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Surface support in extreme ground conditions — HEA Mesh™

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Abstract

Development in high stress environments can lead to severe conditions. In particular, when the rock mass is brittle, or when mining progresses near seismically active geological structures, rockbursts can become a serious hazard. At the other end of the spectrum, when the rock mass is weak and ductile, squeezing ground and high convergence become the challenge that must be managed during and after development mining.

The ground support industry has been very active in developing reinforcement solutions to these challenges, in particular in addressing the rockburst problem. However, the options for high energy absorption surface support remains very limited. The South African deep level gold and platinum mines are successfully using cable lacing, but this option is not practical in mechanised mining. In countries using mechanised mining, the solution to the severe ground conditions to date has been to use a combination of fibre reinforced shotcrete (FRS), mesh, or mesh straps.

In this paper, a new high energy absorption mesh is proposed. This mesh can be mechanically installed using a jumbo and can sustain high deformation and high strength.

1 Introduction

There is no such a thing as rapid development mining when dealing with extreme ground conditions. In particular, conditions can become extreme when the stress is approaching or exceeding the strength of the rock mass. Mining will then take place in a failing ground environment. The rock mass behaviour and mode of failure are important considerations when mining in failing ground. A brittle rock mass will tend to exhibit violent failures and produce a seismically active environment. Exclusion time may be required after each blast to provide enough time for the energy to dissipate through seismicity. The ground support system will have to cater for the potential violent ejection of rocks.

In ductile rock masses, time dependant deformation of significant magnitude can occur and is often referred to as squeezing ground conditions. The typical rates of convergence in squeezing ground can reach tens and sometimes exceed hundreds of millimetres per months. The depth of failure can extend several metres into the sidewalls. Controlling the convergence whilst keeping the integrity of the support system is the aim of the ground support strategy. In both stiff and ductile ground conditions, the support system must be able to accommodate significant deformation and loads (static or dynamic). This combination of high deformation and loads is defined as the energy absorption capacity of the system and can be calculated using the area under a load-deformation curve.

In extreme ground conditions, whether it is a stiff or ductile rock mass, the efficiency of development mining is often related to controlling the conditions and achieving steady and predictable advances. Also, since the proportion of development mining requiring rehabilitation can be significant in such conditions, the implementation of a ground support system that is capable of surviving the load (including dynamic loading) as well as deformation for the entire service life of the excavation takes precedence over achieving low-cost or rapid advances. Although the “rapid” advance remains a desirable outcome, it is often a focus that is secondary to achieving short- and long-term control of the ground conditions.

This paper provides a discussion on how to control extreme ground conditions and introduce a new surface support system called HEA Mesh™.

2 Ground support systems in extreme ground conditions

In mechanised mining, most ground support systems are comprised of reinforcement elements such as rockbolts and surface support, which is most commonly mesh or FRS. In extreme ground conditions, it is important to consider how the support elements work together as a support system.

2.1 Reinforcement

Reinforcement is an "internal" support. The rockbolts are installed within the rock mass creating a layer of reinforced material. Many authors have suggested different mechanisms to explain the reinforcing action of rockbolts (Stillborg, 1994). Some have proposed that a compression arch is formed, others have suggested that a beam is created by tying layers of rock together. Perhaps the most simplistic approach is the one that considers that the reinforcement supports the dead weight of rock. Each of these explanations can be relevant, depending on the prevailing conditions. However, it may be more important to look at the capacity of the reinforcement to accommodate deformation and its capacity to resist static and dynamic loads.

There is a wide variety of reinforcement elements available on the market today that have a good range of capacities. The rockbolts commonly used in underground mines can typically sustain static loads between 10 t (i.e. the 46 mm friction rock stabiliser) and 20 t (i.e. the high tensile strength rebars). Most fully grouted bars are stiff and can only deform a few millimetres before failing. On the other hand, some friction bolts are designed to progressively slide giving, in theory, a ductile behaviour to the reinforcement. In practice, a shearing component to the displacement will often prevent sliding and lock the sliding movement of the bolt, which will then fail after relatively small ground convergence.

Rockbolt suppliers have developed a number of speciality high energy absorption bolts such as cone bolts, modified cone bolts, the Durabar (Grinaker LTA), and more recently the Roofex™ (Atlas Copco) and Garford dynamic solid bolts (Garford Pty Ltd). These bolts are designed to yield at relatively high loads and provide viable options when used in conjunction with surface support to deal with extreme ground conditions.

2.2 Surface support

The surface support is an "external" support. It is installed on the surface of the rock and simplistically, its primary aim is to prevent failure of the rock mass in between the reinforcement elements. In extreme ground conditions, the interaction between the rock mass, the surface support and the reinforcement is more complex and critical to the performance of the support system. This will be further discussed in the next section of this paper.

The mesh commonly used in mechanised mines is a weld mesh with a wire diameter that is approximately 5 mm. According to test results published by Thompson (2004) and Tannant (2004) the tensile strength of the mesh varies between 2 and 4 t, depending on the products. The displacement at the failure of a section of mesh located in between a 1 x 1 m bolt pattern is in the order of 200–300 mm.

The support action of FRS is quite different to mesh. Mesh is a soft surface support loosely held against the rock face. Its supporting action will only start after significant displacement occurs and in most cases, after the rock mass has failed. FRS is stiff and "glued" to the rock and therefore it resists early movement and prevents the loss of confinement within the rock mass. FRS truly helps the rock mass to support itself rather than only containing failed ground, like mesh.

Similar to weld mesh, a 50 mm layer of FRS typically fails at static loads of approximately 5 t, according to round determinate panel (RDP) tests published by Tyler and Werner (2004). However, FRS is much stiffer and typically will loose its support capacity at displacements of less than 50 mm.

2.3 Ground support systems

The combination of reinforcement and surface support forms the complete support system. In non-extreme ground conditions, the reinforcement elements (rockbolts) can support the potentially larger blocks that may form from the back and walls of excavations. The surface support, whether it is mesh or shotcrete, stabilises the smaller blocks in between the reinforcing elements. The typical 10–20 t capacity of the reinforcement is designed to cater for the larger blocks and the 2–5 t capacity of the surface support is adequate for the smaller blocks in between typical rockbolt patterns. In that context, the reinforcement elements work almost independently from the surface support. In fact, it is common to have FRS applied over the rockbolts, and in this case, the surface support works independently to the reinforcement elements.

2.3.1 Ground support systems in squeezing conditions

In extreme ground conditions it is critical that the reinforcement works in unison with the surface support. In squeezing ground, the whole of the rock mass deforms and often, complete sections of opposite walls, floors or backs converge. This mechanism differs totally from the large block/small block concept discussed previously. As the convergence takes place, the rock mass will break into small pieces and will often become a discontinuum material; an assemblage of loose pieces. The surface support must contain this discontinuum material and keep the integrity of the excavation surfaces. It is therefore critical that the surface support covers the entire rock surface and extends all the way to the floor. In many cases, the control of squeezing ground is lost in the lower corners of the drive, because the surface support stops a metre or so from the floor (Figure 1).

Figure 1 Squeezing ground failure in the lower section of a drive due to the support system not extending to the floor

The deformation and load transfer mechanisms in squeezing ground can be described as follows. As the broken rock mass contained by the surface support squeezes (i.e. wall convergence) the surface support, which is connected to the reinforcement by the surface fixtures (plates), will pull on the rockbolts. The load is then effectively transmitted from the surface support to the reinforcement elements. The rockbolts will then contribute to slowing down the convergence, retaining the rock wall surface using their anchorage action in the deeper layers. In squeezing ground, the reinforcement and surface support must work together as a support system.

One of the problems with applying the support systems commonly used in squeezing ground is the mismatch between the capacity of typical reinforcement and surface support. The load bearing capacity of mesh and shotcrete is generally only a fraction of the reinforcement capacity provided by bolts or cables. Also, the displacement capability of mesh is far greater than most reinforcement elements. As a result of the difference in load and displacement capacity between reinforcement and surface support, the failure process will exploit the weakest point in the ground support system and will only be as strong as its weakest component. For example, mesh may rip when the loads exceed 2–5 t, the surface fixture may give up at similar loads or even lower loads if the installation is not of high quality, and shotcrete may crack and loose its support capacity if the convergence exceeds 50 mm locally. Convergence will only slow down if the load on the surface support is transmitted to the reinforcement without failure of the surface lining or its connecting nuts and plates.

2.3.2 Ground support systems in rockbursting conditions

The loading mechanism resulting from far field seismic events is very different to that in squeezing ground. The load is transmitted as strong motions to the excavation surfaces and the support system via low frequency stress waves. In other words, the excavation surfaces experience a vibration with high amplitude and relatively low frequency. With every wave, the rock mass experiences significant deformation, which often shatters the rock and may produce block ejections at high velocity.

Despite the difference in loading mechanism, the discussion on how squeezing ground affects support systems also applies to the dynamic loading from seismic events. As is the case for squeezing ground, under dynamic loads whole sections of excavation surface move as a unit with every stress wave. This movement must be contained by the surface support which transmits the load to the reinforcement through its connecting elements (nuts and plates). If the surface support and the connections survive, the load is transmitted to the reinforcement, which will try to retain the shattered surface using its anchorage action in the deeper layers.

The common mismatch problem between the surface support capacity, the connections and the reinforcement is illustrated in a study by Heal et al. (2006) who investigated 254 rockburst damaged locations. Heal found that in only 30% of the cases the load was fully transmitted to the reinforcement, to the point of rupture or pulling out (Figure 2). Apart from another five per cent of the cases where the reinforcement was too short, the other cases had surface support or the connection failing before the reinforcement was solicited to its full capacity. Hence, the weakest point in the majority of the cases was not the reinforcement but the surface support or the connection. Similar evidence was observed in a recent study of ground support performance in squeezing ground conditions conducted by Potvin and Hadjigeorgiou (2008).

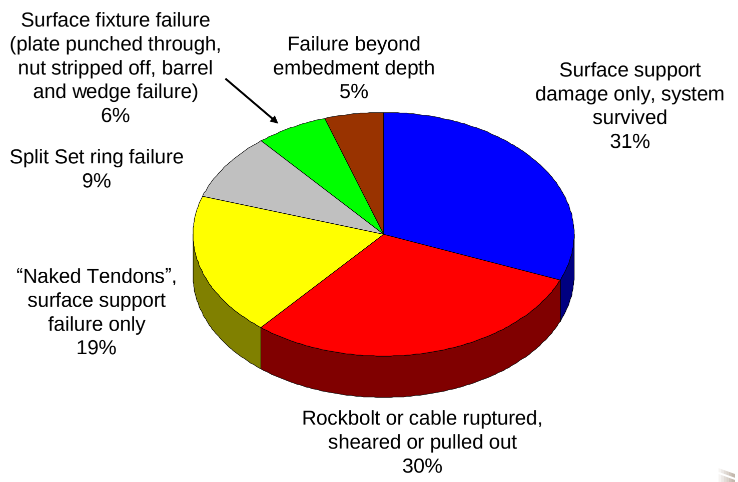

Figure 2 Breakdown of the components of ground support system failures from 254 rockbursts damage observations (after Heal et al., 2006)

There is ample empirical evidence that ground support systems, in extreme ground conditions, require surface supports with higher energy absorption capacity than what is used presently, as well as connections that can transmit static loads matching the bolt capacity (in the order of 10–20 t). Some of the common ground support practices used in extreme conditions are discussed in the next section.

3 Current ground support practices in extreme ground conditions

In Australia there is a perception that when ground conditions become difficult FRS is the surface support of choice to stabilise the ground. FRS has the advantage of providing immediate support action and preventing deterioration rock mass by preserving the confinement. When the rock mass exhibits very rapid deterioration of "in-cycle shotcreting", which means the application of FRS is integrated in the development mining cycle, it is common practice in Australia and ideal to reduce time-dependant rock mass deterioration. The fact that Australian mines are generally relatively shallow with a predominance of mines using decline over shaft compared to South African or Canadian mines, makes the application of in-cycle wet shotcrete efficient and cost competitive.

However, if convergence is one of the problems, FRS will start cracking after only a few millimetres and loose its capacity after some centimetres of convergence. The ground support practices in extreme ground conditions in Australia have gradually evolved towards using mesh over in-cycle FRS. As the shotcrete cracks and forms large concrete plates, the surface still needs to be contained by mesh which is capable of sustaining larger deformations without breaking (Figure 3). The use of FRS overlaid with mesh combines the advantages of both systems. The FRS provides early support preventing early deterioration of the surface and maintaining the confinement. The mesh contains the surface when deformation exceeds the deformation capacity of the shotcrete. This system is initially a stiff system that becomes ductile after failure. The main disadvantage is the time and cost of installing two surface support systems.

Figure 3 Mesh applied over in-cycle FRS is a common practice in Australia where the ground conditions are poor

In Canada, many mines favour a combination of mesh and mesh straps installed over the mesh (Figure 4). The straps are preferably installed where sheets of mesh overlap. The zero gauge mesh straps have thicker and stronger wires which provide extra load capacity to the surface support. This support system also eliminates the common weakness at the mesh overlap, and can transfer the load to the reinforcement quite efficiently. A relatively tight rockbolting pattern is required when the ground is very poor. One of the main drawbacks from this support system is the two pass installation of the surface support; meshing occurs first and is then followed by the installation of mesh. Another difficulty is to systematically align the mesh straps with the overlap, especially when the drive profile is irregular.

Figure 4 Mesh straps installed where the sheets of mesh overlap is a common practice in Canada where the ground conditions are poor

In South Africa, cable lacing is installed manually over mesh to protect the infrastructure where the risk of rockburst is elevated (Figure 5). This is perhaps the highest energy absorption surface support available with an excellent capability to transfer the load to the reinforcement. Unfortunately, the installation of traditional cable lacing has not been mechanised and remains a very time consuming and a manually intensive surface support method.

Figure 5 Typical rope lacing used in rockburst-prone South African mines

4 HEA Mesh

The Australian Centre for Geomechanics (ACG) in collaboration with Onesteel Reinforcing Pty Ltd, is currently working on mechanising the cable lacing technique. The concept is simple and involves the prefabrication of a cable lacing pattern over a commonly used 2.4 x 3 m sheet of weld mesh (Figure 6). The cable used in the prototype HEA Mesh is a 12.7 mm cable bolt clamped to the periphery and at different points onto the weld mesh sheet. HEA Mesh has several advantages in terms of performance compared to regular weld mesh and its installation. It can be done entirely mechanically using a jumbo and remains as easy, rapid and efficient as installing a regular sheet of weld mesh. Effectively, a superior support system can be installed with no productivity loss, compared to a simple bolt and mesh system.

Figure 6 Prototype of HEA Mesh

The 18 t tensile strength cable significantly increases the load bearing capacity of the mesh. Based on laboratory tests, HEA Mesh can sustain loads well over 15 t compared to the 2–4 t of regular mesh. Also, with the cable being free to stretch over its entire length, HEA Mesh has a good capacity to deform. The deformation capacity has also been increased in a different prototype using a crinkle version of the mesh (Figure 7). Laboratory tests on 2.4 x 3 m sheets of HEA crinkled mesh deformed over 800 mm before any wire or weld ruptured.

Figure 7 Crinkle mesh allows for more deformation capacity

One further advantage of HEA Mesh is the excellent capability to transfer the load from the cable into the reinforcement. This is achieved because the cable is effectively laced over the deforming rock surface and wraps around the bolt under the plate. Also, since the load capacity of HEA Mesh is a good match to most other reinforcement methods; one of the previously discussed weak links of the support system is eliminated. Another weak link discussed earlier was where mesh sheets overlap. The overlapping of HEA Mesh results in two criss-crossed cables parallel to the mesh overlaps (Figure 8) this transforms this weak area in regular meshing into a particularly strong area for HEA Mesh.

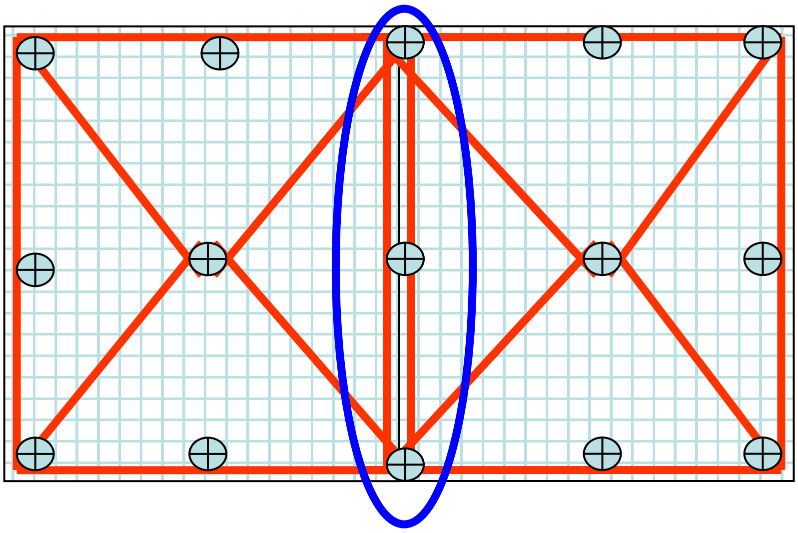

Figure 8 Two sheets of HEA Mesh overlapping. The overlap has two lengths of cable criss-crossing. The cable wraps around the rockbolt underneath the plate producing a good load transfer between the surface support and the reinforcement

5 Conclusion

Development mining in squeezing ground and rockburst prone conditions poses specific challenges in terms of safety and efficiency. In such conditions, the focus is often no longer on achieving a rapid advance but rather on obtaining steady advances and avoiding future ground support rehabilitation work. The support systems commonly used in normal ground conditions fail to work in extreme conditions as they have clear weaknesses. A mismatch of the deformation or load bearing capacity between the reinforcement and the surface support often results in the early failure of the system. The connections between the bolts and the surface support and the overlap of mesh sheets are other well known weak areas of common support systems.

The current ground support practices in extreme ground conditions overcome this problem by installing two different surface supports in a two pass installation. For example, in Australia mesh is often installed over in-cycle FRS and in Canada a mesh strap is installed over mesh. These solutions are costly and slow.

HEA Mesh overlies two surface support systems, weld mesh and cable bolts, as a pre-fabricated sheet, which can be installed mechanically using a jumbo. There is no productivity penalty when installing this superior high energy absorption support system. The system is particularly good at transferring the load from the surface support to the reinforcement and eliminates the weakness of the commonly used support systems. HEA Mesh is currently being trialled in Canadian and Australian mines.

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