IMMEDIATE ROOF STABILITY ANALYSIS FOR NEW ROOM-AND-PILLAR MINING TECHNOLOGY IN “ESTONIA” MINE

TIEŠĀS SLĀŅVIRSMAS STABILITĀTES ANALĪZE JAUNAJĀ KAMERU STABU DEGSLĀNEKĻA IEGUVES TEHNOLOĢIJĀ „ESTONIA”RAKTUVĒS

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Abstract. *This paper analysis the immediate roof (IR) stability by the deformation criteria for new room-and-pillar mining technology with modern machines in “Estonia” mine. The new mining technology based on a blasting method to move from packaged to emulsion explosives, from 2.0 m to 4.0 m boreholes (FRANZ SCHELL machine) and on new undercutting (SMAG machine) method. With such equipped new technology the entry advance rates reached 3.8 m. As a result of such greater advance rates the situations with unsupported room length up to 5.5 m with decreasing the stability of IR can be expected. The analysis of IR stability based on an in-site underground testing by the leaving bench-mark stations and convergence measurements. The main targets of this study to determine the main parameters for supported/unsupported IR deformation in areas with great entry advance rates and risk analysis concept elaboration.*

Keywords: *deformation criteria, room-and-pillar mining, immediate roof, stability, risk analysis.*

Introduction

For more than eighty years oil shale has been mined in Estonia. During that period about 950 million t from estimated four billion tonnes reserves have been extracted. About 99% of electric power and a large share of thermal power were produced from Estonian oil shale. Nowadays the oil-shale industry main goal is to preserve its competitive ability in the market of power resources for relatively cheap and high safety oil shale mining is capable to guarantee this competitiveness in the nearest future. In Estonian oil-shale mines the room-and-pillar mining system with blasting is used [1]. It gives an extraction factor of 70–80%. Loading and transportation of blasted mined rock is carried out by powerful LHD machines with diesel drive like TORO and WAGNER. The average productivity of such technology is 1500 m^3 of rock mass per day. The main problems are the great volume of blasting operations, low mobility and concentration of loading works due to the small entry advance rates (EAR), about 1.5-1.7m per blasting. One of the ways to improve the quality management system in nowadays situation is high safety drilling-and-blasting mining technology application with greater EAR and daily output.

Improved Technology Overview

The main operations carried out in rooms (6-7 m in width) include undercutting, drilling of blastholes, blasting, rock mass loading on the conveyor and roof bolting. The new mining technology based on improved drilling-and-blasting method (Fig.1., A.) to move from packaged to underground emulsion explosives (Nobelit 2000), from 2.0 m to 4.0 m boreholes (Fig.1.,B.) on new undercutting method (Fig.1.,C.) and to automatization of roof drilling-bolting process with roof bolting machine (Fig.1.,D.). The aim of undercutting is to gain additional free space in the oil shale bed which increases the effect of blasting. The old undercutting technology based

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on bottom cutting with the help of the cutter (Ural-33) which gives horizontal cut into the bottom layer A, 15centimeters high and 1.7 to 1.8 metres deep. The new undercutting technology based on 6 large hole drilling with SMAG machine into the central oil-shale layer C, up to 4.7 metres deep with 3×280mm diameter. Roof bolter and face drilling machines are operating with remote controls that provide great safety conditions on a working place.

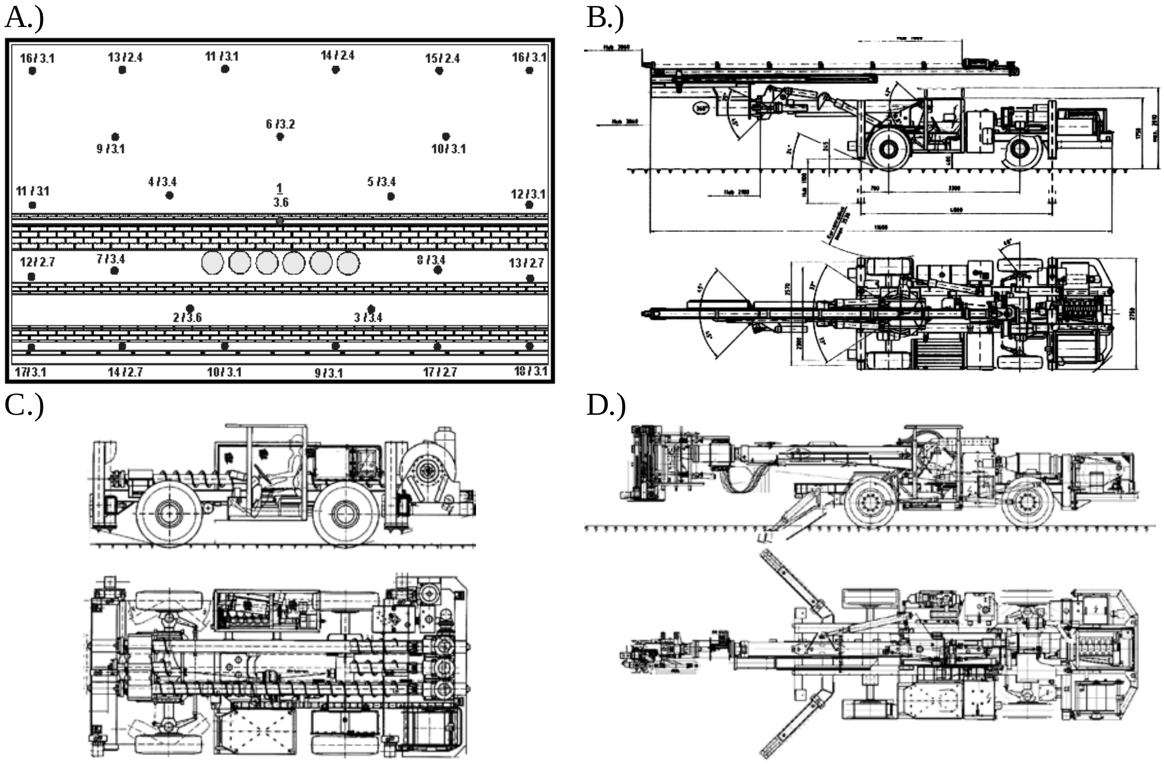

Fig.1. **New blasting pattern (A.); Franz Schell GmbH face drilling machine DHB-41-E-ZF (B.); SMAG undercutting machine GB 280 (C.); SMAG roof bolter FA523V (D.)**

The Study Targets

The width of the room is determined by the stability of the immediate roof. With such improved technology the entry advance rates reached 3.8 m. As a result of such greater EAR the situations with unsupported room width × length up to 7 × 5.5 m with decreasing the stability of IR can be expected. The main targets of this study are to determine:

- ✓ the main parameters for supported/unsupported IR deformation in areas with great entry advance rates, EAR>3.5m with chamber sizes ≥7×7m and excavation height h=3.8 m ;
- ✓ the main IR exfoliation levels by the optical geoperiscope – stratascope;
- ✓ dependence between IR deformation and loads in anchors (deflection rate);
- ✓ the main rates of risk analysis concept.

Geology and Measurement Equipment

During the last 2004 year period was tested new technology in two mining blocks 3103 and 3104 in “Estonia” mine [2]. The geological conditions were quite different. The commercial oil shale bed and immediate roof consist of oil shale and limestone seams. There are six commercial important oil-shale seams that are specified from the bottom to the top by the indexes from A to F (Fig.2.). The typically excavation height is about h=2.8 m, but on the case of weak IR conditions, like in our blocks, it can be up to 3.8–3.9 m. Roof support is to be achieved by usage of the Steeledale SCS roof bail type anchor bolts [3]. In this case expander plug (anchor lock) must be fixed in harder limestone layer G/H. It improves roof control significantly, reducing bolt-to-face distances and exposure of unsupported roof. The analysis of IR stability based on an

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in-site underground testing by the leaving bench-mark stations (BMS) and convergence measurements (Fig.2.).

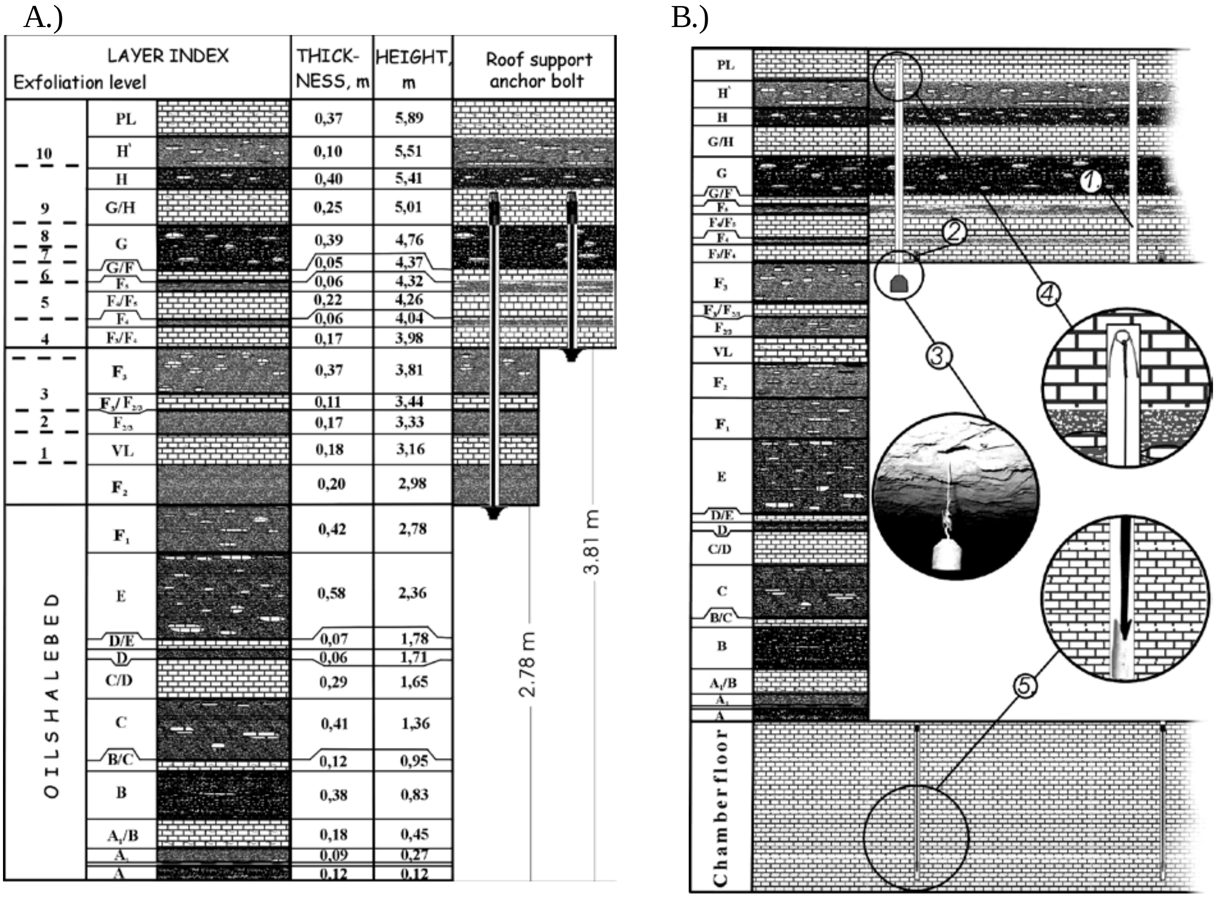

Fig. 2. **Structural cross-section with determined IR exfoliation levels (A.) and scheme of bench-mark stations in the roof/floor (B.)**

*Where, **1.**- bore hole for stratascop; **2.**-bench-mark station on the roof; **3.**-bob for rope-bench-mark station; **4.** - rope-bench-mark station; **5.** - bench-mark station in the floor.*

The deformation measurement was made by the DISTO classic[3] laser distancemeter [3] between two BMS installed in the room floor and on IR (for absolute deformation measurement). To prevent errors from floor (limestone) deformation the BMS (Fig.2.nr.5; Fig.3.A.) installation depth was 1.3m. The twin BMS-s was installed opposite on each other before the blasting, one pair (Fig.2.nr.2 and 5) near the pillar wall and at the room centre another one, no more than 0.5 m from pillar or face. The rope-bench-mark station (RBMS) was installed in the IR drilled bore hole on the depth 2.0 m for pillar deformation and IR absolute deformation on these depth measurements also (Fig.3.B). Absolute uncertainty of convergence measurement does not exceed 1.2 mm at the 95-% confidence level and the maximum relative uncertainty was 0.04%.

For IR exfoliation levels research and to estimate the thickness of exfoliation the optical geoperiscope – stratascope (10x zooming) with 0.12 mm measurement accuracy was used. For dependence finding between IR deformation and loads in anchors (deflection rate) during the experiment period the screwed anchor torque measurements was made also. The torque wrench accuracy is 4%.

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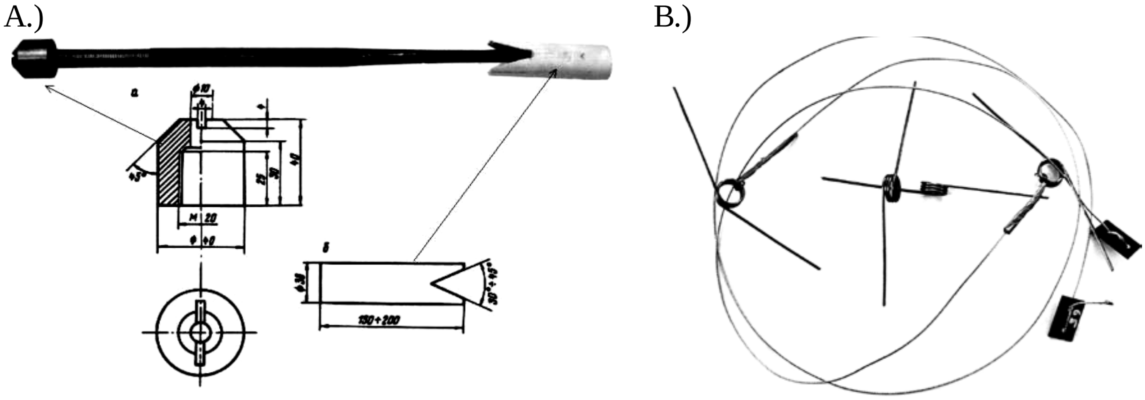

Fig. 3. **Bench-mark station (A.; Fig.2,nr.5) for installation in floor and rope-bench-mark stations (B.) for installation in roof (B.; Fig.2,nr.4)**

Where, a-metal head; b-wood cylinder

Prediction of Stability using Roof-to-Floor Convergence Data

The field of the oil-shale mine is divided into panels subdivided into mining blocks each approximately 300–350 m wide and 600–800 m long. A mining block consists usually of two semi-blocks [1, 2]. The pillars are arranged in a singular grid with cross-sectional area about 45-50 m^2 in "Estonia" mine. The service life of one room in practice is 2-3 months. During this period anchor bolting must support the roof. After this period the anchor bolts must be extracted and reinstalled in new formed rooms. Laminated roof deformation on the basis of plate's hypothesis by the experimental data of Institute of Mining Surveying (VNIMI) in St. Petersburg and Estonian filial of A. A. Skotchinsky Institute of Mining Engineering (IGD, Moscow, Russia) presented on figure 4.A. [4, 5].

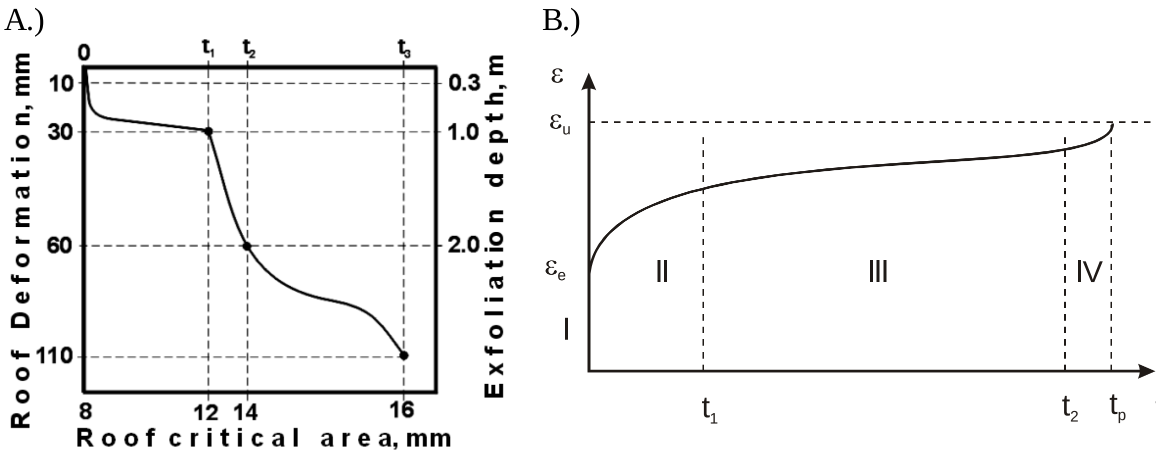

Fig. 4. **Roof-to-floor convergence curve by the VNIMI and IGD data (A.) and typical curve for long-term stability analysis (B.) [3]**

Where, t – time; t_p=t_3 – time at failure; ε – deformation; ε_u – ultimate deformation at failure; ε_e – elastic deformation; ; I – elastic deformation ε_e; II – transient creep $\acute{\varepsilon}<0$ ($\acute{\varepsilon}$ – deformation rate); III – steady-state creep $\acute{\varepsilon}$ = const; IV – transient creep $\acute{\varepsilon}>0$

In general case for Estonian oil-shale deposit it is possible to allocate four stages in this process. During short time interval after the first blasting there are *instant deformations* (ID) up to 10 mm. Then during the time (duration depends on geological conditions) there are two processes: increase of *elastic deformations* (ED) due to reological processes, blasting work and entry advance, and also increase of *creep deformations* (CD) up to the cracks formation moment at t = t_1, when ε=20-30 mm. Then instead of a plate the arch on three hinges is formed completely. The time period from t_1- t_2 is a *transient creep* (TC) period due to a partial crushing of average and left/right hinges of an arch, till the moment of the crushing termination, when ε=60 mm. During

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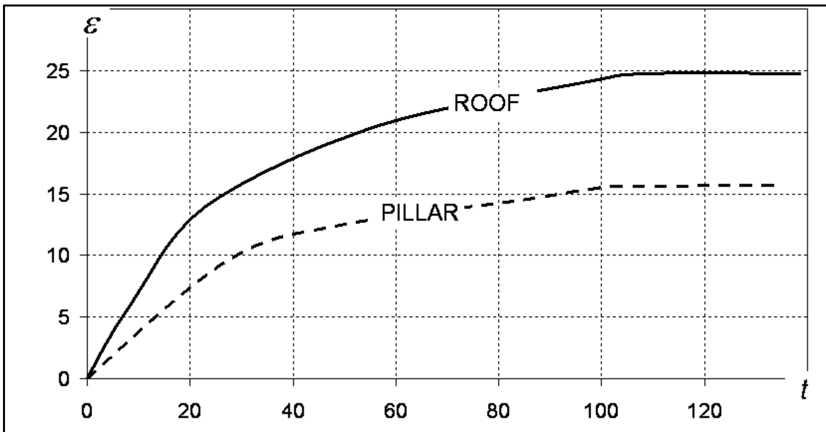
the period t_2-t_3 there is a *steady-state creep* (SSC) in hinges up to their full crush at the t_3, when ε=110 mm and full loss of the roof bearing capacity (full destruction up to depth 2-3,5 m) is happen. Duration of these time periods t_0-t_3 depends from many *geological* (loading, capacity, cracks, etc.) and *technological* (roof critical area, type of explosives initiation, advance rate, supporting and etc.) factors that present difficulties for dependence $\varepsilon=f(t)$ finding.
The *roof-to-floor convergence curve* method (Fig.4.B) is applicable also for the roof long-term calculations (for the period up to 100 years and more); its uncertainty does not exceed 10%.

Results

During in-site testing 16 pair of BMS-s was installed and 19 holes (Fig.6) were viewed by the stratascope in two mining blocks (3103 and 3104) with different geological conditions (with weak and average stable IR) [2]. The results of IR (on the center of the room) and pillars (S=45-50m^2) average deformation presented on figure below (Fig.5). The critical areas (L) of the rooms for our conditions were about 11-12 m.



PERIOD INDEX		ε, mm VNIMI + IGD	ε, mm 3103+ 3104
0	*ID*	10	*3-7*
I.	*ED + CD*	*20-30*	*15-28*
II.	*TC*	*60*	*29-40*
III.	*SSC*	*110*	—

Fig. 5. **Roof-to-floor convergence curves and comparison table for deformation by VNIMI+IGD and received experimental data**

By the VNIMI and IGD data the roof failure is happen (depth of failure ≈ 2.0-3.5 m) when deformation is $f_{max}=6.3L=8.84A+5.3$, mm, where A is room width. For our conditions, $f_{max}=8.84*7.0+5.3=67$ mm. From the comparison table on figure 5 you can see that received experimental data are much closed to the data of VNIMI and IGD. Its mean that the improved technology influences on immediate roof stability estimated by the deformation criterion is not greater than with old technology. Analysis of immediate roof failure cases during the experiment shown that depth of failure about 8-10cm when $\varepsilon=0.4f_{max}$ is possible. Then after IR unsupporting the failure on this depth can be expected with great probability.
By the way of exfoliation level (EL) or depth (h_v) and deflection rate (DR) determination we can estimate the effectiveness of anchor bolting and supporting pattern. Deflection rate of the system "anchor-roof" by the anchor torque (M, N*m) measurements was in average 1.3 mm/t, where loads on used anchors (N, t) was determined by the empirical formula N=0,2722M. On this case DR is a parameter of IR deformation after the vertical load on anchor increasing by one ton. Another very important parameter is exfoliation level of the roof, which was determined by stratascope inspection of 19 holes drilled in the roof. Sixteen of them were drilled in mining block nr.3104 and presented on figure below (Fig.6). The summarized result dependence $h_v=f(L)$ is showed on figure 7.

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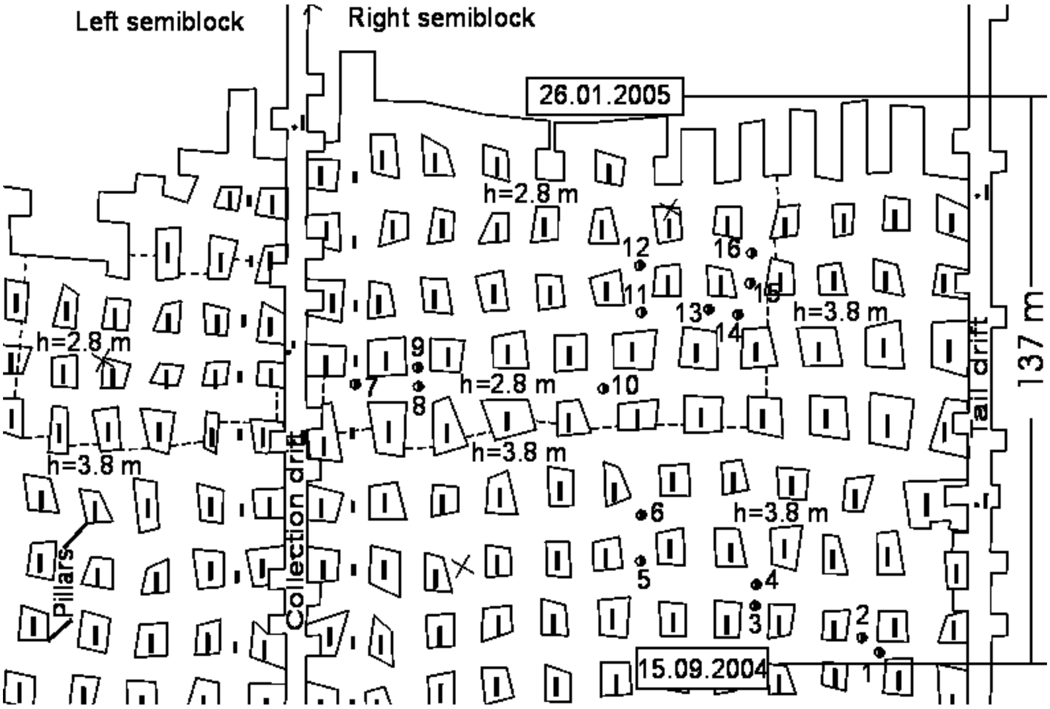

Fig. 6. **The part of mining block nr.3104 "Estonia» mine with places for stratascope inspection**

Where, □- boreholes for stratascope; 1-6 –boreholes equipped with BMS-s when h=3.8m; 7-16 –boreholes drilled in the rooms with exploration height=2.8m, without BMS-s

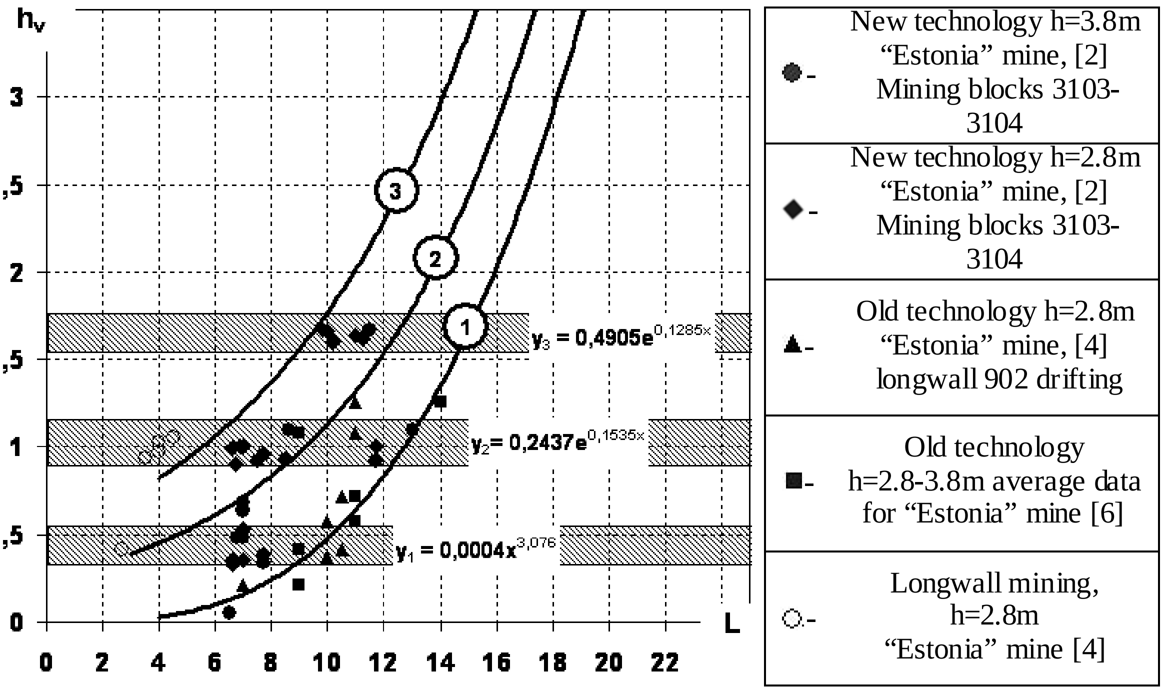

Fig. 7. **The exfoliation depth (h_v) dependence on the critical area (L)**
Where, geological conditions classification by the roof stability: ①-stable; ②- average; ③- weak.

For an obvious reason the EL-s depends on critical area of the roof (Fig.7). More than forty years ago by L.Talve, H.Arukula and A.Reier from Tallinn Polytechnic Institute (TPI, now TTU) was carried out analysis of IR exfoliation levels for Estonian oil-shale manes (old technology). According the results of their report [8] it is possible to summarized dependence $h_v=f(L)$ from the roof stability rate by curves presented on figure 7. The last data for EL-s research in

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"Estonia" mine were presented in reports of IGD in 1987 [6, 7] and plotted as additional points on figure 7. As you can see there are three main exfoliation levels (h_{v1-3}=0.4-0.6; 0.8-1.2; 1.5-1.7m) which are depends from both factors like geological situation and roof critical area. These levels are suitable for both technologies with exploitation height h=2.8-3.8 m.
The risk evaluation of hazard for workers [9, 10] is carried out on the *Likelihood* of events, their *Consequence* and *Risk magnitude* and presented in Table 1.

Table 1.

Old and improved (new) technology risk evaluation

Hazard factors	**Hazard factors influence**	**Likelihood old(new)**	**Consequence old(new)**	**Risk magnitude old(new)**
Roof drilling and supporting	Immediate roof falling	3(1)	5(5)	15(5)
Roof unsupporting	Immediate roof falling	4(4)	5(5)	20(20)
Blasting work	Explosive substance	3(1)	5(3)	15(3)
Face drilling and undercutting	Moving parts of mechanisms, sharp and prickly subject	2(1)	4(2)	8(2)
Equipment Operating	High-altitude work, falling subjects, sliding surface	3(2)	3(2)	9(4)

Where, ***Likelihood*** *define as Very unlikely(1), Low probability(2), Likely(3), Very likely (4).* ***Consequence*** *- Harmless(2), Significance(3), Danger (4), Very danger(5).* ***Rick magnitude*** *are: (1-3)-Minimal. Not required special measures; (4-6)-Low. Special measures on reduction of risk are required; (7-10)-Moderate. Measures of organizational character are required. (additional instructing, training); (11-16)- High. The analysis of the reasons and existing security measures is carried out. Actions on prevention of similar cases are made. The information card is made; (17-20)-Catastrophic. Work stops. The analysis of risk is immediately carried out. Additional actions are developed. Additional instructing or training is carried out. Works cannot be begun while the risk is not reduced.*

Below there are some explanation for the rates of table 1. Old technology use a cutter machine "URAL 33" for face undercutting. The machine moves with the towrope. Rope is fixed by 3-4 meter stanchion, which putting between roof and floor. Typically there is a dangerous if the stanchion is falling. In some cases roof drilling and supporting can be made by manual bore machine only. Vibration and dust only two of the danger influences on miner health. Electricity cable breaking leads to loss of a life. For old equipment operation necessary work on high-altitude and beside dangerous subject that demand special skills. Especially big risk appears at roof supporting/unsupporting. The worker should have time to leave a place before roof falling. The risk minimization achieved by carefully and quality team work. From the table 1 it is visible, that the risk is much lower for the improved technology due to the high safety and remote controllable equipment.

Discussion

Estonian oil shale mines have seen total mining cost benefits when moving to emulsion explosives not in a reduction in powder factor within great advance rates but in the drill and blast productivity improvements achieved from improved logistics, faster transport & charging, improved advance, improved fragmentation, less damage, high safety (explosives preparation at working place), faster mucking and drill set ups.

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Conclusions

During this study the following conclusions were made:

- Immediate roof stability estimated by the deformation criterion is not greater than with old technology.
- Analysis of immediate roof failure cases during the experiment shown that depth of failure about 8-10cm when $\varepsilon=0.4f_{max}$ is possible.
- There are three main exfoliation levels (h_{v1-3}=0.4-0.6; 0.8-1.2; 1.5-1.7m) which are depends from both factors like geological situation and roof critical area. These levels are suitable for both technologies.
- The risk evaluation of hazard for workers is much lower for the improved technology due to the high safety and remote controllable equipment.

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