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RISK ASSESSMENT OF FEASIBILITY OF ROADHEADERS IN ESTONIAN UNDERGOUND MINING

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This paper deals with the risk assessment method of roadheader feasibility in underground conditions of Estonia mine. In modernization of Estonian underground mining, roadheaders that extract oil shale selectively play the most important role. Selective extraction allows reduction of rock mass volumes during the loading, transportation and enrichment processes. Thus, about 23% of limestone extracted together with oil shale will be left in the mine for backfilling the excavated areas. Backfilling increases carring capacity of pillars reducing losses of oil shale and restores, in a certain measure, filtrational, hydrodynamical, and aerodynamic properties of the geological environment.

For selective extraction four variants of different excavation thicknesses, depending on geological conditions, have been proposed. Risk analysis allows comparison of the advantages and disadvantages of full and selective extraction. Risks of oil shale losses during selective extraction are estimated using the event tree. Preliminary calculations have shown sustainability of roadheaders for selective extraction under the mining and geological conditions of Estonia mine.

Introduction

In Estonian underground mining, modernization process concerns, first of all, machines that extract oil shale: continuous miners and roadheaders.

The main goal of using roadheaders and continuous miners is improvement of the extraction process accompanied by replacement of blasting works by selective cutting of rock, introduction of flexible and mobile mining-transportation systems with exploitation of highly mechanized and highly productive machines which can be used in several parts of the mine; optimisation of room and pillar dimensions.

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Nowadays all parameters of a mining block are calculated for a long period, and this reduces the extraction factor to about 10%. Consequently, in the case of the method proposed by us [1], the main requirement is long-term stability of the main roof and greatest extraction factor enabled by the new flexible technology.

In this study the risk assessment method was used for determination of feasibility of roadheaders and continuous miners in conditions of Estonian mines. It was shown that roadheaders are most applicable at selective extraction and continuous miners are preferable for full extraction. Selective extraction has been studied for four types of layer thickness with two possible variants. Selective extraction allows to reduce rock mass volumes during loading, transportation and enrichment processes. Risk analysis enables to compare advantages and disadvantage of full and selective extraction [2]. Besides, backfilling offers the possibility of reducing pillar dimensions and minimises losses of oil shale reserves. Risk estimation of oil shale losses is the case of selective extraction has been made with application of event tree.

Overview of performance of roadheaders and continuous miners

Extremely powerful rock-cutting machines designed for continous excavation of roadways, tunnels and chambers use no explosives. Powered electro-hydraulically and emitting no fumes, these machines are used extensively in mining of coal and other mineral resources and in underground construction projects, where their ability to excavate the desired profile without causing harmful vibrations is highly valued for both environmental and safety reasons [3].

The roadheader family also includes separate, multi-purpose hydraulic cutting heads for mounting on excavators (Fig. 1A). Roadheaders for mining are equipped with powerful, geometrically optimized, transverse cutter heads proven to give the best cutting performance in a wide range of rock formations. Mounted on an extremely robust hydraulic boom (telescopic on some models), they offer a rugged, reliable, highly productive solution for development and direct production duties [3].

Robotic continuous miners are now being developed for more automatic operations (Fig. 1B). These offer a vision of the standard mining method of the future: “intelligent” mining machines are completely controlled by computers, with sensors that pinpoint the positions of all moveable parts, and onboard control systems that run the equipment and collect data on the seam. A robotic miner would have its own navigation and guidance systems, as well as internal diagnostics to spot problems and video equipment to allow continuous monitoring of the mining operation by highly trained personnel located in a safe position either underground or on the surface [4].

(a)

(b)

Fig. 1. a) Roadheader; B) Continuous miner.

In today's world, hundreds of kilometers of tunnels are being excavated for mining and construction purposes. Parallel to the rapid increase in urbanization, the need for tunnels in transportation and infrastructure has also increased. On the other hand, there is a tendency towards underground production methods in mining due to the environmental restrictions and the decrease of mining resources close to the surface of the earth. For economic reasons, early commencement of production is required in underground mining operations. Therefore, mechanized excavation systems have become more advantageous than the conventional methods in such mining projects. Roadheaders occupy an exceptional place among the other mechanized excavation machines. Besides driving tunnels, they have received widespread applications for production purposes at excavating of coal, evaporates, industrial minerals and metallic ores. The performance of roadheaders has been investigated for formations of various types. Their initial investment costs are lower than those for the full-face excavation machinery. They are also flexibly equipped to excavate galleries in various shapes. However, they are not suitable for hard cutting conditions being more preferable for excavating stable rocks of low to medium hardness. Roadheaders are generally classified with respect to their weight as being of light, medium, heavy, and extra heavy types. Heavy types can be used in rocks of higher strength, as the weight is proportional to cutting head power and boom forces. Machine weight of more powerful machines is greater, due to increased boomreaction forces. Otherwise, machine stability is negatively affected and instability may occur. On the other hand, the increase in weight causes a rise in the initial cost of the machine and also problems of sinking of the machine in wet ground. To increase machine stability, side and rear stabilizer pistons are generally used. Side stabilizers may not be useful in tunnels of wide profile. The stability of a roadheader during operation is vitally important for an effective and continuous cutting process [5].

Some researchers have addressed the importance of stability and compared longitudinal- and transverse-head-type roadheaders. As for the transverse cutting-head type, the main component of the resultant cutting force acts vertically on the head. Hence, the transverse cutting-head type is more sensitive to the stability in the vertical direction. On the contrary, the longitudinal-head-type machine is more sensitive to the stability in the horizontal direction. The longitudinal-head-type machines are said to be unable to utilize the full weight of the machine, accordingly they are claimed to require 20–25% more weight than transverse-type machines. It is also reported that, being of the same cutting power, transverse-type roadheaders can cut rock of higher strength than the longitudinal-head-type machines owing to stability considerations [6]. However, it is noted that vertical stability should also be considered at comparison of the stability of roadheaders, since the longitudinal-head-type roadheader can cut vertically as well [5].

Risk analysis of roadheader applicability under conditions of the Estonia mine

Risk analysis for roadheaders is carried out for two methods of extraction. The first method is full extraction and the second one – selective extraction, which allows to reduce rock mass volumes at loading, transportation and enrichment processes. Using selective extraction limestone in the quantity of about 23 vol.% mined together with oil shale can be left in mine for backfilling the excavated areas. It reduces the volume of stored rock waste on the ground surface and decreases harmful influence on the environment. Figure 2 demonstrates that limestone content of layers A, A/A1 and A1 makes 52% of the total amount of rock. On the other hand, extraction layers B, B/C and C containing only 13% limestone are preferred to be mined. Since the diameter of cutting head does not enable to cut separately the 6-cm layer D, C/D, D and D/E must be cut together and left for backfilling.

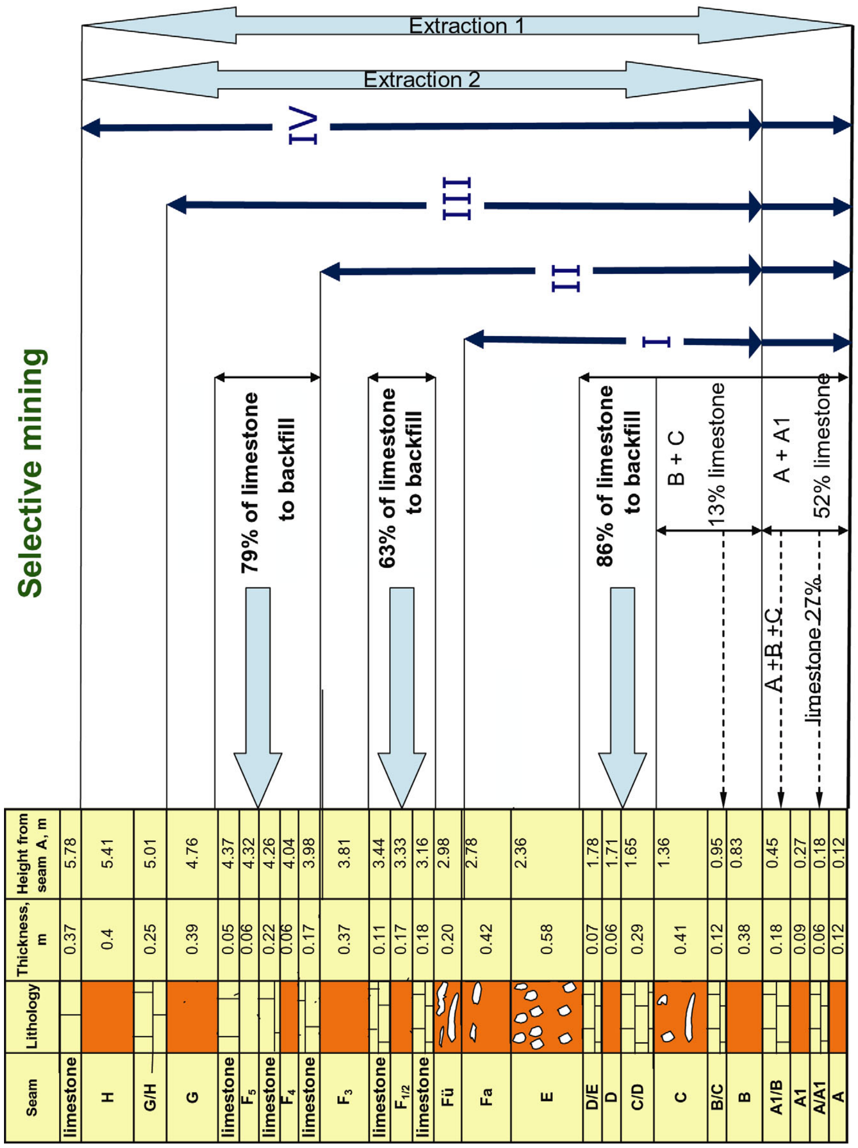

Fig. 2. Cross-section of oil shale commercial bed and extraction possibilities at selective mining.

Four variants of various thickness of development are offered for selective extraction (Fig. 2). The first variant (I) applies to commercial thickness 2.78 m. In this case layers C/D, D, D/E of the thickness 42 cm, that makes 14% of the total amount of rock, are excavated and transported to the mined-out area for backfill. It means that pillars can be designed to have in places of backfilling smaller cross-sectional area that, in turn, reduces oil shale losses with pillars. At excavation height of 4.76 m (III) and 5.41 m (IV), the machine may not perform successfully due to problems arising from machine stability, which adversely affects productivity by 20–30%. However, at the height of 4.76 m selective extracting of limestone layers C/D, D, D/E, F1/F3 and F3/G is carried out in the total thickness of 144 cm, that makes 30% of the total rock amount offering a favorable opportunity to reduce losses with pillars. Limestone content of shale for enrichment makes 8%.

When extracting the layers of thickness 4.76 m anchors must be 60% shorter. One of the adverse factors is choice of such a conical corner of cutting head which will cut in the top part without curvatures, in order to prevent dangerous cusps in the roof. For that reason cusps will appear on the floor, and their elimination will demand additional time. Table 1 presents the amounts of limestone at extraction of different thicknesses. For limestone transportation to waste, additional expenses are needed.

Table 1. **Percentage of limestone going to waste**

Variant of extraction thickness	Selective extraction 1, %. Start from layer A	Height of extraction from layer A, m	Selective extraction 2, %. Start from layer B	Height of extraction from layer B, m	Full extraction, %
I	12.1	2.78	4.0	2.33	24.2
II	9.4	3.81	3.6	3.36	26.5
III	7.6	4.76	2.8	4.31	30.5
IV	11.3	5.41	7.5	4.96	31.4

Risk estimation of four variants of extraction thickness

Risk estimation entails the assignment of probabilities to the events – responses – identified under risk identification. The results of investigation are presented in Figures 3 and 4. The event tree demonstrates probability of risk magnitude (P) for selective extraction thicknesses 1 and 2 (Fig. 2). Figures 3 and 4 show four variants of extraction thicknesses (I, II, III, and IV). Risk magnitude is the result of multiplication of two components. One of them is probable volume of limestone, which demands additional expenses for transportation to waste generation. The second one is losses of thin oil shale layers, which will be left in mine to backfilling. Small number of risk magnitude enables better choice of variants. Selective extraction 2 of thickness I demonstrates smaller risk magnitude on account of less probability of additional transportation of waste to enrichment. Maximal risk magnitude of selective extraction 1 reaches P = 0.0074 in thickness IV on account of higher waste volume. Summarising of event tree data shows clearly that selective extraction 2 yields better results than selective extraction 1, but for actual mining and geological conditions ability of the floor (layer A1/B) to carry the load of roadheader must be calculated. Higher collapsibility of limestone layer A1/B results in its rapid destruction and causes problems of maneuvering and stability.

Fig. 3. Event tree for selective extraction 1.

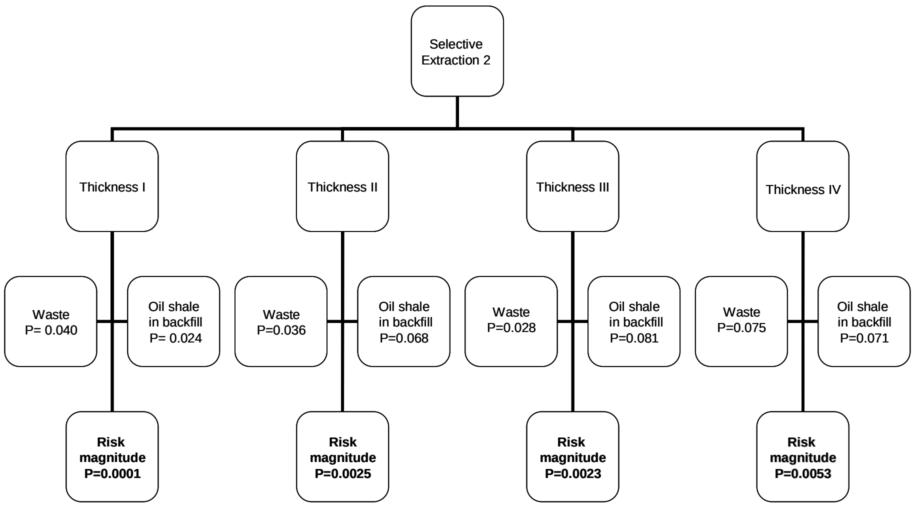

Fig. 4. Event tree for selective extraction 2.

Risk evaluation of selective extraction

Cutting process must be started from the suitable soft middle layer E-Fa and continued to the next layers depending on chosen extraction type. Maximal cutting thickness of cutting head diameter ought not exceed 1200 mm (to avoid extraction of limestone from other layers) [2].

Extracted rock mass from layers C/D, D, D/E, F_1/F_3 and F_3/G will be left to backfill by powerful loading machines in an area specially prepared for this purpose where pillars are weak. The average amount of oil shale in backfill is about 22%.

Immediate loading and transportation of cut mined rock will be carried out by powerful LHD machines with diesel drive. In the case of rock mass transportation delay, roadheader can work without losses in productivity [7].

Productivity may be reduced to 20–30% if the thickness of separated layer is small (420 mm) (Fig. 2 C/D, E, D/E) by comparison with cutting head diameter 1200 mm [7].

Productivity of a roadheader depends on its type and supplied value. To reach greatest productivity, it is suggested to use twin boom in Estonian mining and geological conditions. Deviations in productivity may occur in places where geological conditions are complicated, and a clear result could be achieved only experimentally. The machinery of roadheaders showed largest applicability for selective extraction method. For full extraction a method using continuous miners is suggested [7].

Applicability of roadheaders in Estonian geological conditions

The more widespread use of mechanical excavation systems is a trend set by increasing pressure on the mining and civil construction industries to move away from the conventional drill and blast methods to improve productivity and reduce costs. Roadheaders are the most widely used underground partial-face excavation machines for soft to medium-strength rocks, particularly for sedimentary rocks. They are used for both development and production in soft rock mining industry. In addition to their high mobility and versatility, investment costs of roadheaders are generally lower than those for most other mechanical excavators. Because of higher cutting power density due to a smaller cutting drum, they offer the capability to excavate rocks harder and more abrasive than their counterparts, such as the continuous mineral and the borers [8].

For determining cuttability of oil shale and its interlayers and concretions (Fig. 5), a SDM-1 dynamometric drill was used combined with ASR instrumentation developed by A. A. Skotchinsky Institute of Mining Engineering (Moscow) and Donetsk Coal Mining Institute for testing composite bed rocks [9].

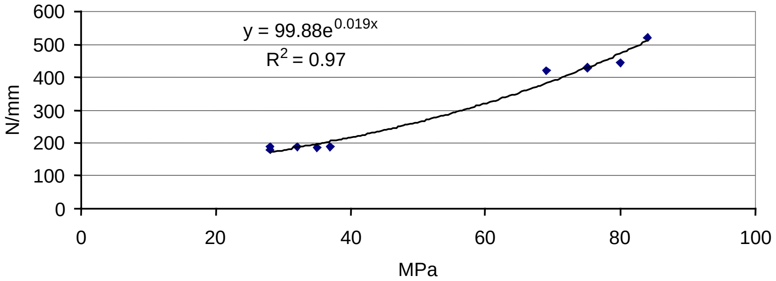

Fig. 5. Cuttability of different layers of commercial oil-shale bed.

Figure 5 demonstrates cuttability of oil shale and limestone layers of the Estonian oil-shale deposit. Variation coefficient of oil shale cuttability for separate layers is 14.1% and that of limestone 11.4%, respectively [9].

Conclusions

Overview of continuous miners and roadheaders demonstrates the best applicability of roadheaders for selective extraction, while continuous miners suit for full extraction under the mining and geological conditions of Estonian underground mines. Cuttability of commercial oil-shale bed was demonstrated at using of both types of machines.

Basing on event tree data, selective extraction 2 demonstrates better results than selective extraction 1. For actual mining and geological conditions the ability of floor (layer A1/B) to carry the load of machines must be calculated. The more collapsible limestone layer A1/B may be destructed more rapidly causing problems with maneuverability and stability.

Selective extraction allows to reduce rock mass volumes during the loading, transportation and enrichment processes. Thus, about 25% of limestone accompanying oil shale at the extraction processes will be left in the mine for backfill in the excavated areas. Backfilling allows to increase capability of pillars thereby reducing losses of oil shale and restoring in a certain measure filtrational, hydrodynamical, and aerodynamic properties of the geological environment. Such a way of development will considerably reduce the amounts of rock waste stored on the ground surface and decrease harmful impact on the environment.

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