Setting the scene: rockpass accident statistics and general guidelines for the design of rockpasses

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Journal Paper

Synopsis

Records over the past ten years indicate that there is potential for serious multiple accidents due to engulfing associated with rockpasses. Significant attention is not usually given to the design of rockpasses, with the implication that mistakes leading to poor performance of the passes are often repeated. This paper outlines general guidelines for the design, support, operation and rehabilitation of rockpasses based on information obtained from the limited amount of literature on the subject.

Introduction

Rockpasses are widely used in the underground mines of South Africa. In the tabular mining environment, a very large number of short stope rockpasses are used. In these mines, the main rockpass systems associated with shafts are much longer. In the massive mining environment, which involves some of the diamond mines and base metal mines, the rock transport and handling systems often include major rockpass systems, used for both interim storage of ore and for transfer of ore to the loading arrangements at the bottom of the shaft.

In this paper, accident statistics over the past 10 years are presented and general guidelines are summarized for the design of rockpasses. The information contained in the paper results from a review of literature on the subject. Specific reference to publications will not be made in the paper, since the content is general. However, a bibliography is included of publications from which material has been sourced.

Rockpass accidents in South African mines

In the context of this paper, which represents an introduction to rockpass design and the problems experienced in rockpasses, it is appropriate to review the numbers and types of accidents that are related to rockpasses. The South African Department of Minerals and Energy (DME) maintains a database of reportable accidents (SAMRASS - South African Mining Reportable Accidents Statistics System). Details of accidents are recorded, including numbers of accidents, numbers killed and injured, type of accident and location of accident. These records, presented in the following figures, illustrate that the numbers of accidents have reduced in the last 10 years, but appear to have plateaued in the last 5 years. Over these last 5 years, the average has been about 6 reportable rockpass accidents per year and 3 deaths per year.

It can be seen from the above records that rockpass accidents remain significant. It is also likely that, in addition to the accidents, there are many rockpass related incidents in the industry that have fortunately not resulted in accidents. The above records also indicate that engulfing accidents, in particular, have the potential to cause multiple injuries and fatalities. Such accidents are particularly dependent on pass performance and operation, which, in turn, are dependent on good initial pass design.

Pass design

The design of passes includes the definition of pass location, orientation, size, shape, length, method of excavation, support, system geometry and operating principles. Storage capacity and required operating life may also be important. Design considerations should be aimed at avoiding problems in the passes. The problems experienced in passes are defined as any occurrences that cause the pass to operate at less than the designed performance level.

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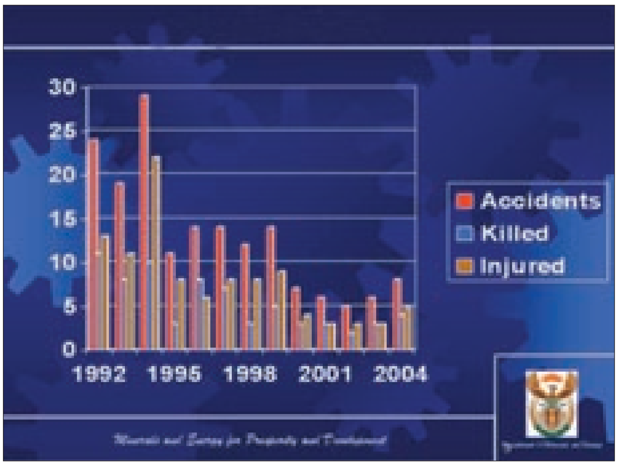

Figure 1—Accident record: falling into rockpasses (source B.J. Erasmus, DME)

Figure 2—Locations of accidents: falling into rockpasses (source B.J. Erasmus, DME)

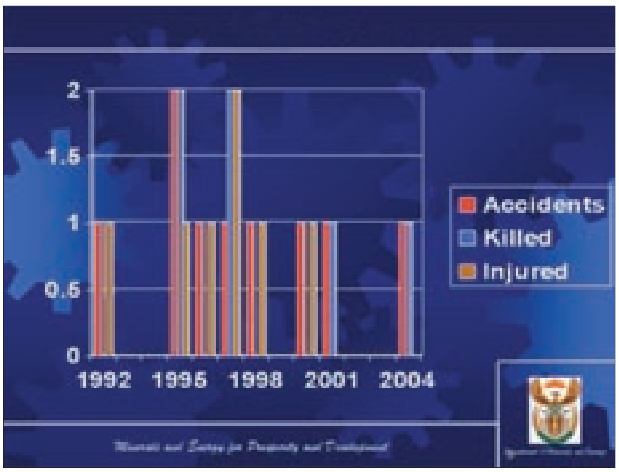

Figure 3—Accident record: drawn in by rockpasses (source B.J. Erasmus, DME)

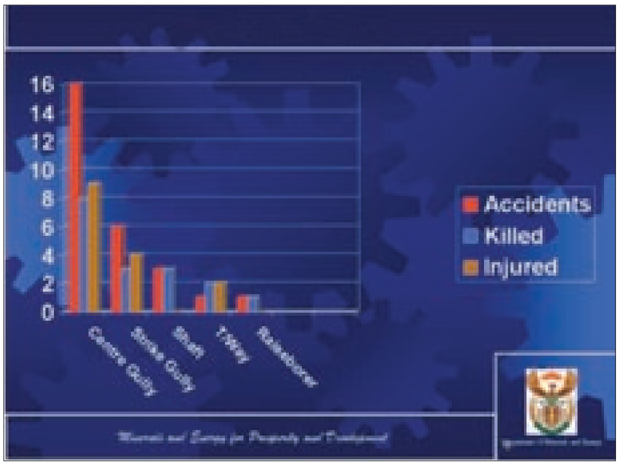

Figure 4—Locations of accidents: drawn in by rockpasses (source B.J. Erasmus, DME)

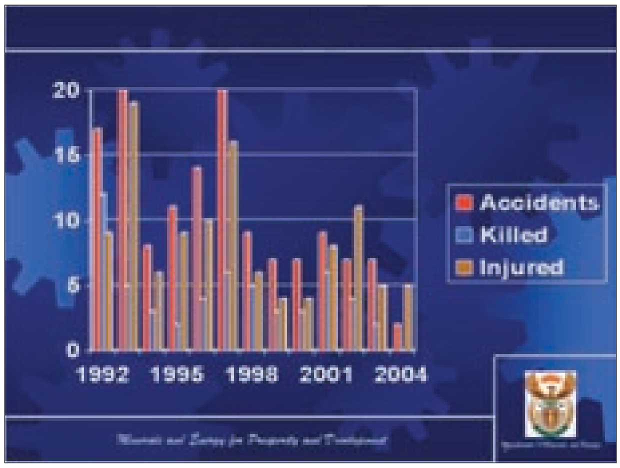

Figure 5—Accident record: engulfed by material from rockpass (source B.J. Erasmus, DME)

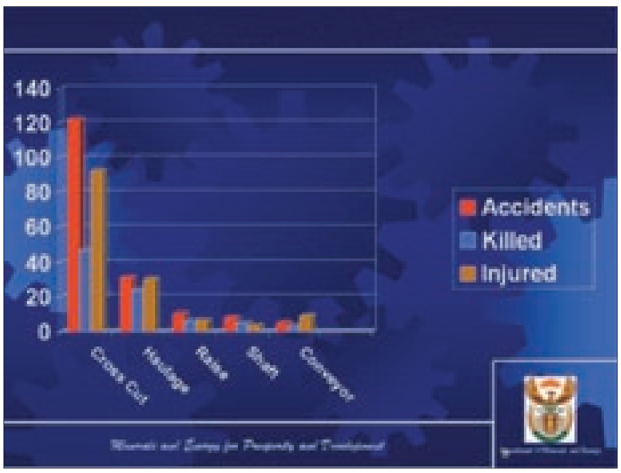

Figure 6—Locations of rockpass engulfing accidents (source B.J. Erasmus, DME)

Setting the scene: rockpass accident statistics and general guidelines

It is considered appropriate to include in this paper information on a recommended general design process. Diligent attention to a process such as this will ensure that a defensible design is produced.

Bieniawski (1991, 1992) defined a series of six design principles that encompass a design methodology. The design principles are summarized below:

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, is essential to any design process. These statements clarify the design thinking at the outset.

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, and 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 incurring costs on geotechnical investigations, with the result that geological conditions are often unknown or, at best, little known. Designs are often 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.

Design principle 3: simplicity of design components—Bieniawski (1991, 1992) indicates that, in terms of the simplicity principle, a design should be broken down into a series of simpler components. It is suggested here 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.

An important step in the design of a rockpass 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 in which the pass is located and the possible mechanisms of instability. 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. 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.

Design principle 5: optimization—Risk integrally involves numerous factors including safety, cost, productivity, seismicity, water, manpower, etc. Therefore, to minimize risk, designs must be optimized. An optimized design will result from the evaluation of the output from alternative designs.

Design principle 6: constructibility—If the design cannot be implemented safely and efficiently it does not satisfy this principle and therefore is also not optimized.

The design methodology corresponding with the above six design principles is summarized in the ten steps given in Table I 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.

Common problems experienced in passes

Common problems experienced in the development and operation of passes are summarized very briefly in the following sub-sections.

Hang-ups

Hang-ups are due to arching of material within the pass, which may have several causes:

- blocks of rock too large for the size of the pass. These may be the rock blocks, which have been tipped, or may result from scaling or collapses from the walls of the pass
- foreign material entering the pass such as steel supports, rock bolts, timber and grout flows
- cohesive arching, which occurs particularly when fine wet material is present ('sticky ore'). Sticky material probably causes the majority of problems in passes and resulting blockages and hang-ups are most difficult to clear. Interaction with other factors such as water, roughness, inclination, bends, compaction, etc. is relevant. The main effects are:

Table I

Design methodology

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

- compaction of the material occurs when sticky material dries out in the pass
- compaction of material due to the impact from the fall of the material
- sticky material may adhere to the sides of the pass, reducing its effective size. This is particularly so at bends and constrictions; and
- sticky material can cause small particles to adhere together to form much larger particles. The resulting pass size to particle size ratio may then be adverse for hang-ups. When sticky material is present, the risk of runaways and mud rushes is greater.

Hang-ups occur commonly in passes. Information from 3 600 passes in gold mines shows that 35% of the passes were subjected to hang-ups, blockages and runaways (Emmerich, 1992).

Blockages

Blockages usually occur at the chute or box-hole beneath the pass, where there is a constriction. Blockages can lead to runaways, particularly if water is present.

Collapses

Collapses may occur within the pass as a result of instability due to the geological structure, scaling due to high stresses, and wear of the pass. Collapses can lead to hang-ups and blockages.

When stress exceeds strength, scaling can occur, leading to collapse and subsequently to hang-ups and blockages. Scaling is exacerbated by the passage of rock down the pass.

Abrasion of the surfaces of the pass, plucking out of rock blocks from the surfaces of the pass, and impact damage are all included in the 'wear' category. Wear leads to enlargement of the pass, to collapses and ultimately to hang-ups and blockages.

Runaways

Runaways are the uncontrolled flow of the contents of the pass past the control chute, and include mud rushes. They are associated with excess water, and often with 'sticky' material and compaction conditions.

Recommended pass design and operating guidelines

In the following sub-sections, general guidelines relevant to rockpass design, development and operation are summarized. These sub-sections deal with aspects that should be taken into account in the planning and design of passes.

Location of passes

In the mine design process, locations of passes should be chosen to avoid poor rock if possible as illustrated graphically in Figure 7. If this is not possible, lining may be necessary.

Orientation of passes with respect to geological structure

Failure occurs more readily for some orientations with respect to the geological structure than for others. In stratified rock masses, passes should be orientated to intersect the strata as near to perpendicularly as possible. This is illustrated in Figure 8.

Orientation of passes with respect to stress

In high stress conditions, the best pass orientation with respect to the stresses is sub-parallel to the maximum principal stress. If other factors allow, this orientation should be used if it is suitable.

Size of pass

The risk of hang-ups due to rock arching is a function of the size of the pass with respect to the size of the rock blocks being passed. To minimize the risk of hang-ups, the size of the pass should be 5 to 6 times the size of the largest fragment of rock being passed. This is illustrated graphically in Figure 9.

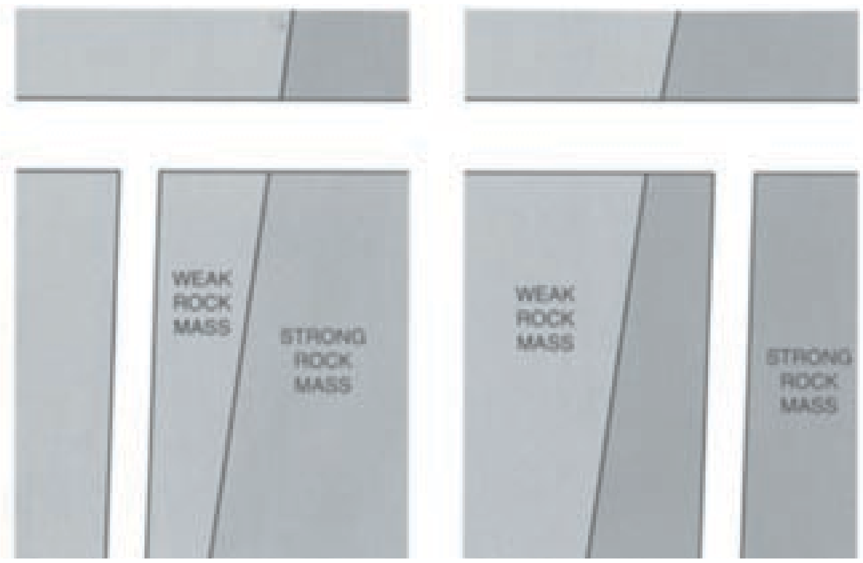

Figure 7—Recommended location of pass with respect to rock quality

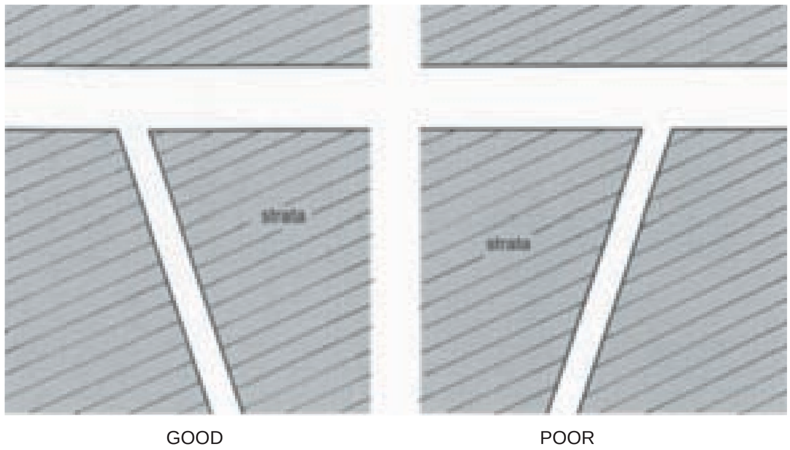

Figure 8—Preferred orientation of pass relative to the strata dip

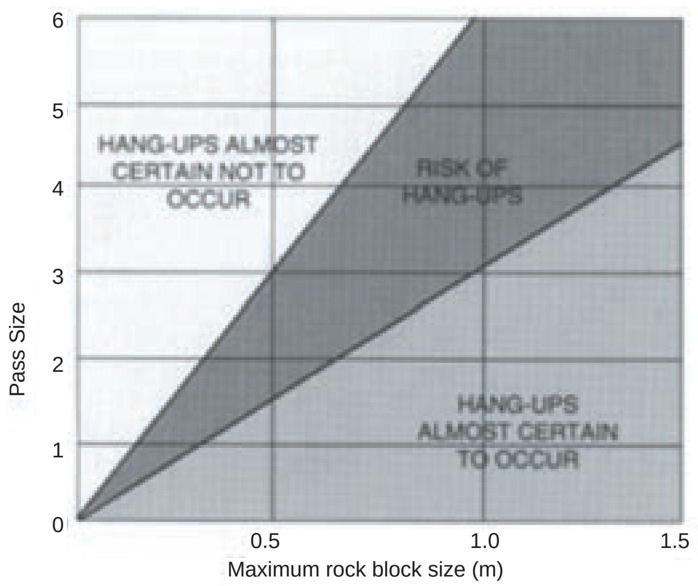

Figure 9—Indication of pass size relative to rock fragment size

If the material being passed contains more than 20% fines, the risk of cohesive arching is present. The size of pass required to cater for this risk is dependent on the value of cohesion as shown in the guideline diagram, Figure 10.

Inclination of pass

The effects of pass inclination are summarized in Table II. The minimum recommended inclination is 55°, which is applicable for dry ore that flows well. In general, the pass inclination should be greater than 60°, and even steeper if wet fines are present.

Length of passes

The longer the pass, the more likely it is to have problems, owing to:

- the greater extent of rock mass traversed
- the greater velocities that material can attain; and
- the greater difficulty of access to clear a hang-up or blockage and when rehabilitation is required

Passes with leg lengths of less than 50 m have rarely had problems.

Method of excavation

The comparative effects of boring and drill and blast excavation are given in Table III. Footwall roughening of bored passes can overcome the adverse effects, and increases the pass size. Blasted passes tend to be larger than bored passes for the same requirement and therefore direct comparison is difficult.

Water in passes

Water entering passes from whatever source is adverse, since:

- formation of sticky ore is likely
- the risk of hang-ups and mud rushes is increased and the flow of rock is affected.

Uncontrolled inflow of water should therefore be prevented. Sealing of passes by grouting may have benefit to pass operation in the long term.

Pass system geometry

The geometries of bends and branch intersections are

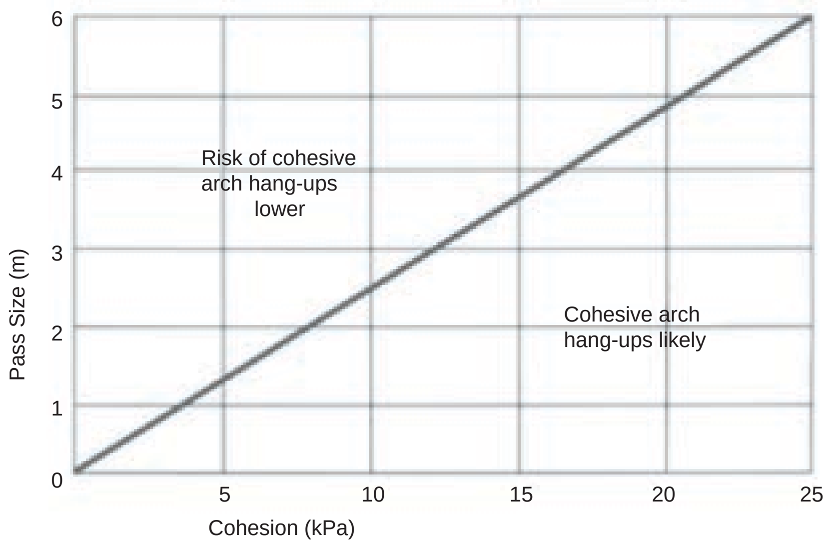

Figure 10—Guideline pass size with regard to 'sticky' material

Table II

Influence of pass inclination

Parameter	Steeper inclination	Shallow inclination
Velocity of rock	Higher. Rocks bouncing against walls can cause damage	Lower
Impact	High. Can cause compaction	Low. Impact for vertical passes can be about 4 times that for 50° passes
Wear	Lower. Only impact damage due to velocity	Higher due to sliding of material on footwall
Length	Shorter	Longer for the same vertical interval
Hang-ups	Less likely. High compaction main adverse effect	More likely. Slower movement of ore, accumulation of material (particularly 'sticky' ore), greater length, are main adverse effects

Table III

Influence of method of pass excavation

Parameter	Bored excavation	Drill and blast excavation
Stability	Better, due to smooth cutting action	Worse, due to blast damage, drilling inaccuracy
Flow of rock	Fast—greater compaction and wear	Slower—greater possibility of accumulation of material
Hang-ups	Less likely—compaction is adverse influence	More likely for same size

important, since they are locations subject to wear, impact, and slowing of material flow, and are therefore more likely locations for hang-ups. Sizes of branches and main passes must ensure that constriction does not occur, as illustrated in Figure 11.

Operating methods

Advantages and disadvantages of controlled and uncontrolled passes are summarized in Table IV. To minimize the risk of hang-ups, material should be drawn regularly to keep the rock column moving. This is particularly important if water is present. This will prevent the consolidation of the material in the pass as far as possible.

Clearing of hang-ups and blockages

Once a hang-up has been located, there are several ways in which it can be cleared, for example:

- bombs (explosives) placed in various ways—blasting sticks, balloons, 'sputniks'
- slug shots. If the hang-up is due to the presence of sticky material, slugshotting may exacerbate the problem
- boreholes drilled from the top of the pass through the rock material and explosives pulled up against the blockage. This is a high-risk method
- explosives placed through percussion holes drilled from upper or lower levels
- use of compressed air and water injected through percussion holes drilled from upper or lower levels
- undermining of sticky ore hang-ups using high-pressure water and air.

Permanent access points into the pass can be beneficial in clearing hang-ups. In clearing hang-ups using explosives, it is the concussion that is usually relied on to loosen the hang-

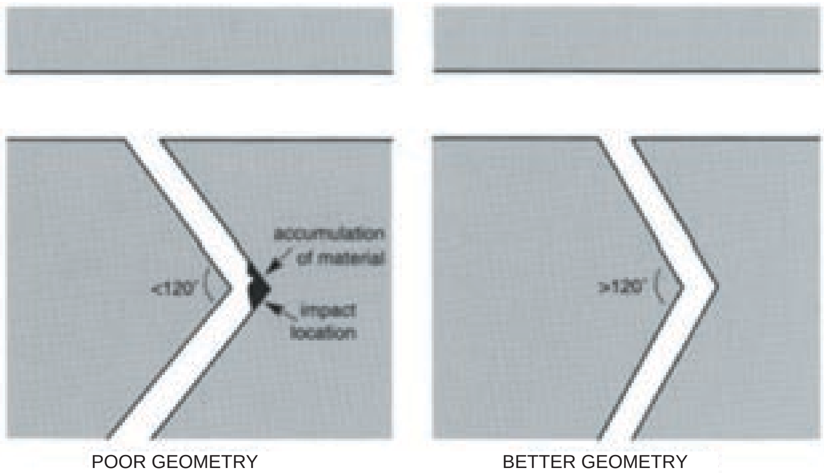

Figure 11—Effect of pass system geometry

Table IV

Influence of operating methods on passes

	Controlled passes	Uncontrolled passes
Advantages	Confinement by rock material promotes stability Reduced impact wear Reduced scaling Collapses minimized Impact compaction reduced	Reduced risk of block arch hang-ups Reduced risk of sticky ore hang-ups Access from top down if necessary
Disadvantages	Hang-up risk due to block arching increased Hang-up risk due to sticky ore compaction increased Increased hazard when clearing hang-ups due to the fact that the pass is full	Reduced stability since no confinement Scaling and collapse risk increased Impact wear Impact compaction increased Damage to box fronts and chutes

ups. The use of explosives is likely to damage the walls of the pass, which can produce geometry changes or roughnesses that can be the nuclei for further hang-ups.

The use of water to assist in clearing of hang-ups in passes can be dangerous since it may lead to mud rushes.

Support of passes

Support is not commonly installed in passes in South Africa. However, the risk of deterioration of passes, hang-ups and blockages may be reduced by implementing support—rock reinforcement, shotcrete, concrete or steel lining—or a combination of these measures. The requirement for support is a specific design consideration that is not addressed in this paper. In summary it will depend on:

- geotechnical factors: rock mass quality, geological structure, *in situ* stresses, stress changes, rock material strength
- construction factors: method of excavation, size, shape and inclination and
- planning factors: desired life, tonnage to be handled, strategic importance, time between excavation and usage.

Rock bolt reinforcement has been used frequently, but not with much success. In blocky rock and scaling rock situations, wear of the pass causes the rock in between the bolts to fall out. Conventional rigid rock bolts are usually inappropriate, since rock impact causes vibrations in the bolt that destroy the bonding of the bolt. Fibreglass bolts and wire rope reinforcement do not have the same disadvantages. Rock reinforcement should be installed in upward-inclined holes so that any impact from material flowing down the pass does not contact the support at an acute angle.

In weak rock, or in fissile, scaling or closely jointed blocky rock, a lining may be the only way of supporting the rock and preventing uncontrolled growth in the size of the pass. When wear is a problem, special types of lining have been used such as corundum and andesite lava based shotcretes and concretes, and steel fibre reinforced concrete. In non-vertical passes, a greater thickness of lining on the footwall, to accommodate wear, increases the life and stability of the pass.

Precast concrete pipes, both in full circle form and as segments, have been used successfully for lining of passes. Steel liners, in the form of complete ‘tubes’, as steel rails set in concrete, or as a combination of both, have also been used.

‘Support’ and steel items in particular are foreign material which, when worn and loosened, can be the cause of hang-ups.

Rehabilitation of failed passes

Pass rehabilitation options include, for example:

- obtain access and install support

install a steel tube or concrete pipe and backfill around this with concrete or waste rock
fill pass cavity with concrete and waste rock, and rebore the pass through this concrete
grout the material blocking the pass and rebore a hole through the grouted mass
replace the pass by reboring or redeveloping a new pass.

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