

Strainburst hazard awareness for development miners

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Abstract

In the course of new mine construction or of expanding mine workings, the mine development crews are the first to encounter the realities of stress related strain behaviour of the rock. These hazards are encountered generally before the more comprehensive seismic monitoring and rockburst management systems, common in production areas, are in place. As such, strainbursting must be considered an important hazard facing mine personnel.

The nature of such hazards, although broadly foreseeable, is that their occurrence is unpredictable. Using a risk-based approach, Cementation Canada has developed practical guidelines for strainburst hazard awareness for its development miners and shaft sinkers. The objectives are to raise awareness, to highlight observable indicators, and to minimise exposure and mitigate the negative impacts of strainbursting, with the ultimate goal of zero harm. This paper covers the background to this challenge, explains how it fits into the Internal Responsibility System (IRS), and provides details of how the programme is being implemented. It is desired to share this programme to improve safety in our industry and to gather feedback in order to continuously improve upon this initiative.

1 Introduction

Across the globe, numerous incidents, injuries and fatalities have been associated with rockbursting. As noted by Potvin et al. (2000), despite all the excellent research and progress in the past decades, the problem is still not well understood. Brady (1990) suggests that given the pervasiveness of rockbursting, it remains the major unresolved ground control problem in underground mining.

In the past few years, Cementation personnel have been in close proximity to several rockburst incidents at various operations. Fortunately most have been close calls and thankfully only a couple of injuries have been sustained despite excavating kilometres of drifts and shafts at significant depths in brittle rock in mining areas notorious for active seismicity, namely Sudbury, Red Lake, Abitibi, Flin Flon and Bathurst in Canada, as well as the Coeur d'Alene in the USA.

As a mining contractor, we strive to safely develop and construct mines. We have a responsibility for the safety of our workforce. One initiative that we are currently advancing is strainburst hazard awareness training following a rational, risk-based approach. Our development miners are the most exposed to the hazard and they are the primary target of the training. However, all employees at underground projects, including maintenance, construction, supervision, safety professionals, management and technical staff are potentially exposed, and the training is to be provided to all of the underground team.

This paper describes this strainburst hazard awareness initiative. It is not meant to be a technical design risk assessment such as that described by Cheung and Kazakidis (2014) but a practical operational initiative. The context including the guiding values and objectives of this programme are described; the challenge – defining strainbursting; giving a contractor/developer's perspective, and the relevance of this subject to the IRS. This is followed by an outline of the risk-based approach. The implementation of the initiative to date is described and future plans are outlined. Some conclusions have been drawn and future enhancements discussed.

1.1 Values

It is a value common to everyone in the province of Ontario that every worker returns home safe and healthy every day (Workplace Safety North vision). At Cementation our belief in working safely and eliminating injuries must pervade everything we do. We are committed to safety because it is the right way to work. Such safety values are shared throughout the mining industry. It is these values that guide us in this initiative.

1.2 Objectives

The objectives of this strainburst awareness initiative are as follows:

- Promote awareness of the strainburst hazard amongst the workforce.
- Coach all levels of underground workers to recognise factors that are commonly associated with strainburst occurrence.
- Provide guidance on what they can do to reduce both the probability of becoming exposed and the consequences of strainbursting.
- Improve communication amongst all levels of our company and the mine owners about the strainburst hazard.

The objectives culminate in an effort to reduce the frequency or number of strainburst incidents by raising awareness to their possible causes, and to reduce associated consequences to achieve zero harm. This initiative also follows the regulatory guidelines of training workers in rockburst awareness in the Province of Ontario (Deck 1997).

2 The challenge

Due to its unpredictable nature, rockbursting is an especially challenging hazard to manage as explained in North America by Blake and Hedley (2003). From a South African perspective, Wagner (1982) states that rockbursts are the most serious and least understood problem facing deep mining operations all around the world. This presents an outstanding challenge. This section provides a brief background on the rockburst phenomena; the challenge from a mining contractor/developer's perspective; and describes the IRS, which forms the basis of occupational health and safety in Ontario, Canada and within Cementation Americas.

2.1 The rockburst phenomena

A rockburst is described by Hoek (2007) as "an explosive failure of rock which occurs when very high stress concentrations are induced around underground opening". This is a technical definition based on the 'cause', which contrasts with the more practical effect definition provided by Kaiser et al. (1996), "damage to an excavation that occurs in a sudden or violent manner and is associated with a seismic event".

Rockbursts commonly are classified into three types: fault slip, pillar, or strainburst (Kaiser & Tannant 1999). Fault slip bursts will occur when mining induced stress changes induce movement along a fault or slip. Fault slip bursts are very similar to earthquakes. Pillar bursts occur where pillars, in whole or in part, suddenly fail due to rock mass strength being exceeded by the stress in the pillar. Finally strainbursts occur along excavation boundaries where rock mass strength is exceeded by the stresses. A brittle, violent failure of rock adjacent to the boundary causes the damage. Three distinct damage mechanisms may be encountered as described by Kaiser et al. (1996) – seismic shake down (rockfall), rock fracturing with rock mass dilatation (bulking), and violent ejection of rock.

2.2 Mine contractor's perspective

As development miners, we are mainly exposed to the strainburst type and are most concerned with events involving violent ejection of rock. Development mining generally does not induce fault slip bursts or

create bursting pillars. In the course of new mine construction or of expanding mine workings, the mine development team is the first to encounter the realities of stress related strain behaviour of the rock. These hazards are encountered generally before the more comprehensive seismic monitoring and rockburst management systems, common in production areas, are in place. As such, strainbursting must be considered an important hazard facing mine contracting personnel.

As recognised in the guideline issued by the Ontario Ministry of Labour (Deck 1997), only a rough evaluation of the potential for bursting at a mine can be made before mining begins. Rockbursting is dependent on the interaction between rock properties, geological structure, mine layout and sequencing etc. The full assessment of bursting potential is not possible until a considerable amount of data has been collected in the course of operations, which occur later than the execution of initial development work.

Contractors are able to bring varied experience from other projects to each new job. However, we do not have the level of site-specific knowledge, nor the technical expertise the owner may have for rockburst hazard planning at any given mine site. However, it is the role of our workers, our crews to be at the face. We rely on clients to share their site specific knowledge. The nature of this site specific expertise may include geological, geotechnical, ground control, seismic monitoring, mine planning and so forth.

So the question is posed – what can we do as contractors? We can implement strategies with the underground team to raise their awareness of the strainburst hazard using general guidelines. This is especially important given the nature of the workforce in mine contracting, with miners moving from project to project – all with differing ground conditions. We can continually update the guidelines by tapping into our clients' knowledge and with experience gained on multiple sites. Our goal is to share this development with all our clients as well as the industry in general. It is all about the common safety values that we all share.

2.3 Internal responsibility system

The basis of the Occupational Health and Safety Act in the province of Ontario is the IRS which was described by Dr James Ham when his Royal Commission looked into mining deaths from silicosis in the mining town of Elliot Lake in 1976. Strahlendorf (2013) describes the IRS as meaning:

“Everyone is personally and directly responsible for health and safety as an intrinsic part of their job. Work and occupational health and safety are not separate activities. Everyone is doing occupational health and safety 100% of the time.”

Cementation promotes the IRS as an important part of any safety management system, and more importantly, as a crucial part of a healthy safety culture. We believe that management has a duty to provide the knowledge and tools for our workers to complete their tasks safely, each and every day. In turn, we expect our employees to communicate concerns and hazardous conditions to their co-workers and supervisors. As shown in Figure 1, if this responsibility is taken seriously by management, and workers are accountable to their co-workers and supervision, then a safe and healthy workplace is achievable.

This approach is the basis of Cementation's Strain Bursting Hazard Awareness sessions. We want to inform our employees of this difficult to predict hazard with significant consequences. We shall then express our aspiration for our employees to actively participate in the identification of key indicators and communication of them to the appropriate personnel: and we shall introduce a process to facilitate this.

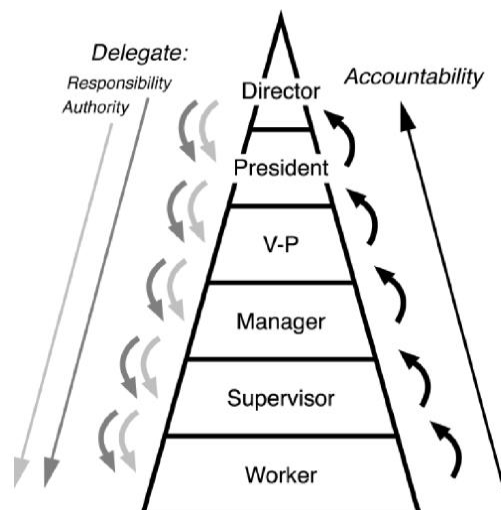


Figure 1 Basic structures of the IRS – authority, responsibility and accountability (from Strahlendorf 2013)

3 Risk-based approach

We have chosen to follow a risk-based approach as commonly applied in mine safety. Risk is the product of the probability of something occurring and the consequences of it happening. Using a risk approach, we ask key questions whose answers formulate the guidelines.

For the challenge of reducing harm from strainburst incidents we ask the following questions about the probability and consequence of strainbursting:

- What factors increase the likelihood of strainburst occurrence?
 - What indicators can be recognised and how do we ensure that our underground workers, especially those at the face, can recognise these factors?
- What can we influence that might reduce the probability of strainburst occurrence?
- If a strainburst is likely to occur, what can we do to reduce the consequence of that event?
 - What can be done so that the worker might avoid the hazard?
 - What controls can be applied to reduce the hazardous consequences of strainbursting?

It is these questions and their answers that form the basis of the hazard awareness training programme. Thus we take a risk-based approach to break down the hazard into specific questions about the probability and the consequences of strainbursting.

3.1 Probability

What factors increase the likelihood (probability) of strainburst occurrence? To answer this fundamental question, we must look at the underlying cause of strainbursting – it occurs where the rock stress exceeds the rock mass strength in brittle rock. So where should we look? Look for factors that induce increased stress or decreased rock mass strength.

What are the factors causing high stress? A general rule is that you get higher stress with depth. However, locked in stresses from previous geological history can lead also to high stress at shallower depths. In fact there are places where rockbursting has occurred at or near surface such as the Rock of Ages granite quarry in Vermont, USA (White 1946). Stress fields can change near faults and other structures. There are the stress changes, risers, etc. induced by excavating holes in the ground. These mine induced stress patterns are higher with over extraction, poor pillar layout, poor excavation shape, etc. Also, sudden changes in excavation profile shape/size can all lead to high stress conditions locally around the excavation.

As was mentioned previously, hard brittle rocks are most prone to bursting. Strainbursts are not likely in weak, yielding rock such as evaporites. Contrasting rock types where weaker and stronger rocks are in contact – the stronger (stiffer) rocks will take on more stress from the weaker rock and become susceptible to bursting. Intrusive geological structures such as the trap dykes in Sudbury tend to be stronger and more brittle. Also weak zones may shed stress to nearby brittle rocks or allow very small scale slips that result in strainbursts.

Thus having recognised the main causal factors, what can we see underground, what observations can be made that may indicate strainbursting conditions? There are many indicators; the presence of any one of these indicators does not necessarily mean that bursting is imminent. We suggest however, the more indicators that are present, the more likely that bursting will occur.

The following are indicators of ground prone to strainbursting:

- When we are deep in the mine or going deeper than ever before, stress will be higher.
- Drilling through various rock types gives a good indication of how hard and brittle the rock is.
- Changes in drill and drillhole behaviour may indicate burst-prone ground: slower drilling speed/ rods jamming/ jerking, squeezing/caving of holes.
- Geological factors – slips/faults/fractures, contrasting rock types, dykes, etc.
- Changes in rock noise.
- Face working, face spitting, or fractures forming or changing.
- We can also look at the size, shape and proximity of excavations. Stress build-up is more likely when there are large excavations with little left behind to support the rock above.
- The changing shape or sudden change in cross-section of a heading has played a prominent role some strainburst activity as well.

Mines with seismic and microseismic monitoring systems in place can note increased levels of local mine seismicity or swarms of regional seismicity that may indicate that bursting is more likely. As development mining contractors we rely on timely communications from the mine operator of these indicators.

Having looked at the factors and indicators of burst-prone ground, can we now reduce the probability of strainburst occurrence? We can reduce the probability of strainbursting by:

- Minimising the effect of rock stress: using proper geometry, sequence and rate of mining. Examples include: avoiding narrow sill pillars, using proper backfill, crossing structures/faults at favourable orientations and/or locations, use seismic data in mine planning, layouts, etc.
- Attempt to drive high stress away from the excavation boundary by using destress blasting or drilling.

Generally the mine owner controls these variables based on their site specific knowledge. However, observations by development miners and input from contractors can provide feedback which will help mine owners improve the mine design and thus the safety of the workplace.

3.2 Consequence

If a strainburst is still likely and despite steps to reduce the likelihood, what can be done to reduce the consequences of such an event?

One approach is to avoid the consequences by retreating, barricading or using remote equipment. These methods require judgement and re-entry protocols. Often mine operators have good experience with re-entry protocols that is shared with us.

Another approach is to try to induce the strainburst activity in a safe controlled manner. An example is hosing down the rock face in question with cold water from a safe distance. If the face is close to bursting, the thermal shock of the cold water can be used to induce the burst.

A third option is to reduce the extent of the damage by installing energy absorbing ground support. There are many new innovative products on the market for such dynamic ground support. These systems have held up well in bursting conditions. However, as a development miner, one must be aware that they are in burst-prone ground when installing these support elements. We must continue to educate development miners on these new ground control processes and materials.

4 Implementation

An employer has a duty to inform its employees of all workplace hazards. In the mining industry, those hazards typically include operating mobile equipment, working at heights, and falls of ground to name just a few. One hazard which presents a challenge of creating awareness is that of strainbursting. It is a particular challenge because strainbursting is difficult to predict. Cementation Canada has developed a presentation to guide our crews in a conversation regarding the dangers of strainbursting. To do this, we focused on enabling employees to recognise the hazards and in addition to reporting those hazards to management, to consider what else they themselves can do to keep safe when such hazards are encountered.

A draft presentation was developed by geotechnical staff and presented to a diverse mining audience at the 2013 Workplace Safety North Mining Safety Conference. The next step was to conduct a session with Cementation's Safety and Training department. These sessions presented the technical information to an audience of safety professionals whose work frequently requires communicating workplace hazards to our workforce. Feedback was invited from these, and with their input, the presentation was modified to improve communication and encourage interaction with employees in the field.

To present this to our underground teams, a representative from our Safety and Training department joined forces with a geotechnical engineer to inform crews at one of our projects in Northern Ontario. To address every worker on the project, thirty-minute sessions were held with all shift crews who work in lateral development, shaft sinking, underground construction, and maintenance.

The presentation covered material found in Sections 2 and 3 of this paper, with a focus on the risk-based approach. The content was aimed at generating discussion about the probability and consequences of strainbursting events and what can be done to reduce the risk. The technical content of the presentation is summarised on a Strain Burst Hazard Awareness Card (Figure 2). This visual reminder is for our underground personnel and is posted in various surface areas, such as the lunchroom and training trailer. Having this posted will serve as a reminder to the crews of some of the indicators to watch out for and ways to reduce the risk. As the card states, the more indicators that are identified, the greater the chance the ground is prone to strainbursting.


| <h1>Strain Burst Hazard Awareness Card</h1> | |  Cementation WE BUILD MINES. SAFELY. |
|--|--|---|
| <p>Definition: Strainburst/Rockburst: Damage to an excavation that occurs in a sudden or violent manner and is associated with a seismic event.</p> | <p>Probability Checklist: The following are indicators of strain bursts:</p> <ul style="list-style-type: none"> <input type="checkbox"/> deep mining <input type="checkbox"/> locked in and mine-induced stress <input type="checkbox"/> stress change at faults/slips <input type="checkbox"/> hard, brittle rock types <input type="checkbox"/> contrasting rock types including dykes, faults <input type="checkbox"/> size, shape, location and changes of mine openings <p>While drilling, watch for:</p> <ul style="list-style-type: none"> <input type="checkbox"/> lower drilling speeds <input type="checkbox"/> jerking or jamming of rods <input type="checkbox"/> pinching/caving of holes <input type="checkbox"/> face spitting or cracks on the face <p>Many Checked Boxes = Strain Bursting Prone Ground Seismic monitoring systems may provide indicators.</p> | |
| <p>Risk-Based Approach: Risk = probability x consequence</p> | <p>Probability: <i>What factors increase the likelihood of strain burst occurrence?</i></p> <ul style="list-style-type: none"> • Rock stress is higher than strength of brittle rock • Bursts occur in areas of high stress or low strength. <p><i>What can we do to lower the probability?</i></p> <ul style="list-style-type: none"> • Mine planning – layout, sequence & rate of mining. • De-stressing – blasting, large diameter holes → <p>Mine operations/engineering control these variables. Look for indicators to control the consequences.</p> | |
| <p>Consequences: <i>What Can We Do To Reduce The Consequences?</i></p> | | |
| <p>Remove worker from the hazard zone;</p> <ul style="list-style-type: none"> - retreat during active seismicity - barricade area, re-entry protocols - remote/mechanized equipment | <p>Safely induce strain bursting activity;</p> <ul style="list-style-type: none"> - spray down face with cold water from a safe distance <p>Reduce/Contain the damage;</p> <ul style="list-style-type: none"> - install energy absorbing ground support - awareness when installing such ground support | |
| <p>Talk to an experienced worker, supervisor, ground control engineer, etc. to execute a safe work plan. ALWAYS COMMUNICATE WHAT YOU SEE, HEAR, FEEL WITH YOUR SUPERVISOR AND CO-WORKERS</p> | | |

Figure 2 Cementation Strain Burst Hazard Awareness Card

4.1 Communication

A large part of the awareness discussion centres on communication. It was stressed to the employees that they be aware of the factors which may lead to strainbursting, and should they be identified, to communicate those signs to supervision and management so they can get the proper people involved in order to mitigate the risks.

The primary communication method available to workers is the 5 Point Safety System card (Figure 3). Each employee is given a 5 Point Card at the beginning of their shift which has a written line-up from their supervisor for the upcoming shift. There are a series of questions and checks which the worker and supervisor sign off on over the course of the shift. These checks, along with the area for Further Action Required enables the worker to express any safety concerns they may have, including sections specific to ground control. Each card is submitted to the supervisor at the end of the shift to report on the shift's work, and to ensure there are no outstanding concerns.

Additional means of communicating potential strainbursting hazards includes the use of the ground control log book located near the wicket. Provided the worker is aware of relevant factors related to strainburst risk, they can be written down. Notes on ground conditions for specific areas/headings are written each shift by supervision and checked by other supervisors, management, and departments like geology and ground control. For these systems to be effective, it is essential for all personnel to contribute to the process, while it is important that the miners at the face are able to communicate what they see and hear to their front line supervisor. This information then goes up the line to management to ensure that the proper professionals can get involved to minimise the potential risk to workers.

Of course, supervisors are required to visit the face on a regular basis. They are also responsible to recognise these hazards and are therefore included in this training programme. Management is responsible for ensuring that the workers recognise the hazards (the main premise of this programme, training workers to be able to do so) and creating a work environment where they are comfortable in reporting their observations.

4.2 Discussion generated

During the awareness sessions held at the project site, we found that one of the ways to generate discussions with the crews was to engage them with questions about their own experiences of strainbursting events. Experienced miners were quick to share some of their past experiences from working at other mines across Canada. Many stories were shared from deep mines in the Sudbury basin and from other areas across the country. Sharing of these stories is very important to raising awareness of the risks of strainbursting, especially for those miners who are relatively new to the underground environment.

One such story came from an experienced development miner. It was largely believed that the mine where we were making the presentation was not prone to strainbursting. However, as this experienced jumbo operator explained to the crew, he has started to see some activity in various sections of the mine. This statement grabbed everyone's attention and helped us immensely in illustrating our point. As this mine goes deeper and these crews drive drifts into new areas of the mine, they must be aware of the changing conditions and increasing likelihood of strainbursting.

Another terrific discussion was generated as we showed a numerical model of a heading at which a strainburst occurred a number of years ago, where sadly two employees were badly injured. By coincidence one of those injured employees was in the room and was able to describe the circumstances which lead to the strainburst. This first hand explanation from an employee who has seen and experienced the powerful consequences of a strainburst was extremely valuable and it was apparent that the entire audience was absorbed with his story.

As the sessions progressed, the presenters were given the impression that several strainbursts at other mines were going unreported because the crews viewed them as simply, 'part of the job.' It was eye-opening to hear the stories come forth, with statements like, "The scary part when working in some of those headings was when things became quiet, because you were so used to the face and walls spitting." The hope is that in providing the crews with additional information and raised awareness about strainbursts, that more incidences will be reported and measures can be put into place which will reduce the chance of loss.

A sample of the discussion brought up by members of the underground team includes:

- "The shaft at X Mine was popping every 15-20 minutes. You were just waiting for the next one to happen. I will never work at that mine again."
- "The bursts at Mine X killed three people when I was working there."
- "My partner in the raise at X Mine got hit right in the forehead when the face spit at him."
- "Those air blasts were pretty scary, never knew when the next one would come."
- "We are starting to see some bursts in the faces at X Mine."
- "My partner and I were digging out the lifters at the face at X Mine when the bottom corner of the drift blew out at us. They say about a tonne of rock was dispersed. I was knocked out from a chunk that hit me. My partner was also badly injured and never worked underground again."
- "Yeah, we stopped using destressing for a couple rounds and there was lots of spitting and air blasts. Destress blasting really works."

4.3 Feedback from awareness sessions

In general, the sessions have been well received by the Cementation crews. The amount of discussion generated was above average as compared with our typical safety meetings, which is a positive sign. One Superintendent who attended a session stated that he felt there was some really good information provided to the crews, and thinks the crews were provided with knowledge that they will be able to take with them to different mines as their mining careers move forward. A client safety officer echoed this notion in stating, "I think it is important that Cementation is educating its employees on the risks of strainbursting because the work force moves around so much. They are bound to see examples of it over the course of their careers". A site safety supervisor simply commented, "this is good, we need to keep reminding ourselves of this".

4.4 Plan forward

Cementation Canada plans to continue to develop this initiative to educate its employees regarding the risks of strainbursting. In continuing with a risk-based approach, we will work with our clients' ground control engineers in order to identify areas where strainbursting will pose a significant risk.

By having the Corporate Safety and Training department involved in the delivery of this presentation, the awareness level of strainbursting hazards has been increased with many individuals who can then carry this knowledge forward into the workplace and to share with other projects.

5 Conclusions

It is known that strainbursts are a significant safety hazard but they are challenging to predict. However, there are several indicators that assist with the identification of this hazard. Cementation is developing a strainburst hazard awareness initiative to improve workplace safety for underground workers – this will include hazard awareness training for workers and the introduction of a strainburst hazard awareness card to help report and communicate observations from underground.

The approach is to empower the worker, through awareness and knowledge to report upon, communicate and act on areas of concern. This abides by the intent of the internal responsibility system.

The guideline will be generic and we plan to use it across our relevant projects. Site specific input for each mine is always required in addition to our guidelines, while incorporating and utilising the expertise of our clients. Like all guidelines, this initiative is under continuous development, so feedback is essential and welcomed. We are open to sharing this information as we are all partners in safety.

Our focus is to encourage the early reporting of key identifiers of strainbursting potential by educating our employees as to what are those identifiers, so that actions can be put in place to help us achieve the goal of zero harm.

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