

GEOLOGICAL ASPECTS OF RISK MANAGEMENT IN OIL SHALE MINING

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The paper deals with risk management problems in Estonian oil shale mines. Investigations are focused on application of the method to determination of the quality of geological data. Various factors relevant to mining technology in Estonian oil shale deposit have been determined. For risk estimation, the empirical and judgmental approaches and the event tree were used. They allow determining the probability of the occurrence of geological features and its influence on the mining process. Analysis of obtained results showed that it is necessary to elaborate special methods for determination of the geological conditions in the mining area. The obtained information affords specialists to improve the quality of geological information and consequently the mine work efficiency. The analysis shows that the used method is applicable in conditions of Estonian oil shale industry. The results of the investigation are of particular interest for practical purposes.

Introduction

In Estonia the most important mineral resource is oil shale. Oil shale industry of Estonia provides a significant contribution to the country's economy. Underground and surface mining in the Estonian oil shale deposit causes a large number of technical, economical, geological, ecological and juridical problems, which cannot be solved on conventional theoretical basis. Risk management is a most powerful tool to solve complicated mining problems. The data, which have been accumulating in the last 40–50 years, concern the experience obtained by oil shale excavating and provide a good basis for investigations.

This study addresses risks associated with stability of the immediate roof in the mines Estonia and Viru, depending mostly on the geological feature. The primary interest of this study concerns evaluating the usability of the

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method and estimating the probability of failure without a detailed assessment of its consequences. The study is based on the world's and Estonian experience. As an example of application, the risk analysis of Estonian oil shale mines has been conducted.

Risk management involves making a judgment about taking a risk, and all parties must recognize the possibility of adverse consequences which might materialize [1–4]. Therefore, owners will be required to deal effectively with the consequences of a failure event. Prevention of the hazardous situation is more moral, ethical and economic than facing the adverse consequences. Having received the information, the management of a mine or open cast can come to adequate political and strategic decisions. The mitigation process will reduce the adverse consequences [1, 5]. Investigations have shown that the share of risk relevant to geological data in mining and environmental protection is very large. It is known that rock mass properties vary and depend on its location. It is impossible to determine exactly all the geological features. The reliability of geological data determines the efficiency and safety of mining and environmental impact. It includes bedding, underground and surface water conditions, existence of karst, joint systems, etc.

Some of the various geological factors relevant to Estonian oil shale mines have been determined. For risk estimation, the judgmental and empirical approaches and event tree have been used. The risk management method allows predicting the probability of failure of the immediate roof in the location of interest. Getting the information allows specialists to mitigate negative influence of risks on the excavation process and environment.

Analysis showed that the risk management method used is applicable to Estonian oil shale mines, which are of particular interest for practical purposes.

Theoretical background

In the world, risk management methods are used in different branches of industry and for many different technical systems. In Estonia, including *Eesti Põlevkivi Ltd*, risk management methods are focused on health safety problems. There is less information about the application of risk management methods to geological conditions and technological processes. In spite of the varied terminology, there is general agreement on the basic requirements [1, 3, 5, 6]. The terminology and risk management/assessment methodology used in the frame of this project are presented below.

Risk can be defined as the likelihood or expected frequency of a specified adverse consequences [1, 4]. Risk management is the systematic application of management policies, procedures and practices to the task of identifying, analyzing, assessing, treating and monitoring risk [1, 3, 4]. Having obtained the risk information, a decision-maker must come to a decision.

Risk assessment is the process of deciding whether existing risks are tolerable [1, 3, 4, 7–10]. It involves making judgments about taking the risk (whether the object or process is assessed as safe enough). Risk assessment incorporates the risk analysis and risk evaluation phases. Schematically the process of risk management/assessment is presented in Fig. 1.

Risk analysis is the process of determining what can go wrong, why and how. It entails the assignment of probabilities to the events. This is one of the most difficult tasks of the entire process. Probability estimation depends on the type and quality of the available data: analytical, empirical or judgmental approaches [1, 3, 7]. Component event probabilities may be assessed using a subjective degree-of-belief approach [2, 4].

Attaining an exact value of probability for technical systems and processes is not a realistic expectation. Tools that are often used to help in risk estimation are fault/event trees [1, 4, 11].

Risk evaluation is the process of examining and judging the significance of risk. It is based on the available information and the associated social, environmental and economic consequences.

Risk acceptance is an informed decision to accept the likelihood and the consequences of a particular risk. 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 failure probability may be decided exclusively basing on economic condi-

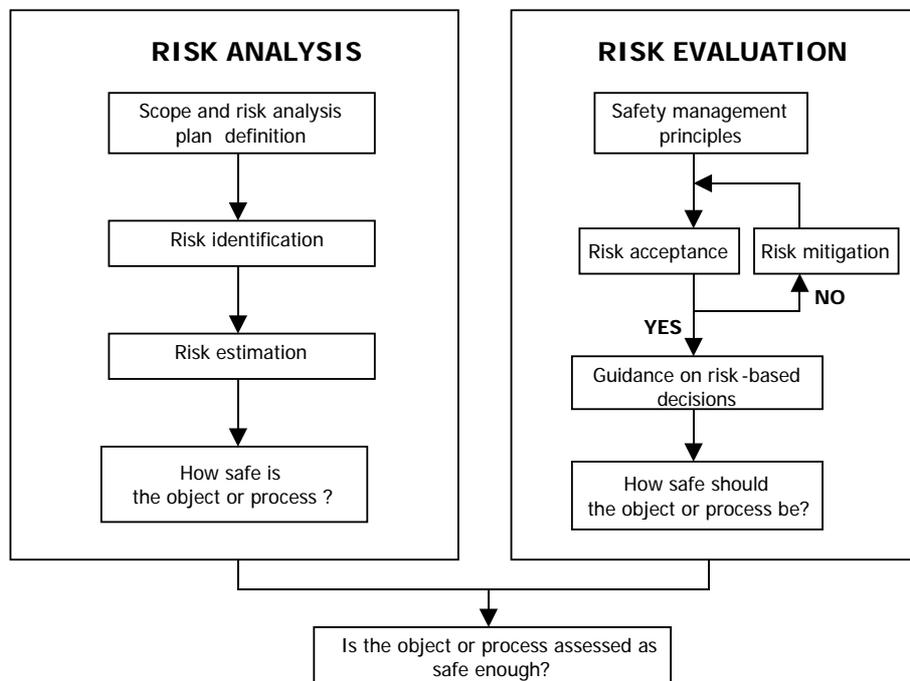


Fig. 1. Risk management/assessment process.

tions and corresponding risk analysis. A target level of 10^{-3} to 10^{-2} for lifetime risk of the object or process may be a reasonable criterion [1, 2].

Risk mitigation is a selective application of appropriate techniques and management principles to reduce either likelihood of an occurrence or its consequences, or both [1, 3–5, 12].

Contributing geological factors

Geological and technological aspects of underground mining can influence the efficiency of mine works and environment protection. The share of geological information in these processes is large enough. Some of various factors which are relevant to Estonian oil shale mines and open casts are presented in Fig. 2.

In the first stage of investigations, the contributing factors are divided into two groups: geological and technological factors. Main technological aspects influencing the stability of a mining block (block of rooms at underground mining) concern the quality of mining and blasting works. Feedback control and adaptive design methods guarantee the stability of a mining block [13].

The influence of geological parameters and features on the mining efficiency and environment protection is significant. Stability of an immediate roof in face is determined by geological features. The presence or vicinity of karst, joints and fissures, and aquifer in the overburden rocks in

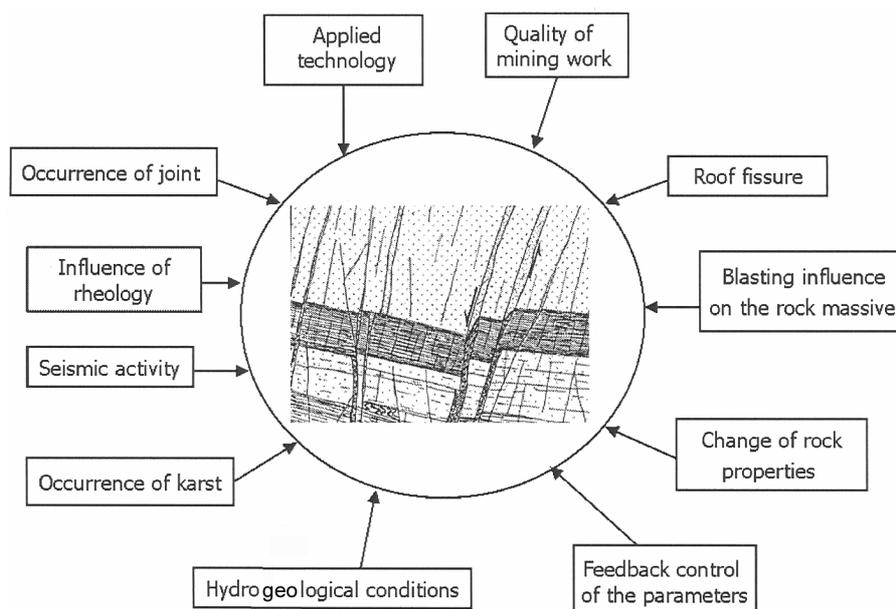


Fig. 2. Factors contributing to the mining process.

face of the mines Estonia and Viru determines the stability of the immediate roof. These factors, in general, have been determined for the Estonia oil shale deposit and are presented in a map. A great deal of the karst and joints inside a mining block area is undetermined, as they are practically impossible to determine. Risk management/assessment methods allow solving these complicated problems.

Seismic activity in Estonia is at such a low level, practically negligible, that it has been considered in this study only to a limited extent.

Immediate roof collapse risk in face, Estonia mine

In the Estonia mine, mining blocks are in different geological conditions. In the southern area the geological conditions are complicated due to the presence of karst, joints, aquifer in the overburden rocks. They influence the stability of the immediate roof. The roof fall risk increases. Figure 3 presents the event tree for immediate roof stability.

Investigation of *in situ* conditions has shown that immediate roof stability depends on two factors: mine work quality (influence 70%) and geological conditions (influence 30%). Investigations have shown that owing to high quality of mine works the probability of roof stability is 90%.

In the Estonia mine the room height is 2.8 m. In normal geological conditions it guarantees the stability of the immediate roof in face. Room height of 2.8 m in complicated geological conditions does not guarantee the stability of the immediate roof. In this case the room height must be increased up to 3.8 m. Investigations showed that the probability of immediate roof collapse in the Estonia mine is 5% (Fig. 3). It is evident that the estimated probability exceeds the limit (10^{-3} – 10^{-2}). On the other hand, it is known that determina-

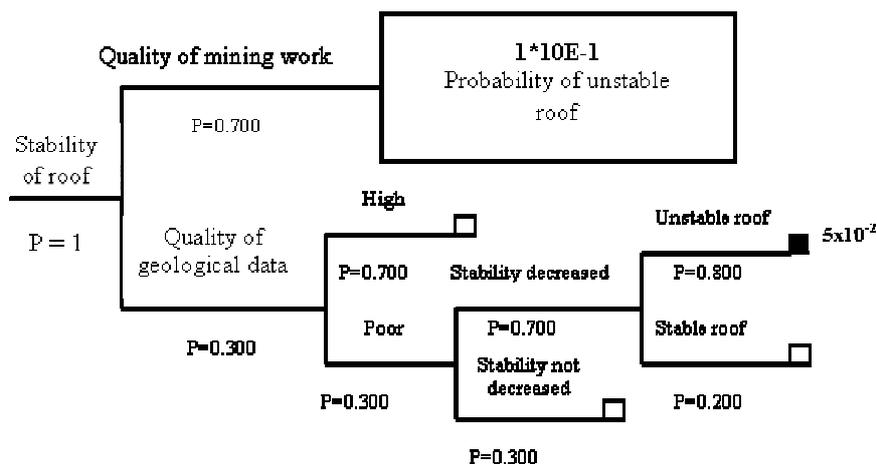


Fig. 3. Event tree for immediate roof stability in face, Estonia mine.

tion of the geological features inside a mining block is practically impossible. It is necessary to elaborate special methods to determine a geological feature inside a mining block. This complicated problem demands additional investigations.

Immediate roof collapse risk in face, Viru mine

The geological structure and features of the immediate roof in stop determines the number and sizes of potential dangerous blocks. Prediction of these factors is practically impossible. Risk management methods allow solution of this problem basing on the experimental data of *in situ* conditions.

The investigation was conducted at the Viru mine in the mining block No. 184 (right wing). 33 collapses of the immediate roof in stop were registered. Caving size ranged from 0.001 m^2 (0.1 by 0.1 m) to 6.0 m^2 (3.0 by 2.0 m). The height of the collapses in the roof varied from 0.05 m to 3 m.

Stability of the immediate roof in stop has been controlled after blasting works. The visible potentially dangerous roof blocks were removed immediately (enforced collapse). Long-term mining experience has shown the efficiency of this method. After that the spontaneous collapses may appear in stop, caused by rheological processes.

For probability estimation an empirical approach was used. All the statistical calculations were based on the actual data of *in situ* conditions. The event tree is presented in Fig. 4.

Analysis of the event tree showed that the probability of spontaneous collapses, which appear during mine works, is negligible (0.015%). The probability of enforced collapses remains below 0.5%. Such collapses are not dangerous because during face inspection the potential dangerous blocks will be removed.

In summary, collapses in stop are not dangerous for workers and equipment. The probability of the collapses is below the limit 10^{-3} – 10^{-2} .

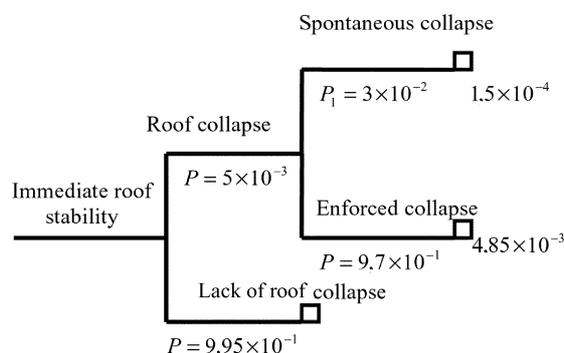


Fig. 4. Event tree for immediate roof stability in face, Viru mine.

Discussion

Risk management/assessment methods allow determining the probability of the immediate roof collapse using the event tree. Having got this information, the mine management may decide about taking risks: are they acceptable or not; are they dangerous for workers and/or for the environment? If this risk is not acceptable, the mine management must preview the risk mitigations methods: use of appropriate techniques or/and management principles to reduce either likelihood of an occurrence or its consequences, or both. In the Estonia mine the room height of 3.8 m reduces the probability of an immediate roof collapse and its negative consequences, being the only true solution.

On the other hand, information about the probability of an immediate roof collapse offers the scientists objects for future investigations.

Conclusions

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

1. Geological and technological factors relevant to immediate roof stability have been determined. The share of geological factors, such as karst, joints, fissures, aquifer, etc. in this process is large.
2. Geological risks by underground mining are estimated by empirical and judgmental approaches. In the investigations the event tree was used.
3. The influence of the quality of geological data on the mining process is significant. It is necessary to elaborate special methods to determine the geological features inside a mining block.
4. The risk management method is a powerful tool to solve complicated mining problems. The analysis showed that the method is applicable in conditions of Estonia oil shale deposit. The results of the investigation are of particular interest for practical purposes.

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REFERENCES

1. *Calow, P.* Handbook of environmental risk assessment and management. – Oxford, Blackwell Science, 1998.
2. *Hoeg, K.* Performance evaluation, safety assessment and risk analysis for dams // *Hydropower & Dams*. 1996. No. 6. P. 69–87.
3. *Rowe, E. W. D.* Risk assessment approaches and methods. // *Society, Technology and Risk Assessment* / J. Conrad (ed.). London: Academic Press, 1980. P. 3–29.
4. *Tint, P.* Risk Assessment at Working Place. Chemical Risk. Published by TUT, Tallinn, 1999 [in Estonian].
5. *Lind, H. G.* Mitigating the risk associated with underground coal pillar extraction in South Africa // *Mining Technology*. Transaction of the Institutions of Mining and Metallurgy. 2004. Vol. 113, No. 4. P. 215–224.
6. *Kristjuhan, Ü.* Actual Problems of Catastrophes and Risk Management I, II. Published by TUT, Tallinn 1997, 1999 [in Estonian].
7. *Williams, D. J., Loch, R. J., Vacher, C.* Risk assessment applied to tunnel erosion of mine spoils // *Proc. of the 11th Tailings and Mine Waste Conference*. 10–13 October 2004, Vail, Colorado, USA, 2004. P. 63–70.
8. *Graham, L. P., Bartsch, M.* Risk analysis safety assessment for use at Swedish dams // *Symposium: Research and development in the field of dams*. Crans-Montana, Switzerland, 7–9 September 1995. P. 12–19.
9. *Andrews, J. D., Moss, T. R.* Reliability and Risk Assessment. – Longman, Harlow, UK, 1993.
10. *Pastakia, C., Jensen, A.* The rapid impact assessment matrix (RIAM) for EIA // *Environ impact Asses rev.*, New York, 1998. P. 461–482.
11. *Alexieva, T.* The Benefits of the Risk Assessment to the Mining Industry. Tailings and Mine Waste. – Balkema, Tokyo, 2002. 295 p.
12. *Duzgun, H. S. B., Einstein, H. H.* Assessment and management of roof fall risks in underground coal mines // *Safety Science*. 2004. No. 42. P. 23–41.
13. *Pastarus, J.-R., Sabanov, S.* A method for securing working mining block stability in Estonian oil shale mines // *Engineering*. 2005. Vol. 11, No. 1. P. 59–68.

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