MONITORING AND ANALYSIS OF ROOM–AND–PILLAR MINING WITH CONTINUOUS MINER IN ESTONIAN OIL SHALE MINES
IGAUNIJAS DEGSLĀNEKĻA IEGŪŠANAS RAP TEHNOLOĢIJAS AR NEPĀRTRAUKTĀS RAKŠANAS MAŠĪNU MONITORINGS UN ANALĪZE

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Abstract. *In this paper, the modeling, analysis and monitoring of a room–and–pillar mining technology in an Estonian underground mines is presented. Technology is based on continuous miner as the primary production machine. Many technical and economic parameters of production, including loss of useful minerals, depend on a correct choice of the sizes for these elements. Without the account of reological properties of covered rocks, in particular the character of change of their long strength, the account of the sizes of rooms and pillars on a certain determined term is impossible. For the modeling, the existing room–and–pillars determination method by IMS and with formulas by V. Undusk, Visual Basic for Application in Excel, MapInfo, and Fast Lagrangian Analysis of Continua was used. Model allows determining the parameters of spontaneous collapse of the pillars and surface subsidence, optimized the working parameters for continuous mining. Proposed method suits for stability analysis, failure prognosis and monitoring.*

Introduction

/ Oil shale mining in Estonia / In Estonian oil–shale mines the room–and–pillar (RAP) mining system with blasting is used, which gives an extraction factor of 70–80%. The cross–sectional area of the pillars is 30–40 m^2, depending on the depth of the oil–shale bed. The main operations carried out in rooms include bottom cutting, drilling of blast holes, blasting, loading of oil shale and supporting. A work cycle lasts for over a week. Up to the present, in Estonian oil shale mines continuous miner used only as roadway driving machine.

About thirty years ago at the ex–USSR oil shale mines there wasn't the progressive mining method with continuous miner, because of the high limestone strength in oil shale bed. Therefore, up to the present oil shale mining with blasting is used in Estonian minefields as a basic mining method. But now, actual state of the market is changed. There is a wide range of choice for mining equipment today. Some of the well–knows of the mining firm–manufacturers are DOSCO, EIMCO, EICKHOFF and etc.

/ Present problem and Goals / In Estonia, one of the problems of today's mining is old fashioned mining machinery and technology. The mines have still some reserves of equipment thanks fact that production level has been decreasing during the last years and also due to fact that in the past mines had several machines in reserve for the broken production machines. The importance of wages will probably rise during the next years (in case of using the same technology). It can be seen that the share of depreciation is low. This is due to reasons described above — reserves of old equipment. The picture will change when more new machinery will be distributed at mines.

These problems are leading to goals of improving of technologies. There are lot of ways and possibilities for doing that, but it can be selected some main directions. The main targets to improve labour productivity could be:

I. selective rock cutting with continuous miner: one direction in the developing of mine could be mechanization of production process. Relatively big amount of manual

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operations needs much of work–force today. In this case we are submit for consideration DOSCO TB2000 or TB2500 as a continuous miner (CM) machine. On Estonian mines there are large unjustifiable experience of 4ПП–3 (miners from ex–USSR) application. But with DOSCO, the best result may be expected

II. optimal choice of the sizes of constructive elements: elucidation of the basic mechanism of covered rocks destruction and main roof supporting.

III. elaboration of the method of surface subsidence prognosis and monitoring: the horizontal bedding and small depth of oil shale seam enable the roof deformations to reach the land surface without essential reduction. Up to the present, 39 failures in Estonian oil shale mines have been registered, which make up 9% from the total number of mining blocks and 2.5% from the mined out area. As a possible reason of happened failures is that rooms and pillars were calculated for a 2 –month period. But nowadays, all parameters calculating for a long time =∞, what reduced extraction factor by ~10%. Therefore, the main requirement for our method is the main roof stability for a long time, and new flexible technology with greatest extraction factor.

Methods

For the feasibility study analysis the methods of changes of rock strength (in terms of oil shale seam) and roof carbonate strata by Institute of Mining Surveying (IMS), and the concept of critical width, conditional thickness and sliding rectangle was used. Visual Basic for Application in Excel and MapInfo was used for numerical modeling. As a background for new room–and–pillar mining method with CM was taking doble–face–longwall (180–200m) mining with blasting, used in ex–Leningrad oil shale minefields at the end of the 1970–s (Fig.1).

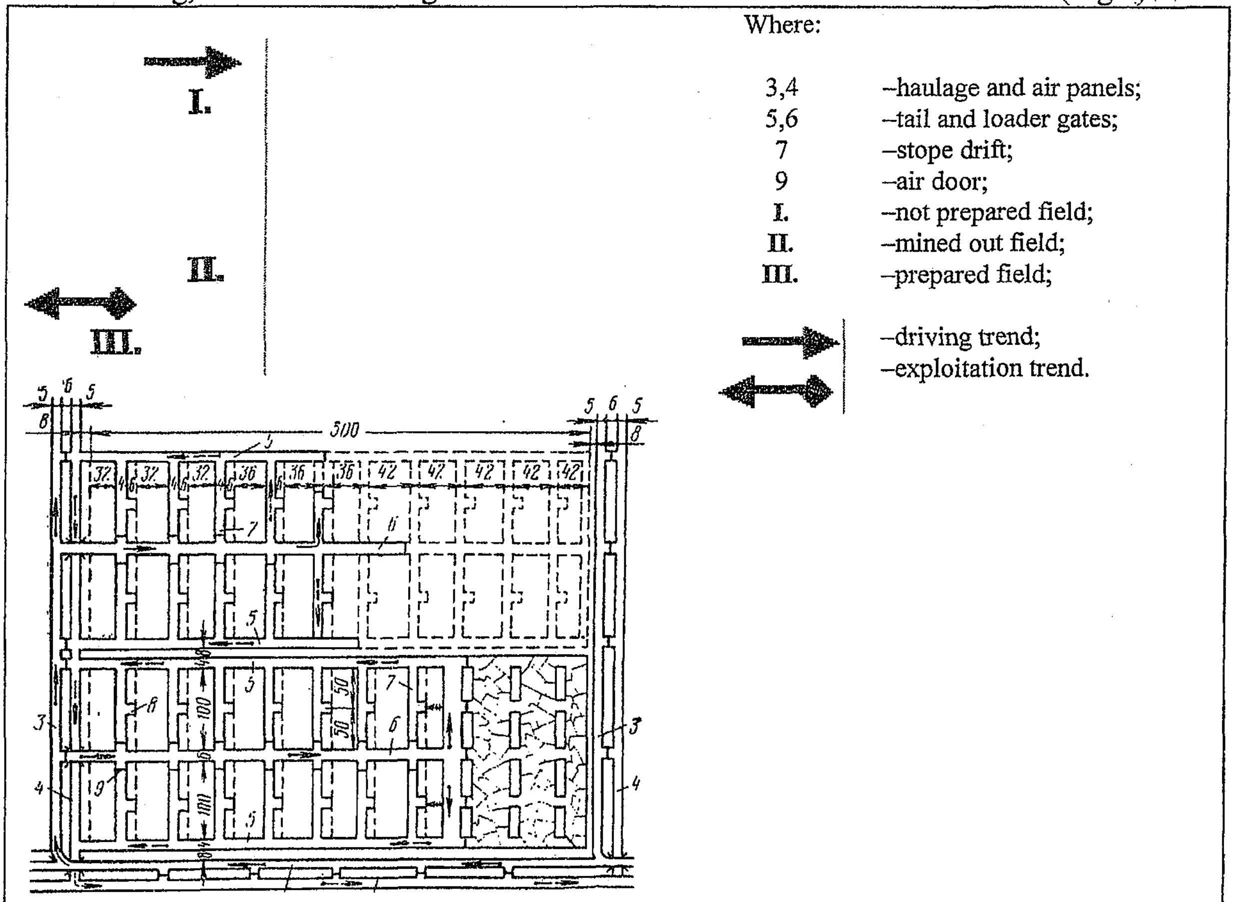

Figure 1. Doble–face–longwall mining (180–200m) in ex–Leningrad oil shale minefields

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Since our excepted method will be described below (Fig.2), at the table1 is presented brief description of main roof properties and others parameters for both minefields. From this table, you can observe that in ex–Leningrad oil shale minefields main roof strength is greatest than in Estonian mines. Therefore, for Estonian oil shale bedding conditions we can use only main roof control method, namely, in a case of room–and–pillar mining with CM.

Table 1

Parameter	Index	Ex–Leningrad minefields	Estonian minefields
Covered rocks thickness	H, m	50–110	35–70
Height of the pillar	h, m	1,8–2,0	2,8–3,0
Immediate roof thickness	hi, m	3,6–4,0	
First step of main roof destruction with Destruction angle	Lo, m w, °	41–66 ~35	37 ~25
Next steps of main roof destruction with Destruction angle	lo, m w, °	9–22 ~25	12–16 ~20

/ Pillars and roof stability prediction / To determine of the bearing capacity of the pillars, the empirical formula developed at the Institute of Mining Surveying (IMS), St. Petersburg [1,2] has been accepted as a calculating method: trend

$$k_t = \alpha + \beta\left(\frac{1}{1+t}\right)^m \tag{1}$$

Where: k_t –is the rate of current rock strength, equal to the relation of rock pillar strength R_t in the given moment of time to its (her) conditional – instant strength R_o;
α , β, m – empirical factors, (α = 0.44; β=$1-\alpha$=0.56; m = 0.6); t – service life of pillars or rooms (in months). Factor α shows the rate of stabilized strength, β and m demonstrate the decrease in the intensity of rock strength. According to [1], the precision of the formula could reach ± 30% and ±12% on average. The formula describes a hyperbolic dependence according to which the value of the factor decreases from k_t=1 (basic strength if t=0) to k_t=0.44 (stabilized strength if t=∞).

The basic concept of the IMS method is that the rock pillar is characterized by two features of strength: basic and stabilized strength. Basic strength characterizes rocks at fast loading, e.g., at pressure testing. Under constant pressure, the current strength of rock decreases, and in some time it will equal the stabilized strength. This perception of rock behavior complies with the concept of material creep known in strength of materials. Unfortunately, this approach explains that the pillar failures, calculated accurately are anomalies.

As a result of blasting works and vertical strength, cross–sectional area of a pillar is not a constant, and decrease by ~10–14% at last 30 days after pillar formation, or if distance from central pillar line to stop–face (L) is greatest or equal than same–one limit distance (L_1), then strength on a pillar stabilized [3].

$$L \ge L_1 \text{ where } L_1 = Htg\,\varpi + 0.5(A+y) \tag{3}$$

In a case of continuous miner (CM), cross–sectional area of a pillar must be less than in RAP mining method with blasting, by ~10–14%. Intrablock pillars in complex work with immediate roof anchor bolting are using for immediate roof supporting within the limits of room sizes (A or b). Actual load $P_{f\,1\text{-}2}$ on an intrablock pillars we can determined (Fig2.) using by V. Undusk formulas (4–5). For intrablock square pillar dimensions:

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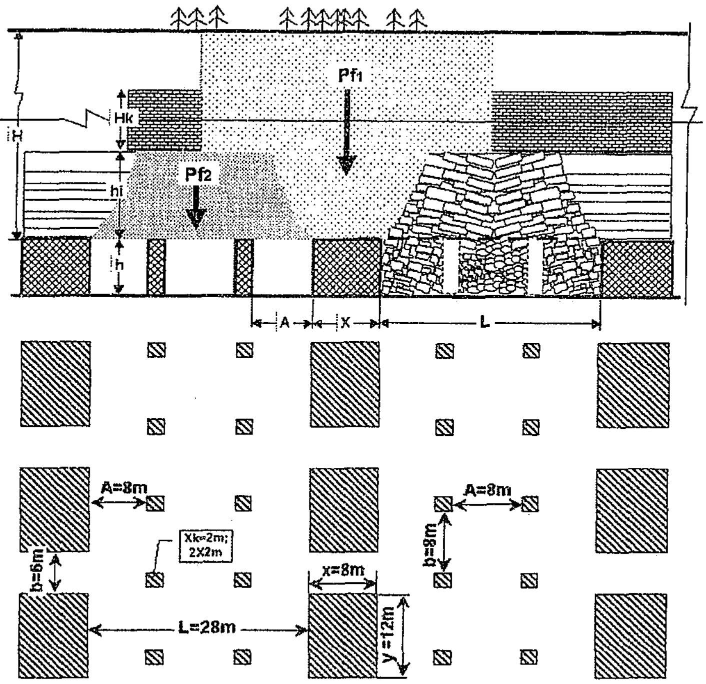
$$x^3+\left[2.33(h-1.29q)-\frac{nHh\gamma}{0.3R_t}\right]\times x^2+\left[3q(1-1.56h)-\frac{nHh\gamma\times(A+b)}{0.3R_t}\right]\times x+ \tag{4}$$
$$+2.33q^2(h-0.43q)-\frac{nAbHh\gamma}{0.3R_t}=0$$

For barrier intrablock pillars:

$$x^2+\left[\frac{7}{3}h-2q-\frac{nHhk_N\gamma}{0.3R_t}\right]\times x-\left[\frac{nHhk_N\gamma}{R_t}(B+l_0+Htg(\omega))+q(\frac{7}{3}h-q)\right]=0 \tag{5}$$

Where: h –height of the pillar, m; hi –thickness of the immediate roof, m; and in a case of mining with CM q=0 and for intrablock square pillars H= hi (because pillars, in this case, using for immediate roof supporting only), k_N –attenuation factor of the barrier pillar;



Where: x, y –the pillar dimensions, m; A, b – rooms sizes, m;
H – covered rocks thickness, m; S –cross–sectional area of a pillar,m^2;
γ–the covered rocks average density (for Estonian oil shale mines $\gamma=0,025$), MPa/m;
k_k –factor of the pillar form; q –factor of the pillar sides destruction, when blasting works are presented, then q=0,6m, and when CM using q=0;
n – the given factor of pillars safety.

Figure 2. Covered rocks strength distribution on a pillars

Using formulas 1–5, we are received pillars and rooms sizes for room–and–pillar mining with continuous miner (Fig.2). Where: Hk – thickness of the covered carbonate rock mass, for our conditions Hk>=26m.

For the stability analysis and monitoring the concept of critical width, methods of support coefficient, conditional thickness and sliding rectangle were used. They suit for modeling on PC.

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The critical width for Estonian oil shale mines is presented by the following formula (Room, pillars .....,1997, Stetsenko, Ivanov, 1981):

$$L > 1.2H + 10 \tag{6}$$

In the three–dimensional case, the critical width transforms into the critical area. The average support coefficient and conditional thickness for a critical area can be expressed by the following equation (Pastarus, 1982, Talve, 1978):

$$K_C = \Sigma S_{pi}/\Sigma S_{ri}\ ;\ C_C = H_a/K_C \tag{7}$$

where K_C – support coefficient for critical area; C_C – conditional thickness for critical area, m; S_{pi} – cross–section area of the i–th pillar, m^2; S_{ri} – roof area per the i–th pillar, m^2; H_a – average thickness of the covered rocks for critical area, m.

Conditional thickness represents the height of a prism whose cross–section equals the pillar cross–section area. Consequently, conditional thickness is related to the load on a pillar. If the load is too much for the pillars, a sudden failure is likely. By the sliding rectangle method, the average conditional thickness of the critical area must be determined for all positions inside a mining block [4].

Results

/ Monitoring of the roof and pillars parameters / The working mining blocks stability depends on the real parameters of the pillars and roof. The feedback of the real situation in a mining block is guaranteed by a monitoring system. This system insures the stability of a mining block against the random deviation of the construction parameters. For this analysis, the concept of conditional thickness and sliding rectangle method are used. Above mentioned methods allow to elaborate the means for stop the spontaneous collapse of the pillars and roof in a working mining block.

As a example was analyzed mining block No. 34 of mine Viru with collapse, where room–and–pillar (RAP) mining system with blasting is used (with extraction factor=81% and service life of pillars t =2 months). Monitoring of the roof and pillars parameters shows that there are one centre of a potential collapse in the case of conditional thickness C_{lim}>=300 m. The area of destruction was about 7000 m^2. In a case of continuous miner (CM), cross–sectional area of a pillar must be less than in RAP mining method with blasting, by ~10–14%. Therefore, for CM mining conditional thickness is C_{lim}>=330 m for the same point of a potential collapse. The investigation results for mining block No. 34 of mine Viru conditions, using presented on the figure 2 mining scheme, you can see on a table 2 below.

Table 2

Mining block No. 34 of mine Viru	Index	Mining method		
		Room–and–pillar with blasting		room–and–pillar with continuous miner (theoretical)
Service life of pillars / rooms in months		tp =2	tth = ∞	tth = ∞
Conditional thickness C_{lim}, m., in centre of a potential collapse	(1)	300	250	300
Extraction factor, %		81	68	89
C_{lim} condition for Spontaneous collapse	(2)	>=300	>=300	>=330
Spontaneous collapse	(1)>=(2)	Present	Not Present	Not Present
Where: tth –theoretical received data and tp –practical received data, if service life of pillars / rooms is equal 2 month or = ∞				

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Analysis showed, that RAP method with CM gives greatest extraction factor, and theoretically without spontaneous collapse. In a case of long time main roof control RAP method with blasting gives the greatest pillars cross–sectional areas and decreasing of extraction factor form 81 to 68%. However, in a case of CM using the special main roof control increase extraction factor up to 89%, i.e. plus about 20%.

The method suit for stability analysis, failure prognosis and monitoring. Consequently, the utility of monitoring was clearly demonstrated.

Discussion

Today there are lot of equipment, which can be used during following years without replacing, taking care about correct maintenance. After some next years should be replaced main production and transportation devices. At the same time will start developing of new parts of mines. Therefore, it can be said that today will be determined directions of future mining processes. One direction in the developing of mine could be mechanization of production process. Relatively big amount of manual operations needs much of work–force today. Second direction could be introducing more flexible mining systems. Today the mining system is relatively fixed and equipment is connected with working places. Considering ideas advanced above can be stated that the future direction could be: flexible and mobile mining and transportation equipment, which can be used in several parts of mine, highly mechanized and high productivity machines.

Conclusion

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

I. selective mining allows to use oil shale without additional costs for him preparation for power–generating plants

II. new technology with flexible and mobile mining allows to decrease lifetime of main roof supporting, sizes of constructive elements, and as a result, expected decreasing of oil shale looses in pillars, that compensated by the economy gained from the rise in the labour productivity;

III. nonutilizable waste in stockpiles is a potential problem in areas of mines, but with oil shale selective mining we can leave no–conditional rock mass in underground mined out areas (in rooms)

IV. main roof improved control is a guarantee for mining block stability for a long time without collapse of pillars and ground surface.

These itemized conditions are some of advantages of selective mining method. The main target could be feasibility study for acquiring new equipment and for comparing of different technologies. This study could be used as one part of feasibility study.

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Bibliography

I. Plahhov, A.V. 1991. “Drafting of Regulations for Protecting Structures and Natural Objects From Damaging Effects of Underground Mining Structures in the Baltic Oil Shale Deposit Area.” (Manuscript), ISM, St Petersburg, [in Russian]

II. Reinsalu E. 2000. “Stochastic approach to room and pillar failure in oil shale mining.” Estonian Scientific Academy Edition, Technical Edition, vol. 6/3, 2000, [in English]

III. Undusk V.S. 1990. “Pillars Destruction in Oil Shale Mines.” Tallinn Technical University Editions, No.718, p 31–40, [in Russian]

IV. Nikitin O. Pastarus J–R., Sokolov P., Monitoring and stability analysis in Estonian oil shale mining, 11th International Congress of the international society for mine surveying, pg. 319–327, Cracow, September 4–9, 2000, [in English]

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