LONG-TERM STABILITY MONITORING OF THE MINING BLOCKS IN ESTONIAN OIL SHALE MINES

Izrakteņu bloku ilglaicīgās stabilitātes monitorings Igaunijas degslānekļu raktuvēs

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Abstract
This paper deals with long-term stability prediction and monitoring methods by room-and-pillar mining system. Roof-to-floor convergence and conditional thickness methods suit for calculations. They allow determination of the location, area and time of the collapse in a mining block. The uncertainty in time is less than 10 % at the 95 % confidence level. Roof-to-floor convergence method is preferred; it takes into consideration all the geological and mining feature in the critical area. Conditional thickness method demands supplementary investigations, determination of the influence factors on the process. The applicability of these methods is clearly demonstrated.
Keywords: *larg-term stability, monitoring methods mining blocks.*

Introduction

The mineral wealth of Estonia is located in a densely populated and rich farming district. It is known that the results of mining may suddenly appear on the environment many years later after the end of excavation. The post technological processes of the underground mining caused and will cause in the future a large number of technical, economical, ecological and juridical problems.

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. Consequently, the post technological processes continue up to present.

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

The stability prediction methods by life-time of the pillars (1), statistical methods (2) and rate of the current rock strength (3) are relatively simple and they are not applicable for long-term calculations. For practical application the prediction and monitoring methods by roof-to-floor convergence and conditional thickness are. The uncertainty in time does not exceed 10% at the 95 % confidence level.

Elaborated calculation methods by roof-to-floor convergence and conditional thickness are applicable in different geological conditions. The surface subsidence parameters will be determined by conventional calculation schemes.

The applicability of the roof-to-floor convergence and conditional thickness methods are clearly demonstrated in theory and in situ conditions.

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

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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.

Mining block stability prediction and monitoring by roof-to-floor convergence

For the analysis, there are two basic approaches to the study the rheological behavior of the materials (4):

1. Macrorheology, which describes the processes and properties of materials phenomenologically.
2. 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 the practical applications, the phenomenological approach for stability calculations is preferred. The analysis is based on the roof-to-floor convergence process of in-situ conditions in a mining block. Roof-to-floor convergence curve takes into consideration all the geological and mining features in the location of the measurement station. Typical roof-to-floor convergence curve (creep) is represented in Figure 1.

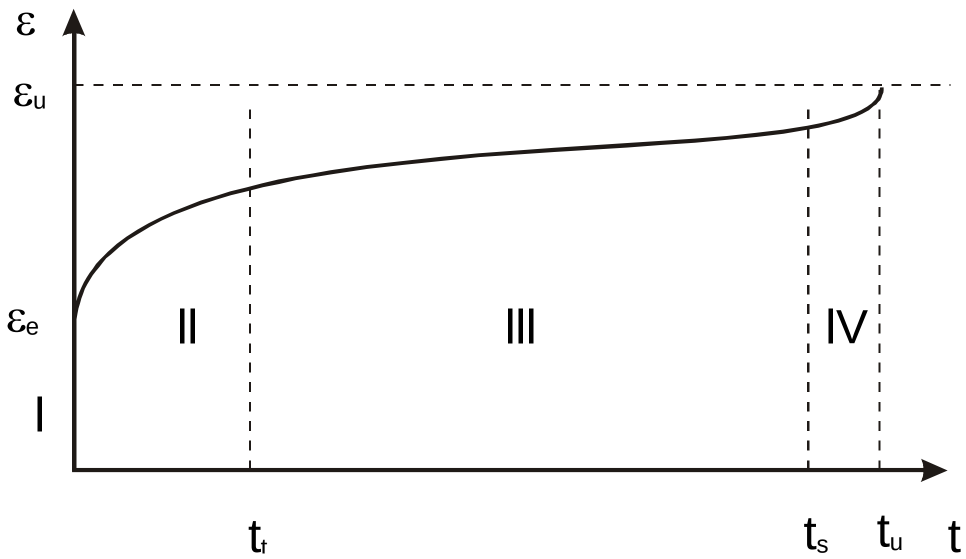

Fig. 1. Roof-to-floor convergence curve

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 phenomenological behavior of rocks can be studied using conventional calculation schemes (5, 6). They are cumbersome and time consuming. For practical applications the deformation criterion is suited. If the current deformation $\varepsilon(t)$ reaches the value of ultimate deformation at fracture ε_c for rock ($\varepsilon(t) > \varepsilon_c$), the fracture of the rocks takes place. The applicability of the deformation failure criterion for rocks is demonstrated in the microrheology (7). The deformation criterion is valuable for steady-state creep (5, 6):

$$\frac{d\varepsilon}{dt} t_p = const \qquad (2)$$

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

Analysis showed that presented method is only applicable for linear rheological model. Investigations of in-situ conditions and laboratory tests have shown that most of rock has linear rheological behavior (5). In the practical application the regions of elastic deformation (I), transient creep (II) and transient creep before fracture (IV) are negligible (Fig.1).

The pillar load and consequently the value of the roof-to-floor convergence depend of the width of the mining block, leading to the concept of the critical width (8). 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. For Estonian oil shale mines it is presented by the following empirical formula (3):

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

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

In the three-dimensional case, the critical width transforms into critical area. It means that the influence of the overburden rock on the value of the roof-to-floor convergence is connected with the critical area.

Investigation showed that the life-time prediction of the pillars is possible to perform by two methods:

1. Deformation rate method. It bases on the deformation rate of steady-state creep and it 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 formula (3):

$$t_p = \frac{\varepsilon_u - \varepsilon_0}{\dot{\varepsilon}} \qquad (4)$$

where $\acute{\varepsilon} = d\varepsilon/dt$ – deformation rate; ε_o – ultimate deformation at stabilized strength.

2. Deformation method at fixed time. Method uses the absolute value of the roof-to-floor convergence at fixed time. Uncertainty in time in this case is larger than by deformation rate method.

The roof-to-floor convergence can measured of in-situ conditions by means of extensometers in the mining blocks. If a mining block is abandoned, the access in one is closed. In shallow mines (depth less than 100-150 m) it is possible to perform the measurements on the surface, using the conventional or modern (GPS) equipments.

On the other hand the dimensions of the mining block determine the quantity of the measured points (40…50) for determination the roof-to-floor convergence. Only in this case it is possible to catch the collapse center inside a mining block.

Analysis by roof-to-floor convergence deformation rate method was made for 5 mining blocks (the mines Ahtme and Viru). The investigation results for mining block No. 62, mine Viru are presented below. The commercial oil shale bed of the thickness of 2.8 m is embedded at the depth of 45 m. Mining block is bordered by barrier pillars. A spontaneous collapse of the pillars in the left mining semi-block took place 3.8 years after the beginning of exploitation. It reached the surface. The area of destruction was about 3000 m^2. The deformation rate of the roof-to-floor convergence was 17.1 mm per year. The prediction time of the mining block collapse is 4.1 years. The relative uncertainty in time is 7.9 % at the 95 % confidence level.

Mining block stability prediction and monitoring by conditional thickness method

For the analysis the concept of critical area, methods of conditional thickness and sliding rectangle were used (1, 3). They suit for modeling on PC. Conditional thickness represents the height of a prism whose cross-section equals the pillar cross-section area. It is

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related to the load on a pillar. If the load is too much for the pillars, a sudden failure is likely. The concept of the critical area is presented in the chapter 3. By the sliding rectangle method, the average 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 uncertainty in conditional thickness does not exceed 5 % at the 95 % confidence level.

The analysis by conditional thickness method was performed for 14 mining blocks (the mines Ahtme, Viru and Estonia). The investigation results of the mining block No. 101 of the mine Estonia are given below (Fig.2). The commercial oil shale bed of the thickness of 2.8 m is embedded at the depth of 61 m. Mining block is bordered by barrier pillars. Analysis shows that there are three centers of a potential collapse in the case of the conditional thickness C>340 m. Unfortunately, the conditional thickness takes into consideration only the geometrical parameters of the room and pillar.

It is visible that presented stability prediction method is cheaper and simpler for practical application than roof-to-floor convergence one. The method bases on the analysis of the conditional thickness contours on the map of a mining block. By the calculations, it must take into consideration the influence of the geological conditions and rock properties on the stability of a mining block (superposition principle). Elaboration of this method is cumbersome, time consuming and demands exact knowledge about the processes in the rock massive and constructions. For the practical application it is necessary to perform the classification of the influence factors on the conditional thickness parameter.

1. Influence of the barrier pillars and rock massive on the stability of the pillars.
2. Load distribution between the pillars by different cross-sectional area.
3. The layers thickness and strength influence on the stability of the pillars.
4. Influence of the faults on the process.

The results of the investigations are presented below. Theoretical investigations and modeling on PC (FLAC-program) show that the influence zone of the barrier pillars and rock massive is equal to half of the critical width. In this zone the load on the pillars is less than in the center of a mining block. Consequently, the collapse does not begin in this zone.

It is known that the strength of the rock increases in the southward direction. Analysis showed that the strength of the pillars increases 1.4 times by the depth of excavation from 40 to 70 m. For calculation the real value of the conditional thickness, using the pillar strength influence on the process, we can get the following formula:

$$C_r = \frac{C}{K_s} \tag{5}$$

where C_r – real conditional thickness, m; C – calculated conditional thickness, m; K_s – ratio of the strength of a pillar, depending on the excavation depth.

Presented calculation method allows taking into consideration all the influence factors on the conditional thickness parameters. It gives the real situation of a mining block and suits for monitoring. Method is applicable for practical purposes.

In the future it must determine all the influence factors on the stability of the pillars and take they into consideration by calculation the conditional thickness parameters. Method demands supplementary investigations.

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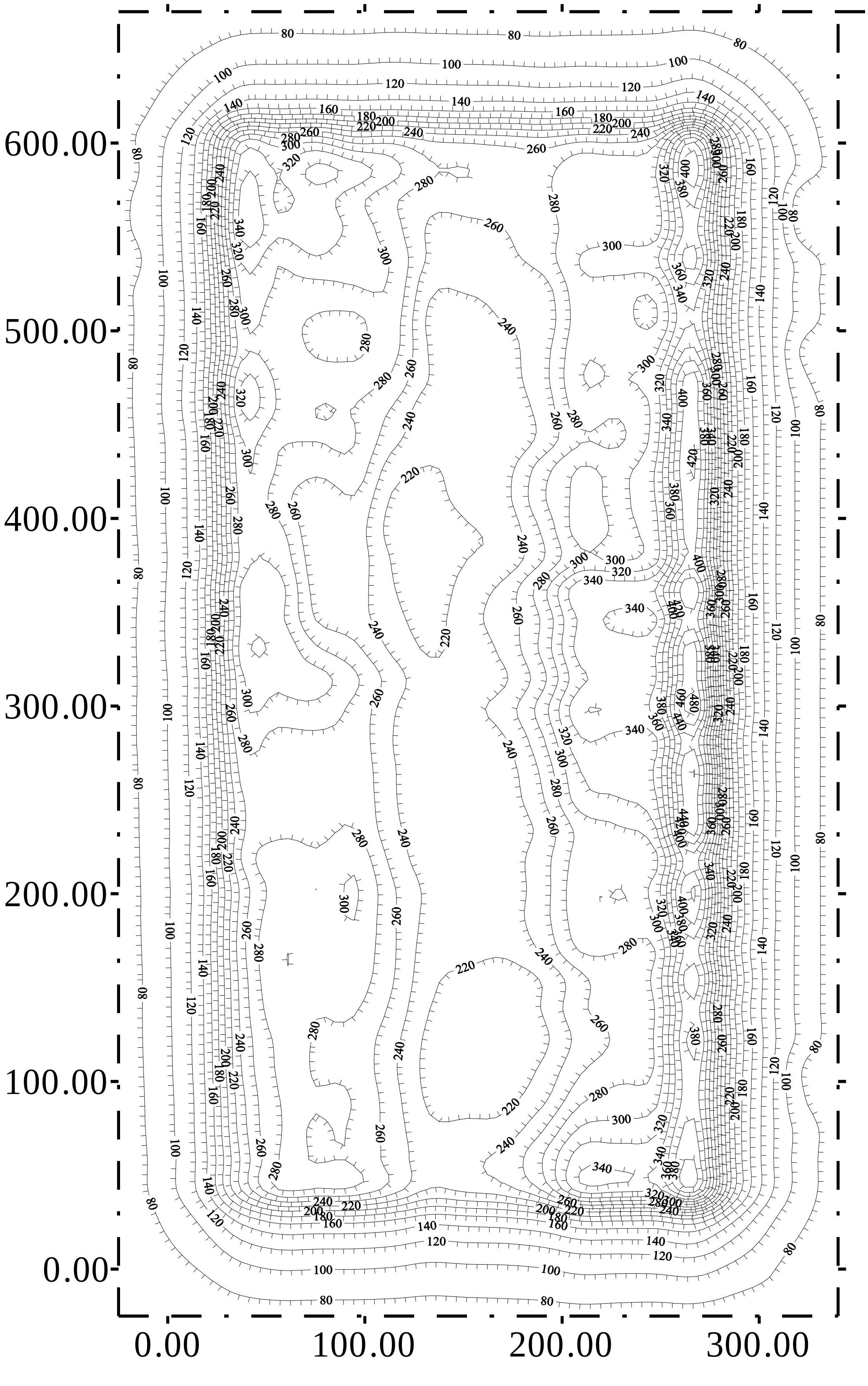

Fig. 2. Conditional thickness contours of the Estonia mine, block No. 101

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Conclusions and recommendations

1. The problem of the post technological processes on the environment is very actual in a densely populated and intensely farmed district, like NE Estonia.
2. The applicability of the roof-to-floor convergence and conditional thickness methods for long-term mining block stability prediction is demonstrated in theory. The practical application of these methods is demonstrated of in-situ conditions. The uncertainty in time is less than 10 % at the 95% confidence level. These methods are of particular interest for practical purposes.
3. Methods allow determining the mining block collapse time, location, and area. The surface subsidence parameters can be calculated by conventional calculation schemes.
4. Prediction methods by roof-to-floor convergence and conditional thickness are applicable in different geological condition, where the room-and-pillar mining system is used. Roof-to-floor convergence method is suited for underground constructions monitoring.
5. Further investigations are aimed at the roof-to-floor convergence deformation method at fixed time and modification of the conditional thickness method.

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