MINING BLOCK STABILITY PREDICTION BY THE MONTE CARLO METHOD

Izrakteņu bloku stabilitātes prognozēšana ar Monte Carlo metodi

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Abstract

This paper analyses the stability of the mining blocks by the Monte Carlo method in Estonian oil shale mines, where the room-and-pillar mining system is used. The pillars are arranged in a singular grid. The oil shale bed is embedded at the depth of 40-75 m. The processes in overburden rocks and pillars have caused the subsidence of the ground surface. Visual Basic for Application was used for the modeling. Through Monte Carlo simulation, room-and-pillar stable parameters can be calculated. Model allows determination of the probability of spontaneous collapse of the pillars and surface subsidence by the parameters of registered collapsed mining blocks. Proposed method suits as an express-method for stability analysis and failure prognosis. It is applicable in different geological conditions, where the room-and-pillar mining system is used.

Keywords: *mining block, collapse, environment, pillar, underground excavation, stability prediction method, subsidence, Monte Carlo method, failure prognosis.*

Introduction

The most important mineral resource in Estonia is a peculiar kind of oil shale. It is located in a densely populated and intensely farmed district. The structure of the productive oil-shale bed makes the rocks more difficult to break from the total massive. It is estimated that about 80-90% of the total underground oil shale production is obtained by room-and-pillar method. The method is cheap, highly productive, easily mechanized, and relatively simple to apply. The area mined by this method reaches 100 km^2. It has become apparent that the processes in overburdened rocks and pillars have caused unfavorable environmental side effects accompanied by significant subsidence of the ground surface. The horizontal bedding and small depth of oil shale seam enables the roof deformations to reach the land surface without essential reduction.

The first spontaneous collapse of the pillars and the surface subsidence in an Estonian oil shale mine took place on 1964. Up to present, 73 collapses have been recorded on the area of 100 km^2 [1].

Geology and mining

The commercially important oil shale bed is situated in the north-eastern part of Estonia. The oil shale bed lays in the form of a flat bed having a small inclination in southern direction. Its depth varies from 5 to 150 m. The commercial oil shale bed and immediate roof consist of oil shale and limestone seams. The main roof consists of carbonate rocks of various thicknesses. The characteristics of the certain oil shale and limestone seams are quite different.

In Estonian oil shale mines the room-and-pillar mining system is used. The field of an oil shale mine is divided into panels, which are subdivided into mining blocks, approximately 300-350 m in width and from 600-800 m in length each. A mining block usually consists of two semi-blocks. The oil shale bed is embedded at the depth of 40-70 m. The room is very stable when it is 6-10 m wide. The pillars in a mining block are arranged in a singular grid.

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Prediction method

There are lots of stability calculation methods, which demand supplementary investigations [2]. Elaborated stability estimation method is suitable for practical application. Visual Basic for Application in Excel was used for numerical modelling. The mining block stability estimation through Monte Carlo simulation model is applicable in different geological conditions, where the room-and-pillar mining system is used.

Monte Carlo Simulation

A useful application of probability and statistics involves sampling by the Monte Carlo method. What is a Monte Carlo Simulation (MCS)? MCS is a computation process that utilizes random numbers to derive an outcome(s). So, instead of having fixed inputs, probability distributions are assigned to some or all of the inputs. This will generate a probability distribution for the output after the simulation is ran. To find the area under a curve, one can use integral calculus. If the curve has no closed form, such as the normal curve, then the area cannot be derived analytically. However, with today's computer technology, one can use Monte Carlo Integration to achieve such task. The area under a distribution is also known as probability [3].

The Monte Carlo Integration procedure is as follow:

- Identify the range of X and Y coordinates where the random number will be placed.
- Compute the area of the rectangle in question, using the X and Y range.
- Run the random process. All the random numbers (X;Y) will land within the rectangle. Count how many points land below the curve.
- Divide the sum of points below the curve by the number of iterations to get the proportion of points below the curve to the total number of points.
- Multiply this proportion by the area to get the probability.

The results of generation can be presented by histogram, like on figure 1.

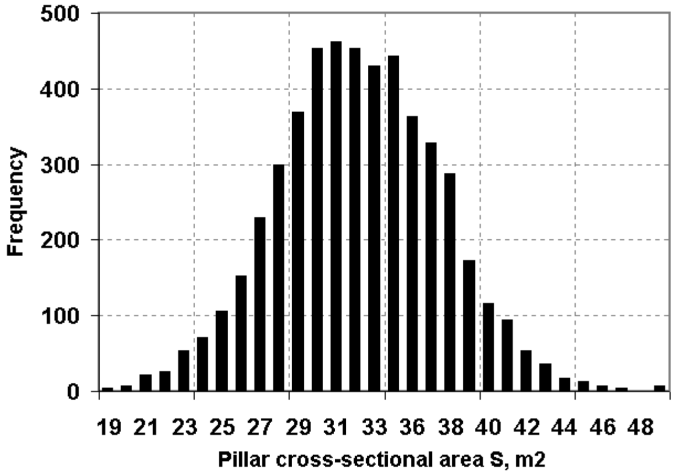

Fig. 1. Pillar cross-sectional areas histogram

If the Monte Carlo sampling procedures were carried to a greater number of samples, then the average of the samples will approach the theoretical average.

On a figure 2. present algorithm, that shows how to create random numbers *Rnd* from a normal distribution given the standard deviation σ and the mean μ, and then computes the confidence interval $x_{max.}$ and $x_{min.}$ given the level of significance, alpha α (%). Upon the completion of this program, the user can type in the alpha level, number of iterations *n*, mean and standard deviation, and then execute the Macro command to obtain the output.

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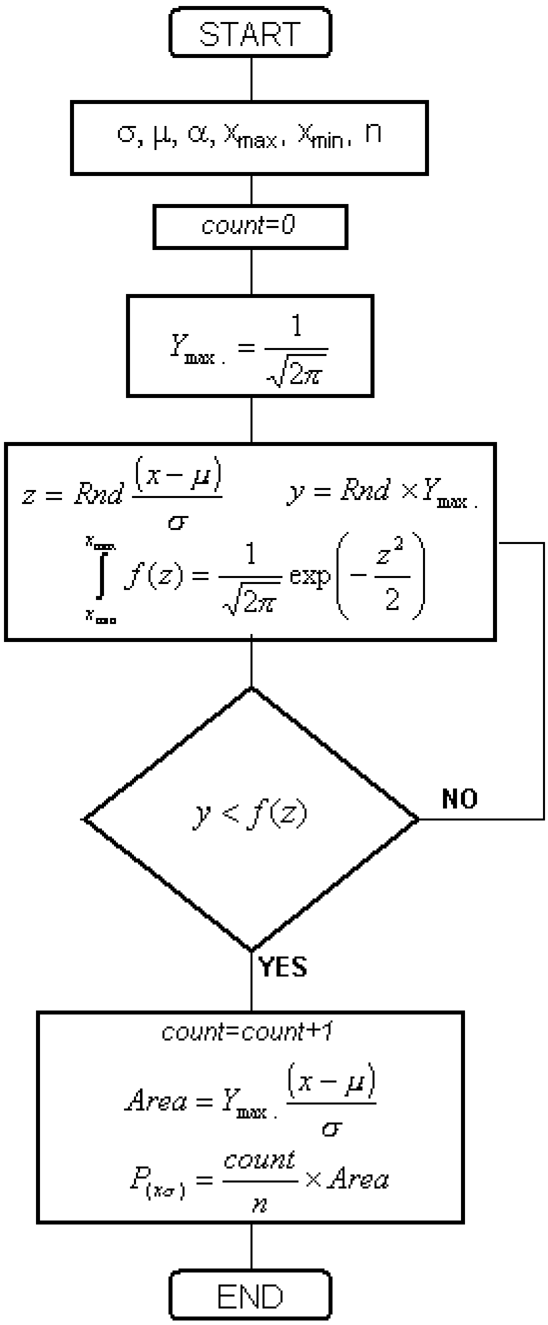

Fig, 2. Algorithm for Monte Carlo Integration Method

It is fairly easy to write computer programs to generate random numbers that are distributed according to some distributions.

The program also can generate a 30-class histogram as shown on figure 1. Classes of frequency will be generated on cells. Users who are familiar with chart generation on Excel can use the data provided on these cells to generate a histogram chart also.

Data preparation

During present study were analyzed 16 spontaneous collapses in 13 blocks plus 26 in 18 blocks received from Talve report [4].

Data analysis showed that the range of the pillars age in the collapsed areas distributed from 4 up to the 57 months. As you can see, the data range is quite great and required correction. In the most of cases, the pillar destruction happens when it is 4-24 months old. So, we have 30 real parameters from total 42 cases. These data you can see on a figure 3.

By our data the average rooms sizes in the collapsed areas A&B = 7.5 × 7.5 m, pillars safety factor n = 1.2 for their life time 24 moths (calculated by the trend line on a Fig. 3). These parameters were calculated by the accepted in Estonian oil shale mines methods [5], based on the tributary area theory using the Sheviakov's and Turners' calculation scheme [6]. Also, by the same formulas [5] we can calculate maximum rooms sizes and receive for our data boundary line II. (see Fig. 4 and table-1). Differently, line II plotted on a figure 4. shows the maximum pillar cross-sectional areas and room sizes (S=f(A&B; H); A&B = 8.5 × 8.5 m) on different depths, which are presented on the collapsed mining blocks.

Nowadays, all parameters for room-and-pillar mining are calculated for a long time, t=∞ (see lines III and IV on a Fig. 4). Line III is plotted for the pillars with safety factor n=1.2 and n=1.3 for the line IV accordingly, when t=∞ and A&B = 8.5 × 8.5 m.

It is well known, that the pillar stability depends from his cross-sectional area, scale factor, room sizes and exploitation depth. Therefore, during Monte Carlo Simulation we will generate random numbers for exploitation depth *–H*, pillar cross-sectional areas *–S*, which are computing for calculated maximum room sizes.

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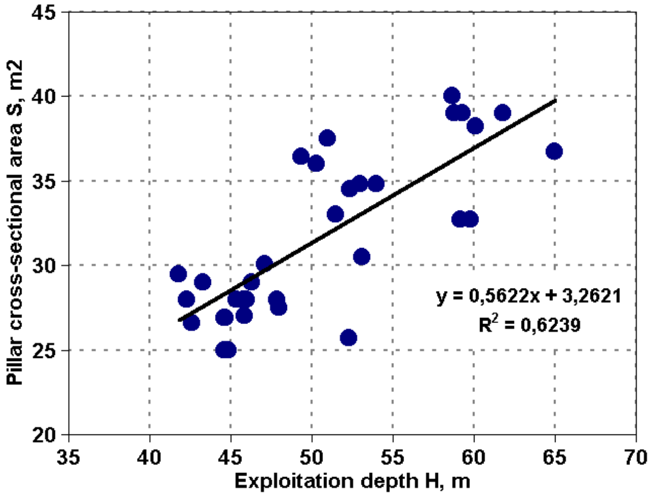

Fig, 3. The pillar cross-sectional areas (30 data points) dependence from the exploitation depth for the pillars (4-24 months old) in collapsed rooms

Monte Carlo sampling

Investigation is based on the following assumption: by normal distribution of the pillars cross-sectional area a potential collapse of a mining block can be expected [2].

Required data for computation:

- standard deviation for pillars square σ_S = 4,5 and the mean μ_S = 32,1 confidence interval $x^S_{\max}$ = 55 m^2 and $x^S_{\min}$ = 20 m^2
- standard deviation for exploitation depth σ_H = 4,5 and the mean μ_H = 32,1 confidence interval $x^H_{\max}$ = 70 m and $x^H_{\min}$ = 35 m (for significance increasing)
- given the level of significance, alpha=1 %.

Data for plotting of random numbers of *H* and *S* received from normally distributed random values:

- $H_N = R_H \sigma_H + \mu_H$
- $S_N = R_S \sigma_S + (0{,}5622\, H + 3{,}2621)$

where H_N and S_N = normally distributed variable with mean (see Fig. 3 for *S* plotting: μ_S=f(H)= 0,5622H + 3,2621) and deviation; R_H and R_S = generated numbers of normalized random deviations.

The application of the Monte Carlo technique to distributions frequently used in mine simulation studies is summarized in table 2. and figure 4. For the practical application were elaborated the special classification of the pillar cross-sectional areas and exploitation depths (see table 2).

From the Monte Carlo Simulation output (fig. 4) and table 2 we can see, that there weren't points above the line indexed –IV. Also, simulation gives probability about 0.6-1% for the line III. It means that our calculated pillar sizes must be between two lines: III & IV, only by this requirement our pillar is calculated for a long time. But there are some limits:

- room sizes A&B≤ 8.5 × 8.5 m;
- oil-shale bed thickness h ≤ 2.8 m;
- exploitation depth H=35-65 m;
- pillar safety factor n=1.3;
- absence of nearest karsts zones.

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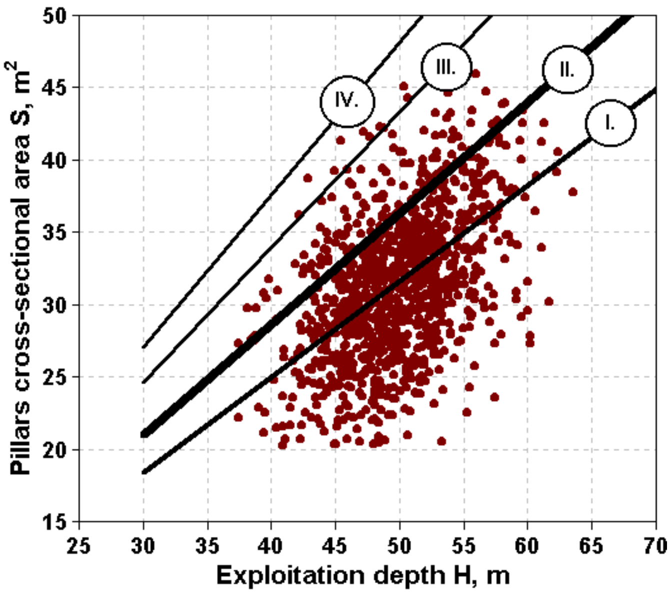

Fig. 4.The Monte Carlo Simulation output

Table 1.

Room-and-pillars parameters for Monte Carlo sampling (see Fig. 3)

	Line number			
Parameter	I.	II.	III.	IV.
Room sizes (A&B), m	7.5	8.5	8.5	8.5
Pillar age (t), month	24	24	∞	∞
Pillar safety factor (n)	1.2	1.2	1.2	1.3

Table 2.

Summarized data table for significance α=1%

Depth H, m	Line nr.		Probabilities of pillar destruction, %						
	>IV.	>III.	Pillar cross-sectional areas S, m²						
			S=20-25	S=25-30	S=30-35	S=35-40	S=40-45	S=45-50	*Sum*
30-35	----	----	----	----	----	----	----	----	*0%*
35-40	----	0,0%	***0,6%***	***0,5%***	***0,1%***	----	----	----	*1%*
40-45	----	0,2%	3,1%	***5,6%***	***3,0%***	***0,6%***	----	----	*12%*
45-50	----	0,3%	4,2%	***13,8%***	***13,3%***	***4,7%***	***0,5%***	----	*36%*
50-55	----	0,1%	8,1%	20,7%	***15,7%***	***8,4%***	***1,9%***	0,1%	*36%*
55-60	----	----	9,5%	28,1%	32,9%	14,1%	***1,5%***	***0,2%***	*11%*
60-65	----	----	----	29,4%	36,8%	17,5%	4,0%	***0,0%***	*1%*
65-70	----	----	----	----	37,1%	17,9%	4,3%	0,3%	*0%*
MAX	0,0%	0,6%	*10%*	*29%*	*37%*	*18%*	*4%*	*0%*	***99%***

Mining block stability analysis

From the data, presented on table 2, we can find probability (%) of pillar destructions for different H and S data ranges. The main idea of table 2 is based on the following assumption: pillars are stable for a long time when the probability of destruction $P \leq 5\%$, and room sizes doesn't exceeds 8,5 m (A&B = 8. 5 × 8.5 m) in width. But, we can't estimate mining block stability by one pillar only. We must calculate the average pillars S inside of rectangle with critical width. The critical width (CW) is the greatest width that the rock above the mine can span before its failure. For Estonian oil shale mines it is presented by the following formula CW= $L \geq 1.2H + 10$, m [7]. In the three-dimensional case, the critical width transforms into the critical area. It determines the center of mining block collapse. For computation sliding rectangle method was used. The results are presented on the map of a mining block by probability contours (Fig.5). The probabilities are indicated corresponding to the above mentioned classification system. The method allows determining the centers of potential collapse of a mining block.

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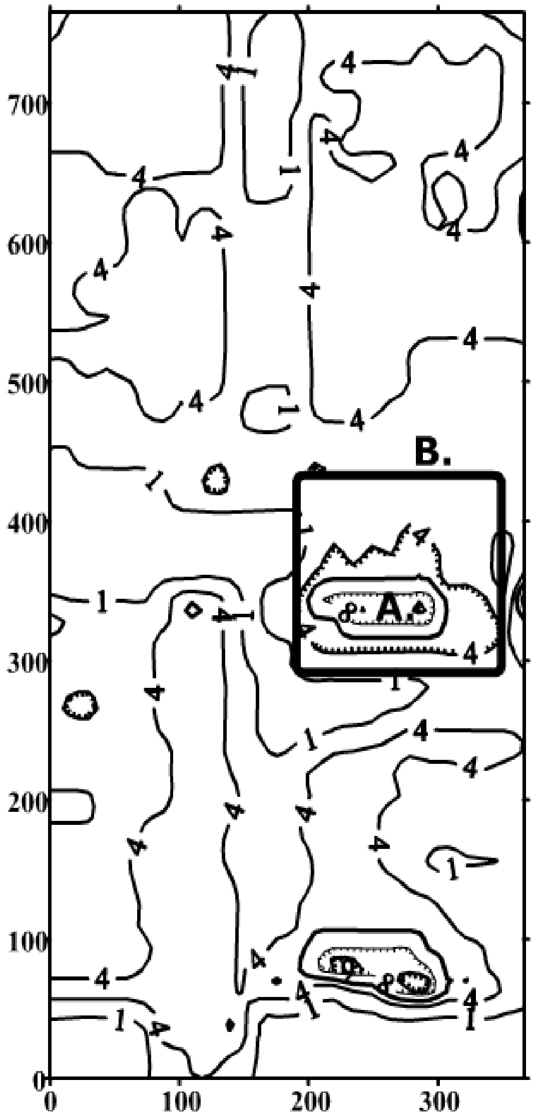

Fig. 5. Probability contours P, % where A.=collapse center; B.= real collapse area

Results

The collapse prognosis (mine Viru, mining block No.141) is demonstrated below (Fig.5).

The commercial oil shale bed of the thickness of 2.8 m is embedded on the depth of 43 m. Mining block is bordered by barrier pillars.

The spontaneous collapse in the right semi-block took place 13 months after the beginning of the mining block exploitation. The lifetime of the pillars in the center of potential collapse was 12 months. The area of destruction was about 16500 m^2. The collapses of the mining blocks reach the surface. Likely enough, the collapses begin in center (A.) with P=6-9% and then extend to the barrier pillars (B.= real collapse area). Analysis showed that the calculation results are close to real parameters of the mining block collapse (Fig.5).

Conclusion and recommendations

As a result of this study, the following conclusions and recommendations can be made:

1. Through Monte Carlo simulation, room-and-pillar stable parameters can be calculated.
2. Model allows determining the probability of spontaneous collapse of the pillars and surface subsidence by the parameters of registered collapsed mining blocks.
3. Proposed method suits as an express-method for stability analysis and failure prognosis. It is applicable in different geological conditions, where the room-and-pillar mining system is used.
4. The method allows determining the centers of potential collapse of a mining block.

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References

1. Reinsalu, E. Post technological processes in mined out areas. Estonian Science Foundation, Grant No. 3403. Tallinn, 2001.
2. Pastarus, J.-R., Nikitin, O. Environmental issues prediction methods for Estonian oil shale mines. Proc. of the International Conference "Environment and Society" Rezekne, Latvia, February 28 – March 2, 2002, p.95-101.
3. Monte Carlo Simulation examples by Anthony Sun, web page address: http://www.geocities.com/WallStreet/9245/
4. Talve L. 1983. Investigation of the convergence characteristics for room-and-pillar mining method on Estonian oil shale mines "«ESTONSLANEC", TPI, Tallinn, p.53, (in russian).
5. Mining-law and legal regulation acts. Ministry of Environment, Ministry of Economy. Part II, Tallinn, 1998, p.185-205.
6. Parker, I.. Mine pillar design in 1993: Computers have become the opiate of the mining engineers. London., Mining Engineering, July and August: 714-717 and 1047-1050. 1993.
7. Stetsenko, V. & Ivanov G. Prognosis of the time depending roof displacements for different span lengths. Oil Shale 11: 13-18. 1981, (EstNIINTI) (in Russian).

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