Determination of the miners’ individual injury risk as a result of the dynamic manifestation of rock pressure

Tatyana Kaverzneva, Vladimir Rodionov, Igor Skripnik, Sergey Zhikharev, Maxim Polyukhovich

Abstract. The injury rate in underground coal mining is extremely high. One of the factors leading to injuries in underground mining is rock bursts. Although rock bursts are not the most common cause of injury in this industry, their consequences are extremely severe. At the same time, the level of injuries as a result of the manifestation of this factor remains high and almost does not change over the past years. The paper presents a method for determining the risk of injury of varying severity as a result of rock bursts. Multifunctional security systems that allow obtaining information about the state of the rock mass are analyzed. Based on the data obtained from these systems, the probability of a rock burst is assessed. The paper also deals with the processing of statistical information on light, severe and fatal injuries caused by rock bursts in the coal mines of the Kuznetsk coal basin. On the basis of statistical data and the results of measurements of the main parameters of the rock mass, the value of the individual risk is determined. It is advisable to correlate the obtained value with the average occupational risk in production.

Keywords: coal mines, individual risk, rock bursts, multifunctional safety systems, injuries, rock mass.

1 Introduction

One of the most dangerous, if not the most dangerous, manifestation of rock pressure is rock burst. In coal mines (it is also found in some salt mines), it is customary to refer (to call it by a more specific term) rock burst to gas-dynamic phenomena, because as a result of the almost instantaneous destruction of the rock mass, a huge amount of gases enter the mine workings together with the rock. Most often, this gas-dynamic phenomenon is formed...
As a result of the destruction of elements of a rock mass or pillars, the consequence of its manifestations are cases of mild, severe and fatal injuries, destruction of lining, machines, mechanisms and various equipment [1, 2, 3].

During a rock burst, acoustic vibrations and a shock wave also occur, and a large amount of coal dust is released. At the same time, shifts in the rock mass are recorded by seismic stations at a distance from several tens to hundreds of kilometers from the impact site [2, 3].

Rock bursts occur as a result of the release of the potential energy of elastic compression of rocks. The release of energy is accompanied by a chain reaction of destruction of the massif's sections, which are in an extremely stressed state [2, 4].

For the first time on the territory of the Russian Federation, a rock burst was recorded more than 70 years ago (1944, the Kizelovsky coal basin). In addition to coal mines, rock bursts were recorded at deposits of iron ore, bauxite, copper, apatite, gold and polymetals.

Local manifestations of rock bursts are pressure bumps, shocks and micro-bursts. Pressure bumps are characterized as a sign of a possible rock burst and represent the breaking off or rebounding of rock pieces with an accompanying sound due to the brittle fracture of rocks that are in a stressed state [4, 5, 6].

The destruction of the coal-bearing strata outside the contours of workings without their release into them is called shocks. The destruction of formation rocks within a small space during their rapid ejection into the mine is called a micro-burst. Micro-bursts are accompanied by rock mass shaking, dust formation and gas release, as well as a sharp sound [5, 6].

The probability of a rock burst is established using instrumental research methods—determining the output of rock mass during well drilling, as well as using acoustic methods (velocity of sound waves) and fixing changes in the magnetic field of rocks [7].

For forecasting and timely prevention of manifestation of rock bursts in coal mines, a rock burst forecasting service is being created. To prevent rock bursts, rock pressure is reduced based on various methods (well drilling, degassing, etc.) aimed at preventing the formation of stress concentration areas. The use of these measures contributes to the fact that the stress zones are shifted deeper into the massif, and their number also decreases [7, 8].

With an increase in the strength of rocks, the depth of mining operations, and rock pressure, the probability of a rock burst also increases. The presence of discontinuous faults also increases the probability of a rock burst [7, 8, 9].

In accordance with the data of the Federal Service for Environmental, Technological and Nuclear Supervision, for the period from 2018 to 2022, 29 accidents occurred at the coal mines of Kuzbass due to this factor (Figure 1).
Fig. 1. Quantity of accidents caused by rock bursts at the Kuzbass coal mines for the period 2018-2022.

Despite the fact that the number of accidents caused by rock bursts is only 5% of the total number of accidents, their number still remains unacceptably high.

2 Materials and methods

Figure 2 shows measurement results of the MIKON-GEO system.
The obtained values of the rock pressure gradient and the magnitude of seismic energy are distributed relative to the threshold values set for specific mining and geological conditions. Next, the number of values exceeding the threshold value is determined, which is used further in the calculations [15].

At the first stage, the probability of rock burst is determined. To determine its value, the values of the parameters coming from the MIKON-GEO type system are used. Within the framework of the developed mathematical model, it is proposed to determine the probability of rock burst separately for seismic energy and for the rock pressure gradient [15].

The mathematical model for determining the probability of rock burst is based on the maximum likelihood criterion. Within the framework of this model, the likelihood ratio of the rock pressure gradient values (seismic energy, distribution density and probability of rock burst) is determined [15, 16, 17].

The likelihood ratio is calculated by formula 1:

$$L = \frac{N_{AT}}{N_{BT}}$$

where

- $N_{AT}$ - number of rock pressure gradient (seismic energy) values above the set threshold value;
- $N_{BT}$ - number of rock pressure gradient (seismic energy) values below the set threshold value.

Distribution density is determined by formula 2:

$$f_{RB} = \frac{N_{BT}}{Q}$$

where

- $N_{BT}$ - number of rock pressure gradient (seismic energy) values below the set threshold value;
- $Q$ - total number of rock pressure gradient (seismic energy) values for the measurement period [15].

The probability of a rock burst for each of the parameters will be calculated by formula 3:

$$R_{RB} = L \cdot f_{RB}$$
In the general case, the value of the rock burst probability will be determined by the formula 4:

\[ R_{RBav} = \frac{R_{RB1} + R_{RB2}}{2} \]

where

- \( R_{RB1} \) - probability of rock burst as a result of manifestation of seismic energy;
- \( R_{RB2} \) - probability of a rock burst as a result of a change in rock pressure (rock pressure gradient) [15].

The individual risk of injury of varying severity is determined by formula 5:

\[ R_{ind} = \frac{N_i}{Q_{av}} \]

where

- \( N_i \) - number of cases of minor, severe or fatal injuries as a result of rock burst;
- \( Q_{av} \) - average headcount for underground coal mining, people [15].

The value of the individual injury risk of varying severity for specific mining and geological conditions, taking into account the probability of a rock burst, will be determined by formula 6:

\[ R_{ind_{RB}} = R_{ind} \cdot R_{RBav} \]

In the event that the obtained value exceeds the value of 2.5 \( \times 10^{-4} \) year\(^{-1} \) (the average value of the individual risk in the professional sphere), it is proposed to carry out organizational and technical measures aimed at preventing rock bursts [18, 19, 20].

3 Discussion and results

As part of the approbation of this model, an assessment of the values of individual risk of varying severity was made for one of the Kuzbass coal mines.

In the first case, no threshold values were exceeded for each of the indicators. Accordingly, the probability of collapse was equal to zero, and the definition of individual risks did not make sense.

In the second case, 30% excesses of seismic energy (39 out of 128 measurements) and 22% (28 out of 128 measurements) were detected. As a result, the following values of individual risks of varying severity were obtained.

The calculation results are summarized in Table 1.

<table>
<thead>
<tr>
<th>Injury</th>
<th>Risk value, year(^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>3.8 ( \times 10^{-4} )</td>
</tr>
<tr>
<td>Severe</td>
<td>2.9 ( \times 10^{-4} )</td>
</tr>
<tr>
<td>Fatal</td>
<td>1.9 ( \times 10^{-4} )</td>
</tr>
</tbody>
</table>

It has been established that the risks of light and severe injuries exceed the value of 2.5 \( \times 10^{-4} \). Accordingly, a decision is made on the need to take measures aimed at preventing rock burst and reducing the risk of injury. The risk of fatal injury was below the acceptable value.

4 Conclusion

As part of the study, a mathematical model was developed that makes it possible to determine the probability of a rock burst by two main parameters of a rock mass.
information received from the MFS, which is of particular importance given the need to equip the country's coal mines with them. Also, the developed mathematical model takes into account statistical information on injuries in coal mines as a result of rock bursts. The adequacy of the proposed model is substantiated by its approbation at one of the Kuzbass coal mines. As part of the above approbation, the need for organizational and technical measures aimed at preventing rock bursts was established. The given mathematical model is substantiated for the MIKON-GEO type system, as it was developed for the indicators used within the framework of this system. At the same time, the model makes it possible to estimate the probability of a rock burst and the value of the individual risk for other systems, already taking into account the parameters used in these systems. At the same time, the issue of adapting this mathematical model based on the maximum likelihood criterion for other MFSs remains an open task and is a matter for further scientific research.

References


