# ANALYSIS OF EARTHQUAKES AVAILABLE INFLUENCE ON „ESTONIA" MINE UNDERGROUND CONSTRUCTION STABILITY

## *ZEMESTRĪČU IESPĒJAMĀS IETEKMES ANALĪZE UZ „ESTONIA" PAZEMES RAKTUVJU KONSTRUKCIJU STABILITĀTI*


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**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 experimental measurement of immediate roof absolute deformation on "Estonia" mine three earthquakes were registered. The main reason of investigation has served jumping characteristic of absolute deformation near a pillar after earthquake. Method of final elements for analysis of deformation modelling is used. Seismic risk assessment for underground constructions stability is presented in this study.*



**Keywords:** *earthquake, mining block, pillar, roof, stability, risk estimation.*


### Introduction

Processes in overburden rocks and pillars have caused unfavourable environmental side effects accompanied 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. It is a large number of technical, economical, ecological and juridical problems.

Nowadays underground oil shale production obtained by room-and-pillar method with blasting. 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 various oil shale and limestone seams are quite different. The strength of the rocks increases in the southward direction. Ground surface subsidence result of pillars collapse. Depth of subsidence depends on extracted seam thickness. The first spontaneous collapse of pillars and surface subsidence in an Estonian oil shale mine took place in 1964. Up to the present, 73 collapses has been recorded [1].

### The Problem Overview

During the period of three 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 3.8 m, that is two times greater than conventional technology can guarantee. 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 × length up to 7 × 5.5 m with decreasing the stability of immediate roof can be expected. The analysis of immediate roof stability based on an in-site underground testing by the leaving bench-mark stations and convergence measurements (see Fig. 1; 2).

During the short period 21.01.2005-04.02.2005 in Baltic region, three earthquakes were registered. The main parameters for two of them presented on the table below (Table 1). Basic precondition to consideration of this paper has served jumping characteristic of absolute deformation near pillar after earthquake which characterised bottom line presented on figure 1.

21.09.2004 in the second part of afternoon in Tallinn area registered earthquaking 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 earthquaking 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.

*Table1.*

**Data of earthquakes during 21.01.2005-04.02.2005**

| | | |
|---|---|---|
| Magnitude: | mb 3.8 | mb 4.3 |
| Region: | BALTIC STATES – BELARUS - NW RU | BALTIC STATES – BELARUS - NW RU |
| Date Time: | 29.01.05 at 13:17:48.0 UTC | 27.01.05 at 14:07:26.7 UTC |
| Location: | 58.96 N ; 22.70 E | 57.23 N ; 25.15 E |
| Depth: | 25 km | 25 km |
| References: | 128 km W Tallinn ; 5 km SW Kärdla | 73 km NE Riga ; 12 km SW Cesis |

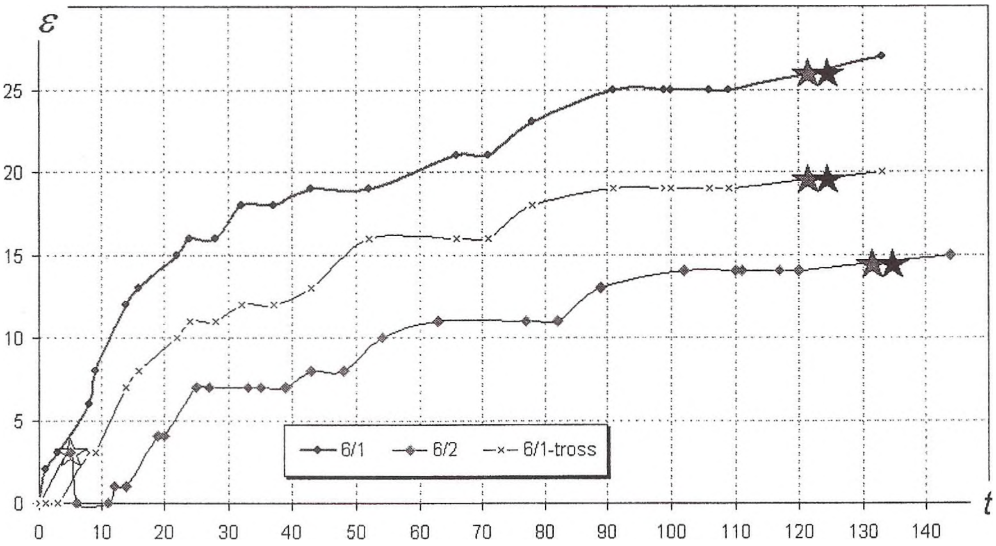



*Fig.1.* **Roof-to-floor convergence curves**

Where, ε- immediate roof deformation, mm; t- period in days; ☆·☆·★- earthquakes in Kaliningrad (21.09.04); in Riga area (27.01.05) and in Tallinn area, near the island Hijumaa (29.01.05)

The bench-mark station 6/2 has been installed (16.09.04) on distance about meter from the working face (see Fig 2). After blasting work (21.09.04) the roof instant deformation in this point made 3 mm (measured before earthquake), and then after earthquake (22.09.04) the roof "jumping" up to zero mark (see Fig. 1, bottom line).

During analysis two hypothesis of given situation was considered. The first one is direct influence of earthquake, the second one is usual phenomenon caused by redistribution of roof deflections after the next blasting.

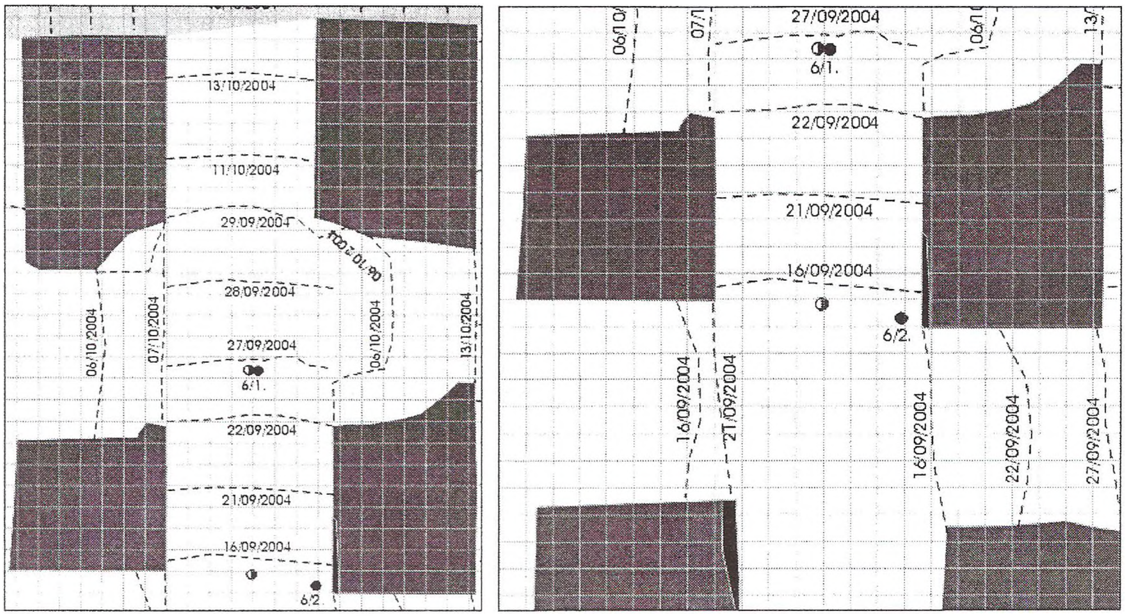



*Fig. 2.* **Inspection area scheme**

Where, face position marked with dotted line and date.

**Influence of Earthquake**

Knowing velocity of massive fluctuations (acceleration) at which there are the pressure causing infringements or collapse in mining developments, it is possible to judge comparative stability at unitary 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.

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/s [7]. On Estonian standards, the same requirements shown as well for railway tunnels and subway overpass [2].

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/s, and for t $\leq$3 years no more than 0.48 m/s [3]. In Estonia, the maximal resolved peak particle velocity for open-casts boards makes 0.48 m/s.

Knowing the basic rock physic-mechanical properties, such for example as velocity of longitudinal waves distribution $V_p$, ultimate extension strength $\sigma_r$, Young module $E$, it is possible to calculate critical peak particle velocity $V_d$ under the formula [4]:

$$V_d = V_p \times \sigma_r / E \qquad (1)$$

According data from Institute of Oil-shale during the experiment at „Tammiku" mine (mining block №2) the velocity of longitudinal seismic waves was 1700 m/s [5]. According to measured velocity of longitudinal seismic waves by experts of Japanese firm KOMATSU in 2002 on "Narva" open-pit the separate industrial layers velocity was from 1039 to 2000 m/s [6]. According to the report of Institute of Oil-shale, the Young module for layer $C$ (one of the weak) is $E$≈7100 MPa and $\sigma_r$≈2.5-3.5MPa.

$$\left.\begin{aligned} V_d &= V_p \times \sigma_r / E = 1053 \times 2500000/7100000000 = 0.37 \\ V_d &= V_p \times \sigma_r / E = 1700 \times 3500000/7100000000 = 0.84 \end{aligned}\right\} \quad 0.4\text{-}0.8,\ \text{m/s}$$

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

## 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 [9]. This statement is based on the empirical formula:

$$\log(E) = 1.5M \qquad (2)$$

Where, M- magnitude and E- energy [10].

The calculation offered by the American Institute of Makers of Explosives (IME), USA, based on the following formula to recalculation of TNT equivalent [11]:

$$TNT = \frac{MQ}{4{,}186 \times 1090} \qquad (3)$$

The blasting energy of Nobelit 2000 $Q_{\text{Nobelit 2000}}$ = 2600 kJ/kg, and $Q_{TNT}$ =1090 kcal/kg or 4.186*1090 kJ/kg. Then to one kg of TNT corresponds about 1.6 kg of Nobelit 2000.

## 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:

$$PPV = A\left(\frac{D}{\sqrt{W}}\right)^{-n}, \text{ mm/s} \qquad (4)$$

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 [2].

## Stability Analysis

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.

$$PPV = 1748\left(\frac{250 \times 10^3}{\sqrt{9 \times 10^8}}\right)^{-1.25} = V_d = 0.12 \text{ m/s} \qquad (5)$$

Using the formula PPV received W= $9*10^8$ kg that corresponds to magnitude ~7.5. It is necessary to note that fact, that the given formula is rather conservative at distance more than 30m. The formula application for greater distances can lead to probable deviation more than 5%. For the more exact estimation, it is necessary to consider such basic earthquake characteristics as depth of epicentre, amplitude, frequency, structure of overburden and mechanical parameters of the rocks.

By the calculation result, we can conclude that probability of earthquake influence on underground construction during the experiment can be excluded.

## Seismic Risk Evaluation

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 [12].

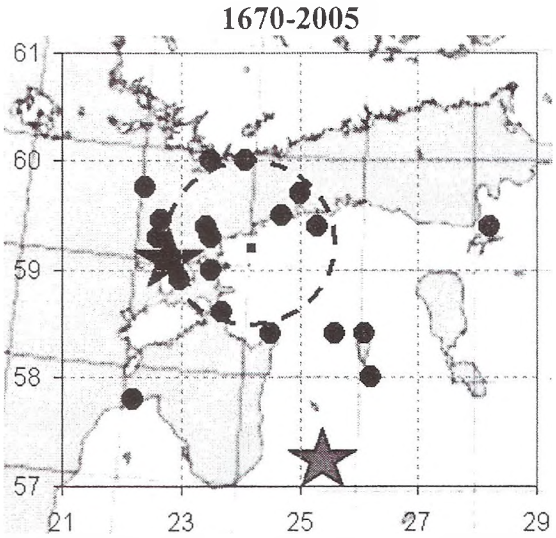



*Fig. 3.* **Map of registered earthquakes from 1670 to 2005, Region within: N 57°-60° E 22°-30°**

☆ · ★ - *earthquake in Riga area 27.01.05 and near Hiiumaa island 29.01.05.*

By the data of Institute of Seismology in Helsinki, explosive activity of open-casts in Estonia territory corresponds to magnitude about 2.

For estimation the probabilities of the events in Figure 4 were taking into account the statistics in Estonia received on the last 100 years, because no clear calculation models have been available for these events. The estimation of risk probabilities is based on calculation of blasting energy in comparison with earthquake magnitude using the formulas (3) and (4). According to calculated data, using the formula PPV received explosive quantity $W = 9*10^8$ kg that corresponds to magnitude ~7.5. Based on statistic information earthquake with magnitude 1-3 could occur 12 times per 100 years P=0.12 and magnitude 3-4 with P=0.02. Ratio of critical magnitude ~7.5 for underground construction to possible earthquake magnitude, using the formula to recalculation of TNT equivalent, give probability of critical loading. Final risk probability received by multiplying magnitude on critical loading. Fig 4.

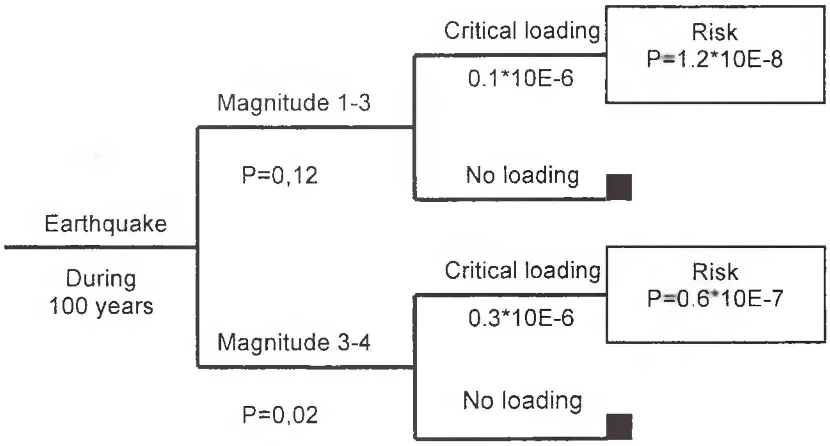



*Fig. 4.* **Event tree for earthquake during 100 years**

## Roof Deformation Modelling by the Final Elements Method

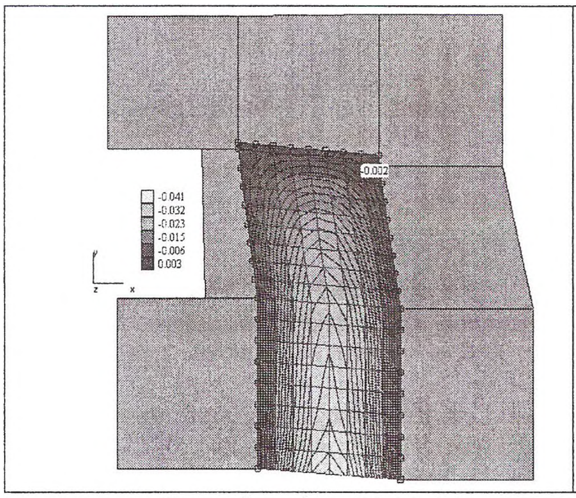
The immediate roof on Estonian oil-shale mines from building mechanics point of view is a multilayered compound plate. Without anchor supporting occur the plate exfoliation between the layers. The top layers can also to preload underlaying layers. In current of time, occur increasing of deformations under influence of rheological and technological factors and after critical value achieving the collapse of lower layers beginning.

For receive the exact decision of influence of next chambers and pillars, it is necessary to consider deformation of continuous plate with complex configuration, receiving statically indeterminate system. The decision of this problem at transition from beams theory to the plate's theory in such statement demands the account of many factors.

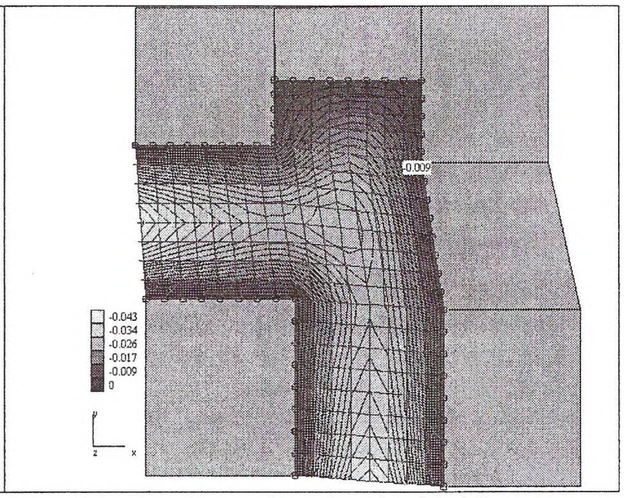
For modelling simplification, unsupported roof like compound plate is considered. The available influence of pillars deformation on modelled roof was not taken into account. By data of analyzed exfoliation levels the roof plate thickness h =1.0 m was accepted [14]. For the FEM modelling demo version of "FEMmodels" software was used [13].

## Results of Modelling

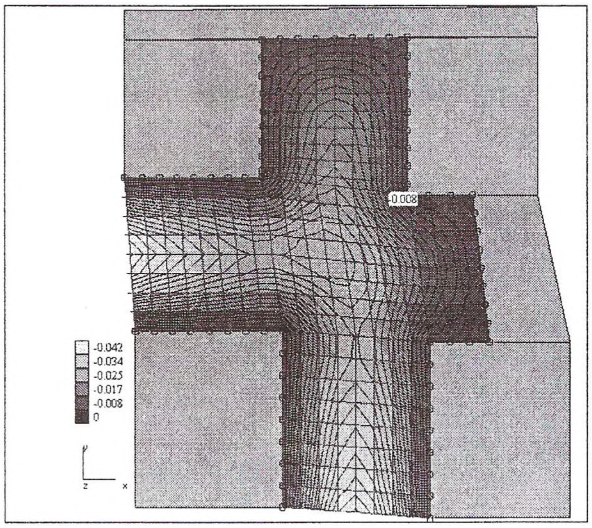
Results of modelling presented in the form of immediate roof deformation isolines at different face positions in the chamber 6. From figures received during modelling it is visible that roof deformation in benchmark 6/2 (16.09.04) could make 2 mm. On 21.09.04, because of jointing with cross-section chamber at the left and in loadings redistribution, deformation increased up to 9 mm, and 22.09.04 has decreased for 1 mm and has made 8 mm (Fig.5)




Face situation 16.09.04




Face situation 21.09.04




Face situation 22.09.04

*Fig.5.* **Roof deformation in benchmark 6/2**

From the point of view of continuous plate, deformation with complex configuration exists opportunity “draw in" already deformed roof as result of roof sag redistribution (possible unloading effect) after the next blasting and additional roof exposure.

## Conclusion

1. By the made calculation of PPV, earthquake influence on underground construction during the experiment can be excluded.
2. The main quantitative approach used in risk analysis is the event tree method. This method was selected as the most appropriate one for the risk analysis of the available earthquake influence on Estonian underground construction. Risk probability during 100 years period made P=0.6*10E-7 for quake magnitude 3-4 and P=1.2*10E-8 for 1-3, respectively.
3. Deformation with complex configuration exists opportunity “draw in" already deformed roof - result of roof sag redistribution after the next blasting and additional roof exposure.

## Acknowledgement

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