

THE ANALYSIS OF ROOF FALL RISK ASSESSMENT METHODS IN UNDERGROUND WORKINGS

Domrachev A.N., Govorukhin Yu.M., Krivolapov V.G., Paleev D.Yu.

National Mine Rescue Centre, Aviatorov av., 54, Novokuznetsk, Kemerovo region, Russia,
nio.ngc2016@gmail.com

This article proves the relevance of the roof fall risk assessment. It bases both in terms of predicting the possibility of their reuse and keeping the coal pillars stability, and the risk of the origin of closed unventilated areas, which unavoidably accumulate explosive gas-air mixtures. The most widespread foreign methods of roof fall risk assessment in mine workings have been considered. They include an algorithm for calculating the index of the level of roof fall risk (RFRI) and the method of assessing the stability of the pillars of the New South Wales University (UNSW). The possibility of using of the roof fall risk assessment methods to improve the efficiency and safety of mining operations in South Kuzbass mines has been tested on a specific example.

Keywords: a probability of risk fall, factor of probability, weight factor, roof support, expert estimation, category of risk

Introduction

The probability of the roof fall in mine workings, both in mining operations and in case of accidents in coal mines depends on many factors: the geological parameters of the mined seams; the schema and the method of seams opening and preparation, mining technology, and others., and its determination is quite a challenge, often not having a unique solution. However, the authors think, that the roof fall risk assessment, and as a consequence, the prospects for their re-use in partial or complete preservation, as well as the risk of an origin of unventilated closed areas, in which the accumulation of explosive mixtures is inevitable, is very important.

During the analysis of reference sources [2-8], it was found out that the most frequent use have expert, probabilistic (statistical) and mixed methods of roof fall risk assessment. The development of the probabilistic method is in the simulation of the risk of roof fall using the Monte-Carlo method, but this approach cannot be recommended as a basis for the implementation of a common procedure.

1. Theoretical part

To perform expert evaluation, we use the index value of the level of roof fall risk (RFRI) [1, 2] by the categories of roof defects for various parameters (Table 1) on the factors given in the table. RFRI is calculated in accordance with the algorithm shown in table 2. When the value of RFRI is 7-32 the risk of the fall is considered to be low, 33-66 – average, 67-138 – high. The numerical value of the roof fall probability can be estimated by the formula (1) as:

$$RFRI_p = \frac{\sum (AV_i \cdot W_i)}{\sum (MAV_i \cdot W_i)}, \quad (1)$$

where

AV_i	– estimate for a given category;
W_i	– a weighting factor of this category;
MAV_i	– the maximum estimate on the i -th category (or =6).

Table 1 – The categories of roof defects for the assessment of RFRI value

Category	Factor	AV _i value interval	Weigh-ting factor W _i
1	2	3	4
Geological	Large angular discontinues, joint frequency, layer thickness	1-5	1
Technological	Shear rupture surface, joint separation, strata shifting, strata separation	1-5	2
Roof profile	Roof rock debris on floor, roof shape	1-5	1
Moisture	Moisture/groundwater	1-5	1

Table 2 – Algorithm of RFRI index calculation

Vertical sum on all categories	$\sum AV_i W_i$
Multiply by 1,1	$1,1 \sum AV_i W_i \prod$
Matching micro seismic activity No micro seismic activity – subtract 5; Presence of micro seismic activity – add 25.	$1,1 \sum AV_i W_i - 5$ $1,1 \sum AV_i W_i + 25$
Matching roof deformation intensity No roof deformation; Constant roof deformation; Accelerating roof deformation.	$1,1 \sum AV_i W_i - 5$ $1,1 \sum AV_i W_i + 15$ $1,1 \sum AV_i W_i + 30$
Index of roof fall.	RFRI

Quantitative expert and probabilistic fall risk assessment is based on the classification by coal mine roof rating (CMRR), which is a number in the range 0 (weak roof) - 100 (maximum strong roof) [3]. The calculation algorithm [4] is a combination of statistical and expert methods and includes sequential selection of the parameters, depending on the geological and mining characteristics with the subsequent calculation of probability based on regressional dependences. For each *j*-th module (rock layer) of the roof individual discontinuity rating is determined - (*IDR_j*). If the module includes only one lithology layer, the *IDR* is defined once for the whole series.

$$IDR_j = CR_j + SP_j, \tag{2}$$

where *CR_j* is the value of cohesion-roughness parameter;
SP_j is the value of spacing-persistence parameter.

Then on the basis of the above data the module rating is determined (unit rating, *UR_i*)

$$UR_i = \min(IDR_j) + MDA_i + US_i + UMS_i, \tag{3}$$

where *IDR_j* - is individual discontinuity rating for *j*-th layer;
MDA_i is parameter of multiple discontinuity adjustment;
US_i is factor of the unit strength;

UMS_i is factor of responsiveness to water content (unit moisture sensitivity).

On the basis of US_i values calculated for each i -th layer (unit), a bed strength parameter SB (strong bed) is calculated, $SB = \max(UR_i)$. Further, in view of US_i values and bolted interval BI the weighted average of the unit ratings RR_w is calculated.

$$RR_w = \frac{\sum_{i=1}^N UR_i m_i}{BI}, \quad (4)$$

where UR_i – unit rating value (rock formation) for i -th unit;
 m_i – rock thickness of the i -th unit;
 BI – bolted interval (bolts length), m.

For certain values of SB и RR_w the adjusted strong bed difference (SBD) of the ground (roof) rock is determined

$$SBD = SB - RR_w, \quad (5)$$

where SB – individual discontinuity rating;
 RR_w – individual unit rating (massive structure discontinuity parameter).
 Strong bed adjustment, $SBAJ$ can be determined as

$$SBAJ = [(0,72SBD \times HSB) - 2,5] \times [1 - 0,33(HSB - 0,5)], \quad (6)$$

where HSB – thickness of the strong roof layer, m;
 SBD – strong bed difference (adjusted roof rock strength).
 The factor $CMRR$ (Coal Mine Roof Rating) is determined as

$$CMRR = SBD + SBAJ + UCA + GA + SA, \quad (7)$$

where SBD – strong bed difference (formula 5);
 SBA – strong bed adjustment (ground (roof) strength factor);
 UCA – unit contact adjustment (contact strength factor);
 GA – ground water adjustment (water content effect factor);
 SA – surcharge adjustment (roof strengthening effect factor).

To determine the probability of roof fall we use two parameters – the probability factor (probability factor (PF)) and the weight (value) of each parameter. Examples of the probability factor and its values for the combination of factors are shown in Table 3.

The probability of a roof fall (retreat mining) during panel (pillar) mining P , % is determined as

$$P = 100 \left[\frac{\sum_{i=1}^n PF_i W_i}{\sum_{i=1}^n MPF_i W_i} \right] = 0,33 \left(\sum_{i=1}^n PF_i W_i \right), \quad (8)$$

where PF_i – the value of i -th factor of the fall probability;
 W_i – the weight of i -th factor of the fall probability.

Table 3 – Parameters affecting the risk of the workings fall

№	Parameters	Value interval	Probability Factor	Weight Factor
1	2	2	3	4
1	Depth of cover H, m	40-600	1 – 4	9
2	CMRR	45 - 85	0 – 4	10
3	Floor rock quality	week-strong	1 – 3	4
4	Overlying massive strata, m	0 – 20	0 – 3	5
5	Multiple-seam interaction/ Interburden thickness	0 – 60h	0 – 4	7
6	Panel width	Sub-, super critical	1 – 3	3
7	Panel uniformity	Uniform –non uniform	1 – 3	1
8	Entry width, m	5 - 7	1 – 3	8
9	Pillar design	Suitable-unsuitable	1 – 4	6
10	Roof bolting (density)	1 – 1.5	1 – 3	7
11	Panel age (years)	1 – 2	1 – 3	2
12	Supplemental support	MRS, timber post	1,4	7
13	Cut sequence	Outside lift, left-right, other	1 ,2, 3	6
14	Final stump	Proper, unproper	1,4	8

Currently, the most common probabilistic method of determining the parameters of new workings protected by pillars and assessing the stability of the existing ones is the University of New South Wales (UNSW) Pillar Design Method [7] acceptable for rectangular and rhomb-shaped pillars. According to this method, the strength (resistance) R for $R \leq 5$

$$R = 8,6 \frac{(w\Theta)^{0,51}}{h^{0,84}}, \quad (9)$$

where w – “adjusted” pillar width, $w = w_1 \sin \theta$, m;
 w_1 – pillar minimum width, m;
 θ – angle between adjacent sides (pillar), typically=0;
 Θ – dimensionless factor (ratio value of width / height of the pillar);
 h – pillar height, m.

For ratio $w/h < 3$ $\Theta = 1$; on condition $3 \leq w/h \leq 6$ the parameter Θ makes

$$\Theta = \left[\frac{2w_2}{(w_1 + w_2)} \right]^{\frac{R-3}{3}}, \quad (10)$$

where w_1 – pillar minimum width, m;
 w_2 – pillar maximum width (or pillar length), m.

When the ratio $w/h > 6$ the parameter Θ makes

$$\Theta = \frac{2w_2}{(w_1 + w_2)}. \quad (11)$$

The current load on the coal pillar is determined by the indirect method

$$S = \rho H \frac{(w_1 \sin \theta + b_1) \left(w_2 + \frac{b_2}{\sin \theta} \right)}{w_1 w_2 \sin \theta}, \quad (12)$$

where b_1 – roadway width (with respect to pillar width), m;
 b_2 – roadway length (with respect to pillar length), m;
 H – depth of overburden, m;
 ρ – density of overburden, MH/m³.

R and S parameters are defined in the stress units (MPa). The Factor of safety FoS is defined as

$$FoS = \frac{R}{S}. \quad (13)$$

The probability of pillar failure (p_{of}) (and workings fall) can be determined as

$$p_{of} = 1 - \Phi \left(\frac{\ln FoS}{\sigma} \right), \quad (14)$$

where σ – mean-square deviation;
 $\Phi()$ – standard function of normal distribution.

The standard mean-square deviation is based on the power model of pillar strength using the University of New South Wales (UNSW) Australian database, thus $\sigma=0.157$.

2. Discussion of results

To assess the possibility of this methodology when evaluating the risk of roof fall in the workings of Kuzbass conditions we have calculated the drift of Sychevsky-IV seam of “Gramoteinskaya” mine.

In case of the width of the sill pillar up to 30 m, the width of workings 4.5 m, and the bolting height of 2.5 m, the probability of the fall using CMRR was 0.168, while the calculation according to the UNSW Pillar Design Method resulted in 0.147, that is an acceptable indicator for predicting the stability of the stope for the period of its operation. A technological reason of a sufficiently high probability of the working fall can be a decision to leave in the roof a coal bench up to 0.75 m thick.

Conclusion

The presented analyzes allowed not only to evaluate the methods for determining the probability of roof fall in mine workings, but also to identify possible areas of the use of the gained results. The authors presume that the obtained results would have the most importance at working out the annual and quarterly plans for the development of mining operations, particularly at the evaluation of the possibility of secondary use of the preserved mine workings, monitoring of the calculated and actual parameters of interchamber and goaf pillars at short wall mining, as well as when forecasting possible unventilated mine workings during rescue operations in coal mines.

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