# IMPROVED UNDERGROUND MINING DESIGN METHOD FOR ESTONIAN OIL SHALE DEPOSIT
## UZLABOTA APAKŠZEMES KALNRŪPNIECĪBAS DARBU PROJEKTĒŠANAS METODE IGAUNIJAS DEGSLĀNEKĻA ATRADNEI

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**Abstract.** *The paper deals with the improved mining design method for Estonian oil shale mines, where the room-and-pillar mining system is used. Design of mining block parameters is based on the instruction used in Estonian oil shale mines. The factor of safety is very large. Consequently, the design method does not take into consideration all the influence factors. It is determined the supplementary influence factors and given the mathematical formulas. In this case the factor of safety is reduced up to 1.2. The improved mining design method is of particular interest for practical purposes.*

**Keywords:** *depth of excavation, design, factor of safety, fracture process, influence factor, influence zone, mining block, pillar cross-section area, room-and-pillar mining, stability.*

## Introduction

The most important mineral resource in Estonia is a special kind of oil shale. It is located in a densely populated and rich farming district. Underground oil shale production is obtained by room-and-pillar method with blasting. This method is cheap, highly productive and easily mechanize.

Design of mining block parameters based on the instruction, used in Estonian oil shale mines [1]. Analysis of the applicable mining block design method showed that the factor of safety is very large. Consequently, it involves the unknown influence factors. In this case to determine the real factor of safety for a certain mining block is practically impossible, which may lead to the negative consequences. Up to present, 73 collapses have been recorded on the area of 100 km$^2$ (about 400 mining blocks). It takes about 18 % of the total number of mining blocks. The collapse of the pillars and the surface subsidence cause and will cause in the future a large number of technical, economical, ecological and juridical problems.

Determination of the supplementary influence factors and elaboration of the mathematical formulas was the main aim of the present work.

Investigation showed that there are four influence factors. Application of these influence factors will reduce the factor of safety up to 1.2.

The improved mining block design method is of particular interest for practical purposes.

## Oil shale mining [2]

In Estonian oil shale mines the room-and-pillar mining system with blasting is used. It gives an extraction factor of 70 - 80 %. The field on the oil shale mine is divided into panels subdivided into mining block each approximately 300-350 m wide and 600-800 m long. A mining block consists usually of two semi-blocks. The oil shale bed is embedded at the depth of 40-75 m. Its height corresponds to the thickness of the commercial oil shale bed, approximately 2.8 m.

The width of the room is determined by the stability of the immediate roof. The latter is very stable when it is 6-10 m wide. In this case bolting must still support the immediate roof. The pillars are arranged in a singular grid. Actual mining practice has shown that pillars with a square cross-section suit best. Intra-chamber pillars are left to secure the solidity of the whole upper-laying rock mass and to eliminate surface subsidence. The cross-sectional area of the pillars is 30-40 m$^2$, depending on the depth of the oil shale bed.

**Theoretical background**

Design of mining block parameters is based on the instruction used in Estonian oil shale mines [1]. It bases on the long-term investigations during 30 – 40 years. Mining block design method takes into consideration nine general influence parameters. They are [1]:

1. $k_o$ – coefficient of the karst influence (takes into consideration the distance from stope up to karst);
2. $k_p$ – coefficient of the roof cracks (depends on the distance between the cracks and joints);
3. $k_t$ – rate of the current rock strength (rock parameters depends on the time);
4. $k_s$ – factor of the pillar easing (attenuation);
5. $k_k$ – factor of the pillar form (depends on the pillar sizes);
6. $n$ – given factor of the pillar and roof safety ($n=1.2 \ldots 1.8$);
7. $k_i$ – coefficient, depends on the importance of the supported object on the surface;
8. $K, M$ – parameters, depending on the rock properties ($K=7$ m, $M=0.54$).

Roof and pillar design method analysis showed that the factor of safety is very large (maximum 1.8). Consequently, it includes the unknown factors. The investigation showed that since 1964 73 collapses on the area of 100 km$^2$ have been recorded. The reduction of the value of the factor of safety is possible, when to introduce the supplementary parameters. Investigation showed that they are:

1. Dependence of load distribution on different pillar cross-section area.
2. Dependence of pillar load on rock massive or barrier pillars influence.
3. Dependence of pillar strength on fracture process.
4. Dependence of pillar strength on excavation depth.

**Dependence of load distribution on different pillars cross section area**

The load on the pillars depends on the cross-sectional area of the pillars and on the stiffness of the roof. Investigation in Estonian oil shale mines showed that the roof is stiff enough and in this case a bigger pillar receives a greater load. Consequently, the failure begins from bigger pillars. Load distribution between the pillars of different cross-section area is given in Fig. 1.
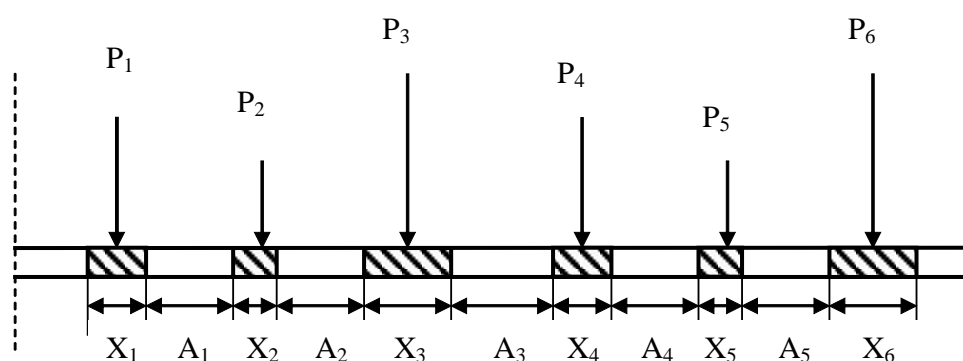


*Fig. 1.* **Load distribution between the pillars of different cross-section area**
**$P_1$, $P_2$, … $P_6$ – load on the pillars; $X_1$, $X_2$, … $X_6$ – width of the pillars; $A_1$, $A_2$, … $A_5$ – width of the rooms.**

For statistical analysis standard programs and a method based on the control of normal distribution of the cross-sectional area of the pillars were used. Investigation was held assuming that by normal distribution of the pillars cross-sectional area a potential collapse of a mining block is likely to be expected. Analysis was made for 12 mining blocks of Ahtme and Estonia mines [2, 3].

Investigation showed that if the pillar sizes differ less and they are stronger, if the normal distribution is not present [3].

The analysis was based on geometrical parameters of mining blocks. The method presented does not take into consideration the rheological rock parameters; and these problems required additional investigations.

### Dependence of pillar load on rock massive or barrier pillars influence

Typically, full load to pillars take place close to the centre of a mining block. Towards the margin of a mining block, there appears a zone where the load on pillars is less than in the centre (Fig. 2). It is related to the influence of the rock massive and barrier pillars.
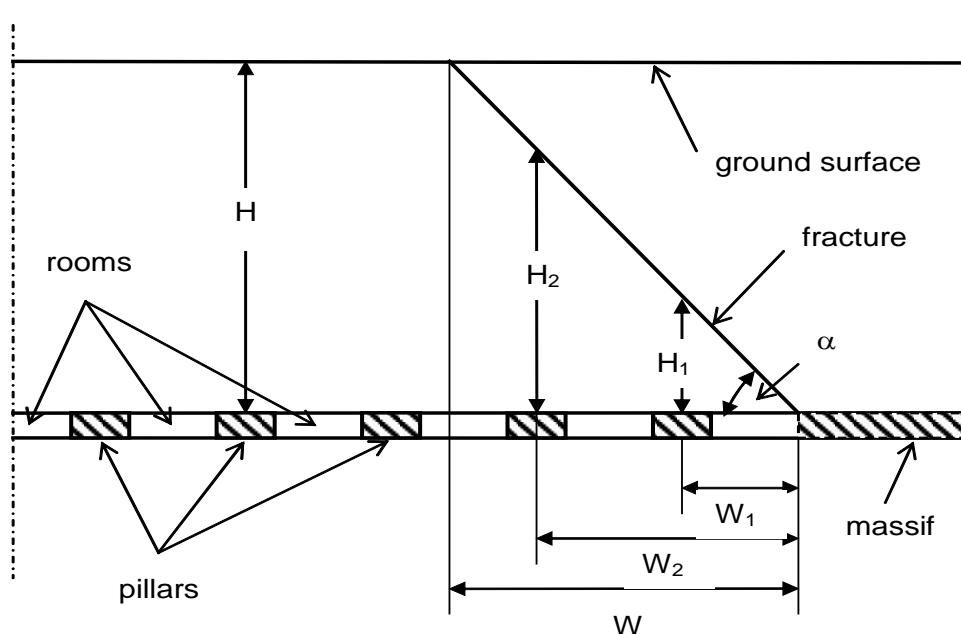


*Fig. 2*. **Geometrical interpretation of the influence zone in a mining block**
**H – depth of excavation, m; $H_1$, $H_2$ – thickness of the overburden rocks, influences on the pillar; W – width of the influence zone; $W_1$, $W_2$ – pillar distance from the rock massive or barrier pillars; $\alpha$ - angle of major influence.**

Theoretical investigation, modeling and experience of in-situ conditions show that the width of the influence zone equals to the half of the critical width [4, 5].

$$W = \frac{L}{2} = \frac{1.2H + 10}{2} \tag{1}$$

where $W$ – width of the influence zone, m; $H$ – depth of excavation; $L$ – critical width, m.
The pillar load ratio in the influence zone is presented by the following formula:

$$K_w = \frac{W_i \tan \alpha}{H} \tag{2}$$

where $K_w$ – pillar load ratio in the influence zone; $W_i$ – pillar distance from the rock massive or barrier pillars, m; $\alpha$ - angle of major influence, deg ($\alpha = 55^0$).

Formula (2) is valid when the distance between the pillar and rock massive (barrier pillars) is in the range $0<W<H/\tan\alpha$, beyond the limit $K_w=1$.

## Dependence of pillar strength on fracture process [6]

Based on the Mohr-Coulomb failure criterion, the theoretical and numerical modeling was performed. For the calculation on PC the FLAC – program was used. Towards the center of a mining block, the vertical load occurs on the top of the pillar, and the orientation of the fracture plan is inclined according to the Mohr-Coulomb's theory (compressional shear fracture). Towards the margin of a mining block, the inclined load occurs on the top of the pillar and the orientation of the fracture plane is vertical (axial fracture). The pillar is stronger by compression shear fracture. The results of theoretical investigations and modeling are close to those in in-situ conditions.

Uni- and bi-axial strength ratio of the pillar is [6]:

$$K_f = \frac{\sin\varphi}{1+\sin\varphi} \tag{3}$$

where $\varphi$ - internal friction angle, deg.

In the case of the compressional shear fracture $K_f = 1$, in the case of axial $K_f < 1$ (Formula 3).

## Dependence of pillar strength on excavation depth

A commercial oil shale bed (pillar) and immediate roof consist of oil shale and limestone seams and the main roof consists of carbonate rocks of various thicknesses. Practical experience evidences that some oil shale bed parameters are not constant and vary depending on the depth and geological conditions. The strength of the rock increases in the southward direction. The probable reasons for that is increase in the thickness of limestone seams and decrease the calorific value of the oil shale seams in this direction. The data of 258 boreholes of Estonian oil shale deposit were analyzed and compressive strength of pillars calculated.

Taking into consideration the 95 % confidence level, southward strength increase is about $1.35 \pm 0.25$ times and can be described by following dependence [2]:

$$K_d = 0.0068H + 0.72 \tag{4}$$

where $K_d \geq 1$ is rate of rock strength increase (for the depth $H \leq 40$ m $K_d = 1$) and deviation are 15 - 28% for the whole of Estonia oil shale deposit.

## Acknowledgment

## Conclusions

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

1. In Estonian oil shale mines the room-and-pillar mining method with blasting is used. Design of the mining block parameters based on the instruction, used in Estonian oil shale mines.
2. Theoretical investigation and experiments of in situ conditions showed that by the calculations, the factor of safety is very large. It contains the unknown factors. Consequently, it is impossible to determine the optimum parameters of a mining block.
3. Theoretical investigation showed that the factor of safety contains four unknown factors. It is opened the physical background and given the mathematical formulas of these factors.
4. Application of these factors for design the mining block parameters improve the design quality. It will reduce the factor of safety up to 1.2.

**References**

1. Mining-law and legal regulation acts. Ministry of Environment, Ministry of Economy. Part II. Tallinn, 1988 (in Estonian).
2. Nikitin, O. Optimization of the Room-And-Pillar Mining Technology for Oil-shale Mines. Doctoral theses. Tallinn, TTU, 2003 .
3. Pastarus, J.-R. Improved method of predicting long-term stability of the mining blocks in Estonian oil shale mines. Proc. of the International Conference "Scientific achievements for wellbeing and development of society. Enabling environment for society wellbeing". (Noviks, G. ed.). Rezekne Augstskolas Izdevnieciba, Rezekne, Latvia, March 4-5, 2004, p.37-42.
4. Pastarus, J.-R., Toomik, A. Roof and pillar stability prognosis in Estonian oil shale mines. Rock Mechanics. Proc. of the ISRM regional Symposium EUROCK 2001 "Rock Mechanics a shallenge for society". Espoo, Finland, 4-7 June 2001, A. A. Balkema/Lisse/Abingdon/Exton (PA)/Tokyo, 2001, p.849-853.
5. Pastarus, Yu.-R. V., Nikitin, O.V. Estimation methods for stability of mining excavations (on the example of shailoil deposit in Estonia). Gornyj Zhurnal. Ruda I Metally, Moscow, 4-5. 2003, p.71-75. (in Russian).
6. Pastarus, J.-R. Fracture process in pillars. Proc. of the International Conference on Structural Integrity and Fracture (SIF 2002). Perth, Australia, 25-27 September 2002, p.343-346.