definition given in the introduction above. According to Stacey (2003), this lack of thorough engineering design in mining might be due to the following reasons:

- the variability of the rock masses in which mining is taking place
- the background training of those involved in rock engineering, which often does not include formal training or exposure to engineering design logic.

Stacey (2003) also states that there is often a misconception that analysis is design, and many sophisticated analyses, with little underlying validity in terms of input data and failure criteria, are often carried out. Analysis is only a tool to obtain answers to the problem

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that has been posed. If the input information is inadequate, and the concept or geotechnical model (including the interpretation of mechanisms of behaviour and choice of appropriate failure or design criteria) is incorrectly formulated, the answers obtained from the analysis may be scientifically correct, but will be wrong with regard to a valid design.

Stacey (2003) summarizes the design principles in rock engineering as defined by Bieniawski (1991, 1992). The principles are as follows:

- *Design principle 1: Clarity of design objectives and functional requirements*—One of the rock engineering design objectives should be to ensure that the hazardous effects of rockfalls and rockbursts are prevented. Unfortunately, this objective has not been met yet and it remains one of the major rock engineering challenges.
- *Design principle 2: Minimum uncertainty of geological conditions*—Rock masses in which mining takes place are very variable. Therefore, rock engineering design takes place in an environment of considerable uncertainty. The rock engineering challenge is to convince management to minimize the uncertainty by spending money on geotechnical investigations and by collecting more geotechnical data. The minimization of uncertainty will provide an environment in which more confident design can be carried out, and hence will reduce risk. The remaining uncertainty must be taken into account in the design by using a probability of failure approach. It is also important that the level of certainty/uncertainty in the geotechnical data be compatible with the level of certainty/uncertainty in the data relevant to the rest of the study.
- *Design principle 3: Simplicity of design components*—An important step in rock engineering design is to develop a geotechnical model. The model should be able to describe the likely behaviour of the rock mass and possible mechanisms of deformation and failure. Appropriate design (failure) criteria can then be decided on, design limits can be defined, required safety factor or probabilities of failure can be defined and an appropriate design analysis method be decided upon. The rock engineering challenge is to develop the geotechnical model before any analyses are conducted.
- *Design principle 4: State-of-the-art practice*—The rock engineering challenge is to use up to date concepts, analyses and methods.
- *Design principle 5: Optimization*—The rock engineering challenge is to minimize risk by optimising the design. This should be an iterative process as new information/data becomes available.
- *Design principle 6: Contractibility*—The rock engineering challenge is to implement the design safely and efficiently.

Examples of rock engineering design

The following examples briefly describe the impact of rock mechanics design on the economics and safety of underground mining operations.

Design of stable stope spans for shallow mining operations

Very few mines design stope panels according to a systematic design procedure or methodology. Rock mass characterization, estimation of rock mass properties, identification of potential failure modes, appropriate stability analyses and other elements of the rock engineering design process are often neglected. Instead, panel lengths are often dictated by the equipment in use and by previous experience under similar conditions. Consequently, stope panel collapses occur on most near surface and shallow mines. Although these incidents often occur during the off-shift period, they pose a threat to the safety of underground workers and to the economic extraction of orebodies. Hence, a methodology for the rock engineering design of stable stope panels between pillars is of vital importance for optimum safety and production in shallow mining operations.

Stope panel instability in shallow mines is often controlled by geological structures. Structurally controlled failures such as beam, block and wedge failures cannot be analysed adequately using rock mass classification approaches. Thus, although rock mass classification should form a fundamental part in the process of designing stable stope panels, particular emphasis should be placed on identifying the most likely failure planes and potential modes of failure. Appropriate analysis techniques should then be carried out in order to assess the stability of stope panels.

Design of stable pillars for bord and pillar and room and pillar mining layouts

The design of stable pillars for bord and pillar and room and pillar mining layouts in hard-rock underground mines are often based on the safety factor (SF) design criteria. The SF is defined as the ratio of the strength of the pillar to the load acting on the pillar and can be expressed as follows:

$$SF = \frac{Pillar\ Strength}{Pillar\ Load}$$

where:

$$Pillar\ Strength = K\frac{W_{eff}^{\alpha}}{H^{\beta}} \text{ and}$$

$$Pillar\ Load = \frac{\rho g h}{(1-e)}$$

where:

K = strength of the pillar rock mass material

W_{eff} = effective pillar width = $4.\frac{A_p}{R}$

A_p = the plan area of the pillar
R = the pillar perimeter
H = pillar height
ρ = density of the rock mass
g = gravitational acceleration
h = depth
e = extraction ratio
α and β are numerical constants

The above pillar strength formula is the only empirical pillar strength formula that has been tested against sufficient field data to be statistically reliable. Salamon and Munro (1967) carried out the most rigorous and thorough back-analysis of *in situ* data and showed that the values for K, α and β should be 7.2 MPa, 0.46 and 0.66, respectively. These values were derived for square coal pillars in South Africa.

Very few *in situ* back-analyses or pillar strength measurements have been performed in hard rock mining environments. Hedley and Grant (1972) back-analysed the behaviour of some uranium pillars in Canada and showed that K = 133 MPa, α = 0.50 and β = 0.75. These values were derived for competent rib pillars.

Wesseloo and Swart (2000) and Joughin and Swart (2000) conclude that rock mechanics engineers often use the Hedley and Grant (1972) power formula constants for designing stable pillars in geotechnical environments that greatly differ from that for which they were originally derived. They also show that significantly higher extraction ratios (approximately 10% higher) could be achieved by following an engineering design approach. Therefore, by using a similar design approach, site specific pillar designs could be carried out.

Support design

Earlier research by Bakker (1993) showed that the majority of rock-related accidents on hard-rock tabular mines in South Africa occur before support has been installed or between the face and temporary support or permanent support. This is the high-risk area where most operations take place. This is also the area where the installation of support is most difficult because of interference with other mining operations. Also, support installed close to the face is subjected to the adverse affects of blasting.

Part of the solution to the rockfall problem lies in the training and education of the workforce at the working face. Workers in this area should be familiar not only with basic support principles and standards, but also with the identification of the relevant hazards associated with the geotechnical area. This constitutes a major challenge to the rock engineering profession.

A further challenge is to design and implement face-support systems, which are not only compatible with other mining engineering systems in that area, but could also provide areal coverage between support units and between the last row of support and the working face.

Support systems should be evaluated not only in terms of technical parameters such as support resistance and yieldability, but also in terms of:

- ➤ The total cost per m^2 or per ton mined. Labour, maintenance and transport costs should be included in these costs
- ➤ The effectiveness of the support system. For example, the effectiveness could be evaluated in terms of stoping width reduction, the reduction in rockfall-related accidents or production losses.

The risk-cost-benefit analysis procedure described by Brummer *et al.* (1994) could be used to evaluate the risks and costs involved in various support options. The approach also provides a method of evaluating the need for upgrading support in the light of possible risks that could exist on a mine.

Stope design for deep mining operations

Rockburst control in deep tabular hard-rock mines is a key design consideration. Despite various shortcomings, the energy release rate (ERR) is still a good measure of the rockburst hazard in these mines. The only controlling parameter in this case is the average convergence, S_V. There are three possibilities of reducing the value of S_V, namely:

- ➤ to mine at the narrowest possible stoping width
- ➤ to fill the mined-out area with good quality backfill; and
- ➤ to leave strategically placed stabilizing pillars so as to minimize stope closure between the pillars.

The challenge is the physical control of the stoping width. Not only does this limit the average convergence in the mined-out area but, at the same time, it reduces dilution of the ore grade and impacts on the costs of hoisting and processing

Drilling and blasting

An excellent rock engineering design philosophy is offered by Hoek (Hoek, 1981, Hoek and Brown, 1980, Hoek and Londe, 1974):

The basic aim of any underground excavation design should be to utilize the rock itself as the principal structural material, creating as little disturbance as possible during the excavation and adding as little as possible in the way of concrete and steel support.....

Using the cause tree analysis approach (Roberts *et al.*, 1981), the rockfall hazard is caused by 'bad ground conditions' AND 'bad support'. Bad ground conditions are often caused or aggravated by bad drilling and blasting practices. Therefore, the first challenge should be to cause as little damage as possible.

Many will argue that drilling and blasting are not the responsibility of the rock engineering discipline. To the contrary, a strong and convincing case can be made that rock engineering starts with good drilling and blasting practices since these determine, to a great extent, the conditions of the rockwalls that have to be supported. Good drilling and blasting techniques could also assist in controlling the stoping width of narrow reefs. Not only does this limit the average convergence in the mined-out areas but, at the same time, it reduces dilution of the ore grade and impacts on the costs of hoisting and processing of the ore.

The use of explosives for rock breaking have always been a stumbling block to high face advance rates and good productivity. Therefore, the second challenge in terms of rock breaking should be to develop more cost effective non-explosive rock breaking technologies.

Controlled or destress blasting, on the other hand, could be used to reduce the risk of rockbursts by liberating the accumulated energy by safe and controllable means. As a result, the rock mass becomes destressed. This technique was first tried in the deep South Africa gold mines (Roux *et* *al.*, 1957), and was widely used later in several other countries, not only to reduce the risk of rockbursts, but also to improve ground conditions under high stress conditions where rockburst have become a major problem. Rock mechanics engineers are challenged to consider controlled blasting strategies proactively and to assist with the implementation.

Design of stabilizing pillars for deep mining conditions

In the case of extreme depths, it is necessary to introduce additional measures to reduce the convergence volume in the mined-out area. A decision has to be made whether to use backfill or stabilizing pillars. In the case of weak strata, the use of stabilizing pillars results in unacceptably high losses of ore reserves. This could have a significant effect on the life of the mine and overall revenue from the mining venture. Therefore, rock mechanics practitioners should not only design stabilizing pillars based on technical requirements, but also consider the financial implications of the design.

Siting of major footwall haulages

The distance below reef of footwall haulages in deep mines determine the length of the cross-cuts. From this point of view, the footwall haulage should be sited as close as possible to the plane of the reef. In this case, however, additional support would be required and provision has to be made for increased cost of maintenance. These costs are compensated for by reduced cross-cut development. The rock engineering challenge is to find the optimal solution based on rock mechanics and economic considerations.

Rockbursts

Rockbursts have been experienced in the gold mines of South Africa for approximately 80 years. Intensive research into the rockburst problem started in 1952 when, on the initiative of F.G. Hill, the Rand Mines Group and the South African Council for Scientific and Industrial Research (CSIR) joined forces to study rockbursts (Hill, 1954).

According to Barcza and Hill (1965), 'The ultimate aim, naturally, is to eliminate rockbursts, but it appears doubtful whether this target can ever be reached. To achieve a significant reduction in the frequency of occurrence or in the severity of rockbursts would in itself be a signal of success. Even to devise means which would ensure that rockbursts occur during off-shift periods or to develop a reliable warning system would be regarded as a most satisfactory achievement.'

Conclusions

The goal of rock mechanics engineering should be to maximize utilization of the mineral resources, to minimize rock-related production losses and to reduce rock-related accidents. Therefore, the main challenge for rock mechanics engineers should be to achieve this goal by considering all the relevant rock engineering design principles. By achieving this goal, the rock engineering profession will gain the acceptance and support from management which it deserves.

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