Abstract
The processes of immediate roof exfoliation and pillars collapse accompanies by significant subsidence of the ground surface. Ground surface subsidence causes soil erosion and flooding, swamp formation, agricultural damage, deforestation, changes in landscape, ground water level decreasing and the formation unstable cavities. During the period of four last years the oil-shale mining at experimental mining block introduced by new blasting technology with great entry advance rates (EAR). With such improved technology the EAR reached 4 m that is two times greater than conventional technology can guarantee, but emulsion explosive volume increase up to two times and explosion occurs during 4.5 seconds (~15 times longer than old technology). 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. Analysis of the immediate roof (IR) stability by the deformation criteria for new room-and-pillar mining technology with modern machinery in “Estonia” mine is presented this paper. The analysis of IR stability based on an in-site underground testing by the leaving bench-mark stations and convergence measurements. The target of this study is to determine the impact of vibration on roof and pillars stability using risk assessment method. Risk analysis of available earthquake influence on mining block is presented in this paper.

Keywords
Deformation, room-and-pillar mining, immediate roof, stability, risk analysis peak particle velocity.

Introduction
Four last years the oil-shale mining at “Estonia” mine introduced with new blasting technology with great entry advance rates (EAR). With such improved technology the EAR reached 4 m, that is two times greater than conventional technology can guarantee. The average productivity of such technology about 3000 m$^3$ of rock mass per day. The main problems of old technology are the great volume of blasting operations, low mobility and concentration of loading works due to the small entry advance rates (EAR), about 1.5-1.7 m 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.

During the last 2004 year period was tested new technology in two mining blocks 3103 and 3104 in “Estonia” mine [1]. The geological conditions were quite different. 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 [2].

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 width of the room is determined by the stability of the immediate roof. As a result of such greater EAR the situations with unsupported room width $\times$ length up to $7 \times 5.5$ m with decreasing the stability of immediate roof can be expected. The analysis of IR stability based on an in-site underground testing by the leaving bench-mark stations (BMS) and convergence measurements (Fig 1).

1. Prediction of stability using roof-to-floor convergence data
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 2. [3, 4].
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 rheological processes, blasting work and entry advance, and also increase of creep deformations (CD) up to the cracks formation moment at $t = t_1$, when $\varepsilon = 20-30$ 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 $\varepsilon = 60$ mm. During 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 $\varepsilon = 110$ 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.

During in-site testing 16 pair of BMS-s was installed and 19 holes were viewed by the stratascope in two mining blocks (3103 and 3104) with different geological conditions (with weak and average stable IR) [5]. The results of IR (on the center of the room) and pillars ($S=45-50$m2) average deformation
presented on figure 3. The critical areas (L) of the

rooms for our conditions were about 11-12 m.
1 = Harmless – no potential for harm, correctable (0-
10, mm) - t0

Boundaries
5 = Local – impact migrates on ground surface
4 = Not confined - impact migrates outside critical
area. (25-30 rooms)
3 = Weakly confined – impact migrates off-site one
row of the rooms
2 = Confined – impact migrates off-site four rooms,
but is contained in small area
1 = Isolated – impact is contained (one room)

As results receive controlability criteria equal
Severity scale multiply on Boundaries scale. (1-10)
controllable - process under control; (11-15)
influenceable - process controlled by changes of
technology; (16-20) process is not controlled. For
our experimental mining blocks process was under
control.

2. Risk analysis of earthquake influence
on rock massive

During the short period 21.01.2005-04.02.2005 in
Baltic region, three earthquakes were registered.
Basic precondition to consideration of this paper has
served jumping characteristic of absolute
deformation near pillar after earthquake.

21.09.2004 in the second part of afternoon in Tallinn
area registered earthquake shocks. It has also
registered in Poland, Belorussia, Russia, Austria,
Latvia, and Lithuania with earthquake magnitude 4.4
[8]. The Kaliningrad earthquake parameters are:
date= 21-Sep-2004; 11:05:03.3; lat= 54.78 lon=
20.29; depth= 15km; ms: 4.1/2; mb: 5.7/3.

Geophysicist of Estonian Center of Geology Olga
Heinlo said DELFI, that earthquake magnitude in
Estonia could be about 3. It was registered two
epicentres of earthquake shocks in Kaliningrad area
with magnitude 5.2. Director of Latvian State
Service of Geology Maris Seglinsh have made
statement that significant earthquake magnitude
observed in north-western part of Estonia at 16.45.

Knowing velocity of massive fluctuations
(acceleration) at which there are the pressure caus ing
infringements or collapse in mining developments, it
is possible to judge comparative stability at unita ry
influence on them of seismic loadings, and seismo-
explosive shock waves outside of operative range.

On such data it is possible to estimate admissible
and critical peak particle velocity at which mining
development stability is lost.

Table1. Data of earthquakes during 21.01.2005-04.02.2005

<table>
<thead>
<tr>
<th>Magnitude:</th>
<th>mb 3.8</th>
<th>mb 4.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region:</td>
<td>BALTIC STATES-BELARUS-NW RU</td>
<td>BALTIC STATES-BELARUS-NW RU</td>
</tr>
<tr>
<td>Date Time:</td>
<td>29.01.05 at 13:17:48.0 UTC</td>
<td>27.01.05 at 14:07:26.7 UTC</td>
</tr>
<tr>
<td>Location:</td>
<td>58.96 N ; 22.70 E</td>
<td>57.23 N ; 25.15 E</td>
</tr>
<tr>
<td>Depth:</td>
<td>25 km</td>
<td>25 km</td>
</tr>
</tbody>
</table>
By the researches results of Ural University admissible peak particle velocity at supporting by the timbering, strengthened by anchors makes 0.9 m/s and critical 1.2 m/sec [9]. On Estonian standards, the same requirements shown as well for railway tunnels and subway overpass [10].

Critical peak particle velocity on USSR standards for underground constructions with service life up to \( t = 4 \)–10 years make no more than 0.12 m/c, and for \( t \leq 3 \) years no more than 0.48 m/sec [11]. In Estonia, the maximal resolved peak particle velocity for open-casts boards makes 0.48 m/sec.

Knowing the basic rock physic-mechanical properties, such for example as velocity of longitudinal wave’s distribution \( V_p \), ultimate extension strength \( \sigma_r \), Young module \( E \), it is possible to calculate critical peak particle velocity \( V_p \) under the formula [12]:

\[
V_p = \frac{V_p \times \sigma_r}{E} = \frac{0.9}{1053 \times 25000000/7100000000} = 0.37
\]

\[
V_p = \frac{V_p \times \sigma_r}{E} = \frac{1.2}{1700 \times 35000000/7100000000} = 0.84
\]

Hence, critical velocity of massive displacement for industrial layer in conditions of Estonian oil-shale deposit will make 0.4 – 0.8 m/sec.

3. Richter Magnitude and TNT Equivalent

The Richter magnitudes based on a logarithmic scale (base 10). It’s means that for each next number you go up on the Richter scale, the amplitude of the ground motion recorded by a seismograph goes up ten times. By the data of Michigan Technological University, magnitude 8 earthquake releases as much energy as detonating 6 million tons of TNT [15]. This statement is based on the empirical formula:

\[
\log (E) = 1.5M
\]

Where, M- magnitude and E-energy [16].

The calculation offered by the American Institute of Makers of Explosives (IME), USA, based on the following formula to recalculation of TNT equivalent [17]:

\[
TNT = \frac{MQ}{4.186 \times 1090}
\]

The blasting energy of Nobelit 2000 Q Nobelit 2000 = 2600 kJ/kg, and QTNT =1090 kcal/kg or \( 4.186 \times 1090 \) kJ/kg. Then to one kg of TNT corresponds about 1.6 kg of Nobelit 2000.

5. Risk estimation of underground construction stability

Every 100 years in Estonian territory occur about 12 earthquakes with magnitude \( 2.38 \leq 2.7 \leq 3.02 \) (p=0.95) and 1-2 with magnitude 3.5–3.9 [18]. Last earthquakes in Estonia territory have been recorded in area of islands Hiiumaa and Osmussaare, and distance from them up to Estonia mine about 250 km. We shall determine earthquake magnitude in area of these islands, capable to influence stability of underground constructions.

\[
PPV = A \left( \frac{D}{\sqrt{W}} \right)^{-n} \text{ , mm/sec} \tag{4}
\]

Where, A- degree of damping of PPV; \( n \) - exponent depending on explosive properties; \( W \) - explosive quantity, and \( D \) - distance.

According to work of MSc. Tomberg for blasting in Estonian underground conditions (ammonite 6ZV) factors have following values \( A=1748; n=1.25 \) [10].

4. Determination of the Peak Particle Velocity

It is obvious, that peak particle velocity \( PPV \) is in direct dependence on such parameters, as distance up to explosion, quantities blasted explosives on delay unit, the basic physical and mechanical properties of the rock. Formula \( PPV \), which apply practically all over the world, in a general view looks as follows:

\[
PPV = A \left( \frac{D}{\sqrt{W}} \right)^{-n} \text{ , mm/sec} \tag{4}
\]
By the calculation result, we can conclude that probability of earthquake influence on underground construction in Estonian oil shale mines is insignificant. By the made calculation of PPV, earthquake influence on underground construction during the experiment can be excluded. But in case if earthquake magnitude will make 4 and epicentre occur directly on underground construction (less 10 m) it will produce dangerous influence on mining block stability. On earthquake magnitude 6 safety distances for mining block must exceed 27 km, magnitude 7 – 150 km and magnitude 8 – 850 km.

6. Conclusions
1. Immediate roof stability estimated by the deformation criterion is not greater than with old technology.
2. Analysis of immediate roof failure cases during the experiment shown that depth of failure about 8-10cm when ε=0.4% max is possible.
3. By the made calculation of PPV, earthquake influence on underground construction during the experiment can be excluded. But in case if earthquake magnitude will make 4 and epicentre occur directly on underground construction (less 10 m) it will produce dangerous influence on mining block stability.

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References
17. http://www.ime.org/calculator/