Review of membrane support mechanisms, loading mechanisms, desired membrane performance, and appropriate test methods

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Synopsis

Excavations in rock are commonly supported with wire mesh, shotcrete, wire mesh and shotcrete in combination, and shotcrete reinforced with various types of fibres. Wire rope lacing and various types of straps are additional forms of support installed over the above types, to cope with severe conditions. These support systems are very important items of 'membrane' rock support. With the recent development of several types of thin sprayed linings, the importance of membrane support is likely to increase in the future. In this paper, a wide range of mechanisms of membrane behaviour, and mechanisms of loading of membranes, is described. The concepts of membrane components, which are single membranes that may be used on their own as rock support, and membrane systems, which are combinations of more than one membrane component, are introduced.

Different situations have different requirements of membrane support, and differences between civil engineering and mining requirements are highlighted. With the different basic requirements in these two areas, the requirements of rock support are correspondingly different. A thorough understanding of the mechanisms of behaviour of the different types of membranes, and the different mechanisms by which the membranes are loaded, is essential before a selection of appropriate support can be made, before appropriate design methods and calculations can be determined, and before appropriate performance test methods for membranes can be defined. The material in this paper contributes towards the understanding of membrane support behaviour.

Introduction

Excavations in rock are commonly supported with wire mesh, shotcrete, wire mesh and shotcrete in combination, and shotcrete reinforced with various types of fibres. Wire rope lacing and various types of straps are additional forms of support installed over the above types, to cope with severe conditions. This type of support has been referred to as 'containment' support, in contrast with 'retainment' support, which consists of rockbolts, dowels, cables, etc. (Stacey and Ortlepp, 1999; Ortlepp *et al*., 1999).

Recently, new types of thin sprayed linings, sometimes referred to as 'superskins' have been developed, their aim being to provide replacements for the traditional forms of containment support. These thin sprayed linings have the advantages of low volume, rapid application and rapid curing. These are all properties which will ease logistics, improve on cycle times, increase mechanization, and improve safety.

All containment support elements will be referred to as membranes in this paper. At one end of the scale, the membrane may be in the form of a structural lining, which may be designed using conventional structural engineering techniques. In this case the membrane is likely to be a thick application of shotcrete, which will be very stiff support, and the purpose will be to prevent any rock failure, or at least, if some rock failure has taken place, to prevent its further development. At the other end of the scale, failed rock will be contained by the membrane in a 'basket'. The type of membrane in this case could be a flexible wire mesh. Rock failure might continue, but it is possible that its development might be inhibited to some extent by the containment.

Containment support is applicable in both the civil engineering and mining engineering industries. The requirements of the support may be, and probably will be, very different in these two situations. Mining excavations are created to extract ore as economically as possible. Mining considerations are:

- safety must be ensured where there is human access
- stresses acting on mining excavations may change as a result of the mining process
- the concept of 'stability' in mining varies:
  - in caving mining, instability is a requirement for successful and safe mining

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  - in open stoping, stopes must remain substantially stable
  - service excavations such as shafts and main access tunnels must be stable for their required life span.
- failure may relate more to serviceability than to failure of the rock or support—as long as the excavation remains open and allows efficient operation, it has not failed. Excavations should be close to their stability limit. If no excavations fail, then it is probable that they are being too conservatively, and hence uneconomically, designed
- 'time'—since mining economics are critical, it is inappropriate to design an excavation to be stable for longer than the required life.

Different mining excavations must be designed for different probabilities of failure, and the values of all of these probabilities will be much higher than those for civil engineering excavations. In contrast, civil engineering requirements commonly are:

- long-term stability (often say 100 years) as there is usually some public access to most excavations
- stability and support, which must be commensurate with the projected life of the excavation. The cost of planned support is usually small in relation to the overall project cost
- no cracking of concrete or shotcrete, since this may be interpreted as failure. Excavations must be designed for a very low probability of failure
- no failures, since the consequences of failure may be severe.

With the different basic requirements, as indicated above, the requirements of rock support in the two situations are correspondingly different. A thorough understanding of the mechanisms of behaviour of the different types of membranes, and the different mechanisms by which the membranes are loaded, is essential before a selection of appropriate support can be made, before appropriate design methods and calculations can be determined, and before appropriate performance test methods for membranes can be defined. Such testing is essential to determine the capacities of the various types of membrane support, which, in turn, are essential inputs for the design of support. It is to be noted that, for a support system to be optimal, the capacities of retainment and containment support elements must be matched. Therefore, there is little point in using a membrane with large deformation capability unless the retainment components of the support system have compatible characteristics. It is possible that badly matched components may perform better than they should do, owing to poor quality installation, which allows 'undesigned' yield to take place and to reduce the likelihood of failure of inadequate elements (Stacey and Ortlepp, 1998).

Mechanisms of behaviour of membrane support

In this paper, an attempt has been made to categorize various mechanisms of membrane behaviour, which might be applicable as the membranes fulfill their function of providing rock support. Some mechanisms have been described by Brown (1999), but no other publication has been found that summarizes the wide range of mechanisms that might occur individually and in combination.

Promotion of block interlock

The effect of this mechanism is the preservation of the rock mass in a substantially unloosened condition. There are several sub-mechanisms involved in the promotion of block interlock. These are:

- the interlock that is promoted by the bonding of the membrane to the rock, and the tensile strength of the membrane. Shear on the interface between rock and membrane is prevented by the bonding, and rotation of blocks is restricted (Figure 1). A bonded membrane can be thought of as being a 'marginally active' support
- the development of shear strength on the interface between the membrane and the rock, in the situation in which bonding of the membrane does not occur effectively, as a result of irregularity of the interface surface (Figure 2). A rough rock surface will enhance this mechanism and the applicable membrane will be shotcrete
- the penetration of membrane material into joints and cracks, which will inhibit movement of blocks (Figure 3). This mechanism is considered to be particularly relevant in very high stress situations in which some loosening will have taken place and in which on-going stress-induced fracturing is occurring. For example, in the 'dog-earing' situation, inhibition of the development of fracturing at the tip of the dog ear (the

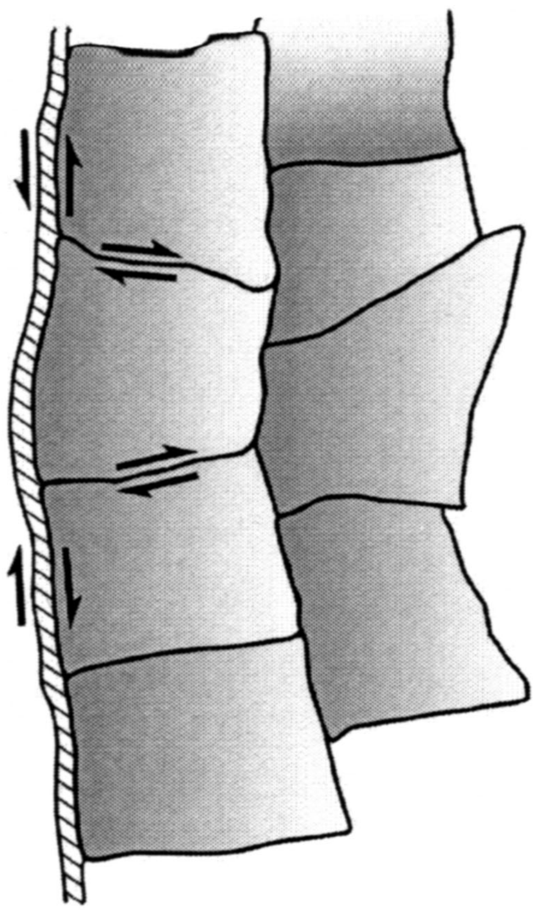

Figure 1—Shear and rotational resistance with a bonded membrane

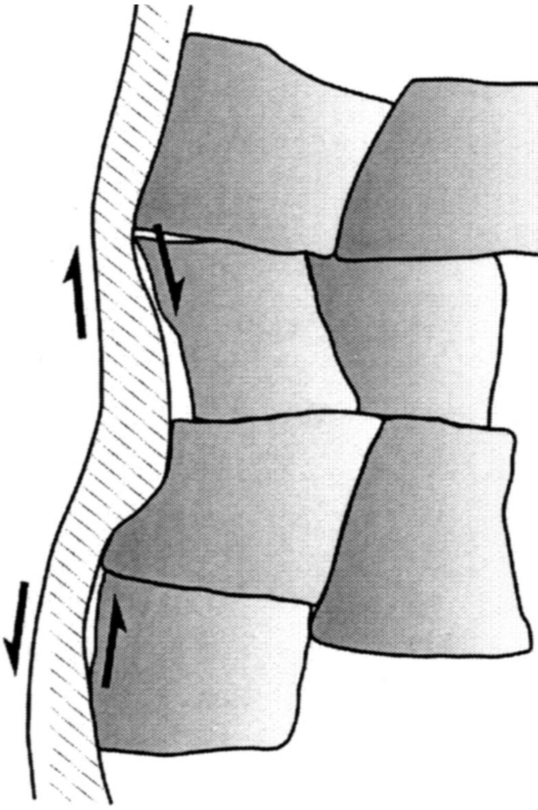

Figure 2—Physical shear interlock with poorly bonded membrane

process zone (Martin *et al.*, 1997)), by application of a membrane, will enhance stability. As illustrated in Figure 4, it is easy to imagine that a thin coating of a membrane (or even low modulus shotcrete), applied at an early stage in the development of fracturing, will arrest or at least inhibit the fracturing process

➤ prevention of block displacement by two mechanisms—the shear strength of a stiff membrane, and the tensile strength of a thin bonded membrane (Figure 5). In the former, the bonding (if any) and tensile strength will play a minor role, and conversely, the shear strength will play a minor role in the latter.

All of these sub-mechanisms will limit the dilation of the rock mass. Shotcrete and other applied membranes will be the membranes that will be appropriate to capitalize on these mechanisms. In contrast, it is unlikely that any of these mechanisms will develop with a wire mesh membrane, which will only serve as a net to catch loose fragments. It is only once sufficient bulking of the fragments has occurred to build up some support pressure that further fracture and failure development may be inhibited by wire mesh.

Air tightness

For a rock mass to fail, dilation must take place, with opening up occurring on joints and fractures. If such dilation can be prevented, failure will be inhibited. Coates (1970) suggested that, if the applied membrane is air tight, entry of air will be prevented or limited, and hence dilation will be restricted (Figure 6), and this mechanism is identified as a contributory support mechanism by Finn *et al.* (1999). It is doubted that it is likely to be a significantly effective mechanism in a static loading environment. However, in dynamic loading situations, in which rapid entry of air into the rock mass will be restricted, it is possible that an air tight membrane might promote stability, to some extent, through this mechanism. Clearly wire mesh and membranes

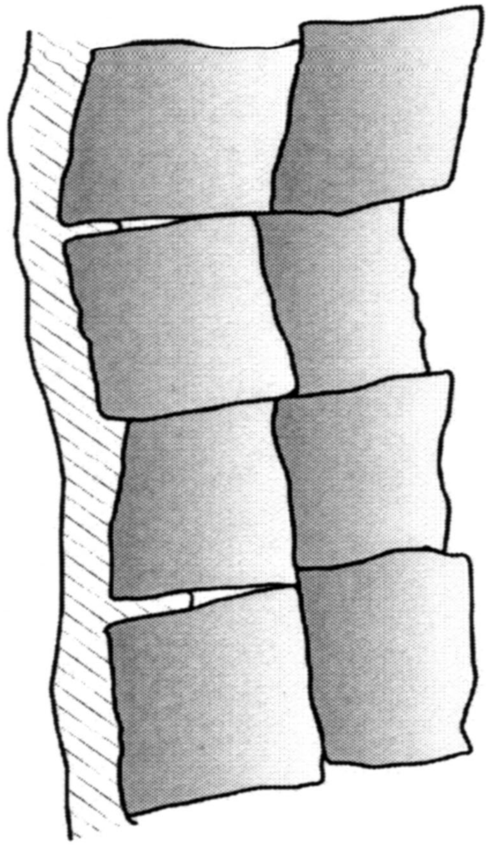

Figure 3—Plugging of open joints and fractures

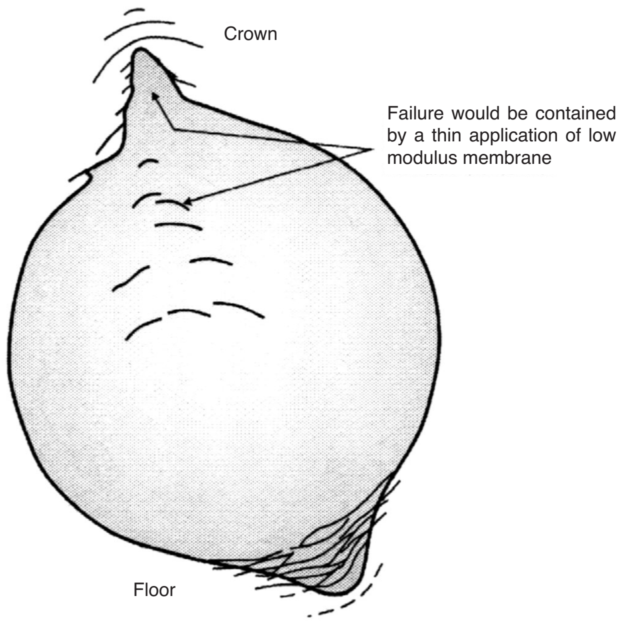

Figure 4—Stress-induced spalling likely to be contained by low modulus membrane

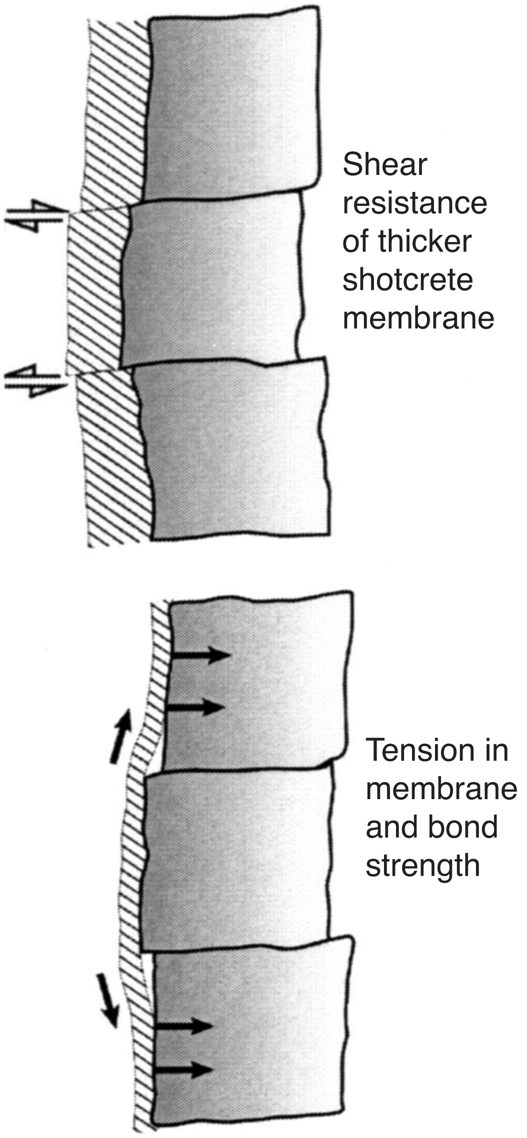

Figure 5—Shear resistance of thicker shotcrete membrane, and resistance provided by tension in membrane and membrane-rock bond strength

containing cracks will not contribute as far as this mechanism is concerned, but thin sprayed linings might be effective.

Structural arch

Deformation of the rock mass induces stresses in the membrane, which then resists further deformation of the rock mass, as illustrated in Figure 7. This is the mechanism that would most commonly be required for the support of civil engineering excavations and 'permanent' mining excavations such as shafts. The 'beam anchored by bolts, roof arch and closed ring' described by Brown (1999) fall into the structural mechanism category. Important in this structural mechanism is the strength of the membrane and its flexural rigidity. Shotcrete membranes of significant thickness are likely to be the only membranes that can provide this mechanism, even though the effect may be small in some cases. It should be noted that rigid structural linings

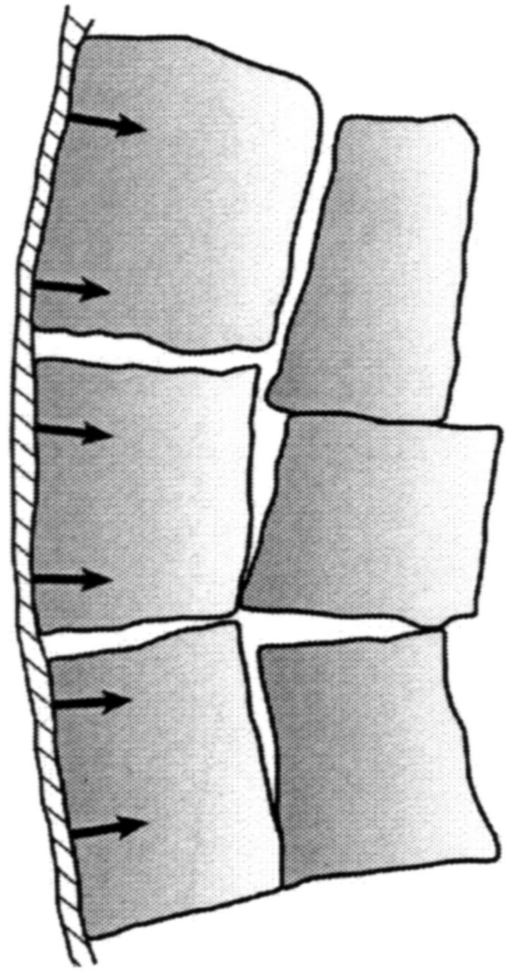

Figure 6—Airtight membrane promotes 'suction' support pressure

are sensitive to stress changes and the resulting deformations, and may therefore fail prematurely.

Basket mechanism

When the membrane develops the form of a basket, which then contains the failed rock, it will be acting mainly in tension, as illustrated in Figure 8 (photo). In this situation there are three considerations: firstly, the flexural rigidity or membrane ductility, which will serve to resist the deflection of the membrane to form a basket; secondly, the tensile strength of the membrane material itself will be important once a basket has begun to form; and thirdly, in the case in which there are two constituents, such as mesh-/or fibre-reinforcing in shotcrete, both the tensile strength of the matrix material and the tensile strength of the cracked matrix (to which the tensile strength of the reinforcement contributes) are important. Both of these will affect the flexural rigidity of the membrane. In the third case, as illustrated in Figure 9 (photo), the behaviour of the reinforcement is particularly important. This reinforcement may undergo material yield, and thus enhance the basketing effect. Alternatively, and considered to be more important, the membrane may yield by progressive pull out of the reinforcement elements from the matrix material on either side of the crack. The characteristics of the fibres are

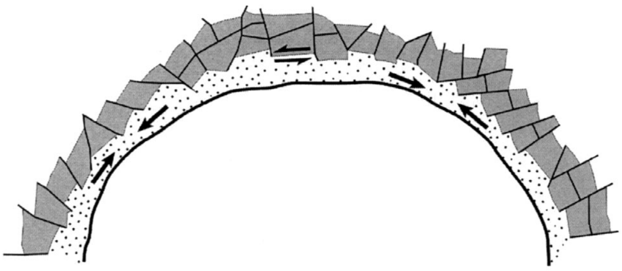

Figure 7—Compressive stresses induced in structural membrane provide support resistance

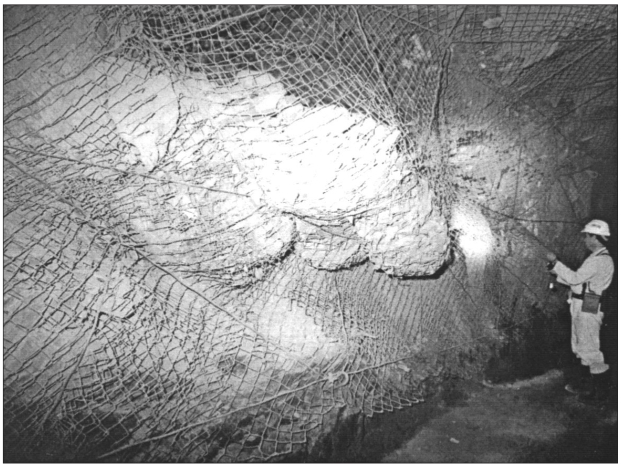

Figure 8—Basket mechanism of support

Figure 9—Pull-out of fibres across crack in shotcrete

important in this regard. Smooth steel fibres, which do not bond with the matrix, but rely on their physical shape to provide resistance to pull out, are likely to yield better than fibres with which the matrix bonds well. Further, it is logical that, the longer the fibres, the greater the capacity for yield of the membrane. Also with regard to pull out, weldmesh is a rigid reinforcement owing to the mechanical interlock and pull out yield is not possible. In contrast, the wire strands of diamond or chain link mesh can pull out, and yield is possible.

Slab enhancement

Brittle rock, under high stresses, often forms slabs or incipient slabs in the surface zones of excavations. Under increasing deformation, such slabs may fail due to buckling. The application of membrane support, in which the membrane is bonded to the rock surface, effectively thickens the slab, decreasing its slenderness and increasing its resistance to buckling, as illustrated in Figure 10. Alternatively, a membrane may create a much tougher, less brittle, slab.

Beam enhancement

Similar to slab enhancement is beam enhancement—a membrane on the underside of a roof beam may enhance the bending performance, and hence stability, of a roof beam. The membrane may contribute and increase in the tensile strength or reduce the likelihood of formation of tensile cracking due to bending.

Extended 'faceplate'

All membranes will extend the area of influence of rockbolt and cable faceplates (Figure 11). The magnitude of this extended influence will probably be greatest for stiffer membranes such as shotcrete, and least for flexible wire mesh.

Durability enhancement

Some rock types deteriorate on exposure and when subjected to wetting and drying. Common examples in southern Africa are kimberlite and basalt. The purpose of membrane support in this case may be to seal the rock to prevent exposure and hence preserve the inherent strength of the rock. An additional or secondary requirement may be to provide support. In diamond mines, a sealing membrane has been applied after excavation, and shotcrete subsequently applied to provide the support. Sealing is necessary in this case since the water content in the shotcrete is sufficient to cause deterioration of the surface of the kimberlite (Bartlett and Nesbitt, 2000).

Mechanical protection

Wire mesh and thinner membranes, to a lesser extent, are very susceptible to mechanical damage. Often shotcrete is applied, not only as part of the support system, but to provide protection to the other support components against mechanical damage. This is an extremely important mechanism, since mechanical damage will very quickly destroy the effectiveness of the support. Shotcrete, with special aggregate and reinforced with steel fibres, has been used in cases when resistance to abrasion is required.

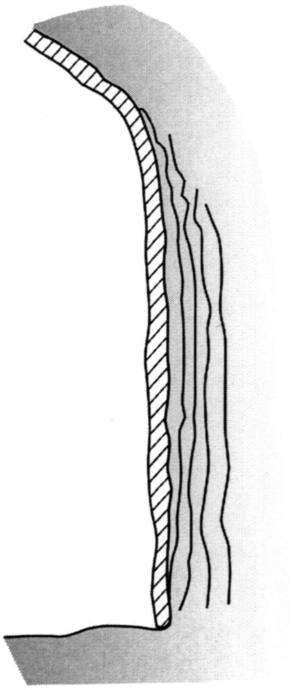

Figure 10—Increasing the effectiveness of slabs

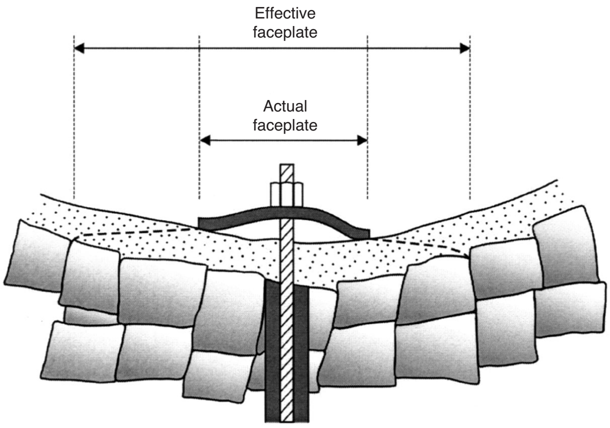

Figure 11—Extended faceplate action

Mechanisms of loading of containment support

Membrane support is subjected to different mechanisms of loading. The most common mechanisms are summarized below.

Wedge and block loading

When a block or wedge of rock is defined by joint planes, it may displace and load the membrane locally. With 'rigid' and bonded membranes, shear stresses will be induced in the membrane along the perimeter of the block, and, if breakdown of the bond occurs, the membrane will tend towards a localized or point load acting on a 'basket'. These mechanisms are illustrated in Figure 5. Wedge or block loading mechanisms can be both static and dynamic.

Distributed surface loading

In this mechanism, membrane support is subjected to a distributed load imposed on the membrane by the rock. The retention of the membrane will generally be by point supports provided by rockbolts and associated face plates. The distributed load may be due to several alternative situations:

- failed rock, under the action of gravity (static)
- squeezing rock conditions, due to high stresses or swelling (static). Swelling may be particularly relevant in the case of non-durable rocks, whose decay product involves significantly swelling material, for example kimberlite
- dynamic loading under rockburst conditions. In tunnels it has been observed that a thickness of rock, typically about 1 m, is ejected at high velocity during rockburst events (Ortlepp, 1993). This rock, which is usually well fragmented, imposes a dynamic, distributed load on the membrane.

Distributed loading causes the membrane to provide support with a basket mechanism as shown in Figure 8. Localized deformation of the membrane may occur at the locations of rock joints. This will particularly be the case when the membrane is well bonded to the rock surface, and when the roughness of the rock surface prevents interface shear from occurring, as illustrated in Figures 1 and 2. If such a localized loading mechanism causes local failure of the membrane, the value of high quality bonding between membrane and rock is questionable. A lower quality bond, which allows yield and shear displacement on the interface, may be preferable.

Stress-induced loading

A membrane which is well bonded to the rock will be subjected to the same deformations as the rock. The membrane material may be stiffer, or more brittle, than the jointed, fractured rock mass, and therefore may fail prematurely under the deformations imposed on it. This may be by shear, bending, buckling or tension as illustrated in Figure 12. More complicated failure mechanisms such as combinations of these, and possibly others, may also occur. The result could be stress-induced spalling of the membrane, as shown in Figure 13, in particular if the membrane consists of high modulus material such as strong shotcrete.

Water pressure loading

When a rock mass contains water, a continuous membrane support might be subjected to water pressures. These will be distributed pressures which may be sufficient to fail the membrane. The membrane should therefore be drained unless it has been designed to withstand the potential water pressures.

Bending loading

In mining excavations it is very rare that support is installed in the floor. The implication is, therefore, that support tends to be installed in the roof and sidewalls only, with the result that, although deformation may be contained in these three areas, the floor may deform freely, as illustrated in Figure 14. The consequence could be greater convergence at floor level than roof level, and hence bending loading on the membrane support particularly in the haunch areas.

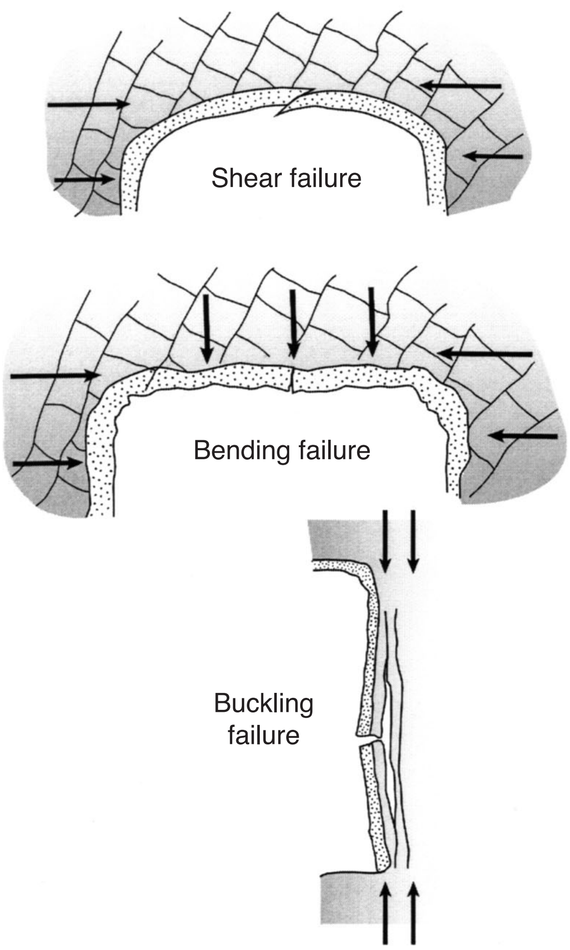

Figure 12— Shear, bending and buckling failures of stiff, brittle membranes

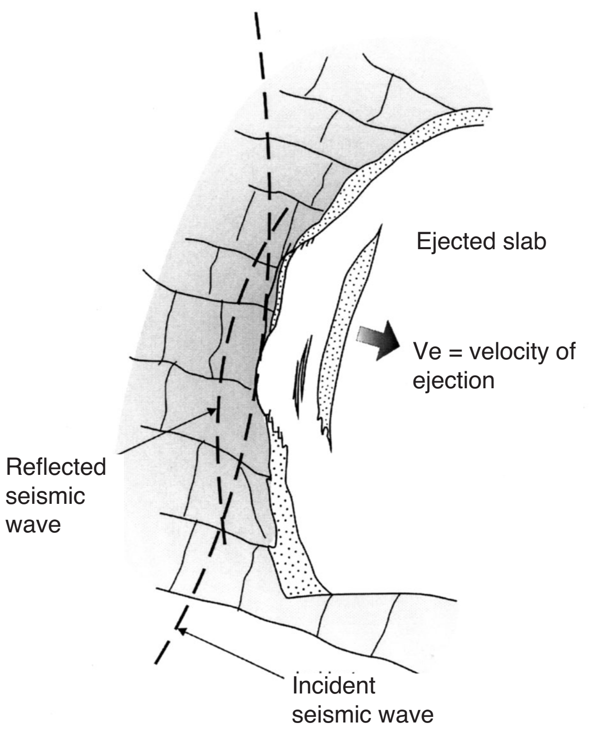

Figure 13—Seismic spalling of brittle membrane

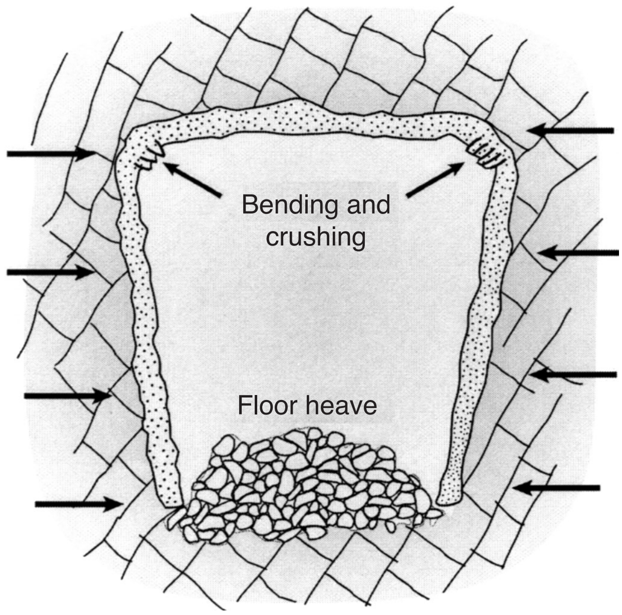

Figure 14—Bending and crushing of thicker membranes

Discussion

It is important to highlight several effects of the above loading mechanisms:

➤ localized deformation of membranes may lead to localized failure. Therefore, even if a membrane material has an elongation of 100% or 200%, the localization of deformation of a well-bonded membrane may result in failure after a total opening of only a few millimetres. In such cases, it may be preferable for the rock-membrane bond to be less effective, to allow some shear to take place on the interface, and hence for the deformation to be less localized

➤ the membrane is one part of the support system, which usually also includes rockbolts. The interaction between the membrane and the rockbolts is extremely important. The behaviour of the rockbolts influences the behaviour of the membrane and may dictate the characteristics desired of the membrane.

Appropriate membrane support

Different types of excavations in different environments will have different requirements of membrane support. For example, membranes in civil engineering excavations will be expected to prevent deformation of the rock after they have been applied, or at least contain deformations without cracking. Conversely, whilst these characteristics may be desirable in very high stress situations, they are not possible to achieve. Under very high stress and significantly squeezing conditions, it is not possible to prevent significant deformation or cracking of ‘brittle’ membranes (unless, possibly, the membrane is a massive concrete lining). Under rockbursting conditions, it is almost certain that substantial deformation and cracking of membranes will occur. Therefore, prevention of cracking or parting of applied membranes may be desirable, but it may be impossible. The practical requirement may then rather be that the ‘failed’ membrane should continue to contain the rock, allowing the excavation to continue to perform its designed function.

The ideal membrane will have the following characteristics:

- ➤ very stiff, to prevent or minimize the deformation of the rock
- ➤ large deformation capability without failure, and the ability to maintain high load capacity during this deformation
- ➤ yieldability, to absorb energy in the case of dynamic loading (and repeated dynamic loading)
- ➤ toughness, to resist mechanical damage.

It is unlikely that a single membrane with all of these characteristics will ever be developed. It is much more likely that the desired solution will be achieved with the use of combinations of various types of single membranes. It may therefore be more appropriate to refer to single membranes as 'membrane components' and combinations of membrane components as a 'membrane system'. Examples of appropriate membrane components, and membrane systems, are given below.

- ➤ *Civil engineering excavations*—for these usually low stress, low stress change environments, a stiff membrane, consisting of high quality, high strength shotcrete, reinforced with weld mesh or steel fibres, usually in a layer of significant thickness.
- ➤ *Highly stressed mining excavations*—since it is not practical to attempt to prevent deformations, the membrane must contain the failed rock and hence inhibit the development of further failure. The requirement is therefore a flexible membrane, such as a thin sprayed lining, or shotcrete with a lower quality matrix (lower modulus, less stiff) reinforced with diamond wire mesh, or long polypropylene (50 mm) or stainless steel (40 mm) fibres. Such fibres are necessary to prevent loss of performance due to corrosion of exposed fibres in cracks. For severe conditions, additional reinforcement such as wire rope lacing or tendon straps may be necessary over the previous membrane. The geometry of the wire ropes and their system of anchoring or retaining will vary to suit the particular application. A surface covering of shotcrete may be required to minimize mechanical damage.
- ➤ *Mining excavations subjected to rockbursts*—the membrane system must be able to decelerate the mass of rock which has been ejected at high velocity, and absorb all the energy involved, without failing. An appropriate membrane system will be as for highly stressed excavations, but wire rope lacing or tendon straps would be a requirement. Use of wire mesh as a basic membrane instead of shotcrete or other applied membrane is possible. For very severe conditions, some or all of yielding mesh, yielding straps and yielding rope lacing could be used. It is expected that yielding rockbolts would be used as retainment support.

From the above, it can be seen that, to cater for increasing levels of severity of both static and dynamic loading, the membrane support system will consist of different membrane components added progressively as severity levels increase.

It is quite clear from the above that the mechanisms of behaviour of the membrane *components*, the mechanisms of loading of the membrane *components*, the corresponding mechanisms for the membrane *system*, and the desired membrane support characteristics, will be different for each membrane system. It is also likely that the same membrane component may perform differently as an individual membrane than as a component of a membrane system. For example, Ortlepp *et al.* (1999) found that diamond mesh performed better as a membrane *component* than weldmesh. However, with the addition of wire rope lacing (an additional membrane component), the weldmesh and lacing membrane system performed better than the diamond mesh and lacing membrane system.

Consideration of membrane testing

Testing relevant to membranes can fall into at least three categories:

- ➤ testing of membrane material to determine material properties, as well as quality control on the material
- ➤ testing of the membrane component using a 'representative' component test method
- ➤ testing of the membrane system using a 'representative' system test method.

The first of these deals with standard laboratory tests of such properties as tensile strength, tear strength, shear strength, compressive strength, etc., which will provide necessary information for characterizing the membrane component material.

Owing to the different requirements of membrane components and systems for different situations, the 'representative' test methods are likely to be different in each case. Spearing and Champa (2000) have described four different component test methods that are used in different countries. These tests involve different test geometries and different scales. Three of them allow for static loading only, and one caters for static and dynamic loading. The results that are obtained from these four methods will not be comparable and will not provide a means of determining whether one membrane component is better than another.

In addition to the above test methods, test methods for welded wire mesh have been described by Tannant *et al.* (1997) and Thompson *et al.* (1999), and simple demonstration tests for a membrane by Wojno and Kuipers (1997).

Specifically with regard to the testing of shotcrete, Morgan (1998) has identified numerous tests for flexural strength and toughness which are used in various countries. Of these, the EFNARC rectangular plate test and the Australian RTA circular plate with determinate (three point) support test appear to have gained advantage for the evaluation of shotcrete for excavation support purposes. The large-scale shotcrete panel test method described by Kirsten and Labrum (1990), and specifically aimed at shotcrete support for mining tunnels, has been in use for many years.

It is considered that an appropriate test method is one which is representative of the conditions to which the membrane system will be subjected, and which will allow alternative systems to be compared under these conditions.

An example of this is the dynamic loading test method used by Ortlepp and Stacey (1996) to evaluate the effectiveness of several membrane systems in rockburst situations. This method allowed the testing and comparison of a range of wire mesh and shotcrete membranes, some with wire rope lacing, with large energy inputs. The method attempted to take into account the continuous nature of membranes, by introducing extended boundary conditions, and a simulated jointed rock mass in contact with the membrane was used. It was shown with this test method (Stacey and Ortlepp, 2001) that a membrane consisting of special yielding mesh with yielding wire rope lacing could absorb an energy input of 70 kJ/m^2 without failing. This energy input is considered to be equivalent to a severe rockburst.

Based on the above considerations of membrane behaviour mechanisms, membrane loading mechanisms, and requirements demanded by the excavation situation, it is considered that it should be possible to develop a set of suggested testing methods. It is expected that such methods would be equivalent, for example, to the various suggested testing methods published by the International Society for Rock Mechanics. Such suggested methods serve as good practice guidelines, and even as standards in certain cases.

Conclusions

Membranes are very important items of rock support. With the recent development of several types of thin sprayed linings, their importance is likely to increase in the future. A wide range of mechanisms of membrane behaviour, and mechanisms of loading of membranes has been described in this paper. The concepts of membrane components and membrane systems have also been suggested:

- *membrane components* are single membranes, which may be used on their own as rock support. Examples are wire mesh, shotcrete, or the new thin sprayed linings, installed individually
- *membrane systems* are combinations of more than one membrane component. Additional components may be combined, or added, to increase the capacity or behavioural characteristics of the support. Examples are the addition of tendon straps and wire rope lacing to fibre-reinforced shotcrete support. The membrane system then consists of three membrane components.

It has been illustrated that different situations have different requirements of membrane support, and the differences between civil engineering and mining requirements have been highlighted. Owing to these different requirements, it is unlikely that a standard membrane test is feasible. It is considered that it might be possible to develop a set of suggested methods for membrane testing, which could serve as good practice guidelines for the evaluation of membrane components and membrane systems.

A thorough understanding of the mechanisms of behaviour of the different types of membranes, and the different mechanisms by which the membranes are loaded, is essential before a selection of appropriate support can be made, before appropriate design methods and calculations can be determined, and before appropriate performance test methods for membranes can be defined. The material in this paper contributes towards the understanding of membrane support behaviour.

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P9 pay-day wrapped in platinum*

A revolutionary approach to the design and construction of platinum processing operations has increased revenue for South Africa's third-largest producer by several million rand a month.

Lonmin Platinum was the first to trial the JKMRC-AMIRA P9 project's Floatablity Characterization Test Rig, which has led to increased metal recovery at the company's Karee operation, north-west of Johannesburg.

Built by Baker Process—now Eimco-the P9 FCTR is essentially a portable pilot plant of flotation cells, pipes and monitoring equipment placed beside an actual processing plant.

Like a medical doctor's stethoscope the FCTR reads the 'heart beat' of the processing plant. By temporarily redirecting mineral slurry through its bank of small pilot-scale flotation cells, it can help determine the overall 'health' of the operation.

Lonmin Chief Metallurgist Mr Bert Knopjes said the company embraced the FCTR concept as a quick and easy way to evaluate circuit changes and trial new equipment before any expensive decisions were made inside the actual processing plant.

'The FCTR is having an influence on new plant design,' Mr Knopjes said.

'The recoveries on a new UG2 ore plant, modelled using the concepts of process control and circuit flexibility found in the FCTR, are so far four per cent higher than our other UG2 plants—and we don't think these others are that low either'.

The results were so impressive that Lonmin has built their own version of the P9 FCTR which will influence the design and construction of two new plants coming on line in 2002. This is in addition to applying results obtained from FCTR technology to fine-tune Lonmin's five other concentrators on the platinum belt.

Being first in the queue through P9 project sponsorship, Lonmin's use of the test rig has paid off.

'There are things we have installed in our new processing plants that we wouldn't have done without P9's FCTR,' Mr Knopjes said.

'We would have liked to have kept the original FCTR for ever, but we had to let it go to Australia as part of P9's international research programme.'

The original test rig was relocated mid-way through 2001 to WMC's Kambalda nickel mine in Western Australia.

Unfazed, Lonmin has since decided to build not one but two FCTRs to replace the P9 rig. Modelled on the original P9 version, the first of Lonmin's test rigs has been built and installed at the Eastern Platinum concentrator, which has a throughput of 190,000 tonnes a month.

'When it comes to identifying areas of potential on our existing plants I can't afford to build just one rig to replace the P9 FCTR,' Mr Knopjes said.

'If these projects are going to make money I can't wait the five years it would take for one FCTR to cover each plant.'

Lonmin Platinum's Research and Development Superintendent, Dr Craig Goodall, said the involvement of the P9 project has continued throughout the design phase of the Lonmin rig.

'We've bounced a lot of ideas for our FCTR off Dr Emmy Manlapig and Professor J-P Franzidis from the JKMRC, and Dr Malcolm Powell and Martin Harris at UCT,' Dr Goodall said.

'The layout of the Lonmin FCTR is larger than the original due to the inclusion of automatic sampling on all feed tail and concentrate streams, which could be done as there isn't the restriction of having to dismantle the rig and ship it long distances in a container.'

He said the Lonmin FCTR would only need to be transported by road as far as the furthest concentrator located 30 kilometres away.

'The new FCTR has as much control as any full-scale plant, including Mintek's PlantStar, which includes milling and flotation control modules,' Dr Goodall said.

'All of the level controls and sampling are automatic, the air input into all of the cells is controlled by air valves attached to rotameters, and you can adjust the inputs using PI controllers.

'We've tried to improve on the things we thought could be improved on from the first FCTR.'

The Lonmin FCTR also has a number of pilot milling, screening and classification units.

Dr Goodall said the FCTR was designed to be a flexible platform able to test different circuit configurations.

'We've included quite a few of the design elements of the P9 FCTR in the recently commissioned UG2 section of the Karee plant, such as being able to move the feeds up and down the banks,' he said.

'Each cell now has its own feed port, as well as a connection to the previous cell, allowing us to produce individual high, medium and low grade concentrates, instead of just one grade at a time.

'From an overall point of view it's the FCTR's flexible features that we've designed into Karee.'

He said the new Karee UG2 plant took less than three months to commission, largely due to the way it was built with circuit configuration ideas from the FCTR, and an exceptionally high level of process control.

'Karee is now performing two per cent better than its designed grade and recovery which translates into a lot of money—perhaps as much as several million rands a month.'

While the P9 FCTR has helped remodel the mixed ore mill at Karee, the Lonmin-built FCTR at Eastern Platinum will be used to decrease cleaner tails grade by 66 per cent.

'We have been using our new FCTR at Eastern to run a fine milling test programme,' Dr Goodall said.

This new FCTR will move to Karee in October 2001 to pick up where the P9 rig left off at the end of 2000, optimizing the circuit, and to commence test work for an open cut mine to be commissioned late in 2002.

'We don't have the flexibility to change the plant at Eastern Platinum in the way we did at Karee, but we are building two new plants, and we will certainly use the FCTR's flexibility in their design.'

The money spent on the FCTR—estimated at about AUD$1million—was insignificant when compared with the potential gains from new plant design, Mr Knopjes said.

'A good project is a two-per-cent gain in platinum recovery, which we'll get, no doubt, so the cost of the unit is insignificant.'

An important spin-off for Lonmin Platinum is the application of the FCTR for training purposes.

'We pride ourselves on having the most capable people in the industry, or at least the biggest share of them,' Mr Knopjes said. 'Other than using the FCTR for our own R & D, we will have the finest tool in the industry to train metallurgists.'

It was on this basis that South Africa's Department of Science, Technology, Arts and Culture injected R500000 into Lonmin's FCTR research and development programme.

This financial assistance helped Lonmin acquire Mintek's PlantStar system for the rig. Because of this enhanced degree of control and instrumentation, Lonmin can train its metallurgists to understand and control the milling and flotation responses to changes on a live plant.

'Through our use of technical innovations such as the FCTR we are creating an environment where we can attract people of triple A plus character to the mining industry in South Africa, and hopefully hang on to them for a while,' Mr Knopjes said. ◆

* *Issued by: David Goeldner*