The link between the design process in rock engineering and the code of practice to combat rock fall and rockburst accidents

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Synopsis

The paper deals with the importance of design and of codes of practice in ensuring safe working conditions in mines. The design principles involved in the design process are dealt with, and the importance of a logical design process is emphasized. The links between the requirements for developing a code of practice, embodied in the existing guidelines for the preparation of such a code, and the design principles and process are considered in some detail. Finally, suggestions are included, which may provide improvements to the code and hence, ultimately, lead to further improvement in safe working conditions.

Introduction

Engineering design usually involves the development of a 'solution' (the design) to a known 'problem'. There is no unique solution, and different engineers will produce different solutions—some solutions will work better than others, but all solutions should 'work'. The reason that solutions are not unique is probably because of the very wide scope of the issues involved in design. In reviewing the engineering design process, Bieniawski (1991, 1992) quotes the definition of engineering design from ABET (1987):

'Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation. In addition, sociological, economic, aesthetic, legal and ethical considerations need to be included in the design process.'

Engineering design is an integral aspect of codes of practice to combat rockfall and rockburst accidents in mines, the preparation of which is mandatory for South African mines. The objective of the requirement to implement a code is to reduce the number of rockfall and rockburst related accidents—that is, to improve the safety conditions in mines. There is therefore a direct link between safety in mines and rock engineering design.

The design process

Satisfactory engineering design involves a design process. According to Hill (1983), as discussed by Bieniawski (1988), the design process is a sequence of events within which the design develops logically, and a process that provides a work plan in the planning of a design programme. A defined process can serve as a checklist of activities that must be carried out to ensure that a satisfactory design results. The defined process or methodology can be considered as a form of quality control that ensures that all aspects that should be taken into account in the design, are taken into account.

Bieniawski (1988) discussed the design process in mining, and concluded 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. This lack of thorough engineering design in mining might be due partly to the variability of the rock masses in which the mining is taking place, but is more likely to be due to the attitude that mining people often have – 'Our mine is different, and therefore what applies elsewhere, does not apply here.' This attitude has probably inhibited the development of good design practice and, in the rock engineering field, it is probably true to say that it is only since codes of practice have been required that many rock engineering personnel on mines have been exposed to the concept of design, rather than the concept of analysis. A second possible reason for the lack of thorough engineering design is the

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background training of those involved in rock engineering. Mining engineers often do not learn the design process explicitly, but pick it up implicitly as part of their training. In rock engineering there are also many non-engineers (geologists, in-service trained personnel, scientists, etc.) who have had no training or exposure to engineering design logic.

Design principles in rock engineering

Bieniawski (1991, 1992) dealt specifically with engineering design in the rock mechanics field. He defined a series of design principles that encompass a design methodology. The design principles are summarized below and the link between them and the design methodology follows. The design principles defined by Bieniawski will be dealt with below in the context of rock engineering in mines in which rockfalls and rockbursts occur.

Design principle 1: Clarity of design objectives and functional requirements

A statement of the 'problem' and a statement of the design objectives, taking account of any constraints that are present, to satisfy this problem, are essential to any design process. These statements clarify the design thinking at the outset. If this is not done, different engineers may interpret the problem differently and hence may design solutions for different problems.

With regard to rockfalls and rockbursts, a design objective should presumably be 'to ensure that the hazardous effects of rockfalls and rockbursts are prevented'. This is directly in line with the objective of the code of practice, which is to reduce the numbers of accidents resulting from rockbursts and rockfalls. Since rockfall and rockburst accidents continue to occur in South African mines, and since the rock-related fatality and injury rates in the industry have not reduced in the last 15 years (Adams, 2003), it may be concluded that this presumed design objective is not being met. It is possible that other design objectives may exist in the industry or that the formal statement of a design objective has not been satisfactorily considered.

Design principle 2: Minimum uncertainty of geological conditions

The rock masses in which mining takes place are very variable, which is true of any natural material. Rock engineering design therefore takes place in an environment of considerable uncertainty. In mining, which is almost always tightly cost controlled, there is usually an aversion to spending money on geotechnical investigations, with the result that geological conditions are often unknown or, at best, little known. An example of this is knowledge of jointing in the rock mass. For a civil engineering tunnel, a comprehensive site investigation is usually carried out, and this will involve mapping of joints and interpretation of their conditions and influences on stability. Although the South African gold mines have been operating for more than a century, there are no satisfactory data on jointing in these mines. In most of these mines, designs are carried out with inadequate knowledge of the *in situ* stresses, the rock material strengths and deformation properties, and the rock mass behavioural conditions.

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 method, for example, by using a probability of failure approach.

Design principle 3: Simplicity of design components

Designers often rush into carrying out complicated analyses using sophisticated analysis methods. These methods often require input data, the knowledge of which is very uncertain. There is therefore a mismatch between the sophistication of the method of analysis and the lack of sophistication of the input data available. The use of sophisticated analysis methods often leads to the false confidence that a good design analysis has been carried out. Bieniawski indicates that, in terms of the Simplicity Principle, a design should be broken down into a series of simpler components. In this paper it is suggested that the principle should be viewed, in addition, in its broadest context—simpler designs, design methods and design analyses are easier to understand and therefore likely to be more robust. Where there is a simple way, it is to be preferred to a complex or sophisticated way, provided that it addresses the design requirements.

An important step in rock engineering design is to develop a geotechnical model. This may be conceptual, but it is important to be able to describe the likely behaviour of the rock mass and the possible mechanisms of deformation and failure. Only once this has been done, can appropriate design (failure) criteria be decided on, design limits be defined, required factors of safety or probabilities of failure be defined, a design model (or models) be developed, and appropriate design analysis methods be decided upon. It is to be noted that these steps are carried out before any analyses are conducted. This will ensure that the design is appropriate, and as simple as possible.

Design principle 4: State-of-the-art practice

The implication of this principle is that up to date concepts, analyses and methods must be used whenever they are appropriate. In the case of the South African mining industry, there have been many rock engineering research projects carried out with the ultimate aim of reducing the numbers of accidents due to rockfalls and rockbursts. This research has provided many new concepts, analysis methods and support methods, but very few of the research findings have been implemented in the industry. From this observation it would appear that not enough attention is being paid to this design principle by the South African mining industry.

Design principle 5: Optimization

Risk integrally involves numerous factors including safety, cost, productivity, seismicity, water, labour, etc. Therefore, to minimize risk, designs must be optimized. In addition, since conditions in which mining is taking place (economic, political, mineral price, depth, seismicity, geology, etc.) change over time, it is likely that designs will need to be optimized again when conditions change. An optimized design will result from the evaluation of the output from alternative designs. Monitoring during the progress of mining (associated with the final stage of the design methodology, as can be seen in the table below) will provide data that may facilitate design optimization. An example of this is the use of seismic monitoring results to assist in the management of seismicity in a deep level gold mine (Murphy and Brenchley, 1999).

Design principle 6: Constructability

If the design cannot be implemented safely and efficiently it does not satisfy this principle and therefore is also not optimized. It will be necessary to review the design and repeat, either partially or completely, the design methodology.

Design methodology or process

The design methodology presented by Bieniawski (1991, 1992), corresponding with the above six design principles, is summarized in the ten steps given in the table below. The link is given between the step in the methodology and the corresponding principle. This methodology represents a thorough design process and can be used as a checklist to ensure that a defensible design has been carried out.

The role of analysis in design

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 science, whereas design is engineering. It may be observed from the table below that 'analysis', which involves analytical (including numerical), empirical and observational methods, occupies only one step of the overall design methodology, and is bridged by design principles 3 and 4. Analysis is only a tool to obtain answers to the problem 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. That is, the sophisticated analysis has provided results for the wrong problem. This illustrates that the other steps in the design methodology are in fact much more important than the analysis step—they are fundamental to a successful design, whereas the analysis simply follows from these other steps.

The role of monitoring in design

Monitoring is an extremely important aspect of design. It could range from being purely visual to the use of sophisticated instrumentation. One of the main aims of such monitoring should be to check whether the mechanism of behaviour of the designed structure or opening is as expected and whether the design criteria used were appropriate. If the behaviour and/or criteria are not as expected then it will be necessary to loop back to an earlier step in the process and reassess the design. It may even be necessary to carry out a completely new design. The sooner that monitoring information or data can be obtained the better, since costly errors and consequences will then have the best chance of being avoided.

The code of practice to combat rockfall and rockburst accidents in tabular metalliferous mines

As a result of the very serious history of accidents in the South African mines, the Leon Commission of Enquiry into health and safety in the mining industry was established, and the report of this commission was published in 1994. Falls of ground, including rockbursts, represented one of four main areas of concern identified. Following from this commission of enquiry, the Mine Health and Safety Act was promulgated in 1996. In terms of the Act, the Chief Inspector of Mines may require mines to prepare codes of practice, for example a code of practice to combat rockfall and rockburst accidents. A code of practice was a new concept in the mining industry, and guidelines for the preparation of a code were necessary. In the early development of a guideline for the preparation of a code of practice to combat rockfall and rockburst accidents, the following principles were taken into account (Gudmanz, 1998):

- stope and gully support require special attention
- the support rules should be based on the best available knowledge and experience
- support rules should be framed to take into account local conditions, and different parts of the same mine may require different support systems
- the nature and extent of the proposed support rules should be commensurate with the accident record on the mine
- the support system specified in the code should be installed as expeditiously as is reasonably practicable.

Although it is almost certain that the developers of the early guideline were not aware of the design principles defined by Bieniawski (1992), the above principles do overlap to a certain extent with some of Bieniawski's principles. For example, the second point above implies that support rules should be based on state of the art knowledge. The third point implies that knowledge of the geotechnical conditions in the mine should be good, and this corresponds with the principle of minimization of uncertainty.

The most recent guideline document drawn up (Department of Minerals and Energy, 2002) demonstrates a greater overlap with Bieniawski's design principles than indicated above, although again it is unlikely that those involved in developing the guidelines knew of Bieniawski's

Step	Description	Design principle
1	Statement of the problem (performance objectives)	1
2	Functional requirements and constraints (design variables and design issues)	1
3	Collection of information (site characterization, rock properties, groundwater, *in situ* stresses)	2
4	Concept formulation (geotechnical model)	3
5	Analysis of solution components (analytical, numerical, empirical, observational methods)	3, 4
6	Synthesis and specifications for alternative solutions (shapes, sizes, locations, orientations of excavations)	3, 4
7	Evaluation (performance assessment)	5
8	Optimization (performance assessment)	5
9	Recommendation	6
10	Implementation (efficient excavation and monitoring)	6

principles and design methodology. Areas in which there is correspondence with the principles and methodology are identified in the following.

- ➤ Sections 5.2 'Geological Setting' and 5.3 'Mining Environment' deal with collection of information and are relevant to the design principle 'Minimization of Uncertainty'.
- ➤ Section 5.4 'Ground Control Districts' deals with the division of the mine into areas in which similar geotechnical behaviour is expected. This implies careful attention to the reduction of uncertainty, which is particularly relevant to this design principle.
- ➤ Section 5.5, dealing with mine rockfall and rockburst incident analysis, provides background to the design objectives and the identification of the risks to be addressed in the code. However, a particular design objective, or design objectives, are not dealt with specifically.
- ➤ In the introductory part of Section 8, dealing with aspects to be addressed in the code, design objectives are considered in general terms. However, as with Section 5.5, a particular design objective, or design objectives, are not dealt with specifically.
- ➤ In Sections 8.1, 8.1.1, 8.1.2, 8.3, 8.4, 8.5, 8.6 and 8.7, design issues are dealt with, and design methodology and criteria are referred to. Section 8.9 specifies that design methodologies used must be properly motivated and documented. These design issues are relevant to design principles 3 to 5 in general terms.
- ➤ The whole of Section 8.8 and parts of Section 8.2 deal with monitoring, which is relevant to evaluation, optimization and implementation in the design methodology and to design principle 5.

It can be seen from the above that there is significant overlap between the defined requirements for drawing up a code of practice and the rock engineering design methodology and principles presented by Bieniawski (1992). However, it is considered that there is insufficient overlap in certain areas to ensure that the design process followed is adequately robust. These areas are dealt with in the discussion below.

Discussion and conclusions

The main areas in which there is a lack of sufficient overlap between the guidelines for drawing up a code of practice and the design methodology and principles are considered to be the following:

- ➤ Design objectives are dealt with in very general terms and specific design objectives are not demanded. It is considered that a requirement for statements on specific design objectives would focus attention and would also provide specific targets against which design methodologies, actual designs, and performance achievements could be assessed. Design objectives should represent the philosophy and commitment of corporate and senior mine management. Possible examples of specific design objectives are the following:
  - to obviate falls of ground in working areas
  - to reduce fall of ground incidents by X% per year
  - to prevent any accidents due to falls of ground;
  - to achieve accident rates better than or equal to those in …… (e.g. USA, Australia, Canada, Europe, etc.).
- ➤ Minimization of uncertainty is not given enough emphasis. It is impossible to carry out adequate designs if the information on which the design has to be based is inadequate. It is common in mining that insufficient attention is given to the collection of geotechnical information ahead of the design requirement, and that the collection and documentation of available information from exposed, encountered conditions are usually ignored. It is most important that geotechnical conditions are quantified, for example, by using rock mass classifications. The use of classification methods is now common on the platinum mines, and provides a basis for unambiguous understanding of the quality of the rock mass. Routine classification will allow for meaningful correlation to be carried out between rock mass conditions and many other factors such as rockfall incidents, advance per blast, rate of face advance, production, etc.
- ➤ Insufficient 'thought' is given to methodology steps 4, 5 and 6. It is apparent that standard design and analysis approaches are often used on an ongoing basis, without any evaluation process as to whether they are actually applicable and appropriate. Too often, designs are simply analyses, carried out by rote rather than with careful engineering understanding.
- ➤ There is usually insufficient evaluation of behaviour. Physical monitoring, except for seismic monitoring, is carried out on a very limited basis. As indicated above, unambiguous quantification of conditions is necessary and this could be done from careful visual observation. Monitoring is important since critical independent evaluation of behaviour is essential for determining whether the design methods used, and hence the designs implemented, are valid, or whether the designs should be revised. Independent audits of design methods and designs, as are commonly carried out in civil engineering, are a means of controlling the quality of design work.
- ➤ Finally, optimization of designs is important to minimize problems. Designers need to have considered alternative designs so that they can justify the design that they have actually adopted.

It may be stated that the codes of practice that have been implemented are very important documents. They require the mines to consider and document their design criteria and methodologies, which are fundamental to good design. However, it is considered that the following suggestions could improve the quality and impact of the codes on safety in the mines:

- ➤ Specific design objectives should be required, against which performance can be measured quantifiably.
- ➤ More real investigation of geotechnical conditions, to minimize uncertainty, and comprehensive monitoring of behaviour, using quantified observational or physical monitoring methods, should be required to provide solid foundations for design.

➤ Regular evaluation of designs, taking into account the monitoring and quantified observational data, should be required to ensure that designs remain valid. Independent auditing of the designs is a means of quality control.

In conclusion, it is considered appropriate to review the accident record in South African mines in the context of a thorough design process. Figure 1 shows the statistics on fatal accidents over the past 20 years (Adams, 2003), and it can be seen that there has effectively been no reduction in rock-related fatality rates in the gold mines over this 20-year period and that the rates for platinum mines are trending slightly upwards.

The fact that there has been no reduction in the fatality rates implies that there has been no improvement in the design, and therefore that there has been no feedback loop linking observations to changes in design, to improve the design. In this context, design refers to the overall design process, which includes both design of the mining method and design of the support. In the mining method for narrow tabular orebodies, the majority of mining and supporting activities, and hence mining personnel, are concentrated in the stope face area, and it is in this area where most accidents occur. Since rock-related accidents imply failure to prevent rockfalls in the stope face area, it may be concluded that the designed support is inadequate or the design itself (which includes lack of support) is inadequate, or both are inadequate.

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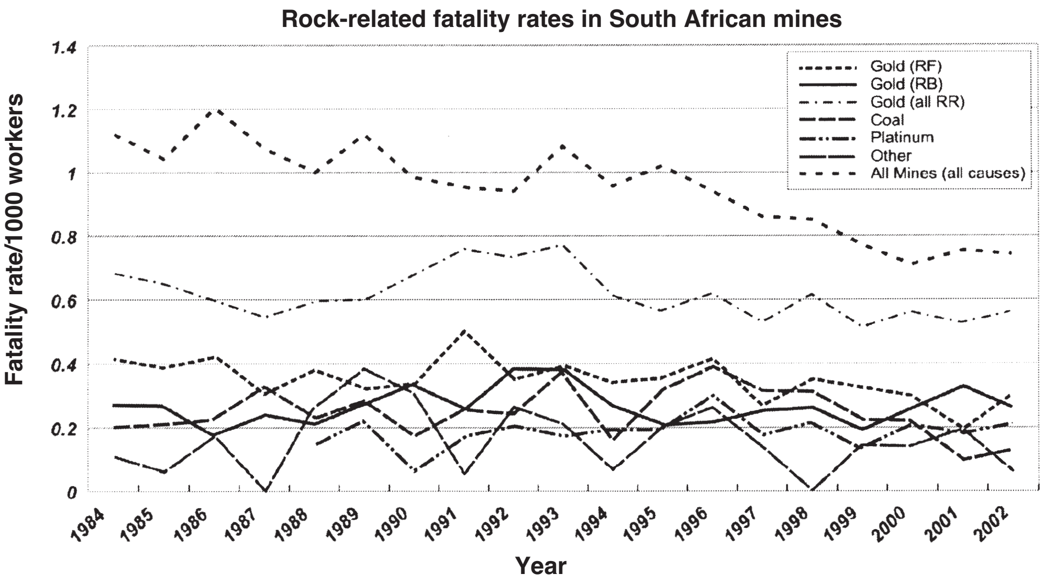

Figure 1 Accident statistics for South African mines (Adams, 2003)

De Beers' Finsch Mine safety record accredited by the Mine Health and Safety Council*

The Mine Health and Safety Council has awarded De Beers' Finsch Mine the Safety Achievement Flag, in the category 'other mines', for its consistent and best safety improvement record over the last three years.

Finsch Mine is the first De Beers' mine to receive this award under the Mine Health and Safety Council Award Scheme, which took ownership of the scheme from the Chamber of Mines in 2000. Deputy Chief Inspector of Mines George Mojapelo presented the flag to general manager Mike Brown at a flag raising ceremony at the mine on 20 January 2004.

Speaking at the ceremony, Mike Brown said: 'Such an achievement does not happen by chance but is the result of dedication from management and employees, induction programmes, training, and a behaviour-based safety programme. Worth mentioning is the outstanding co-operation we have with our contract workers, most of whom are employed in the high risk underground sections, but who have managed to maintain an impressive safety record.'

Awarding the flag, George Mojapelo said: 'Luck had nothing to do with Finsch Mine's achievement, because not only has the mine been awarded the Safety Achievement Flag, it has also achieved NOSA 5 Platinum Star Status, came second in the Northern Cape underground mines' competition and achieved 95% in the Department of Minerals and Energy (DME) audit.'

The mine has not had a fatality in seven years and also qualified for three million fatality-free shifts during December 2003.

Each year, the DME assesses the safety risk of each participating entity and compares it to the previous year's record, to establish whether there has been any significient improvement. The final evaluation is conducted by a panel convened by the DME to determine the best performer in each category: ultra deep gold and platinum mines (>2 000 m), shallow to deep gold and platinum mines (<2 000 m), coal mines, and other mines. ◆

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Upgrades enhance caterpillar underground mining machines*

Three Caterpillar underground mining loaders from the Caterpillar Elphinstone stable–models R2900G, R1600G and R1300G—have been upgraded for improved performance across several key areas.

The R2900G features advanced electrical systems on all variants, including the R2900G XTRA (20 metric tonne capacity) that now also benefits from larger 35/65 R33 tyres for prolonged tyre life when operating at maximum carrying capacity in high cycle applications.

Both the R2900G and the R1600G (as well as the R1700G) incorporate new Caterpillar ACERT™ engine technology that improves emission levels by meeting the US EPA Tier 2 regulations on diesel exhaust emissions. Manufacturers are required to improve emission/economy levels in three stages or 'tiers' to meet set EPA guidelines by 2007.

By incorporating the new Tier 2 technology, Caterpillar Elphinstone's customers benefit immediately from the latest improvements in the drivetrain system.

The R1300G now features a more efficient electrical system, improved operator station ergonomics, as well as increased ground clearance at the rear of the unit. The carrying capacity of the R1300G has been increased from 6.5 to 6.8 metric tonnes.

'These upgrades effectively place us way ahead of the South African requirement to reduce emissions,' says Andy Watt, product manager: underground for Barloworld Equipment Mining. 'This is only the beginning as Caterpillar is now moving towards Tier 3 engine certification for this model and plans to incorporate this into its units in the coming year.' ◆

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