# A philosophical view on the testing of rock support for rockburst conditions

by T.R. Stacey*


## Synopsis

Physical testing of rock support for rockbursting conditions has been carried out for over 40 years. A review of this testing shows that it has been mostly component–based, rather than actually testing support systems. Further, it is concluded that none of the testing is truly representative of rockburst loading in a similitude sense. Similitude conditions are not achievable, mainly because the real conditions in a rockburst event, such as seismic source location and magnitude, wave frequencies, amplitudes, and interactions, are not all known. Because such information is not available, and because the results of all testing carried out to date have not been able to define, for support design purposes, the capacity of support systems, ongoing physical testing of rockburst support systems is essential. It is essential that the test should simulate, or actually take place in, a supported rock excavation. A rock support system is a combination of individual support components that work together to retain and contain the rock. In doing this, the components are subjected to loading by the rock and to interactive loading between one component and another. It is necessary to prove the capacity of such rockburst support systems by subjecting them to severe loading, as in direct blasting. The direct blasting approach, pioneered more than 40 years ago, probably still provides the greatest validity as a significant test of rockburst support capabilities, even though it does not simulate a rockburst. Direct blast testing of rockburst support systems in a surface environment, such as in a quarry or on exposed rock cutting surfaces, could represent a practical development of the approach, facilitating the execution and monitoring of tests.



**Keywords**

rockburst, rock support systems, dynamic testing


## Introduction

The formal design of support for underground excavations requires knowledge of the demands to which the support will be subjected and the capacity of the support. Stability will usually be achieved if the capacity exceeds the demand. The capacities of individual elements of support such as rockbolts, wire mesh, and shotcrete can be calculated from their mechanical properties and the loading conditions to which they will be subjected. It is a straightforward matter to calculate the capacity of a rockbolt under tensile loading using the strength properties of the steel and the dimensions of the bolt. However, rockbolt performance also depends on installation quality, which includes the effectiveness of anchoring, the extent of grouting, the strength of the grout, the surface condition of bolt, etc. Similarly, capacities of mesh and other individual components will be influenced by installation quality and numerous other factors, making the value of theoretical calculations questionable. In real underground situations, however, the performance of support elements on an individual basis is rarely of much relevance, since it is the performance of the rock support system that is of importance. A rock support system is a combination of individual support components that work together to retain and contain the rock. In doing this, the components are subjected to loading by the rock and to interactive loading between one component and another. Therefore, a rockbolt could be subjected to a combination of tensile, shear, bending, and torsional loading by the rock under static and, particularly, dynamic conditions. Similarly, other components of support – wire mesh, shotcrete, fibre-reinforced shotcrete, face plates, straps, lacing, etc – could be subjected to combinations of loading mechanisms. Connection between the rockbolts and the surface support also implies that the surface support will impose loadings on the rockbolts, and *vice versa*. Owing to these complex situations, theoretical determination of the capacity of a support system is very unlikely to be successful, particularly in a dynamic loading environment. The weakest link principle will usually apply in that, if one component fails, it is then likely that the whole support system will be incapable of containing the damage.

* *School of Mining Engineering, University of the Witwatersrand.*

An alternative approach to determining the capacity of rock support systems is to carry out physical testing of support components and support systems. However, although such testing in relation to support for rockburst conditions has been carried out for many years, satisfactory determination of the capacity of rock support systems for design purposes is not yet a reality. Stacey (2011) indicates that, since the support system capacity is unknown, and since, in addition, the demand on the system in a rockbursting event can also not be determined with confidence, a clear case of design indeterminacy results.

This paper will focus on the philosophy of physical testing of the capacities of rock support systems.

### A review of past physical testing of rock support elements and systems

To place the testing of support systems into context, it is appropriate to indicate the behaviours experienced in rockburst events. Rockbursts are very violent events that commonly result in considerable damage to excavations (Ortlepp, 1997). Rock is usually ejected, and when this is the case, the ejected rock is commonly observed to be fragmented into relatively small blocks and slabs, as illustrated in Figure 1. Rockbolts, and surface support elements such as wire mesh and shotcrete, often fail. In such events, conventional rockbolts and cables often exhibit brittle failure. Another common observation is that when the surface support fails, the ejection of rock often leaves the reinforcement elements exposed, protruding out of the rock as shown in Figures 1 and 2.

Gravity does not play a significant role in rockburst events, and ejection can be in any direction. Floor-heave and sidewall ejections are common, as shown in Figure 3. It can be seen from these illustrations that rockbursts are very violent events, resulting in unpredictable damage.

In summary, a rockburst event results in the ejection of a volume of rock, often at significant velocity. Back-analyses of rockburst damage observations have yielded data on ejection velocities. Many results are in a range up to 10 m/s, but in one case Ortlepp (1993) calculated a velocity exceeding 50 m/s. Since energy involves the square of the velocity, support systems are required to absorb large amounts of energy if rockburst damage is to be contained.

Figure 1—Rockburst damage and fragmentation (photograph W.D. Ortlepp)

A summary of the dynamic testing of rock support carried out in various countries has been presented by Hadjigeorgiou and Potvin (2007), and an interpretation of all the results obtained has been presented by Potvin *et al.* (2010). These two papers deal with testing using blasting and drop weight impacts to represent rockburst loading. They did not refer to the early blasting tests carried out by Ortlepp (1969), who was probably the first to carry out dynamic testing of rock support. He carried out two tests on rockbolt and mesh support systems installed in a tunnel, one with conventional rockbolts and the other with the yielding rockbolts that he had developed (Ortlepp, 1968). The rockburst loading was represented by blasting, with blastholes 430 mm apart drilled parallel to the tunnel axis about 600 mm outside the tunnel perimeter. The geometry of this test is shown in Figure 4.

Figure 2—Exposed, protruding rockbolts after a rockburst (photograph W.D. Ortlepp)

Figure 3—Floor heave caused by a rockburst (photograph W.D. Ortlepp)

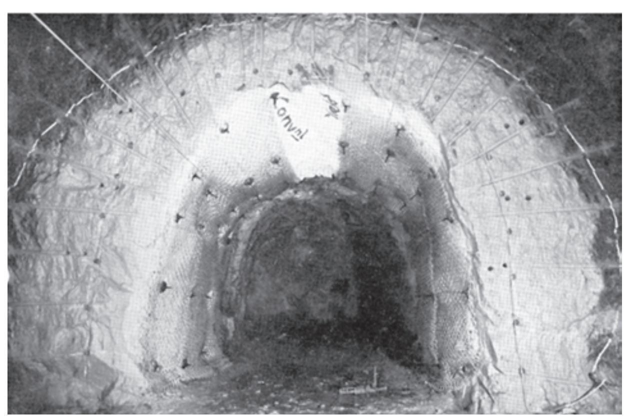


Figure 4—Test chamber before the first blast (Ortlepp, 1969)

In the first test, the explosive intensity was excessive and all support failed. A second test with reduced blast intensity proved that the support system, consisting of yielding rockbolts and a double layer of 8 gauge 50 mm aperture linked wire mesh, could contain the energy of the blast. Ortlepp's sketch of the tunnel profile after the test, shown in Figure 5, clearly illustrates the effectiveness of his yielding support system on the right hand side of the tunnel, and the ineffectiveness of the conventional support system on the left hand side.

Ortlepp (1992b) repeated this type of blasting loading test in a different mining environment, and the result was similar. Measurements during the test showed an ejection velocity of the conventionally supported wall of 10 m/s. A short while after completion of this test, a nearby tunnel was damaged in an actual rockburst, and the damage observed was indistinguishable from that in the blasting test. This indistinguishable characteristic of the result the blasting test perhaps lends credibility to the test as being representative of the effects of real rockburst loading.

More recent blasting 'rockburst' tests carried out by several researchers are described by Hadjigeorgiou and Potvin (2007). These include the test carried out by the CSIR in South Africa, the geometry of which is shown in Figure 6. Hagan *et al.* (2001) provide a summary of tests, with details provided by Milev *et al.* (2001), Reddy and Spottiswoode (2001), Haile and Le Bron (2001), and Hildyard and Milev (2001).

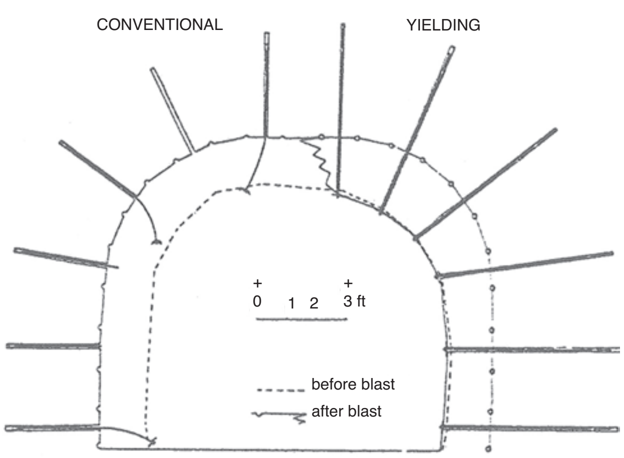



Figure 5—Profile of the tunnel after the second test (Ortlepp, 1969)

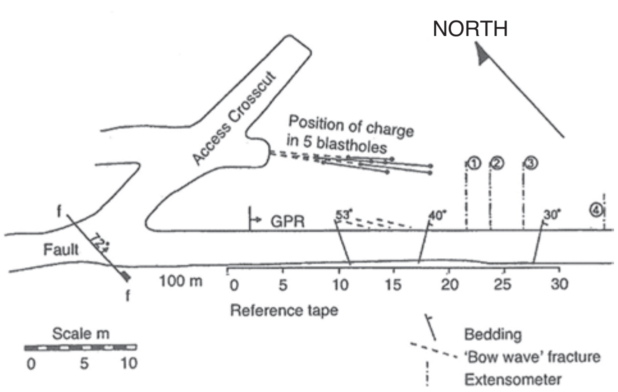



Figure 6—Geoetry of the indirect blasting test (Hagan *et al.*, 2001)

Tests carried out in Canada are described by Espley *et al.* (2002), Archibald *et al.* (2003), and Tannant *et al.* (1993), and those in Australia by Heal and Potvin (2007). The results, which are summarized by Potvin *et al.* (2010), indicate that gas pressure 'was a problem' in some of the tests.

The tests described by Archibald *et al.* (2003) are very interesting in that they represent blasting tests of a range of support systems. However, the surprisingly low level of damage observed is perhaps indicative of the fact that explosive energy and the use of a single blasthole may have been insufficient to 'test' the support satisfactorily. It is probable that the initial damage was due to the shock wave reflection, and subsequent damage was due to the cratering effect from the blast.

The testing described by Hagan *et al.* (2001) minimized gas loading, and indicated ejection velocities were in the range of 0.7 to 2.5 m/s, determined from high-speed video recording. Ground velocities of 3.3 m/s were recorded by an accelerometer. Rock support involved in the test consisted of fully cement grouted rockbolts only. 'Rockburst' damage occurred on the tunnel wall where the PPV exceeded 0.7 m/s. High-intensity damage occurred where the ground velocity of 3.3 m/s was recorded.

A similar blasting geometry was used by Potvin and Heal (2010) to ensure that the dynamic testing of the rock support was not influenced by gas pressure. In their first test they measured PPVs in the range of 0.3 to 2.4 m/s. Two support systems were used: cone bolts (yielding rockbolts) and high energy absorption (HEA) mesh; and cone bolts with mesh and fibre-reinforced shotcrete. Minor damage of the support was observed. The same location was used for the second test, with the implication that the rock mass was possibly 'damaged' (fractured) by the first blast. In this second test, PPVs of 0.6 m/s to 3.0 m/s were recorded, and significant damage occurred. A mass of rock of about 100 t was ejected, with both support systems sustaining damage.

Owing to the difficulty of carrying out blasting tests, Ortlepp (1992a) proposed the use of a 'synthetic concrete sidewall' for ejection. This concept was subsequently implemented in a quarry as the vertical ejection of the concrete mass (Ortlepp, 1994), with the ejection again achieved by blasting. Ejection velocities of the order of 12 m/s were measured and the tests demonstrated that 'low-strength' cone bolts yielded satisfactorily in tension, without breaking, at these velocities. Yield displacements of the order of 0.5 m occurred in these experiments in absorbing the energy of ejection produced by the blasts. In contrast, much stronger, fully-grouted rebar bolts failed in the tests and had a low energy absorption capacity. All of these tests were of groups of rockbolts, not of support systems involving a combination of support elements. In addition, they involved tensile loading only, and bolts were not subjected to shear, or combinations of stresses such as tensile and shear.

One may question whether blast loading is a satisfactory representation of rockburst loading (one of the philosophical considerations to be dealt with in the next section), since shock waves, and subsequently (and substantially), gas pressure (i.e., a blowing outwards) provide the loads. In contrast, in a rockburst, a mass of rock is suddenly accelerated, with no gas pressure involved. In fact, the dilation of the rock mass involved in the ejected material will probably result in a brief negative air pressure. The use of blasting for rockburst test purposes has disadvantages—it is costly; it requires special environments, usually underground; and it is usually not repeatable. As a result, alternative laboratory testing methods, usually involving some form of drop weight system, have been developed for evaluation of rock support. An example is shown in Figure 7. Such 'laboratory rockburst' testing of rock support components and systems has been carried out in several countries using somewhat different testing methods (Ortlepp and Stacey, 1994,1997,1998; Yi and Kaiser, 1994; Kaiser *et al.*, 1996; Stacey and Ortlepp, 1999, 2001, 2002a, 2002b; Gaudreau *et al.*, 2004; Li *et al.*, 2004; Player *et al.*, 2004, 2008a, 2008b; Plouffe *et al.*, 2008; Li and Charette, 2010). Further, the references and bibliography provided by Kaiser *et al.* (1996) indicate numerous unpublished reports of testing, authored mainly by Tannant.

Most of these test methods and results referred to above have been described by Hadjigeorgiou and Potvin (2007) and the results summarized by Potvin *et al.* (2010). Figure 8 shows one of the graphs from Potvin *et al.* (2010), giving, from the above publications, the estimated capacities of various components and combinations of surface support. It can be seen that very significant levels of energy can be absorbed by appropriate support, provided that yield, or displacement, can take place. The value of wire rope lacing in absorbing energy is also apparent from Figure 8, a contribution that was specifically identified by Stacey and Ortlepp (2002a). As can be seen from this diagram, wire rope lacing can enhance the capacity of mesh and shotcrete by as much as seven times.

The results in Figure 8 show the capacities of containment support (mesh, shotcrete, liners, straps, lacing), but do not provide data on capacities of *systems*, which are combinations of retainment and containment support elements, as well as the connecting components (nuts, faceplates, etc). The performance of a *support system* will depend on the performance of all of these components. The link between a rockbolt and containment support such as mesh usually involves a steel faceplate on the bolt. Such plates often fail because of irregular rock-bearing surfaces or non-axial loading on the bolt. Tests carried out, in which loading simulated 'real' conditions rather than idealized flat-surface bearing conditions, demonstrated that plate capacities were much less than their specified values (Van Sint Jan and Palape, 2007) because the plates failed in a folding mode. Nut failures were also observed in these tests. Plate capacities are enhanced by the use of lacing and/or straps, which spread the load rather than allowing it to be concentrated on the plate alone.

A drop weight testing facility that was able to test support systems for use in tabular mining stopes was described by Ortlepp *et al.* (2001). The essential components of this facility were the collapsible roof, which represented the hangingwall of the stope, and a drop weight that provided the impact energy. Figure 9 illustrates a section through the facility. The collapsible roof consisted of three clamped 'cracked' beams, made up of 12 high-strength concrete 'slabs' representing the fractured hangingwall. The 'slabs' were assembled into beams, with steel threaded bars providing a clamping force.

Figure 7—A drop weight testing facility

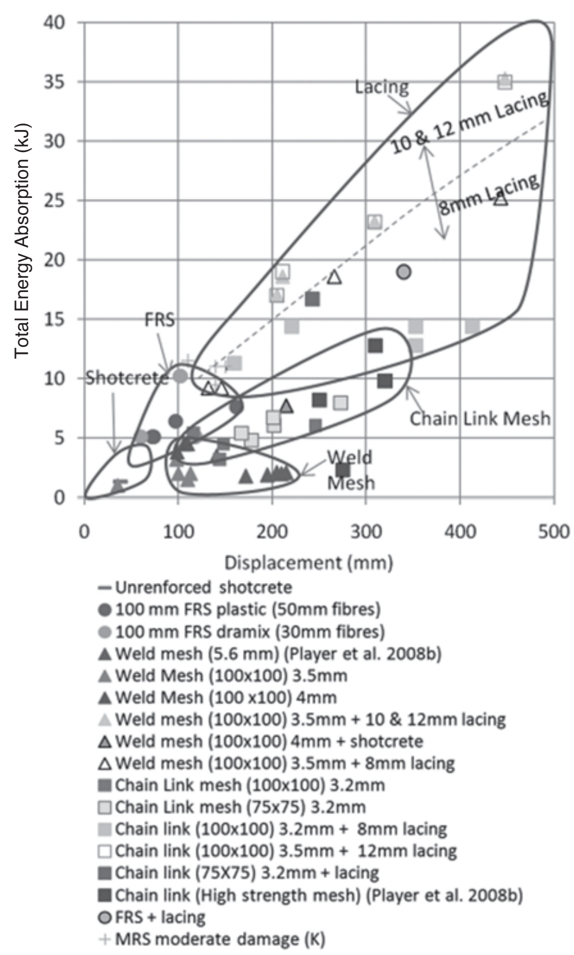
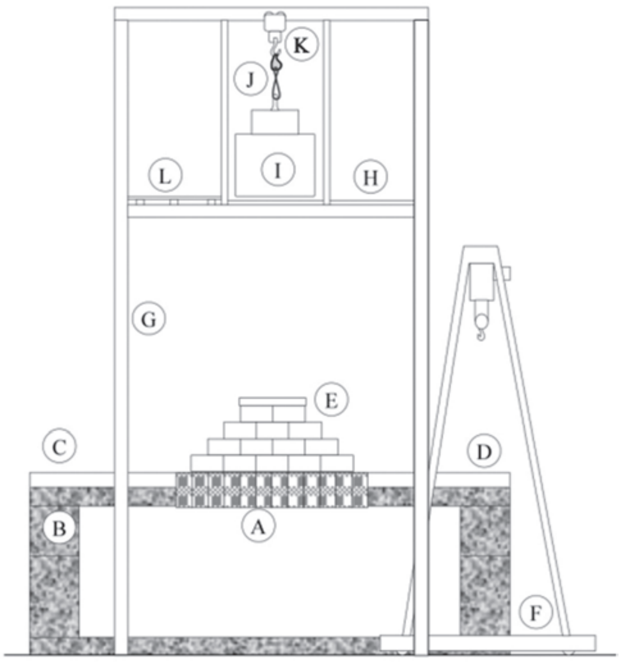



Figure 8—Performance of surface support systems under dynamic loading (Potvin *et al.*, 2010)




A – Collapsible roof
B – Corner Column
C – Deck
D – Side beam
E – Load distribution pyramid
F – Portal crane
G – Main support column
H – Floor
I – Drop weight
J – Quick release shackle
K – 10 t hoist
L – Berthing platform for drop weight

**Figure 9–Section through the large-scale drop weight testing facility**

The two side-beams, two decks, and the three 'cracked' beams forming the collapsible roof were supported at the corners by four concrete pillars. Prestressed stope support could be accommodated, and holding-down ties were required to hold the roof in position while the stope support was being prestressed.

The dynamic load was imposed on the collapsible roof by dropping a solid steel cylinder of 10 t mass from the requisite height onto the facility. The impact was taken on a steel plate, and distributed through a pyramid of steel-clad concrete blocks. The drop weight fell freely from a maximum height of about 3 m to deliver a maximum impulse of 300 kJ at an impact velocity of 7.7 m/s.

The facility was thus representative of a stress-fractured tabular gold mine hangingwall clamped by a confining stress. Support systems consisting, for example, of props and straps or mesh over the 9 m$^2$ area, could be tested. The philosophical question is whether this testing facility actually simulates a rockburst, or simply provides a support system testing facility that can carry out repeatable tests.

Thus, in summary, this review of alternative testing methods has shown that, while data is available on individual *support components*, knowledge of the capacities of *rock support systems*, from theoretical calculations or in the form of data from practical testing programmes, is absent.

## Philosophical considerations regarding physical 'rockburst' testing of rock support

The information provided above clearly indicates that quantified data on capacities of support systems does not exist, and therefore it is not possible to carry out a formal design of a rock support system applicable to rockbursting conditions.

## Comments on testing approaches

### *Testing of individual support elements*

Is there merit in testing individual elements? The simple answer to this question is that testing of individual rock support elements is essential in order to be able to understand and compare their capacities with alternatives. Such tests are also necessary to check on quality of the components and to ensure adherence to specifications; for example, type of steel and steel behaviour, resin and grout quality, etc. The tests must be appropriate to the dynamic behaviour, however. For example, a conventional pull test on a grouted rockbolt is usually not appropriate for determining the capacity of, or the behaviour of, that bolt.

### *Drop weight testing*

The advantages and disadvantages of drop weight testing are as follows:

Advantages
- Relatively simple and quick to perform
- Can provide repeatable results
- Suitable for comparative testing and quality control testing.

Disadvantages
- Impact loading may not be representative of rockburst loading
- Direct impact on surface support is not considered to be representative of rockburst loading
- When impact via a load spreader is used, the load/energy to which the support is actually subjected is unknown
- Appropriate representation of lateral continuity of support is unlikely to be achieved
- The effect of the stress in, or confinement of, the rock mass is usually not taken into account
- The methods published have generally not achieved satisfactory testing of support systems involving both retainment and containment elements. A probable exception to this is the large-scale facility described by Ortlepp *et al.* (2001) for tabular stope support system testing.

The momentum transfer concept used by Player *et al.* (2008a, 2008b) is an interesting variation on drop weight testing. It is likely that it provides more realistic 'rockburst' loading than the impact drop test, but the arresting mechanism may introduce an unknown into this area. The method also shares many of the disadvantages listed above.

It may be concluded that a drop weight test is a dynamic test that does not really simulate 'rockburst' loading, and generally is not able to test support systems.

### *Direct blast testing*

From the published information on testing that has been carried out on rock support using direct blasts (for example, Ortlepp, 1969), it is clear that this constitutes a severe test of the support. We do not know the detail of what happens in such as test, since only the result can be observed. The gas pressure will have a strong influence, which is perhaps the main reason why such a test is very different from a rockburst. However, from his observations, Ortlepp (1992b) believes that the damage produced in such a test is indistinguishable from rockburst damage. Nevertheless, this type of test certainly cannot be claimed to simulate a rockburst.

Part of the volume of rock in the angled blasthole tests by Tannant *et al.* (1993) involved direct blasting damage. Initial damage was due to the reflected shock wave, and small rock fragments were ejected. Subsequent damage was the result of gas pressure, involving the ejection of large volumes of rock. Similarly, the tests described by Archibald *et al.* (2003) represent a combination of both indirect and direct blast tests.

### *Indirect blast testing*

Indirect blast testing of rock support is probably the closest simulation of rockburst loading. It removes the issue of gas pressure almost completely. However, questions remain as to whether wave interaction, wave frequency, source mechanism, source location, and source magnitude as a result of the blast are sufficiently similar to those in a rockburst event. Indirect blasting tests are not repeatable since the site of the test will generally be destroyed in the test. If not destroyed, the rock mass will probably have been significantly modified by the blast so as to be unusable for repeat testing. It is also likely that indirect blast testing will be too costly and too inconvenient in an underground mine environment to be practical for comparison of the performances of different support systems. If tests are carried out at more than one site, even if blasts are identical, comparison of results may be difficult, since rock mass and confinement conditions will differ from site to site. Thus, while the results of indirect blast tests will be of interest, they are unlikely to provide satisfactory support design data. They are unlikely to become a 'standard' test for rockburst support.

## ***The philosophical questions***

The fundamental question is, 'What is the purpose of the physical testing of rock support?' Some of the possible aims of the testing are:

- ➤ To quantify the capacity of the support for formal design purposes, i.e. to provide detailed data for rock support design
- ➤ To evaluate support performance and provide empirical data for empirical design purposes
- ➤ To check on the quality of the support and its installation
- ➤ To prove that the support can withstand the energy involved in the expected magnitude of seismic event, and therefore limit damage to the excavations
- ➤ To expose the support to severe conditions that will prove that the support can withstand such conditions and ensure the safety of personnel under such conditions.

Questions that arise regarding the testing of rock support systems for rockbursting conditions are:

- ➤ Should the test simulate a rockburst, i.e. should similitude conditions be achieved?
- ➤ Should the test simulate a supported rock excavation?
- ➤ Should the test be a practical one that can be used to compare the performance of alternative systems?
- ➤ Should the test be one that can be used for quality control?
- ➤ Should the test be a *severe* test of the support?

The more important of these questions are dealt with below.

**Can we hope to achieve similitude with a rockburst?** Although seismicity has been monitored carefully for many years, generating large volumes of data, and thorough inspections of rockburst damage locations have been carried out, with observations from these inspections documented (Durrheim, 2012), we still cannot define with any confidence what characteristics will occur in a future, specific rockburst. We do not know the following main items of information (that would be necessary to ensure similitude conditions) with any confidence: the location and magnitude of a potential seismic event; the characteristics of the seismic waves, their interactions, and their interaction with the excavation surface; the ejection velocity that will result from the seismic event; the direction of action of the ejection force; the mass of rock that will be involved in the ejection; and the characteristics of this volume of rock mass and its confinement. It is therefore clear that we have no basis for developing a test that simulates a rockburst.

**Is it necessary for the test to simulate a supported rock excavation?** If we hope to be able to test rock support systems, then it is essential that the test should simulate, or actually be conducted in, a supported rock excavation. A rock support system is a combination of individual support components that work together to retain and contain the rock. In doing this, the components are subjected to loading by the rock and to interactive loading between one component and another. Therefore, a rockbolt could be subjected to a combination of tensile, shear, bending, and torsional loading by the rock, and by other support elements attached to it, in a rockburst event. Similarly, the other components of support such as wire mesh, fibre-reinforced shotcrete, thin spray-on liners, straps, lacing, face plates, etc, could similarly be subjected to combinations of loading mechanisms. Connection between the rockbolts and the surface support implies that the rockbolts will impose loadings on the surface support, and *vice versa*. It will be impossible to evaluate the behaviour of support in these complex situations unless real support systems installed in real rock masses are tested.

There is much merit in developing a standard test that can be used to compare support performance (and be used for quality control). This was a conclusion of Hadjigeorgiou and Potvin (2007), who also suggest that results from such tests could be correlated with rockburst behaviour from case studies, leading possibly, in the future, to an empirical design approach.

**Should the test be a *severe* test of the support?** Safety is of paramount importance, and if we are to achieve safety of personnel in rockbursting conditions, then rock support systems must be able to withstand severe conditions. Since neither the demand on the support, nor the capacity of the support, are known with confidence, the only way to maximize safety is to ensure that the rock support is capable of withstanding severe conditions. Since similitude is not achievable, the most practical way in which severe testing of rock support can be carried out is by direct blasting, as was done by Ortlepp (1969) more than 40 years ago. He demonstrated in his severe testing that use of a support system incorporating his yielding rockbolts was successful in containing damage, whereas conventional support was destroyed. In spite of the success of those bolts, they were not implemented in the mines, and 40 years later, yielding rockbolts are still not implemented universally in rockbursting mines in South Africa.

**Where to with physical testing of rock support?** Physical testing of rockburst support should clearly be continued with the aim of testing its capacity and possibly providing design data. Where feasible, underground blasting tests are encouraged as severe tests of the support. If suitable testing facilities are available on surface, such as in a quarry or on exposed rock cutting surfaces, then installation and direct blast testing of rockburst support *systems* is recommended. Such testing on surface has the advantage of not interfering with mining operations. It also facilitates access, installation of support components, visual and video monitoring, and other instrumentation and measurements. The use of surface 'rockburst' testing of support systems was described by Archibald *et al.* (2003), and review of this procedure is of value. However, as indicated above, the level of support damage induced in the tests was very low, indicating that, if severe conditions are to be achieved, additional blast holes and greater explosive charges will be necessary.

Observation, interpretation, and documentation of real rockburst damage must continue, with the hope of correlating observed behaviour and rockburst event magnitude with behaviour in direct blasting tests, perhaps using a damage classification approach.

**What about support costs?** The introduction of 'severe support' is likely to increase direct costs of support. However, support component costs are only one of many costs associated with the consequences of rockbursts. Other consequential costs include accidents and associated costs, including work stoppages; clean-up costs and rehabilitation costs; the cost of loss of production in operations directly affected by the damage; the costs of loss of production in areas more remote from the damage, owing to loss of access; cost due to reassignment of crews; the cost associated with loss of ore; and costs that are difficult to quantify, such as public perception, reduction of mining company share price, reduced worker morale, labour unrest, etc. Therefore, if rockburst damage can be reduced or prevented, both direct and indirect costs that might be associated with damage will be minimized. Recent research by Rwodzi (2010) has shown that indirect costs far outweigh direct support costs, with loss of production usually being the major indirect cost. The introduction of 'severe support' is therefore likely to reduce overall costs and create value for the mine. The same argument applies to rockburst support testing – without such testing, improved support design and innovation will not result. Therefore, costs associated with such testing are a necessary part of the value creation investment.

## Conclusions

A review of physical testing of rockburst support over a period of more than 40 years has indicated that most testing has been component-based rather than testing support systems, and that none of the testing really simulates actual rockburst conditions. Testing methods have included direct and indirect blasting tests, and drop weight tests. It is concluded that it is not possible to obtain rockburst similitude conditions in a test. It is impossible to design rockburst support systems using a conventional approach, since neither the demand on a support system nor the capacity of a support system can be satisfactorily defined. Therefore, it is necessary to prove rockburst support systems by subjecting them to severe loading, as in direct blasting. Therefore, the blasting approach pioneered by Ortlepp (1969) more than 40 years ago probably still provides the greatest validity as a significant test of rockburst support capabilities, even though it does not simulate a rockburst. It is suggested that direct blast testing of rockburst support systems in a surface environment, such as in a quarry or on exposed rock cutting surfaces, could be a practical approach that does not interfere with mining operations, and which also facilitates access for installation of support components, and for visual and video monitoring, as well as other instrumentation and measurements.

The introduction of 'severe' rockburst support in mines will result in increased support costs. However, recent research has shown that the cost of support is a small fraction of the consequential costs associated with support failures, collapses, and accidents. Therefore, prevention or containment of rockburst damage is almost certain to create value for the mining operation.

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