THE ART OF ROCK SUPPORT IN BURST-PRONE GROUND

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Rock support in burst-prone ground requires a good understanding of the rock mass behavior under high stress condition and the behavior and functionality of each rock support element. Seven principles, which can lead to making the right judgment and decision with regards to ground support in burst-prone ground, are presented. The success of using MCB cone bolt based rockburst support in a few Canadian mines is illustrated along with our recent development to further improve the dynamic performance of MCB cone bolt.

1 Introduction

A rockburst is a violent failure of hard brittle rock under high stress. Rockbursts can cause fatalities to workers in a split of a second. For example, on January 7, 1982, a rockburst (ML = 3.2, Richter or local magnitude) struck the Taozhuang coalmine in Shandong Province in China, resulting in five deaths, six injuries, and permanent loss of mine stopes (500,000 tons of high grade coal). Rockbursts can also cause damage far beyond the source locations and it is one of the major causes of production disruptions in many deep mines around the world.

Mine wide seismic monitoring systems have been widely used in deep mines. A seismic monitoring system constantly monitors for rock noise in the mine. It can locate a seismic event and provide additional information about the event such as magnitude, moment, energy ratio, etc. Monitoring of seismic events in mines is a very useful tool in outlining potentially hazardous ground conditions and assisting mine management in effective re-entry decision. However, a seismic monitoring system cannot predict when and where a rockburst will happen and mine safety can only be guaranteed by proper engineering and effective rock support.

Due to large uncertainties in rock mass properties and boundary conditions (e.g., in-situ stress), all engineering design, calculations, and seismic monitoring will have to rely on effective rock support as the final line of defense to safe guard workers, equipments, and mine operation. This is not to say that proper mine planning and rock engineering combined with seismic monitoring is not important, but emphasizes that rock support is an important consideration in order to overcome the rock mass property and behavior uncertainties so as to ensure a safe working environment in burst-prone ground. In addition to maintaining a safe working environment, proper rockburst support also ensures profitability for the mine by protecting the investment underground.

Rock support in burst-prone grounds differs from conventional rock support where controlling gravity induced rock falls is the main concern. Rock support in burst-prone grounds needs to address a few things such as dynamic loading and large rock dilation due to rock failure. Over the years, various lessons have been learned and experience gained, often in the bitterest ways. This paper intends to summarize some of those experiences in such a way that the art of rock support in burst-prone ground can be practiced by any engineers by following a few simple principles.
2 Rockburst Damage Mechanism

2.1 Rockburst Research

Extensive rockburst researches have been conducted in South Africa, Canada, Australia, and many other countries. One of the most comprehensive rockburst research studies in Canada from 1990 to 1995 eventually led to the publication of the Canadian Rockburst Support Handbook [6]. Multi-year mine seismicity research has been carried out in Australia and the Mine Seismicity Risk Analysis Program (MS-RAP) has been developed and used by the mining industry. The International Symposium on Rockburst and Seismicity in Mines (RaSim) has been the place for the exchange of ideas and discussion for engineering solutions since 1982. Those collective efforts have greatly improved our understanding of rockburst.

2.2 Rockburst Damage Mechanism

A rockburst is defined as damage to an excavation that occurs in a sudden or violent manner and is associated with a seismic event [5]. Rockbursts can be classified into three types [2]: (a) fault slip burst, (b) pillar burst, and (c) strain burst. When the event induced stresses exceed the capacity of the unsupported or supported rock, even temporarily, failure is initiated or triggered.

Typical rockburst damage to underground excavations include stress induced rock fracturing, bulking of roof and sidewalls, floor heave, shearing of rock, rock falls and ejections, etc. A rockburst can be self-initiated or trigged by a remote seismic event. Violent rock failure can be in any of the three forms – block ejection, seismically induced fall of ground, and rock fracture with dilation (strain burst). Quite often, all three forms of damage can be observed in a large rockburst event.

Severity of rockburst damage can be classified as minor, moderate, and severe [6]. For a typical opening of 5 by 5 m, the minor, moderate and severe damages can be characterized by fractured or loosened rocks of less than 0.25 m, 0.25 to 0.75 m, and more than 0.75 m, respectively. The degree of expected damage will determine the dynamic rock support demand. Under severe damage conditions, the rapid tunnel closure up to 300 mm or more is possible due to rock bulking. When a seismic wave reaches an opening, it can accelerate the blocks of rock and potentially eject the blocks out. The ejected blocks of rock possess kinetic energy; therefore, the applied rock support must be able to absorb or dissipate this kinetic energy. If the damage mechanism is associated with seismically induced rockfalls, it will be necessary to strengthen the support systems such that the factor of safety against failure under static conditions is significantly increased [6].

As stated before, violent rock failure cannot be avoided when mining at depth, hence, dynamic rock support is required to perform underground construction in seismically active mines. The demand on the support includes three aspects – dynamic energy absorption capacity, large displacement accommodation capacity, and load carrying capacity. All three of these are needed in order to ensure safety.

The role of rock support in underground construction can be classified into three major functions – reinforce, retain, and hold [6]. Under dynamic loading condition, the rock support system must be able to absorb energy and survive the rockburst event. There have been many publications on rockburst support (e.g., Hedley [2], Kaiser et al. [6], Ortlepp [8], and many others), but it is often hard for practicing engineers to master the essence of rock support in burst-prone ground. Hence, it is our intention to present the gained knowledge and experience in the form of a few easy-to-grasp guiding principles. These principles were gained through practical experience by many throughout the world and interaction with ground control engineers. We believe that a better understanding of the following seven principles is important to have a better rock support in burst-prone ground.
3 The Art of Rock Support in Burst-prone Ground

3.1 Avoid Rockburst Principle

The supreme excellence in rock support in burst-prone ground is to avoid rockburst conditions and the best rock support in burst-prone ground is no support at all. This may sound paradoxical but is completely true. Why fight if you can avoid it? The best strategy is to stabilize the rock without fighting against the loads and stresses in the rocks using heavy rock support. Ržiha, a famous nineteenth century German tunneling engineer, once commented on tunneling that – “The true art in tunneling lies in the anticipation of the development of large rock pressure, which is far more effective than to find the means of resisting rock pressures which have already developed.” Strategies to mitigate and control rockburst risk and hazard are shown in Figure 1 and it is important to consider the order of priority when executing those strategies. The first thing to consider, of course, is to avoid rockburst risk and the last thing to do is to accept rockburst risk, which often means we need rockburst resistant rock support under this circumstance.

Methods to avoid rockburst risks include changing of drift location, use of different excavation shapes, changing the stope size and/or shape, altering mining sequencing and potentially switching mining methods. For example, a proper pillar design can eliminate the soft loading condition in a mine, thus prevent pillar bursts from happening. Re-entry management should be considered to avoid personal risk due to rockburst. No personnel should be permitted to work in areas where seismic activity is still high after a major event. Methods to transfer rockburst risk include destress blasting and altering timing of blasts. To minimize rockburst risk, backfill of mined stopes should be considered. When all these and other methods are exhausted and the rockburst problem is still present, we will have to accept the reality and institute effective rockburst support.

Avoiding difficulty and confrontation is one of the fundamentals of Tao in Chinese culture. If we can achieve this, we are following Tao in our professional work.

3.2 Flexibility/Yielding Support Principle

When a seismic event occurs, rocks can be subjected to large impact loads. When brittle rock fails, it is always associated with large rock dilation. Therefore, the installed rock support system must be able to absorb dynamic energy while at the same time accommodate large rock deformation due to rock failure. Practical rock support
has its limit in terms of capacity. Hence, the installed rock support system should focus on controlling the rock behavior after failure, not on preventing the rock failure from occurring.

In addition, when mining at depth, the excavation-induced stresses around underground openings are so high that rock fracturing is inevitable. The stresses are further elevated when the rock is loaded dynamically. In many situations, it is no longer possible to increase the load carrying capacity of the reinforced rock system economically, and the support behavior must be fundamentally changed to allow for yielding. Jager et al. [3] showed the dilation pressure resulting from brittle failure in a deep tunnel sidewall exceeded 0.4 MPa. When the rock fracturing process is dynamic, it is likely that the pressure will be considerably higher, exceeding the capacity of most practical rock support systems. For reference, the support pressure that can be achieved by a moderately dense pattern of rockbolts is about 0.1 MPa. To provide a support pressure of 0.4 MPa, very thick cast-in concrete would be required which is clearly not economically practical for most mining applications.

In general, rock pressure decreases with increasing rock deformation. If the rock support system is able to yield in a controlled fashion, we can reach a dynamic equilibrium in the whole deformation process and the system will eventually reach a new static equilibrium. Things in nature always try to reach an equilibrium – a cup of hot coffee sitting on the table will eventually reach room temperature, water tends to run down hill to a lower, more stable place, and a rock mass will deform to find its most natural bearing state itself.

Hence, the key point is that the rock support system must allow the rock mass to deform, which means that the rock support system must be yieldable. Yielding support system can tolerate large tunnel convergence without “self-destruction” of the system while providing necessary support to ensure safety and maintain serviceability of the tunnel. A yielding rock support system is a system in harmony with its surrounding rocks.

![Figure 2 Load-displacement curves of various rock bolts (data except conebolt are from Stillborg [14]).](image)

Cook and Ortlepp [1] first suggested the use of yielding support in the deep gold mines in South Africa. Not surprisingly, conebolts were first developed in South Africa. The conebolts were groutable yielding tendons developed by the Chamber of Mines Research Organization (COMRO) in 1987 [4] for use in cement grouted holes. Noranda Inc. added a mixing blade for use with polyester resin cartridges and the resulting conebolt was
called the MCB (Modified Cone Bolt). When subjected to static loading, the cone functions as a wedge-style mechanical anchor similar to standard mechanical rockbolts. However, when subjected to dynamic loading, the MCB conebolt can yield or plow through the resin, thus absorbing the dynamic energy through controlled deformation. As can be seen from Figure 2, conebolts and friction sets can maintain their load carrying capacity while experiencing large deformation, and they are amongst the most widely used yielding support elements in deep underground mines. MCB conebolts have been successfully applied in some Canadian mines with severe rockburst problems and friction sets have been used for support in moderate bursting grounds. More discussions on the application of conebolt are presented in Section 4.

If we compare a rockburst to a storm, we often see large strong trees broken or rooted up due to high winds. However, when a bamboo is subjected to a similar storm, it bends and sways but is seldom broken. Let your rockburst support system emulate bamboo’s strength and flexibility.

3.3 Address the Weakest Link Principle

Standard support using rockbolts or rebars (or both) with wiremesh is widely used for ground support in Canadian mines. This type of rock support system is not effective when a rockburst strikes, not because the rockbolts do not have sufficient holding capacity, but because the link between the mesh and the bolts is weak. This linkage is the weakest link in the system. In fact, the surface retaining element is often the weakest link in most rock support systems. The connection between bolt and screen fails in 75-80% of large rockburst events. One example is given in Figure 3. The drift was supported by rockbolts and wiremesh. The ejected blocks from the rockburst stripped the mesh from the bolts yet most rockbolts were left in the wall with little damage to themselves and the plates were not even deformed. This picture clearly shows that the linkage between the bolts and the mesh was weak. Had the linkage been stronger, the damage might not have been as severe or could have been completely avoided.

Figure 3 Rockburst damage to a drift at a mine in Canada. If the bolt mesh weakest link had been properly addressed, we might have seen a completely different picture.

A chain is only as strong as its weakest link. Most people seem to have no problem understanding this, however not everyone realizes that there is a weak link in rock support systems in use today in mines. In this case, the effectiveness of a rock support system comprised of rockbolts and mesh to resist the dynamic loading, does not depend on the strength and capacity of the bolts and mesh, but rather on the connection between the bolts and the mesh. Therefore, when designing rock support for burst-prone ground, we must address the
problem of the weakest link. This problem has been recognized by a few researchers and a comprehensive investigation is provided by Simser [10].

The surface retention component failure is often caused by use of mesh with too low a strength, sharp-edged steel plates cutting the mesh, ejection at the mesh overlap, failure of the bolt threaded section, plate failure, failure of nut, etc. Hence, there are many ways to improve the capacities of the system’s “weakest link.” One example is the use of relatively large plates to connect the rockbolts to the wiremesh. At Otter-Juan Mine in Australia, they adopted 350×300 mm, 3 mm thick plates with 4 mm diameter wire mesh, and the end anchored thread bars proved effective in slight to moderate rockburst conditions [15]. In some Canadian mines, 300×300 mm #0 gauge (7.7 mm in diameter) mesh plates are used in combination with standard steel plates to provide a wider coverage area to prevent the plate from punching through wire mesh. In this case, the mesh thickness will also determine the degree of dynamic protection that the system can sustain. For years, the South Africans have successfully used a surface retention system called cable lacing for rockburst support. Rockbolts are installed with mesh and cables are woven through the yielding tendons in a diamond shape. The lacing increases surface retention and in the event of a rockburst, the mesh and cables work in tandem to capture the ejected rock and transfer the load to the surrounding tendons. A similar system is used in Canada. It comprises 30 cm wide 3 m long #0 gauge mesh straps. The above examples address the weakest link problem and the design strength can be increased or decreased based on each mine’s individual needs following a thorough risk assessment.

Based on our experience, we recommend installing conebolts using relatively large plates (minimum 150×150 mm) and #0 gauge mesh straps. The reason is simple – we want to eliminate the weakest link in the rock support system. Addressing the weakest link in a rock support system often can result in greater system performance for a relatively smaller effort. We do not need a completely new chain; all we have to do is to replace the weakest link by a stronger one. Always remember that a rock support system is only as strong as its weakest link.

3.4 Integrated System Support Principle

The authors are often asked by miners and ground control engineers whether one “super” bolt can be developed to replace all other bolts to combat rockburst problems in deep mines. Our answer is always a big “No!” For example, extensive effort was put into the development of a “super” spray-on liner that was intended for use in highly stress ground. Spray-on liners have some sought after properties, however, it is doubtful if they can replace other surface support elements such as shotcrete, straps, lacing or mesh. Very often, we need a rock support system that is comprised of different rock support components. The clever ground control engineer looks to the combined effect of an integrated support system, and does not rely only on any individual element. He or she then has the ability to pick out the right combination of support elements and utilize the combined synergies.

In some people’s mind, when you mention the term rockburst support, all they can think of is the application of conebolt or friction set. For example, they would think that rebars are too stiff and therefore conclude that rebars should not be used for rockburst support at all. The fact is that stiff rebars, in combination with mesh or shotcrete, can control the rock fracturing and hence rock dilation in hard rocks very well (when the stress is relatively low to moderate). When a rockburst strikes or when the rock stress is high, rebars can break (usually at the threaded section near the plate) and lose their holding or surface retention function. However, if we add conebolts with straps to the rock support system, we then form a two-tiered defense system. Rebars will reinforce the rock mass to ensure that it is not fracturing pre-maturely (static support). When the rock masses do fail, the yielding support will ensure that they are properly retained.
Similarly, some engineers do not like shotcrete in burst-prone grounds because they have seen that shotcrete became part of the “fly rock” when a rockburst occurred. The fact is shotcrete can be very useful to enhance the installed rockbolt and mesh rock support system. They will enhance the weak link between the bolt and mesh, and they can prevent key blocks from moving and therefore enhance the overall integrity of the rock mass. From our integrated system support approach, we understand that shotcrete is a very useful component in the team and we need to use it at the right place and at the right time when it is needed (this is like using defenders wisely in a sport game). To prevent shotcrete from flying off with rocks, a second layer of mesh can be used. Quite often, if conebolts and straps are installed over top of any applied shotcrete, the problem of “fly rock” can be resolved.

For this reason, we need to understand the function (reinforcement, hold, and retain) of each support component – rebar, rockbolts, friction sets, conebolts, cablebolts, wire mesh, shotcrete, lacing, straps, etc. Some support components have multiple roles in terms of the three support functions (reinforce, retain, and hold) but may be strong in one aspect and weak in the others. It is essential that the various support elements be combined to maximize their capabilities for support in burst-prone grounds. An effective rockburst support system is not the application of a single “super” bolt or liner, but rather the optimal use of various support components.

3.5 Simplicity Principle

Rockburst support does not necessarily have to be complicated. That means that the rock support elements should be relatively easy to be manufactured, installed, and maintained. Regardless how effective it is, if a rock support element is complicated to manufacture and the cost too high, operators will be reluctant to use it. If it is difficult to install and production is adversely affected, its acceptance by the mine operators and workers will suffer.

The new MCB33 conebolt is a good example of simplicity. The bolt is comprised of a smooth bar with a threaded end on one side to accommodate a nut and washer plate and a cone shape at the other end. It is relatively easy to manufacture and simple to install. The bolt is installed in a 33 mm drill hole using 30 mm resin cartridges. The 33 mm diameter is the standard drill bit size used in most Canadian mines for virtually all short bolt installations, i.e., 0.5 to 3 m bolt lengths. The use of resin instead of cement grout ensures quick installations and acceptance by both the mine management and the mine workforce. One bit size means that a one pass bolting system can be implemented, greatly improving the bolting efficiency. In addition, the yielding mechanism of the MCB33 – cone plow through resin – can be easily understood by both engineers and miners alike. Ultimately all mine personnel need to understand the support elements and buy into the system to ensure their safety.

When it comes to rock support in burst-prone ground, it is always beneficial to follow Albert Einstein’s advice – “Make everything as simple as possible, but not simpler.”

3.6 Cost-effectiveness Principle

By cost-effective, we mean two things – the rockburst support system should not cost a lot of money, and even though using rockburst support may cost extra money but it is money well spent. This first point needs no explanation at all and the second point seems to be difficult to be understood by many mine operators.

We know that making underground construction safe and reliable costs money. However, we must be very clear that spending money to ensure safety and spending it well are two different things. When a rockburst occurs, it usually comes as a BIG “surprise.” In Canadian mines, if a worker is killed by a rockburst event, the mine could be shut down for an extended period of time during a lengthy investigation. When a critical access such as ramp is severely damaged by a rockburst event, it often means of loss production for months and the revenue loss is compounded by costly rehabilitation. It is estimated that the rehabilitation cost is 10 to 20 times
higher than the initial development cost. The cost of a yielding support system (e.g., cone bolt or other bolt system) may be slightly higher when compared to a standard rock support, however, if costly rehabilitation and lost production (and possibly litigation) can be avoided by using rockburst support systems, this is the most economical option. The key point is that if the price tag for a rockburst event is high, the cost of preventing it in the first place, using rockburst resistant rock support system, can be remarkably low (Figure 4). Many accidents have told us that prevention in burst-prone ground yields more benefits than cost.

However, it is not necessary to install rockburst support everywhere in a mine because this is excessively expensive. Therefore, we need to know or anticipate where rockburst damage could potentially occur. A few tools are available to assess the seismic hazard in a mine, such as analysis of microseismic monitoring data, integration of geology, and adaptive use of numerical modeling results. Unfortunately, rockburst risk assessment is still at its early development stage and coupled with the complex nature of rock mass property and excavation behavior, we will have to rely heavily on rock support to cushion the uncertainty with regard to location and severity of the rock mass damage due to a rockburst event.

For rock support in potentially high-risk rockburst grounds, a penny saved could be a dollar lost.

![Figure 4 Illustration of cost-benefit for rockburst support.](image)

3.7 Observational Construction (Anticipate and be Adaptable) Principle

Burst-prone ground conditions and rockburst damage severity potential change constantly. Where will the seismic event occur? How large of an event might it be? What mode of damage might it produce? We all understand that it is not possible to answer all of these questions. Therefore, it is unrealistic to have a fixed design that cannot be changed. In general, the choice of a particular rock support system depends on the ground conditions encountered, the mining sequence, available material, and the experience of the engineers and miners at the mine site.

In actual application, we have a good knowledge of the capacity of the rock support but a poor knowledge of the anticipated dynamic loads (demands). One may follow the guideline in the books (e.g. Canadian Rockburst Support Handbook [6]) to start his/her design of rock support, but the design needs to be verified and altered using field observation and monitoring. A few trial-and-errors are needed to assess the expected demand and then match it with appropriate rock support under given boundary conditions.

A good rockburst support system is the one that will stabilize the excavation for the conditions to be expected not only at the time of excavation, but also during the life of the operation. It should be capable of adapting to changes from these conditions as they are put into services. Adaptability is the ability of a system to adapt itself efficiently and quickly to changing circumstances. Adaptability means “survival of the fittest.” If a rock support system design cannot adapt to the changing ground condition, it is not going to be a good design.

When unexpected ground behavior is encountered, it is unwise to stick to old principles or old tricks. Let your underground excavation and rock support methods be regulated by the infinite variety of ground conditions. The art of rock support in burst-prone ground is not to rely not on the likelihood of the unexpected
ground behaviors are not coming, but on our own readiness to receive them, not on the chance of the ground deformation forces are not attacking, but rather on the fact that we have made our rock support system unbeatable.

Wayne Gretzky, one of the most famous hockey players in NHL history, once said, "Skate to where the puck is going, not where it is." If you cannot anticipate, you will never become a good hockey player. Similarly, if you cannot anticipate, you will never become a good ground control engineer to combat rockburst. Your ability to anticipate and adapt can be greatly enhanced if you gain more underground experience (that is right, you have to go underground to see rockburst damage!). You ability to safe guard your fellow workers and company property can be significantly increased if you understand the seven principles (Figure 5) we outlined in this paper. As Ralph Waldo Emerson, an American essayist, philosopher and poet (1803 – 1882), said, “As to methods there may be a million and then some, but principles are few. The man who grasps principles can successfully select his own methods. The man, who tries methods, ignoring principles, is sure to have trouble.”

![Figure 5 Summary of seven rockburst support principles (Rainbow Principles, as indicated by the color in the figure).](image)

### 4 Case Histories and Recent Research and Development

#### 4.1 Rockburst Support in Canadian Mines

Numerous methods exist to test a rock support system’s dynamic energy absorption and effectiveness such as using a controlled blasting. For example, a test tunnel was reinforced with tensioned conventional end-anchored bolts on one side and yielding end-anchored bolts on the other and blasted with the same pattern and charge on both sides [8]. The test result convincingly demonstrated that yielding rockbolts could withstand the dynamic loading, whereas the other sidewall of a tunnel supported with conventional end-anchored rockbolts was destroyed.

As time passes, the effectiveness of the yielding support system has been proven by many practical applications in burst-prone mines around the world. In Australia, the use of conebolt for rockburst support had been proven effective at Big Bell Mine [16] and Beaconsfield Mine. Conebolt + strap yielding support system has been used in a number of mines in Canada and the results consistently show that the system works. At the Brunswick mine in Canada, several rockbursts severely damaged sections supported by conventional rock support system while the conebolt supported area was virtually undamaged [12]. On Oct. 13, 2000, a Mn=2.5
(Nuttli magnitude) rockburst event caused the collapse of an intersection involving approximately 1860 tons of material. A small portion of the crosscut immediately east of the intersection had MCB conebolts installed. The right-hand side of the tunnel was supported by 2.3 m conebolts in a 1×1 m pattern with #0 gauge mesh straps and chainlink mesh. The left-hand side of the tunnel was supported only by rockbolts with chainlink mesh. The foreground of the area was supported by rebar and steel fiber reinforced shotcrete. After the rockburst event, it was revealed that the right-hand side of the tunnel suffered no visible damage at all while the rest of the area suffered severe damage. The intersection also collapsed despite the fact that it was supported by standard rebars, cablebolts, screen, and shotcrete. The good performance of the conebolt supported tunnel section held the ground so well that many people speculated that the rock might not be hit hard as the rest of the area. However, close onsite examination revealed that the conebolts had fulfilled their role to dissipate energy as some conebolts displaced as much as 180 mm [11]. Subsequent use of conebolt based rock support system at the mine site proved to be exceptionally well.

On September 11, 2008, a major rockburst (Mn=3.8, Nuttli) occurred following a series of seismic events immediately after a crown blast in the middle 100 orebody between 3050 and 3200 L, at Vale Inco Copper Cliff North Mine in Sudbury, Ontario, Canada. This large rockburst event, in association with other significant seismic events (Mn > 1.2), caused an enormous amount of damage. The damage was so widespread that it was extended from 2700 to 3710 L around the 100/900 orebody region. In total, more than 2500 tons of material was displaced at different locations on different levels, and most of the damage was observed to be associated mainly with major geological structures [17]. One of the reasons for the extensive damage was that the level of installed ground support was relatively light (a mix of resin rebars and mechanical bolts with wiremesh), and the support system has limited energy absorption and holding capacity. After the occurrence of the major event, mitigation plans were put in place to ensure that the remaining ore bodies can be mined safely and efficiently. The mine management swiftly adopted the conebolt based dynamic rock support system. On top of the primary support (#4 gauge welded wiremesh, 1.98 m FS46 (46 mm) friction bolts on a 1.22×0.76 m pattern for wall and 2.44 m resin rebars on a 1.22×0.76 m pattern for back), 2.34 m long MCB conebolts on a 1.22×1.83 m pattern with #0 gauge mesh straps were implemented as the secondary (rockburst) support. On Feb. 2009, a Mn=2.9 (Nuttli) seismic event occurred in this same area causing further damage to the drifts; however all conebolt supported were undamaged [17]. Based on rockburst risk assessment, areas of high rockburst risks will be systematically supported by enhanced rock support using conebolts and straps.

Conebolt based rockburst support system has been successfully used at Vale Inco’s Creighton Mine and Garson Mine in Sudbury, Ontario, Canada. Over the last decade, the ground support system for Creighton Deep has been continuously improved based on trials and analyses of the ground response and stress levels. Primary support systems have been improved with the development and implementation of the FS46 friction sets for wall bolting and Swellex bolts when mining under or beside sand fill. In areas where secondary support (cablebolts) or rockburst support (conebolts with #0 gauge mesh straps) is required, the support is installed when driving the development, prior to driving any secondary crosscuts or approximately every four rounds. Delayed installation of conebolts and straps can cause various challenges over time, and the main challenge experienced is the difficulty to install conebolts due to ground deterioration from high in-situ stresses. Combined with other initiatives, the numbers of rockbursts have been reduced and the down times in the mine after major seismic events have been minimized. Today, damage after large seismic events (due to fault slip) is often minor or insignificant [7]. At Garson Mine, whenever the drifts passed the sub-vertical dyke of olivine diabase, strain burst resulted and damage occurred even when the standard rock support system (rockbolts with shotcrete or mesh) was used. After the introduction of conebolt based rockburst support at the mine site, no severe rockburst damages have been reported in the dyke areas.

Another convincing successful application of MCB conebolt based rockburst support system is at Xstrata’s Kidd Creek Mine in Timmins, Ontario, Canada. A magnitude Mn=3.8 seismic event, happened in January 6,
2009, causing extensive damage to four levels (6800, 6900, 7000 and 7100 L) at the mine. One drift supported by standard rock support with mesh and rebar totally collapse. A few pieces of mining equipments were buried and likely destroyed. Fortunately, the event occurred at about 4:40 a.m., as the nightshift at the mine was going off duty and heading to surface. No injuries were reported. Careful underground inspection by mine site ground control engineers (and the authors) confirmed that in areas where conebolt based rockburst support were installed, they were remarkably in good shape and that damage was extensive in adjacent areas where only standard rock support (rebars and meshes) was used. Currently, rehabilitation of the damaged areas is ongoing and it is expected that the whole rehabilitation will take at least six months (D. Counter (2009), personal communication).

4.2 The Next Generation Conebolt

Mansour Mining Inc. is the exclusive manufacturer of MCB conebolts (patented). Continuous research and development is being carried out to improve the performance of the product.

The South Africa conebolt is coated with wax and the MCB conebolt is greased to diminish the bonding between the grout and the bolt. However, spinning of the bolt to mix the resin can strip off almost all the coating, leading to unwanted bond between the bar and the resin. This has been demonstrated by static and dynamic tests in laboratory. The authors conducted a series pull tests using steel pipes. 1.2 m long conebolts (17.3 mm diameter) were installed in the pipes with fully encapsulated resin. After the resin is set, the cone section (about 0.1 m) was cut off and the remaining bolt was pulled until the bolt started to slide in the resin. It was found that for an embedment length of 0.94 m, the maximum load recorded was 127 kN, which is very close to the yielding load of the steel. St-Pierre et al. [13] conducted dynamic drop tests at CANMET and found that the influence of grease on the bolt behavior was not obvious. In two of their tests, the cones were cut off and a drop weight of 1016 kg from 0.5 m (5 kJ input energy) was used to test the dynamic capability of the smooth bars without cones. The resin embedment length was estimated at 1.2 m. The bar which was greased sustained six drops with a total input energy of 35 kJ and the non-greased bolt accepted five drops with a total input energy of 30 kJ. Note that 5 kJ impact energy is large enough to break a fully bonded rebar at the threads.

It is obvious from both the static and dynamic testing that grease is not doing a good job to debond the bolt from the resin. The fact that a smooth bar, whether greased or not, can sustain reasonably high pull out loads or absorb certain amount of impact energy indicates that there is a reasonably large friction force existing between the bolt and the resin. A fully encapsulated smooth bar is, fundamentally, a friction bolt. The frictional force is distributed along the grouted section of the bolt and it becomes obvious that it will limit the cone’s ability to plow through the resin when subjected to dynamic loading. Mansour Mining conducted dynamic drop tests in 2008 with an impact energy of 16 kJ (drop weight 1115 kg, drop height 1.5 m). Test results showed that greased bolts perform only slightly better on average than non-greased bolts (62.5% total displacement due to cone movement versus 50%). In addition, the test results showed that the bolt could withstand 16 kJ of impact energy 3 to 4 times before the bolt breaks. The maximum accumulated steel strain recorded was 10.4% before the bars broke. Again, this indicated that large friction component existed between the bolt and resin interface that prevented the cone to efficiently plow through resin under repeated loading.

In order to improve the static and dynamic performance of MCB conebolts, it has been realized for a long time that an effective debonding agent was required. We know that wax can be a good debonding agent; however, the manufacturing process is both complicated and costly.

Recently, the authors developed a new patented debonding agent in the form of a heat shrink plastic sleeve installed over the shaft of the bolt. Laboratory testing combined with in-situ pull tests confirmed the new system’s functionality. Dynamic drop test at CANMET’s Bell Corners testing laboratory confirmed that this new debonding agent is much more effective as a debonding agent over grease used in the original design.
There are currently two different cone sizes in use – MCB38 for 38 mm boreholes and MCB33 for 33 mm boreholes. Because rebars and rockbolts all use 33 mm boreholes, it makes much more economical sense to use the MCB33 conebolts, i.e., one bit and one resin. This eliminates one bit and one resin size from inventory. In addition, it is possible to install all standard and rockburst support systems in one pass. Hence, our recent research and development was focused on MCB33 conebolts. Our new design of MCB33 is presented in Figure 6.

To prove our new design, 46 in-situ pull tests were performed at five mines, and eight dynamic drop tests were conducted at CANMET in April, 2009. Four plastic sleeve debonded conebolts (17.2 mm diameter) were tested at 16 kJ and the results are comparable to the results of previous tests using grease as the debonding agent. Dynamic drop test results showed that on average 99.6% of plate displacement was from cone plow on the first drop as compared to 82.9% in the old design. In the second drop, the cone plow percentages for the new and old designs are 75% and 29.2%, respectively. One new bolt showed an abnormal behavior in the second drop without cone plow. If this data were excluded, the cone plow would be 100% in the second drop for the new bolts. In the third drop, the cone plow percentages for the new and old designs are 99.6% and 4.7%, respectively. It is seen that the new design allows the cones to plow through the resin very effectively while the old design relied more on steel stretch to absorb the impact energy of repeated dynamic loading.

Three MCB33 with plastic sleeves were tested at 26 kJ impact energy (1784 kg weight, 1.5 m drop height). It resulted in 100% and 99.9% cone plows in the first and second drops, respectively. This means that all the impact energy was absorbed by cone plow in the test. In our previous drop tests on MCB conebolts, the highest impact energy tested was 22 kJ with significant steel stretch. Close to perfect cone plow at 26 kJ was very encouraging and we decided to use the last available bolt to test at a higher energy level. The bolt was subjected to a 33 kJ impact from a single drop (2229 kg weight, 1.5 m drop height) and survived. Cone plow constituted 76.3% of the total displacement and the steel stretch was 23.7% which represents of steel strain of only 5.6%.

Figure 7 presents the relationship between bolt displacement and absorbed impact energy. Data other than MCB are obtained from Player et al. [9]. It is seen that when threadbars fail at the thread, the absorbed energy is very low (< 2 kJ). The fully bonded threadbars are tested using load transfer by separating the bolt in the middle of the installed pipe. The debonded threadbars have about 1.6 m debonded section which can allow the steel to stretch. All data points are from the first drop loading. Four threadbars failed but there were no conebolts failures on the first drop. A very good linear correlation between steel strain and energy absorption can be seen from the threadbar data. It is observed that the cement grouted South Africa conebolts and at least two of our old MCB conebolts follow the trend line, indicating that the dominant energy absorption mechanism of those conebolts had been steel stretch with very little cone plow. On the other hand, the new MCB design allows the cone to plow much more efficiently, and their capacities to absorb dynamic energy are thus substantially increased.

Theoretical consideration based on extrapolations of dynamic test data suggests that the 17.2 mm diameter conebolt may be able to absorb in excess of 40 kJ of impact energy in a single event. Previously tested largest single impact energy was only 22 kJ and our recent test has increased the energy to 33 kJ. With the success of
our test, we anticipate that the new design of the conebolt may allow the bolt to absorb energy higher than 40 kJ in a single event. Future tests will be conducted to confirm this.

![Figure 7 Energy dissipation of MCB33 and other bolts versus plate deformation. “New” and “Old” stand for plastic sleeve and grease debonded conebolts, respectively.](image)

### 5 Conclusions

Rockbursts are a complex natural phenomenon occurring in deep underground construction. Much effort has been put into research to understand why it happens and to anticipate where it will happen. Unfortunately, due to the complexity of rock mass and the boundary conditions, we still do not have great confidence in our analysis and “prediction,” at least the reality tells us so. As mining progresses to deeper grounds, violent rock failure cannot be avoided and it will have to be dealt with on a routine basis by implementing a rockburst resistant support strategy.

Rockburst support is not a mystery, not a skill that only a few can master. We present the art of rock support in burst-prone ground in seven principles. Once you understand them, you can make your right judgment and decision according to the ground condition. Because we have had the general principles previously determined, there will be no perplexity to know what to do when we are dealing with rockburst damage.

The use of yielding support is a key component when designing a rockburst support system. Although we place the principle of avoiding rockburst in the first place, however, when every effort has been taken to reduce the rockburst risk at a mine using sound mining methods etc, the risk will unfortunately not go away. Our final line of defense is not our ability to “predict” when and where a rockburst will occur, but rather on the fact that we have made our rockburst support system unbeatable. We present the observational construction principle (anticipate and be adaptive) as the last principle simply because this is the skill that we all need to have in order to win the battle against rockburst damage, and it is an effective skill to deal with uncertainty.

MCB conebolt based rockburst support systems have been proven to be very effective to mitigate/limit rockburst damage. Recent development at Mansour Mining Inc. has greatly improved the dynamic capability of the conebolt and it is expected that it will perform even better in severe rockburst situations. The new MCB33
conebolts can be used in a one-pass rock support system to facilitate rapid drift development in underground mines.

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7 References