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Design of rock support system under rockburst condition

Peter K. Kaiser[1], Ming Cai[2*]

[1] *Centre for Excellence in Mining Innovation, Sudbury, Ontario, Canada*

[2] *Bharti School of Engineering, Laurentian University, Sudbury, Ontario, Canada*

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Abstract: As mining and civil tunneling progresses to depth, excavation-induced seismicity and rockburst problems increase and cannot be prevented. As an important line of defense, ground control measures and burst-resistant rock support are used to prevent or minimize damage to excavations and thus to enhance workplace safety. Rock support in burst-prone ground differs from conventional rock support where controlling gravity-induced rockfalls and managing shallow zones of loose rock are the main target. Rock support in burst-prone ground needs to resist dynamic loads and large rock dilation due to violent rock failure. After reviewing the rockburst phenomenon, types of rockbursts, damage mechanisms, and rockburst support design principles and acceptability criteria, this paper describes that the support selection process in burst-prone ground is iterative, requiring design verification and modification based on field observations. An interactive design tool for conducting rockburst support design in underground tunnels is introduced to facilitate cost-effective design.

Key words: rockburst; rockburst damage; rock support; design

1 Introduction

As the depth of mining and civil underground construction increases, stress-induced rock fracturing is inevitable and when stored energy is suddenly released, rocks fail violently, leading to seismic events and rockbursts. A rockburst is defined as damage to an excavation that occurs in a sudden or violent manner and is associated with a seismic event (Hedley, 1992; Kaiser et al., 1996). Many hard rock mines in Canada, China, Chile, South Africa, Australia, Sweden, and other countries, and some deep civil tunnels in Switzerland, China, and Peru have experienced rockbursts to various degrees. Two recent civil projects that experienced severe rockburst damage are the Jinping II hydropower intake tunnels in China and the Olmos Trans-Andean tunnel in Peru.

Considerable research effort, at an international scale (e.g. Australia, Canada, South Africa, China), has been devoted to the understanding of the rockburst phenomenon. Micro-seismic monitoring systems are in operation at most burst-prone mines and tunnel construction sites around the world. From the waveform records, the time, location, radiated energy, seismic moment and other source parameters of a seismic event can be obtained. Monitoring of seismic events in mines or along tunnels therefore is a very useful tool for outlining potentially hazardous ground conditions and assisting construction management in effective re-entry decision-making. Advanced three-dimensional (3D) numerical modeling and visualization can identify potentially hazardous areas and assist in planning and design underground structures.

Rockburst risk can often be reduced by selecting appropriate mining or excavation methods and sequences, and by strategically placing developments and other infrastructure. However, due to uncertainties in rock mass properties and boundary conditions (e.g. in-situ stress, fault zone distribution), engineering design will have to rely on ground control measures with burst-resistant rock support as an important line of defense to ensure workplace safety. For this reason, it is imperative to design proper burst-resistant support systems when mining and tunneling at depth. No excavation in burst-prone ground should be advanced without the installation of burst-resistant support systems (Stacey, 2011).

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*Corresponding author. Tel: +1-705-675-1151;
E-mail: mcai@laurentian.ca

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The design of rock support in burst-prone grounds differs from conventional rock support where controlling gravity-induced rockfalls and managing shallow zones of loose rock are the main target. Rock support in burst-prone ground needs to resist dynamic loads and large deformations due to rock dilation, called bulking, during the violent failure of rock. The term “bulking” is used to describe volume increases of the rock mass near an excavation due to geometric non-fit during the transition from competent to fractured and then to broken rocks. Near excavations, bulking is unidirectional toward the excavation (perpendicular to the wall), a function of the applied tangential strain, and highly dependent on the confining stress. For this purpose of rock support in burst-prone ground, the designers must understand the rockburst damage mechanisms, assess the rock support demands, and be able to select the right support products to fulfill several support functions. Furthermore, the 3D complex geological and geometrical conditions as well as the uncertainty or variability of design input parameters complicate the design. Hence, rock support design becomes an interactive and iterative process of selecting proper support elements to form a rock support system which has enough capacity to meet the expected demands.

Because of these complexities, it becomes quickly evident that such a design process cannot be carried out for all underground excavations in a consistent manner if the design is conducted manually. Tremendous time and effort would be required to manually conduct such design work and costly mistakes could be made if the design engineers do not pay attention to details. Hence, a design guideline which explains the principles and methodologies as well as rock support system capacities is required for design professionals. Furthermore, a rockburst support design tool which helps to streamline the design process and integrate past and current knowledge is needed for the mining and civil construction industries.

In response to industry’s needs, an R&D project is currently on-going at Laurentian University in Canada to produce a concise design guide and to develop an interactive design tool for rock support design in burst-prone grounds. In this paper, after reviewing the rockburst phenomenon, types of rockbursts, damage mechanisms, rockburst support design principles and design acceptability criteria, the design tool which can be used to facilitate a systematic and consistent rock support design in burst-prone grounds is introduced.

2 Rockbursting and rockburst damage

2.1 Rockburst phenomenon

Rockburst is a 20th century phenomenon as the first recorded incident occurred in the early 1900s in the gold mines in the Witwatersrand, South Africa (Blake and Hedley, 2003). Rockbursting is the result of sudden and violent failure of rocks. There is a clear linkage between rockburst activities and mining depth. As mining migrates to deeper ground, in-situ stress becomes high relative to the rock strength and the likelihood of rockburst drastically increases. Rockbursts are mostly associated with hard rocks and geological structures such as faults and dykes and in mining are often related to high extraction ratios and associated with mining methods causing unfavorable stress conditions.

2.2 Types of rockbursts

Ortlepp and Stacey (1994) and Ortlepp (1997) classified rockbursts into five types (strainburst, buckling, face crush/pillar burst, shear rupture, fault-slip burst). In a broad sense, buckling type rockbursts can be grouped into strainbursts, and shear rupture type rockbursts can be considered as fault-slip rockbursts. For brevity of discussion, we consider here three rockburst types, i.e. strainburst, pillar burst, and fault-slip burst. Rockbursts are either mining-induced by energy release causing damage at the source (e.g. strainburst without significant dynamic stress increase from a remote seismic event) or dynamically-induced rockbursts with damage caused by energy transfer or significant dynamic stress increase from a remote seismic event (e.g. strainburst with dynamic stress increase caused by a remote seismic event).

Rock mass failure occurs when the excavation-induced stress exceeds the peak strength of the rock mass. In many deep underground excavations, strainbursts are the most common rockburst type; they can be mining-induced due to static stress change caused by nearby mining or dynamically-induced due to dynamic stress increase caused by a remote seismic event (called dynamically-induced strainbursts). An example of strainburst damage is shown in Fig. 1.