

# CONCEPT OF RISK ASSESSMENT FOR ESTONIAN OIL SHALE MINES

## *RISKA NOVĒRTĒŠANAS JĒDZIENS IGAUNIJAS DEGLĀNEKĻA RAKTUVĒS*

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**Abstract.** *The paper deals with the risk assessment problems in Estonian oil shale mines, where the room-and-pillar mining with blasting is used. This study addresses risks associated with the collapse of mining blocks, including environmental problems. Some of the various factors, which are relevant to Estonian oil shale mines, are determined. For risk estimation the event tree is used. Investigation showed that the likelihood and the consequences of the risk are not acceptable. Risk mitigation process reduces the likelihood. The used concept of risk assessment method is applicable for Estonian oil shale mines. It may be used for different purposes and levels. The results of the risk assessment are of particular interest for practical purposes.*

**Keywords:** *collapse, event tree, mining block, mitigation, probability, risk analysis, risk assessment, risk evaluation, risk management, surface subsidence.*

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### **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.

Underground mining in Estonian oil shale mines causes a large number of technical, economical, ecological and juridical problems. The data, which have become available in the last 40...50 years, provide a foundation for the ideas recommended to be used in risk assessment.

This study addresses risks associated with the collapse of mining blocks, including environmental problems. Up to present, 73 collapses on the area of 100 km<sup>2</sup> (about 400 mining blocks) have been recorded. Application of risk assessment to Estonian oil shale mines raises a unique set of problems, because each mine and mining blocks is a unique system within its own distinctive environment.

The risk analysis is use of available information to estimate the risk to ground surface subsidence from hazards. Some of the various factors, which are relevant to Estonian oil shale mines, are determined. Probabilistic risk analysis is a more rational basis for evaluation. For the risk estimation the event tree is used. Having received the risk information, and knowing the risk valuation criteria, we come to a decision.

The primary interest in this study has been in evaluating the usability of the methodology and in evaluating the probability of failure without detailed assessment of consequences.

Analysis showed that the used concept of risk assessment method is applicable for Estonian oil shale mines. The concept of risk assessment may be used for different purposes and at different levels: at the mining block design stage; as bases for decision-making when selecting among different remedial actions for mined out area within time and financial restraints; to relate ground surface subsidence risk levels to acceptable risk levels established by society for other activities. The results of the risk assessment are of particular interest for practical purposes.

### **Concept of risk assessment**

Risk assessment is the process of deciding whether existing risks are tolerable and risk control measures are adequate. It incorporates the risk analysis and risk evaluation phases. Risk assessment involves making judgment about the taking of risk and all parties must recognize that

the adverse consequences might materialize and owners will be required to deal effectively with the consequences of the failure event [1, 2, 3]. The primary steps of a risk assessment are presented in Fig. 1.

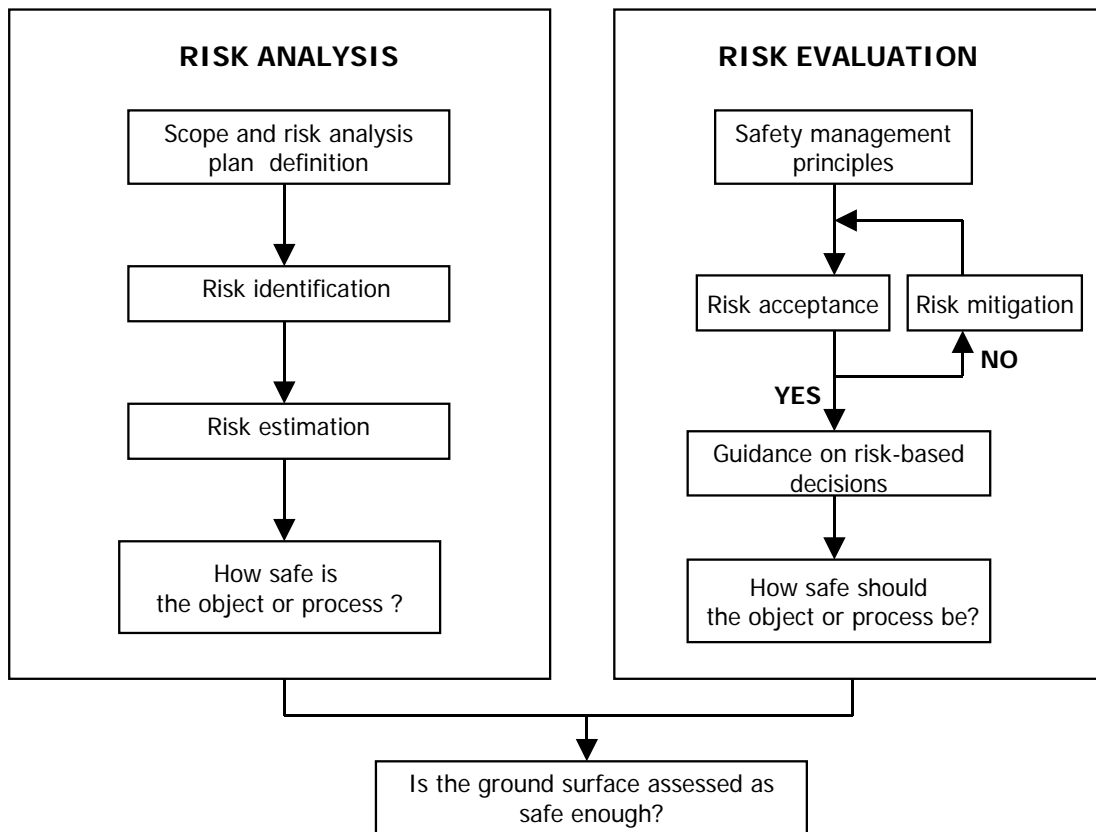


Fig. 1. Risk assessment [3]

### Risk analysis

Risk analysis is used for performing safety assessment for many different technical systems. Many authors have described the sequential steps that comprise technical systems risk analysis. Concerning the varied terminology, most are in general agreement over the basic requirements [1, 2, 4]. Risk analysis includes (Figure 1):

1. Scope and risk analysis plan definition
2. Risk identification
3. Risk estimation

The description of the system, scope and expectations of the risk analysis should be defined at the outset. An iterative approach should be adopted with qualitative methods being employed at the early stages of the process. If more information becomes available, use of quantitative analyses is required.

Risk identification is the process of determining what can go wrong, why and how [3]. Failure can be described on many different levels. Conceptualization of the different possible failure modes for a technical system is an important part of risk identification. One should first take into account as many types of failure as possible. The initial list can then be reduced by eliminating those types of failures considered implausible.

Risk estimation entails the assignment of probabilities to the events and responses identified under risk identification. The assessment of appropriate probability estimates is one of the most difficult tasks of the entire process. Tools that are often used to help in risk estimation are fault trees and event trees [1, 2, 4]. Probability estimation can be grouped into three general approaches depending on the type and quality of the assailable data [3]:

1. Analytical approach uses logical models for calculating probabilities.

2. Empirical approach uses existing databases to generate probability.
3. Judgmental approach uses experience of practicing engineers in guiding the estimation of probabilities.

Attaining an exact value of probability for technical systems and processes is not a realistic expectation. Component event probabilities may be assessed using a subjective degree-of-belief approach (Table 1.).

*Table 1.*

**Verbal description of uncertainty [5]**

<b>Verbal description of uncertainly</b>	<b>Uncertainty</b>
1. Virtually impossible	0.01 (0.001)
2. Very unlikely	0.10
3. Completely uncertain	0.50
4. Very likely	0.90
5. Virtually certain	0.99 (0.999)

### **Risk evaluation**

Risk evaluation is the process of examining and judging the significance of risk [1, 3, 6]. Risk evaluation stage is the point at which values and judgments enter the decision process, by including consideration of the importance of the estimated risks. Risk evaluation is fundamental to risk assessment and risk-based decision making. The principal role of risk evaluation in risk assessment is the generation of decision guidance against which the results of risk analysis can be assessed. It requires a statement of the owner's safety management principles and of the values and preferences of the public (prevailing financial, legal and regulatory conditions). The risk evaluation process should be clearly communicated to all interested groups. The extent, to which each of these basic principles apply depend on the nature of the risk assessment. Risk evaluation includes.

1. Risk mitigation
2. Risk acceptance

Risk mitigation is a selective application of appropriate techniques and management principles to reduce either likelihood of an occurrence or its consequences, or both [2, 3, 6]. Risk mitigation is a logical step following risk estimation. If the calculated risk of the existing system is judged to be too high, alternatives are proposed to reduce the risk of failure. These alternatives are incorporated into the risk model and re-evaluation is conducted to estimate their impact. After repeated study the decision makers can be provided with suitable alternatives and their estimated costs for consideration in improving overall technical system safety.

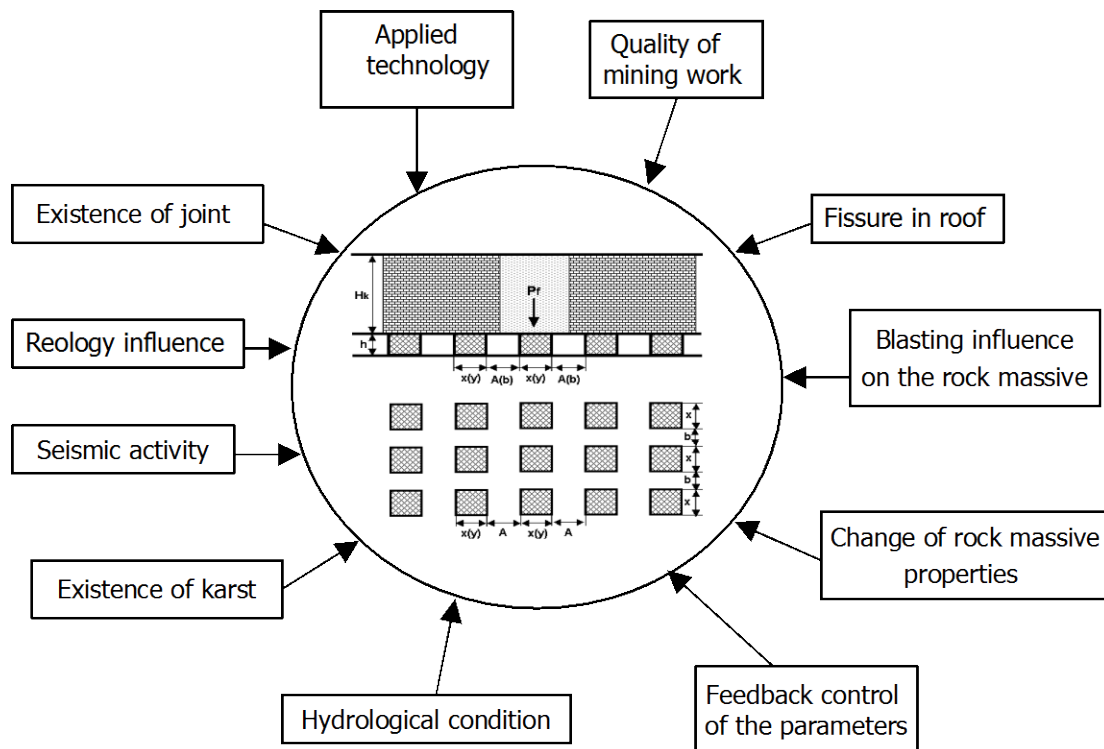
Risk acceptance is an informed decision to accept the likelihood and the consequences of a particular risk [1, 2, 3]. In some countries, there is a certain risk level that is defined as the limit of unacceptable risk. For failure events with no potential fatalities or irreparable damage to the environment, the target annual failure probability may be decided exclusively base on economic considerations and corresponding risk analysis. A target level of  $10^{-3} \dots 10^{-2}$  rather than  $10^{-6} \dots 10^{-5}$  may be a reasonable criterion [5].

### **Risk management**

Risk management is the systematic application of management policies, procedures and practices to the task of identifying, analyzing, assessing, treating and monitoring risk [1, 2, 6]. Having received the risk information, and knowing the risk evaluation criteria, a decision-maker must come to a decision. The decision process includes consultations with stakeholders and community, insurance issues, legal defensibility of decisions, risk information to decision-maker and to the public [3].

### Investigations in Estonian oil shale mines

Technical and geological aspects by underground mining can influence on collapse of a mining block and surface subsidence. Some of various factors which are relevant to Estonian oil shale mines are presented in Fig. 2.



**Fig. 2. Contributing factors for mining block collapse and surface subsidence**

Main technical aspects, which can influence on the stability of a mining block, are quality of mining and blasting works. Investigation showed that room and pillars sizes in Estonian oil shale mines may deviate from project values. Maximum deviation is about  $\pm 1$  m. It depends on quality of the applied machinery and miners. On the other hand the rock mass properties can change, caused by blasting works. In the roof and pillars appear supplementary cracks, which decrease the strength of the rocks.

Feedback control and adaptive design methods guarantee the stability of a mining block [7].

Influence of the geological parameters on the mining block stability is significant. Rheological behavior of rock was studied and taken into consideration by calculations [8].

Karst and fissure (joints) influence on the stability of a mining block is evident. These factors are determined for Estonian oil shale deposit and presented on the map of a mining block.

Especially attention must be paid to hydrological conditions. Many old mines are completely flooded. It is not known, what will appear in the future, after 20 – 30 years.

Seismic activity in Estonia is at such a low level that it has been considered in this study only to a restricted extent. It is practically impossible.

The above mentioned technical and geological influence factors can lead to the damage of the ground surface. Importance of these factors in mining block collapse and surface subsidence process demands supplementary investigations.

Event tree presents the risk estimation. For the probability determination the judgmental and subjective degree-of-belief approaches are used (Table 1).

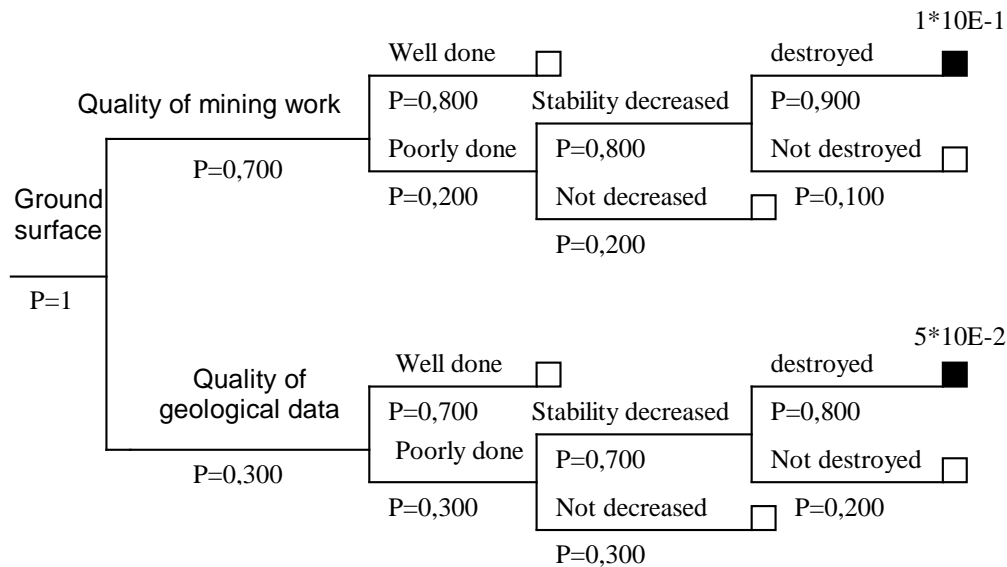


Fig. 3. Event tree

Presented event tree shows the ground surface damage form two factors: quality of mining works and geological data. In the case of quality of mining works the estimated probability of surface subsidence is  $10^{-1}$ . The probability of surface subsidence when concerning quality of geological data is of  $5 \cdot 10^{-2}$ . The summarized total probability of surface subsidence is of the order of  $1.5 \cdot 10^{-1}$ .

The estimation probability of the surface subsidence exceeds 15 times the limit ( $10^{-3} \dots 10^{-2}$ ). Consequently, the risk for mining blocks is not acceptable (Fig.3). Risk mitigation methods allow reducing either likelihood of the mining block collapse or its consequences, or both.

Design of mining block parameters based on the instruction, used in Estonian oil shale mines [8]. Analysis of the applicable mining block design method showed that the factor of safety is very large (1.2 – 1.8). Practically, it is impossible to determine the adequate factor of safety for a mining block. Consequently the factor of safety contains the unknown factors. Determination of the unknown factors is the task for the future.

On the other hand, the method of adaptive design can reduce the probability of a working mining block collapse [7]. It based on the monitoring system, which allows determining the potential collapse center in a mining block. Based on this data, it is possible to modify the pillar sizes. This method increases the stability of a mining block.

These above mentioned risk mitigation methods reduce likelihood of the mining block collapse and it consequences. In this case the risk will be acceptable. If not, alternatives will propose to reduce the probability of the collapse and surface subsidence. It demands supplementary investigation.

### Conclusions

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

1. Underground production in Estonian oil shale mines is obtained by room-and-pillar method with blasting. It causes a large number of technical, economical, ecological and juridical problems. The data, which have become available in the last 40...50 years, provide a foundation for the ideas recommended to be used in risk assessment.
2. This study addresses risk associated with collapse of mining blocks, including surface subsidence. The primary interest in this study has been in evaluating the usability of the

- methodology and in evaluating the probability of the mining block collapse and surface subsidence without detailed assessment of consequences.
3. Some of the various factors, which are relevant to Estonian oil shale mines, are determined. For risk estimation the event tree is used. The probability of mining block collapse and surface subsidence is  $1.5 \cdot 10^{-1}$ .
  4. Investigation showed that the likelihood and the consequences of the risk are not acceptable. It exceeds 15 times the limit. Risk mitigation process reduces the likelihood.
  5. Analysis showed that used concept of risk assessment method is applicable for Estonian oil shale mines. Presented method may be used for different purposes and at different levels. The results of the risk assessment are of particular interest for practical purposes.

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