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Mining block stability monitoring by roof-to-floor convergence

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ABSTRACT: This paper deals with prediction of long-term stability and methods of monitoring of the room-and-pillar mining system. Roof-to-floor convergence method is preferred as it takes into consideration all geological and mining features in the critical area. It allows determining the location, area and time of a collapse in a mining block. The uncertainty in time is less than 10 % at the 95 % confidence level. The optimum quantity of the measuring stations was determined by the conditional thickness method suitable for modeling on PC. The applicability of the method is clearly demonstrated.

1 INTRODUCTION

The mineral wealth of Estonia – oil shale - is located in a densely populated and rich farming district. Underground oil shale production uses room-and-pillar method with blasting. This method is cheap, highly productive, easily mechanize, and relatively simple to design.

It has become apparent that the processes in overburden rocks and pillars have caused unfavorable environmental side effects accompanied by significant subsidence of the ground surface. They cause and will cause in the future a large number of technical, economical, ecological and juridical problems. On the other hand, the collapse in a working mining block stops the mining works. The first spontaneous collapse of the pillars and the surface subsidence in an Estonian oil shale mine took place in 1964. Up to the present, 73 collapses on an area of 100 km² have been recorded.

Working out of the methods of long-term stability prediction and monitoring in the mined out area is the main aim of the present work.

Methods of stability prediction by life-time of the pillars (Pastarus & Nikitin 2001), statistical methods (Pastarus & Tomberg 2001) and by the rate of the current rock strength (Pastarus & Toomik 2001) are relatively simple, but not applicable for long-term prediction. For practical application the prediction and monitoring method by the roof-to-floor convergence is suitable. The uncertainty in time does not exceed 10% at the 95 % confidence level. As the reference point installation and roof-to-floor convergence measurements are expensive, cumbersome and time-consuming, their optimum quantity was de-

termined by the conditional thickness method, suitable for modeling on PC (Pastarus & Nikitin 2001, Pastarus & Toomik 2001).

Prediction by the roof-to-floor convergence is applicable in different geological conditions, where the room-and-pillar mining system is used. The surface subsidence parameters will be determined according to conventional calculation schemes. The applicability of the roof-to-floor convergence method is clearly demonstrated in theory and in in-situ conditions.

2 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 oil shale reserves in Estonia are estimated to be approximately 4 thousand million tons.

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 certain oil shale and limestone seams are quite different. The strength of the rock increases in the southward direction.

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 wide and 600-800 m long 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.

3 THEORETICAL BACKGROUND

For the analysis, there are two basic approaches to study rheological behavior of the materials (Ranalli 1995):

- Macrorheology, which describes the processes and properties of materials phenomenologically.
- Microrheology, where the attention is focused on the processes and properties of materials at the atomic level, and on how these affect the phenomenological behavior.

For practical applications, the phenomenological approach for stability calculations is preferred. The analysis is based on the roof-to-floor convergence process in in-situ conditions in a mining block. A typical roof-to-floor convergence curve (creep) is presented in Figure 1.

Phenomenological behavior of rocks can be studied using conventional calculation schemes: analog models, equations by L. Boltzmann and V. Volterra, G.S. Erzhanov (Erzhanov et al. 1970, Bulychov 1989). These are cumbersome and time-consuming. For practical applications the deformation criterion is suitable. If the current deformation $\varepsilon(t)$ reaches the value of ultimate deformation at fracture ε_u for rock $\varepsilon(t) > \varepsilon_u$, the fracture of the rocks takes place. The applicability of the deformation failure criterion for rocks is demonstrated in microrheology (Rosenberg 1967). The deformation criterion is valid for steady-state creep (Erzhanov et al. 1970, Bulychov 1989):

$$\frac{d\varepsilon}{dt} t_p = const \quad (1)$$

where $d\varepsilon/dt$ - deformation rate; t_p - collapse time at the fracture.

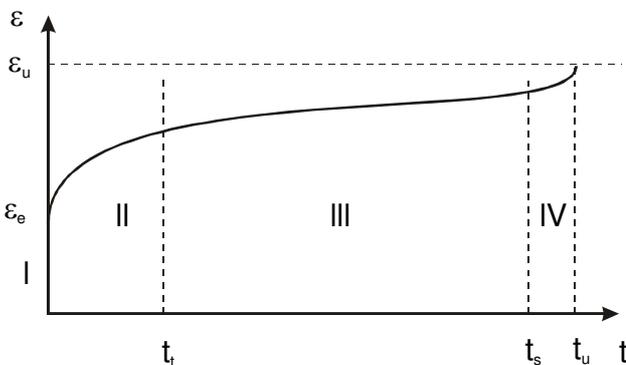


Figure 1. Roof-to-floor convergence curve
 ε - deformation; t - time; ε_u - ultimate deformation at fracture; $\dot{\varepsilon}$ - deformation rate; I - elastic deformation ε_e ; II - transient creep $\dot{\varepsilon} < 0$; III - steady-state creep $\dot{\varepsilon} = const$; IV - transient creep before fracture $\dot{\varepsilon} > 0$; t_t - transient creep limit; t_s - steady-state creep limit; t_u - time at fracture.

The analysis showed that the presented method is applicable only for linear rheological model. Investigations in in-situ conditions and laboratory tests have shown that most of rock mass is characterized by linear rheological behavior (Erzhanov et al. 1970). In the practical application the regions of elastic deformation (I), transient creep (II) and transient creep before the fracture (IV) are negligible (Fig.1).

The life-time of the pillars is calculated by the deformation rate method (Bulychov 1989). It bases on the deformation rate of steady-state creep and is preferred for the calculations. The uncertainty in time is less than 10 % at the 95 % confidence level. Pillar life-time prediction equation is derived from the formula (1):

$$t_p = \frac{\varepsilon_u - \varepsilon_0}{\dot{\varepsilon}} \quad (2)$$

where $\dot{\varepsilon} = d\varepsilon/dt$ - deformation rate; ε_0 - ultimate deformation at stabilized strength; ε_u - ultimate deformation at fracture.

Graphical interpretation is presented in Figure 2.

The roof-to-floor convergence can be measured in in-situ conditions by means of extensometers in the mining blocks. The roof-to-floor convergence curve takes into consideration all the geological and mining features at the site of the measuring station. That is connected with the critical area.

The critical width is the greatest width that the rock above the mine can span before its failure, or, if there are pillars, the width we must mine before the pillars accept the full weight of the overlying materials (Parker 1993). In fact, the best indicator of critical width in a given situation will be provided from old mine maps, by records of failure and surface subsidence, and from measuring roof-to-floor convergence in the mines. In the area of Estonian oil

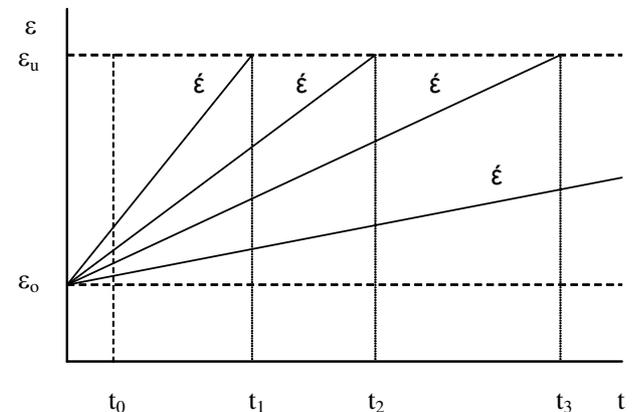


Figure 2. Time dependent deformation of a pillar
 ε_u - ultimate deformation at fracture; ε_0 - ultimate deformation at stabilized strength; $t < t_0$ - elastic deformation and transient creep; $t > t_0$ - steady-state creep; t_1, t_2, \dots - life-time of pillars; $\dot{\varepsilon}_1, \dot{\varepsilon}_2, \dots$ - deformation rates

shale mines it is presented by the following formula (Pastarus & Toomik 2001):

$$L \geq 1.2H + 10 \quad (3)$$

where L – critical width, m; H – thickness of the overburden rocks, m.

In the three-dimensional case, the critical width becomes the critical area. The latter is the minimum area where the destruction of the pillars and surface subsidence is possible. Likely enough, the collapse begins in one critical area (potential collapse center) and then extends to the barrier pillars.

On the other hand, the dimensions of the mining block determine the quantity of the measuring points (40...50) for determining the roof-to-floor convergence. Only in this case it is possible to establish the collapse center inside a mining block. For reducing the quantity of the measuring points in a mining block, a method was worked out. The concept of critical area, methods of conditional thickness and sliding rectangle suitable for modeling on PC and were used to perform the calculations (Pastarus & Nikitin 2001, Pastarus & Toomik 2001).

Conditional thickness is a geometrical parameter which considers the depth of excavation and the parameters of the pillars and roof in in-situ conditions (Pastarus & Toomik 2001). Geometrical interpretation of conditional thickness is given in Figure 3.

It represents the height of a prism whose cross-section equals the pillar cross-section area. The conditional thickness is presented by the following formula (Pastarus & Nikitin 2001, Pastarus & Toomik 2001):

$$C = \frac{HS_r}{S_p} \quad (4)$$

where C – conditional thickness, m; S_p – cross-sectional area of a pillar, m²; S_r – roof area per pillar, m²; H – thickness of the overburden rocks, m.

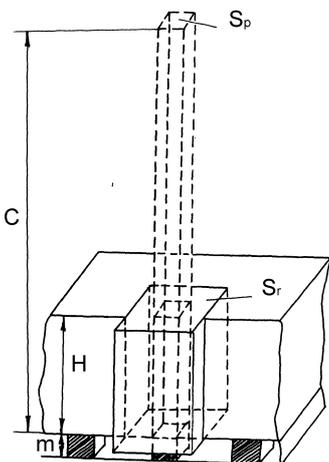


Figure 3. Geometrical interpretation of conditional thickness

Conditional thickness includes sufficient information and is suitable for stability calculations. It is related to the load on a pillar as follows:

$$\sigma = C\gamma \quad (5)$$

where σ – normal stress at the top of a pillar, Pa; γ – weight density of the overburden rocks, N/m³.

If the load is too much, a sudden failure of the pillars is likely to occur. Conditional thickness for the critical area can be expressed by the following equation (Pastarus & Nikitin 2001):

$$C_c = \frac{H_a L^2}{\sum S_{pi}} \quad (6)$$

where C_c – conditional thickness of the critical area, m; H_a – average thickness of the overburden rocks in the critical area, m; S_{pi} – cross-sectional area of the i -th pillar in the critical area, m.

By the sliding rectangle method, the conditional thickness of the critical area must be determined for all positions inside a mining block. The results are presented by conditional thickness contours. The relative uncertainty in conditional thickness is 1.5% at the 95% confidence level. The presented method allows determining the center of a potential collapse in a mining block.

Using the map of a mining block, where the conditional thickness contours are given, we may determine the locations of the potential collapse centers, where the spontaneous collapse is likely. In this center we must install the measuring station for determining the roof-to-floor convergence. This method allows reducing the quantity of the measuring points in a mining block to 10-15.

The roof-to-floor convergence and conditional thickness methods allow predicting the life-time of a mining block and reducing the quantity of the measuring stations. The quality of calculation results is guaranteed. The utility of this method is demonstrated below.

4 RESULTS

Roof-to-floor convergence deformation rate method was used to analyze 5 mining blocks in the mines Ahtme and Viru. The investigation results for the left semi-block No. 41 of the mine Ahtme are presented below. The commercial oil shale bed of the thickness of 2.8 m is embedded at the depth of 53 m. The mining block is bordered by barrier pillars. A spontaneous collapse of the pillars in the left mining semi-block took place 16 months after the beginning of exploitation. It reached the surface. The area of destruction was about 24,000 m². Figure 4 presents the conditional thickness contours.

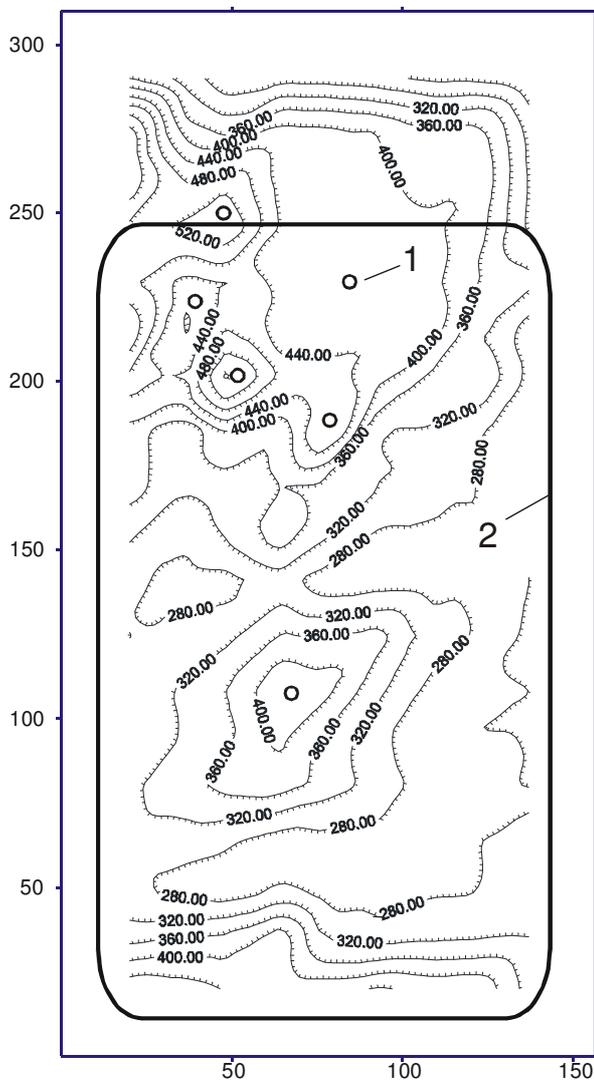


Figure 4. Conditional thickness contours. Mining block No. 41, Ahtme mine
1 – measuring station; 2 – contour of the destruction area.

The analysis shows that there are 4 centers of a potential collapse in the case of the conditional thickness $C > 400$ m. The measuring stations were installed in these centers and in the sites where $C > 400$ m. The age of the pillars in the centre ($C > 480$ m) of a potential collapse was 8.5 months. Likely enough, the collapse begins in this center and then extends to the barrier pillars. The collapse center $C > 520$ m is on the influence of the rock massive (stope) and the age is less than 8.5 months. The collapse does not begin from this center.

Investigation showed that the ultimate deformation at stabilized strength ε_0 is 22.5 mm, and ultimate deformation at fracture by 33-36 m² cross-section area of the pillars ε_u is 79.0 mm. The deformation rate of the roof-to-floor convergence was 6.1 mm per year. The prediction time of the mining block collapse is 9.3 years (Formula 2). The relative uncertainty in time is 9.4 % at the 95 % confidence level. The results of theoretical and of in-situ investigations in Estonian oil shale mines showed that they are close to the modeling results.

5 CONCLUSIONS AND RECOMMENDATIONS

- 1 The problem of the mining block stability is very actual in a densely populated and intensely farmed district like NE Estonia.
- 2 The applicability of the roof-to-floor convergence method of predicting mining block long-term stability is demonstrated in theory and checked in in-situ conditions. The uncertainty in time is less than 10 % at the 95% confidence level. The optimization of the measuring station quantity was performed by the conditional thickness method. This prediction method is of particular interest for practical purposes.
- 3 Method allows determining the mining block collapse time, location, and area. The surface subsidence parameters can be calculated by conventional calculation schemes.
- 4 Prediction method is applicable in different geological conditions, where the room-and-pillar mining system is used. The method is suited for monitoring underground constructions.

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