Risk Assessment of Pillars Stability for Experimental Mining Blocks in Estonian Oil-Shale Mines

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Abstract

This study addresses risk associated with pillars dimension using new room-and-pillar mining technology with modern machines at Estonian oil shale mines. Processes in overburden rocks and pillars have caused unfavourable environmental side effects accompanied by significant subsidence of the ground surface. The aim of this work was to determine the damage of new technology on pillars dimension and to define the coefficient of blasting operation influence (q).

During the last three years, oil shale mining at an experimental mining block introduced a new blasting technology with great entry advance rates (EAR). With such improved technology the EAR reached 4 m, two times greater than conventional technology can guarantee. However, explosive volume increased up to two times and explosions occur during 4.5 seconds (~15 times longer than old technology). In places with complicated mine-geological conditions in the mining blocks, deviation of pillars dimension from project value was up to 16%, because pillar parts broke during the three to four week period after the blasting operations. Observation of two experimental mining blocks showed that pillars dimension was reduced an average of 7%.

Experimental data for different mine-geological conditions allow consideration of the influence of blasting operation on pillars dimension. A coefficient to improve accuracy parameters for new technology was added to the formula for calculating pillars. Design of pillars parameters for old technology is based on the instruction used in Estonian oil shale mines, where the coefficient of blasting operation influence is q = 0.6. Using the improved formula, it is possible to reduce the disturbance of new mining technology on pillars dimension. The correct choice avoids collapse in a mining block, and guarantees stable parameters and minimal losses of the oil-shale reserves.

Introduction

For 90 years, oil shale has been a mineral resource in the economy of Estonia. This study addresses risk associated with pillars dimension using new room-and-pillar mining technology with modern machines at Estonian oil shale mines. The processes in overburden rocks and pillars have caused unfavorable environmental side effects accompanied by significant subsidence of the ground surface. The processes cause a large number of technical, economical, ecological and juridical problems. The first spontaneous collapse of pillars and surface subsidence in an Estonian oil shale mine took place in 1964. Up to present, 73 collapses on the area of 100 km^2 (about 400 mining blocks) have been recorded. Collapse in a mining block also stops the mining works (Pastarus et al., 2005, Pastarus et al., 2006.)

Underground oil shale extraction by the room-and-pillars method with blasting is rather inexpensive, highly effective and easily mechanized. It gives an extraction factor of 70–80%. The field of an oil shale mine is divided into panels, which are subdivided into mining blocks, each approximately 300-350m in width and 600-800m in length. A mining block usually consists of two semi-blocks. The height of the room is 2.8m or 3.8m. The room is very stable when it is 6-10m wide. However, bolting must still support the immediate roof. The pillars in a mining block are arranged in a

singular grid. The commercial oil shale bed and immediate roof consist of oil shale and limestone seams. There are six commercial important oil-shale layers; from the bottom to the top they are denoted as A to F (Figure 1). The compressive strength of oil shale is 20-40 MPa and that of limestone 40-80 MPa. The volume density is 1.5-1.8 Mg/m^3 and 2.2-2.6 Mg/m^3, respectively (Pastarus et al., 2005).

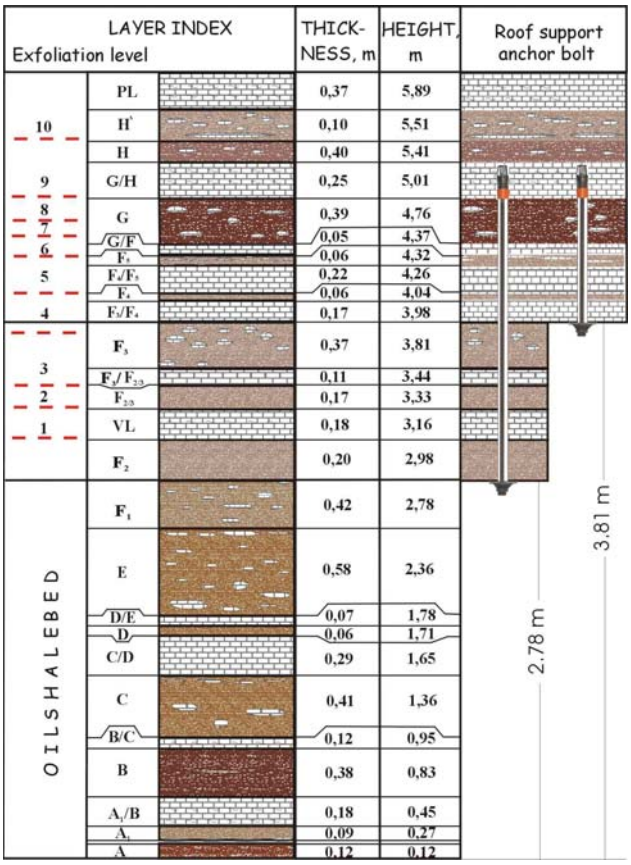

Figure 1. Schematic geological section of commercial oil shale bed and extraction thickness

Data that has become available in the last 40 to 50 years provides a foundation for the ideas used in risk assessment. Application of risk assessment to Estonian oil shale mines raises a unique set of problems, because each mine and mining block is a unique system within its own distinctive environment (Pastarus et al., 2006)

Risk analysis of new technology

The new mining technology is based on an improved drilling-and-blasting method which moves from packaged to underground bulk emulsion explosives, from 2.0m to 4.0m boreholes on new undercutting method, and to an automated roof drilling-bolting process using a roof bolting machine (Nikitin and Sabanov, 2005). Loading and transportation of blasted mined rock is carried out by powerful LHD machines with diesel drives (Figure 2).

The aim of undercutting is to gain additional free space in the oil shale bed which increases the effect of blasting. The old undercutting technology was based on bottom cutting with the help of the cutter (Ural-33), which gives horizontal cuts into the bottom layer A, 15cm high and 1.4 to 2.0m deep. The new undercutting technology is based on six large holes drilled into the central oil-shale layer C, up to 4.7m deep and with 280mm diameter (Figure 3). Roof bolter and face drilling machines are operated with remote controls that provide greater safety conditions in the work place (Nikitin and Sabanov, 2005).

NOBELIT 2000 is an emulsion explosive that was developed for blasting operations

Figure 2: Working mining block

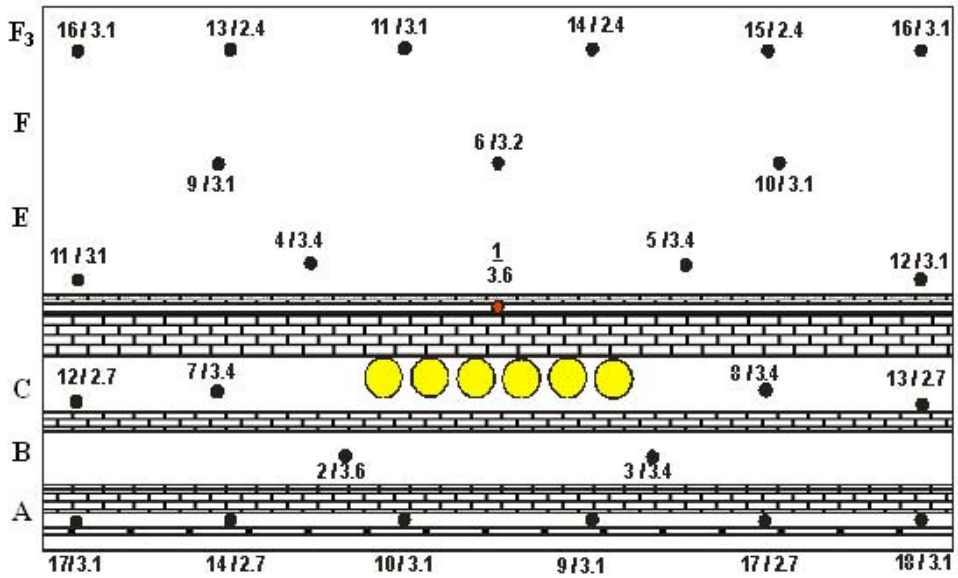

Figure 3. Blasting pattern for new technology.

under conditions in the Estonian oil-shale deposit (e.g., dust explosion hazard). It is waterproof, entirely fills a borehole, has a high level of safety, and a low sensitivity to mechanical and temperature loads. Parameters of NOBELIT 2000 are presented in Table 1.

Preparation time of the emulsion explosive substance in boreholes is 45 minutes. Short-delay detonators (0.25 seconds) DYNADET with series of 1 to 18 are used (Figure 3). Total blast duration is 4.5 seconds (~15 times longer than old technology) (Pastarus et al., 2007).

Based on the instruction for Estonian oil-shale mines (Mining-law and legal regulation acts, 2005), pillar width for square parameters can be obtained by following

Table 1.Parameters of NOBELIT 2000

Parameters	Value
Blasting energy, kJ/kg	3191
Evolving gas volume, l/kg	929
Energy density, kJ/kg	792
Detonation velocity, km/s	3.5-4.5
Density, g/cm^3	0.85
Cutoff diameter, mm	0.85
Brisance, mm	18

$$x^3 + \left[2.33(h-1.29q) - \frac{nHh\gamma}{0.3R_t}\right] \times x^2 + \left[3q(1-1.56h) - \frac{nHh\gamma \times (A+b)}{0.3R_t}\right] \times x + 2.33q^2(h-0.43q) - \frac{nAbHh\gamma}{0.3R_t} = 0 \quad (1)$$

formula:

Where x is pillar width; y is pillar length; A is chamber wight; b is chamber length; H is overburden rock thickness; h is pillar height; γ is overburden rock average density; n is pillars safety factor; R_t is pillars current strength; and q is the coefficient of blasting operation influence. Figure 4 demonstrates the parameters for formula 1.

New technology applied in Estonian oil shale mines has revealed technical, organizational, and human circumstances problems. Explosive volumes per one face increased up to two times under 15 times longer blast duration, and the expected pillars cross-sectional area was considerably reduced. Scope and expectation of the risk analysis were defined at the first stage of explosive operation testing. Identification of geological conditions to which the study relates was made. The proposed risk

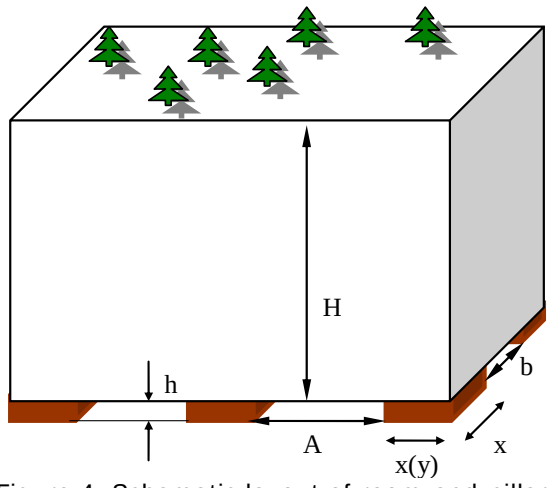

Figure 4. Schematic layout of room-and-pillar

analysis assumed deterioration in the bearing capacity of pillars. Determination of q was the main goal of pillars dimension measurement.

Risk estimation of blasting influence

During 2004-2005, the new technology was tested in two mining blocks: 3104 and 3105 of the "Estonia" mine. The mine-geological conditions were quite different. The typical excavation height is about 2.8m, but in the case of weak immediate roof conditions, like in our blocks, it can be up to 3.8–3.9m. Roof support is achieved by usage of bail type anchor bolts (Nikitin et al., 2006). In this case expander plug (anchor locks) must be fixed in harder limestone layers G/H (Figure 1). This improves roof control significantly, reducing bolt-to-face distances and exposure of unsupported roof.

The pillars measurement showed that the project dimensions differed considerably from real values. As a result of emulsion explosive application, pillar side breakage exceeded the corresponding value accepted for cartridge explosive technology. In the mining block 3104, mine-geological conditions were very complicated: karst, streaming water, tectonic joints. Distance between tectonic joints in areas of complicated geology was 3-10m. Mining block 3105 was in somewhat better condition and assessed like average, but in a small area streaming water from a large number of tectonic joint was present. Breaking of pillars parts after blasting operations occurred and continued for three to four weeks before it slowed or stopped.

For normal mine-geological conditions the deviation of pillars dimension was similar to that of cartridge explosive technology. The coefficient of explosive operation influence can be applied for four different mine-geological conditions. The normal, average, low stable and unstable mine-geological conditions are accepted by the mining law instruction (Mining-law and legal regulation acts, 2005). In places of complicated mine-geological conditions in the mining blocks, deviation of pillars dimension from project value achieved 16% on account of blasting operations influence (Figure 5).

Figure 5: The area of complicated geological condition on mining block 3105.

Results of measured vertical pillar deformation were much closer to data received for old (cartridge explosive) technology. This means that the improved technology influences on

pillars stability as estimated by the deformation criterion is not greater than with old technology.

However, drilling six large holes for undercutting caused fall formation in the face (mostly in areas with tectonic joints) (Figure 6). Nonuniformly blasting may have been the cause; falls also disturb pillar dimensions.

Experimental data for different mine-geological conditions allows consideration of the influence of blasting operations on pillars dimension. To the equation for calculation of pillars dimension (formula 1) were added coefficients to improve the accuracy of parameters for the new technology. Table 2 presents coefficient of blasting operation influence (q) for different mine-geological condition using the new technology.

Conclusion

Design of pillars parameters for old technology is based on the instruction used in Estonian oil shale mines, where the coefficient of blasting operation influence is q = 0.6. Using an improved formula, it is possible to reduce the disturbance of new mining technology on pillars dimension. The correct choice is important, it avoids collapse in a mining block and guarantees stable parameters and minimal losses of the oil-shale reserves.

Table 2: Coefficient of blasting operation influence

Mine-geological condition	Coefficient of blasting operation influence, (q)	Distance between tectonic joints, m
Normal	0.6	20
Average	0.7	10-20
Low stable	0.9	10
Unstable	1.2	3-5

Acknowledgement

Estonian Science foundation (Grant No. 6558, 2006-2009) supported the research.

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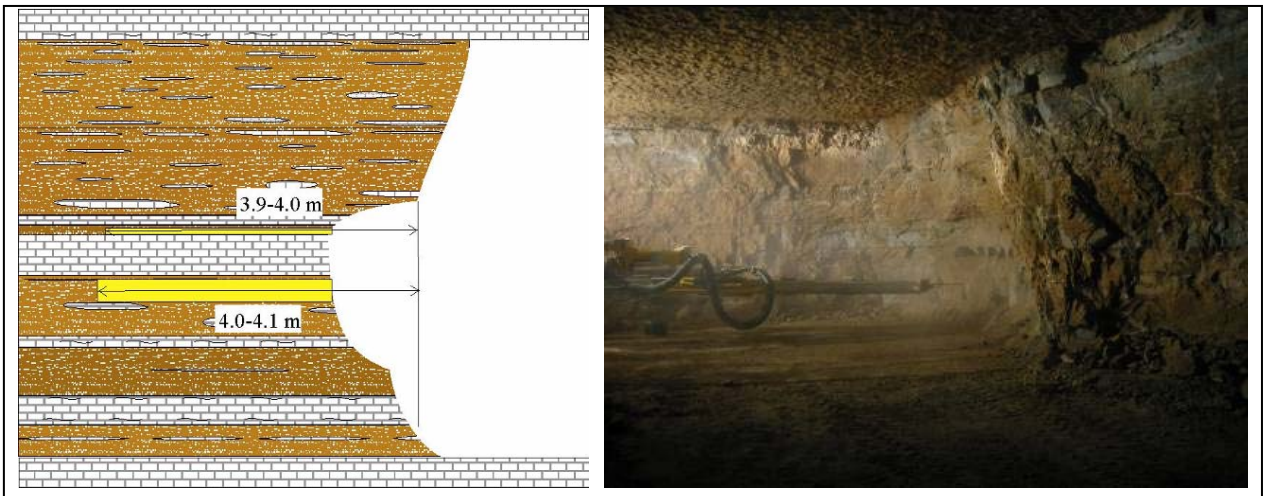

Figure 6. Face fall after undercutting layer C.

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