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Energy sources of rock burst and the influence of the surrounding rock mass

Charlie C. Li

ENERGY SOURCES OF ROCK BURST AND THE INFLUENCE OF THE SURROUNDING ROCK MASS

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ABSTRACT: The kinetic energy for rock ejection in a rock burst event is converted from the strain energy stored in the burst rock, a portion of strain energy released from the surrounding rock mass and a portion of seismic energy transferred from fault-slip seismicity. The kinetic energy is mainly contributed by the burst rock itself in a small-scale strain burst, but the energy released from the surrounding rock mass plays a major role in a large-scale rock burst. Intergranular and extensional cracking is dominating in burst-prone rocks, while in the non-burst-prone rocks the dominating cracking is intragranular and shear. Both the crack density and the average opening width of cracks are very small in burst-prone rocks.

EXTENDED ABSTRACT

Rockbursts are classified into two categories — strain burst and fault-slip rockburst — in accordance with the major contributor of the kinetic energy. In a strain burst event, the rock mass is often massive and intact before bursting. The kinetic energy for strain burst is mainly converted from the strain energy stored in the rock mass. A strain burst may be triggered by the elevated tangential stress after excavation, which is called a self-initiated strain burst (Cai and Kaiser 2018), or by a fault-slip seismicity event, which is then called a fault-slip triggered strain burst (Li et al. 2022). In a fault-slip triggered event, the fault-slip seismic waves play only a role of triggering, but the kinetic energy is still converted from the strain energy stored in the rock. In other cases, the fault-slip seismicity is so powerful that it contributes the major portion of the kinetic energy in a burst event. This is the so-called fault-slip rockburst. This type of burst can occur either in a massive intact rock mass or in a pre-fractured rock mass. A good understanding of the kinetic energy sources of a burst event is helpful for the design of dynamic ground support.

Both energy release and energy conversion are involved during a rock burst event. The potential energy in a rock burst event is composed of the elastic energy stored in the rock to burst, the elastic energy released from the surrounding rock mass, and the seismic energy transferred into the burst rock. The potential energy is dissipated by rock fracturing, rock ejection and a small portion for heat and vibration. Neglecting the portion for heat and vibration, the energy conversions are illustrated in a conceptual model shown in Fig. 1. In the diagram, the thin solid curve on the left represents the load-displacement curve of the burst rock, and the thick solid straight line on the left is the response line of the surrounding rock mass. Line OA represents the behavior of the burst rock in the pre-failure stage. Point A represents the ultimate load level of the rock, that is, the rock strength. The hatched area, denoted as W_d, represents the energy dissipated for rock damage during loading. That energy portion is quite small in hard rock compared with the elastic strain energy stored in the rock before the rock bursts, which is represented by the area bounded by BACB, denoted as $W_b = (W_{bf} + W_{bk})$. A portion of the elastic strain energy W_b is dissipated by rock fracture, denoted as W_{bf}, and the remainder is converted into kinetic energy, denoted as W_{bk}, to eject rock after the load passes the peak load A. After bursting, the boundary of the burst pit deforms along the thick line AD. The slope of the line represents the overall stiffness of the rock mass surrounding the burst pit. The strain energy released from the surrounding rock mass is represented by the area bounded by ADCA, denoted as $W_m = (W_{mf} + W_{mk})$, where W_{mf} is the portion of the energy dissipated by rock fracture and W_{mk} the portion converted into kinetic energy. Overall, the total strain energy available for rock fracture and rock ejection in the post-failure stage, denoted as W_e, is the sum of the elastic strain energy stored in the burst rock, W_b, and the energy released from the surrounding rock mass, W_m, that is, $W_e = (W_b + W_m)$ when fault-slip seismicity is not involved in the burst event. When the burst is triggered by seismicity, the seismic energy must be also taken into account. The seismic energy input W_s is also partially dissipated by rock fracture (W_{sf}) and partially converted to kinetic energy (W_{sk}). In general, the total kinetic energy for rock ejection, denoted as W_k, in a rock burst event is the sum of the kinetic energies from the burst rock (W_{bk}), the surrounding rock mass (W_{mk}), and the seismic waves (W_{sk}), that is, $W_k = (W_{bk} + W_{mk} + W_{sk})$. The kinetic energy contributed by the burst rock itself, W_{bk}, depends on the rock type and is a constant per unit volume for a given rock type, thus being called the intrinsic burst energy of the rock. The kinetic energy contributed by the surrounding rock mass,

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[1] *Professor, NTNU Norwegian University of Science and Technology, Trondheim, Norway. Email: Charlie.c.li@ntnu.no*

W_{mk}, is associated with the stiffness of the surrounding rock mass. Similarly, the energy dissipated by rock fracture, denoted as W_f, is also the sum of three components, that is, $W_f = (W_{bf} + W_{mf} + W_{sf})$.

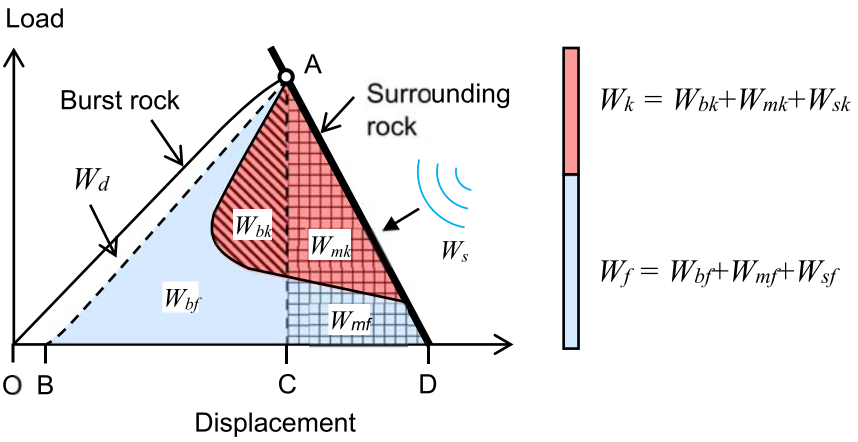

Figure 1: A conceptual model for the energy conversions in a rock burst event

Two prerequisites must be satisfied for a strain burst event to occur: first, the tangential stress in the rock must reach the level of the rock strength, and second, there must be excess energy to eject rock after rock fracture, that is, $W_k > 0$.

The potential energy in the burst rock can be estimated based on the behavior of the rock and the stress state of the rock before bursting. The potential energy released from the surrounding rock mass, $W_m = (W_{mk} + W_{mf})$, is not easy to obtain. In theory, it should be the product of the total load on the burst boundary and the displacement of the boundary. Assuming that the boundary of a strain burst pit is as shown in Figure 2, the energy released from the surrounding rock mass is calculated as

$$W_m = \frac{1}{2}\int_0^A (\vec{\boldsymbol{p}} \bullet \vec{\delta})\, dA \tag{1}$$

where $\vec{\boldsymbol{p}}$ is the resultant stress vector on a differential area dA of the burst boundary, and A is the area of the burst boundary.

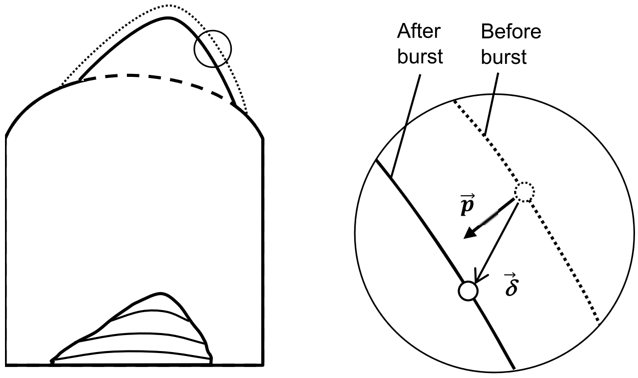

Figure 2: Sketches illustrating the positions of the burst boundary before and after a strain burst

An ABAQUS 2D numerical model was constructed to simulate strain bursting of breakout failure, aiming to demonstrate the influence of the surrounding rock mass to the rock burst. The circular tunnel in the model was 8 m in diameter. Only the upper half of the tunnel was simulated owing to the symmetry of the problem, Figure 3. The model dimensions were 40 m × 20 m (width × height). The x-displacement and y-displacement were restrained on the horizontal and upper boundaries of the model, and the y-displacement was additionally restrained on the bottom boundary of the model. The out-of-plane of the model was completely restrained, i.e., a plane-strain condition was assumed. With such a boundary condition applied, no external energy could enter the system. The in situ stresses applied to the model were 40 MPa horizontally and 20 MPa vertically. The breakout notch was created in the middle of the tunnel roof in every burst simulation. The width of the notch was kept constant at a value of 3 m, whereas the depth varied from 0.2 m to 2.7 m in the simulations. The model material was homogeneous, isotropic, and elastic. The properties of the material were a Young's modulus value of 70 GPa and Poisson's ratio of 0.2. The modeling was performed in two steps for each burst depth. In the first step, the principal stresses along the boundary of the potential burst were calculated and the strain energy stored in the potential burst rock, W_b, was calculated after the tunnel excavation. In the second step, the burst rock was removed to create the breakout notch and the model was then run to equilibrium. The average displacement vector of each element on the burst boundary was then registered. The work done by the surrounding rock mass along the burst boundary, W_m, is calculated according to Eq. (1). The simulated results for the released strain energies are presented in Figure 3. As shown in the diagrams, the energies released from both the burst rock and the surrounding rock mass increase with the burst depth, however, the increase in the energy from the surrounding rock mass accelerates with increasing burst depth. The released strain energy W_m increases nonlinearly with burst depth or volume. The burst rock releases more energy than the surrounding rock mass when the burst depth is small, e.g., 0.2 m, implying that the burst magnitude is dominantly determined by the energy released from the burst rock itself in shallow burst events. In contrast, the energy released from the surrounding rock mass plays a more important role than the energy released from the burst rock when the burst depth is relatively large, such as at a depth value of 2 m.

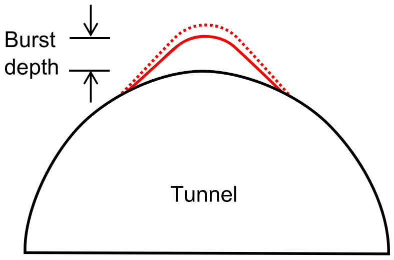

Figure 3: Sketches illustrating the tunnel and the burst pit in the numerical model

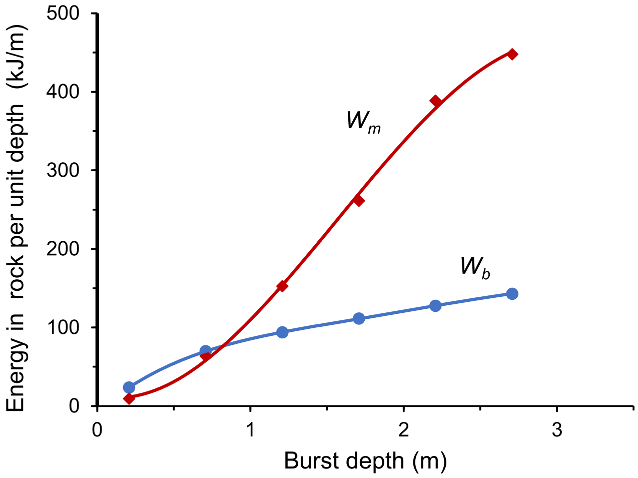

Figure 4: The simulation results of the strain energy in the burst rock, Wb, and the energy released from the surrounding rock mass, Wm, versus the burst depth

In conclusion, the energy sources for rock burst are the strain energy stored in the burst rock, the strain energy released from the rock mass, and the seismic energy transferred into the burst rock. The role of the surrounding rock mass depends on the scale of the rock burst. The magnitude of a shallow strain burst is mainly determined by the kinetic energy released from the burst rock, whereas, the kinetic energy of a deep strain burst could be mainly contributed by the surrounding rock mass.

Based on the microscopic observations of uniaxially loaded rock specimens by Wan and Li (2022), intergranular and extensional cracking is dominating in burst-prone rocks like brittle granite, while in the non-burst-prone rocks like ductile marble the dominating cracking is intragranular and shear. Furthermore, both the crack density and the average opening width of cracks are very small in burst-prone rocks.

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REFERENCES

Cai, M and Kaiser, P K, 2018. *Rockburst Support*, Vol. 1 Rockburst Phenomenon and Support Characteristics. MIRARCO – Mining Innovation, Laurantian University, Canada.

Li, C C, Zhao, T B, Zhang, Y B and Wan, W K, 2022. A study on the energy sources and the role of the surrounding rock mass in strain burst. *International Journal of Rock Mechanics & Mining Sciences* 154: 105114. 8p. doi.org/10.1016/j.ijrmms.2022.105114.

Wan, W K and Li, C C, 2022. Microscopic and Acoustic Interpretations of the Physics of Rock Burst and the Difference in Fracturing Patterns in Class I and Class II Rocks. Rock Mechanics and Rock Engineering 55: 6841–6862. doi.org/10.1007/s00603-022-03015-2.