DEVELOPMENT OF SOFTWARE TO EVALUATE ROOF FALL RISK IN BORD AND PILLAR METHOD - DEPILLARING PHASE

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Abstract

Roof fall is one of the major problems of the bord and pillar coal mines during the depillaring phase. Roof fall not only causes considerable damage to the mining equipment but also to the miners. To keep in view, development of software is essential for the calculation of roof fall risk to reduce the accidents to a certain extent. In this paper, the software has been developed and tested on seam-2, the main panel of RK-5 underground coal mine, Singareni Collieries Company Limited, India and corresponding roof fall risk was calculated. The best combination of the parameters causing roof fall risk was evaluated to reduce the risk.

Keywords: Roof fall risk, parameters, software, probability, risk factor.

1 INTRODUCTION

Roof falls in underground mines are one of the most significant hazards for miners. Roof fall can threaten miners, damage equipment, disrupt ventilation and block critical emergency escape routes. The hazardous nature of roof fall risk can be illustrated from statistics of accidents in Indian mines.

A total no. of 278 fatal accidents took place due to roof fall from 1998 to 2010 in different coal mines of India and is listed in Table 1 year wise [2]. Accidents due to fall of roof occurred in the same proportion in bord and pillar development as well as depillaring methods. In underground coal mines, bord and pillar is one of the oldest method used for extraction of flat and tabular coal seams. Pillars are left behind to support the roof and preventing it from collapse. To increase the utilization of coal, the pillars are extracted after development known as depillaring method. Depillaring mining is one of the most hazardous activities because it creates an inherently unstable situation. The process of depillaring method removes the main support after extraction of the pillars to an extreme extent and allows the roof and overlying rocks to cave. As a result, pillar line was extremely dynamic and highly stressed. The software was developed based on the equation designed to calculate the risk of roof fall during retreat mining in room and pillar coal mines [1].

Table 1: Trend of fatal accidents in coal mines due to roof falls in India [2]

Sl. No.	Year	No. of roof falls
1	1998	35
2	1999	33
3	2000	27
4	2001	30
5	2002	23
6	2003	18
7	2004	26
8	2005	18
9	2006	13
10	2007	13
11	2008	14
12	2009	17
13	2010	11

2 PARAMETERS CONTRIBUTING TO THE ROOF FALL DURING DEPILLARING METHOD

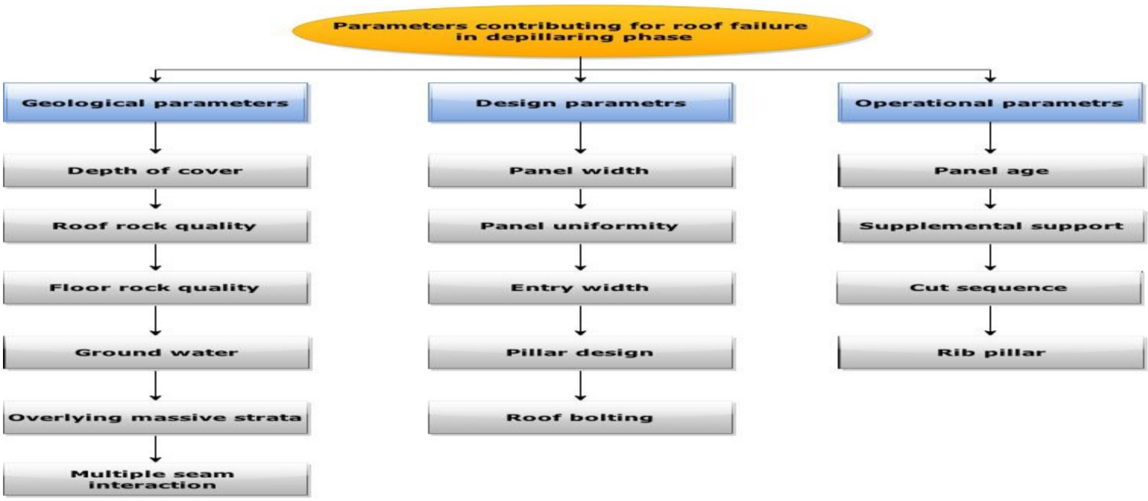

Figure 1: Flow chart of major parameters contributing for roof failure in depillaring phase

The parameters contributing to the roof fall during depillaring phase can be divided into three categories, and they are

a) Geological parameters
b) Design parameters
c) Operational parameters

2.1 Geological Parameters:

DEPTH OF COVER

Increasing the depth leads to increase of virgin stress levels in rock mass, both vertically and horizontally. So, achieving sufficient stability is harder at greater depths, and special precautions are required to ensure ground stability [1].

ROOF ROCK QUALITY

The quality of roof fall rock has a significant role in the occurrence of roof fall. Various methods have been presented for classification and evaluation of roof in coal mines, but most applicable is coal mine roof rating (CMRR). When CMRR approaches '0', the roof is weaker and when it approaches '100', the roof is stronger. Based on CMRR value, the probability of roof fall risk [1, 5] can be classified into five categories.

- Extreme 0-45
- High 45-55
- Moderate 55-65
- Low 65-85
- Negligible 85-100

FLOOR ROCK QUALITY

Floor, pillar and roof treat as a system in bord and pillar mines. It plays an important role. When the floor rock doesn't have suitable quality, pillars penetrate into the floor, which leads to roof convergence and ultimately its failure. If the floor heave is found to a greater extent, then it can be considered as a weak floor. If no heave is observed, then the floor is considered as strong. In other cases, it is considered as moderate [1, 4].

GROUND WATER

The presence of groundwater resource and strata containing water above the extracting panel is one of the effective parameters of roof instability. If the roof is dry, the roof fall is not probable, if the roof is wet, the probability of roof fall is low, if dripping occurs, the probability is high, and if flow of water is steady, then the probability is extreme [1].

OVERLYING MASSIVE STRATA

One of the most important influencing parameters on roof cavability is the existence of massive strata such as sill over the panel. Massive strata can cause intense roof fall during retreat mining because these strata tend to be hang up in large spans, but after achieving a critical span, they break violently. Based on research, the nature of immediate roof strata (up to 20 m over the coal seam) has a significant role in cavability and creation of gob. Therefore, if the massive strata are in this range, the probability of roof fall is high. In these situations, partial pillar extraction with proper cut sequence is effective to prevent violent roof fall [1].

MULTIPLE-SEAM INTERACTION

In many coalfields, coal seams are formed close to each other and as series separated by rock strata (interburden). The mining of two adjacent seams is called multiple-seam mining and the ground control problems caused by this mining method are called multiple-seam interaction. Ground instability is greatest hazard due to multiple seam interaction [1].

If thickness of extracting coal seam is 'h' and interburden thickness is 'T' then

- $T < 4h$ interaction is extreme
- $4h < T < 10h$ interaction is high
- $10h < T < 24h$ interaction is moderate
- $24h < T < 60h$ interaction is low
- $T > 60h$ interaction is negligible

2.2 Design Parameters:

PANEL WIDTH

Panel width affects abutment loads distribution and over- burden caving mechanism during retreat mining. Moreover, with increase of panel width, the height of tensile zone developed in the overburden increases, which can cause violent failure and eventually full caving of overburden. Width to depth ratio panels [1] is divided into three categories:

- sub critical ($P/H<2\tan b$)
- Critical ($P/H=2\tan b$)
- Super-critical ($P/H>2\tan b$)

Where, P is the panel width, H is the panel depth and b is the abutment angle. Super-critical panels have more width in comparison with two other categories.

PANEL UNIFORMITY

Panel shape and panel's pillars shape and size are important in panel uniformity. Because irregular panel shapes make pillar lines uneven during retreat mining and this causes unpredictable an uncontrollable roof falls. Moreover, panel development consisting uniformly sized pillars is recommended strongly, because non-uniform and unequal sized pillars cause non-uniform stress distribution and therefore decrease the roof stability [4].

ENTRY WIDTH

One of the most important methods of decreasing the roof instability at intersections is that entries creating an intersection should be mined to the minimum possible width, in order to make the operation of extraction safe and the haulage equipment possible [1]. Regarding the equipment which are used in room and pillar mines now a-days (continuous miner, shuttle car and LHD), the proper width of entries is about 4.5 to 5m and also at width more than 7m, roof fall and support problems are probable based on researches done by Jeffrey [7].

PILLAR DESIGN

Proper pillar design has a significant role in roof stability. Analysis of retreat mining pillar stability (ARMPS) program is an effective means for pillar design and prediction of pillar stability during retreat mining [1]. ARMPS was developed by Mark and Chase in 1997[8]. Stability factor depends on depth of cover, and roof quality (Coal Mine Roof rating - CMRR). If H is the depth and S is the safety factor of pillar then design is said to be suitable if it follows Table 2, else it is considered as unsuitable.

Table 2: Suitable safety factor for stability of the pillars during retreat mining[3]

Depth of cover (H)	Weak and intermediate roof (CMRR < 65)	Strong roof (CMRR > 65)
$H \leq 200$ m	≥ 1.5	≥ 1.4
$200 < H \leq 400$ m	$0.9 < S < 1.5$	$0.8 < S < 1.4$
$400 < H \leq 600$ m	0.9	0.8

ROOF BOLTING

Experimentally, installation of one roof bolt in one square meters of roof (bolt density = 1) in coal mine entries seems to be safe but this value is not adequate at intersection because intersections are subjected to abutment loads during retreat mining, and therefore require extra roof bolting. Based on bolt density, the probability of roof fall risk at intersections [1] is divided into three categories:

- High, when bolt density is less than 1
- Moderate, when bolt density is between 1 and 1.5
- Low, when bolt density is more than 1.5

2.3 Operational parameters:

PANEL AGE

As time passes, the roof of mine becomes weaker. Supplemental bolting is often required, particularly in intersections, to prepare old panels for retreat mining. If the panel age is less than one year, no additional support is needed and the probability of roof fall is low. But in older panels, the probability of roof fall increases [1].

SUPPLEMENTAL SUPPORT

Supplemental roof support is necessary in depillaring phase to increase the safety and minimize the risk of injury from roof falls. Timber posts and mobile roof supports (MRSs) provide supplemental support for retreat mining. Nowadays, using MRS is recommended strongly because using timber posts as pillar line supports has many disadvantages and the most important is that timber posts are passive supports and roof convergence would be small [1] .

CUT SEQUENCE

Mines employ a wide variety of cut sequences to recover pillars and most of them can be divided into three categories

- Left– right (also called Christmas tree or twinning) in which cuts are taken on both sides of the entry and it does not require place changes and bolting
- Outside lift in which cuts are taken on just one side and similar to left–right, it does not place changes and bolting
- Cut sequences that require cuts to be bolted

These methods are usually used when the pillars are so large that they must be split before they are fully recovered. Split-and-fender and pocket-and-wing are two common types of these methods [1].

3 CALCULATION OF ROOF FALL RISK

Risk is defined as the chance of occurrence of unwanted events that will have adverse effects on purposes. It is measured in terms of probability (P) and consequence (C). Roof falls during retreat mining continue to be one of the greatest geotechnical risks faced by underground coal miners and cause a lot of loss, injury or fatalities. Therefore, the roof fall risk [1] can be defined as:

$$R_{rf} = P * C \tag{1}$$

3.1 Probability

In order to make the roof fall probability quantitative, two measures have been considered. The first one is to assign the probability factor (PF) for each sub-category. The second one is to give a weight to each parameter. The probability factor is an index which represents the probability of roof fall for each sub-category and was obtained from Table 6 based on proposed method by Joy [1]. Based on this table, the probability factor can be a number between 0 and 4; 0 shows that the roof fall probability is negligible and 4 shows that the roof fall probability is extreme. Since the effects of different parameters on roof fall are not the same, it is necessary to give a weight to each parameters based on its importance on roof fall occurrence. In this study, a weight between 1 and 10 was assigned to each parameter based on judgments of mining engineers and ground control experts (Tables 3–5). 1 indicates the least effective parameter and 10 shows the most effective parameter on roof fall [1].

Table 3: Geological parameters influencing roof fall risk [1]

Sl. No.	Parameters	Probability factor	Weight
1	Depth of cover (m) • Less than 40 • Between 40 and 200 • Between 200 and 400 • Between 400 and 600 • More than 600	 4 1 2 3 4	9
2	Roof rock quality (CMRR) • Less than 45 • Between 45 and 55 • Between 55 and 65 • Between 65 and 85 • More than 85	 4 3 2 1 0	10
3	Floor rock quality • Weak • Intermediate • Strong	 3 2 1	4
4	Groundwater • Dry roof • Wet roof • Dripping • Steady flow	 0 1 3 4	2
5	Overlying massive strata/D • Do Not present • Present/Less than 20 m • Present/ More than 20 m	 0 3 1	5
6	Multiple-seam interaction/ Interburden thickness • Not present • present/Less than 10 h • Present/Between 10 h and 24 h • Present/Between 24 h and 60 h • Present/More than 60 h	 0 4 3 2 1	7

Where, D- Distance from the coal seam, h – Thickness of the coal seam

Table 4: Design parameters influencing roof fall risk [1]

Sl. No.	Parameters	Probability factor	Weight
1	Panel width • Sub-critical • Critical • Super-critical	 1 2 3	3
2	Panel uniformity • Uniform • Partly uniform • Non-uniform	 1 2 3	1
3	Entry width (m) • Less than 5 • Between 5 and 7 • More than 7	 1 2 3	8
4	Pillar design • Suitable • Unsuitable	 1 4	6
5	Roof bolting • Bolt density less than 1 • Bolt density between 1 and 1.5 • Bolt density more than 1.5	 3 2 1	7

Table 5: Operational parameters influencing roof fall risk [1]

Sl. No.	Parameters	Probability factor	Weight
1	Panel age (year) • Less than 1 • Between 1 and 2 • More than 2	 1 2 3	2
2	Supplemental support • Mobile roof support • Timber post	 1 4	7
3	Cut sequence • Outside lift • Left–right • Other sequence	 1 2 3	6
4	Final stump • Proper • Improper	 1 4	8

The probability of roof fall during retreat mining [1] is calculated as:

$$P = \left[\left(\sum_{i=1}^{n} PF_i * W_i\right) / \left(\sum_{i=1}^{n} MPF_i * W_i\right)\right] * 100 \qquad (2)$$

Where, PF_i, MPF_i and Wi are probability factor, maximum probability factor and weight of i-th parameter, respectively. The MPF for nine parameters is 3 and for the other parameters is 4 (Tables 3–5). Therefore, the above equation can be summarized as follows:

$$P = 0.33 * \left[\left(\sum_{i=1}^{n} PF_i * W_i\right)\right] \tag{3}$$

Table 6: Probability of an event in mining industry [6]

Sl. No.	Probability	Description	Probability Factor (PF)
1	Extreme	Common or frequent occurrence, ‘‘happens all the time’’	4
2	High	Is known to occur, ‘‘it has happened or it probably will happen’’	3
3	Moderate	Could occur, ‘‘I have heard of it happening’’	2
4	Low	Not likely to occur, ‘‘highly unlikely to happen”	1
5	Negligible	Practically impossible, ‘‘doubt it could ever happen”	0

3.2 Consequence

The roof fall during retreat mining can cause injury, disability and fatality of miners, damage to equipment, disruption and delay in mining operation simultaneously [1]. Furthermore, most of the roof falls caused burial of continuous miner and mobile roof support (MRS). The necessity to recover this equipment because of their high initial costs has caused several days of delay in mine production. Therefore, consequence of roof fall during retreat mining is catastrophic, which is the highest rank of consequence, and the number 1 (highest rank) can be allocated to it [6], which cause elimination of consequence term from derived equation 1.

3.3 Evaluation of roof fall risk

Considering what was mentioned in two previous sections, derived equation can be presented as:

$$R_{rf} = 0.33 * \left[\left(\sum_{i=1}^{n} PF_i * W_i\right)\right] \tag{4}$$

Based on equation (4), the roof fall risk during retreat mining (R_{rf}) is between 0 and 100. When the R_{rf} is approaching to 0, the roof fall risk during retreat mining is low and when R_{rf} is approaching to 100, the roof fall risk is very high [1]. In this study, the roof fall risk during retreat mining based on R_{rf} values is divided into four categories: low, medium, high, and very high (Table 7).

Table 7: Classification of roof fall risk during retreat mining [1]

Risk category	Rrf value	Roof fall probability	Level of roof fall risk
Low	0-28	Improbable	Acceptable
Moderate	28-48	Possible	Acceptable with management review, monitoring and auditing
High	48-70	Probable	Undesirable and requires control measures widely
Very high	70-100	Very probable	Unacceptable

4 DEVELOPMENT OF SOFTWARE

Software was developed using asp.net to calculate the roof fall risk in bord and pillar mining-depillaring phase and tested on seam-2, the main panel of RK-5 underground coal mine, Singareni Collieries Company Limited (SCCL), Godavarikhani district, Telangana state, India. Data collected from the above said mine has been summarized in Table 8.

Table 8: Data collected from RK-5 mine

Sl. No.	Parameters	Data
1.	Depth of cover (m)	180
2.	Roof rock quality	56
3.	Floor rock quality	Intermediate
4.	Ground water	Wet roof
5.	Overlying massive strata	Present < 20m
6.	Multiple seam interaction	Present/ less than 10H
7.	Panel width	Sub critical
8.	Panel uniformity	Uniform
9.	Entry width (m)	4.5
10.	Pillar design	Suitable
11.	Roof bolting density	1.75
12.	Panel age (Years)	1.5
13.	Supplemental support	Timber post
14.	Cut sequence	Left right
15.	Final stump	Proper

5 5. RESULT

All the above data (Table 8) are entered into the software and found that roof fall risk was ~ 52.47 in RK-5 mine which represents high risk category, as the roof fall risk was between 48 and 70. By changing the supplemental support from timber post to mobile roof support, the roof fall risk for RK-5 mine was reduced to 45.54 which interprets moderate category i.e. between 28 and 48. Since, this software provides the roof fall risk in advance so that preventive measures should be taken to avoid the accidents. The pictorial view of calculation of roof fall risk with different roof supports of RK-5 mine have been represented in Figures 2 – 3.

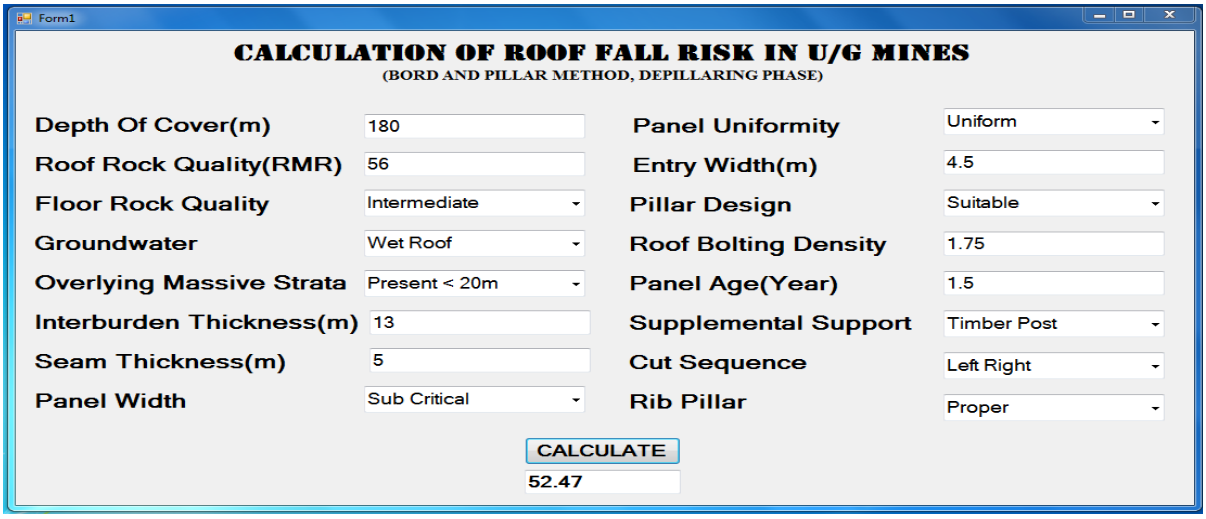

Figure 2: Pictorial view of software of RK-5 mine when supplemental support is timber post

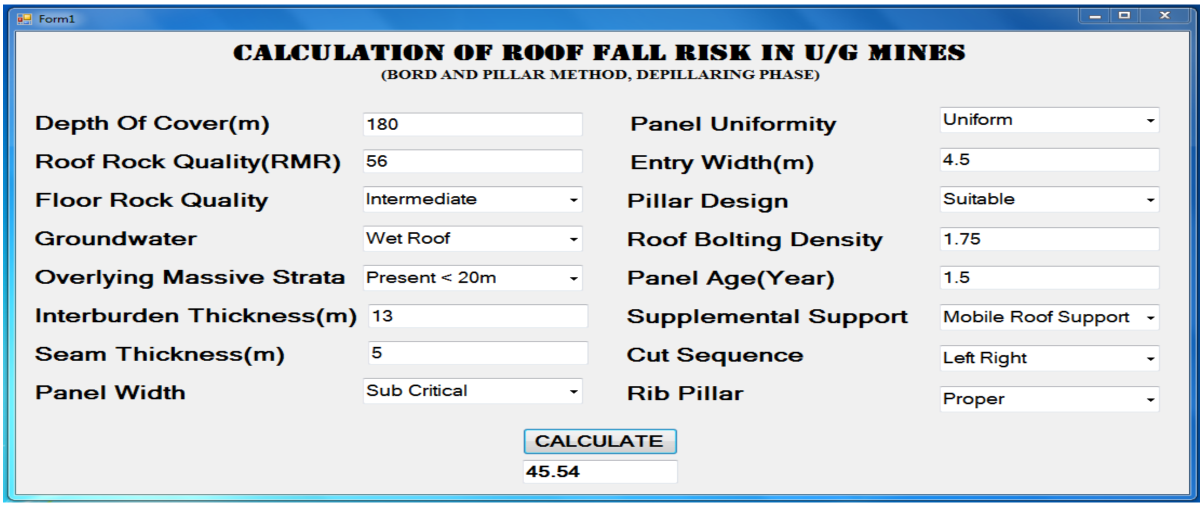

Figure 3: Pictorial view of software of RK-5 mine when supplemental support is mobile roof support

6 CONCLUSIONS

Depillaring method is mostly associated with high amount of risk and most of the accidents causes due to roof failure. By development of software for the prediction of roof failure, we can reduce the number of accidents to a certain extent. Use of software eases the calculation of roof fall risk with different combinations of parameters causing roof failure and finds the suitable risk factor. The combination with the least risk factor can be adopted in the mine and hence accidents due to roof failure can be reduced. When changing the support from timber to mobile roof support, the roof fall risk of RK-5 underground coal mines was changing from high risk category to moderate risk category, so, we can take preventive measures in advance with the proposed software to reduce the roof fall risk to a certain extent with feasible constraint.

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