Risk assessment of pillars bearing capacity under rock dump in Estonian mine “Viru”

Sergei Sabanova\textsuperscript{a}, Juri-Rivaldo Pastarus\textsuperscript{a}, Oleg Nikitin\textsuperscript{b} and Erik Väli\textsuperscript{b}

\textsuperscript{a}Department of Mining, Tallinn University of Technology, Tallinn, Estonia;  
\textsuperscript{b}Department of Development, Estonian Oil Shale company, Jõhvi, Estonia

Abstract

This paper deals with risk assessment of pillars bearing capacity under rock dump formation in area allocated above chamber blocks number 13, 24 and 25. The specified chamber blocks were excavated by room and pillars method 23 years ago. Calculation of allowable rock dump volume is made from actually existing pillar safety factor in these chamber blocks. By way of checking calculations were received critical pillars bearing capacity which will guarantee control collapse and uniform subsidence. By the practical way determined safety (stable) rock dump height, volume and area for avoidance unexpected deformation. These practical experiments allows assuming that a pillars property in the mining block with normal condition has no significant changes during 22 years and laboratory test confirm empirical formula of the long-term rocks strength in Estonian mining condition. It is taken into account safety parameter for control subsidence of mining block.

Keywords: rock strength, pillar, subsidence.

Introduction

The commercially important oil shale is located in the north-eastern part of Estonia and excavated by underground and open-cast methods. In “Viru” mine oil shale production is obtained by room-and-pillar method with blasting. It gives an extraction factor of 74 – 81 \%. This method is highly productive, easily mechanize, and relatively simple to design. In “Viru” mine mining blocks approximately 300-400 m in width and 600-800 m in length each, which usually consists of two semi-blocks. The height of the room is 2.8 m and stable when it is 6-10 m wide. However, in this case the bolting must still support the immediate roof. The pillars in a mining block are arranged in a singular grid and have a square cross-section 30-45 m\textsuperscript{2}.

The total amount of oil shale extraction is about 2.5 million tons annually. The losses of oil shale in mining are about 25 % (caused by un-mined supporting pillars). Per one tonne of extracted oil shale half ton waste is generated in the process of oil shale enrichment. The total volume of waste generated on “Viru” mine landfills is 35 million tons.

Up to the present about 73 pillars spontaneous collapses accompanied significant subsidence of the ground surface on the area of 112 km\textsuperscript{2} has been occurred. They cause a large number of environmental problems. On the other hand, on account of restricted area for waste generation and to reducing environmental problems were decision formate rock
dump above developed mining blocks. This solution help to avoid spontaneous collapse in mining blocks and control the ground surface subsidence in inspected area [1].

The mining block 13 was in stable condition from year 1985. When height of the rock dump was exceeding 20 m subsidence begins. Other two mining block 24 and 25 nowadays are stable with rock dump height 12 m.

**Risk analysis of long-term rock strength**

Rock strength data in the key importance for the choice of the sizes of constructive elements used in room-and-pillar mining. Without taking into account the rheologic properties of rock, in particular the character of the change in their long-term durability, the calculation of the sizes of rooms and pillars for a certain term is impossible [2].

The character of changes in time of oil shale bed and roof limestone strata is described with sufficient accuracy by the following empirical formula of The State Research Institute of Mining Geomechanics and Mine Surveying (VNIMI), St. Petersburg has been accepted as a calculating method:

\[ k_t = \alpha + \beta \left( \frac{1}{1+\frac{t}{m}} \right)^m \]  

Equation (1) was developed on the basis of observation materials collected in oil-shale mines. Factor \(\alpha\) showing the rate of stabilized strength is averaged \(\alpha = 0.44\); \(\beta\) and \(m\) demonstrate the decrease in the rock strength intensity, \(\beta = 1 - \alpha = 0.56\) and \(m = 0.6\). The precision of the formula could reach \(\pm 30\%\) (average \(\pm 12\%\)) with estimated standard deviation 0.0908. The formula describes a hyperbolic dependence according to which the value of the factor \(K_t\) decreases from \(k_t = 1\) (basic strength if \(t = 0\)) to \(k_t = 0.44\) (stabilized strength if \(t = \infty\)). From the equation (1) long term rock strength determine as dependence:

\[ R_t = k_t R_0 \]  

The basic concept of the VNIMI method is that two strength features characterize the rock pillar: basic strength and stabilized strength. The basic one characterizes rocks at fast loading, e.g. at pressure testing. Under constant pressure the current strength of rock decreases, and in a while it will equal the stabilized strength [3].

Results received from laboratory test in the Department of Mining (MI), Tallinn University of Technology and the experimental data bases on dependence of rock strength in time (VNIMI) presented in Figure 1.
Figure 1. Dependence of rock strength in time.

Figure 1 showed changes of rock strength after 264 month, which can confirm empirical formula (1). Laboratory tests (MI) showed that current compressive strength equal $R_t = 9.99$ MPa under the water content 12%.

**Risk evaluation of pillars bearing capacity**

Basing on the instruction for Estonian oil-shale mines [3] from the formula for square pillar parameters, current strength can be obtained by following formula:

$$R_t = \frac{\gamma HF(x^2 + x(A + b) + Ab)}{0.3(x^3 + 2.33x^2(h - 1.29q) + 3xq(1 - 1.56h) + 2.33q^2(h - 0.43))}$$

Table 1. Chamber block 13 parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>5÷6 m</td>
</tr>
<tr>
<td>$b$</td>
<td>7÷8 m</td>
</tr>
<tr>
<td>$A$</td>
<td>7÷8 m</td>
</tr>
<tr>
<td>$q$</td>
<td>0.6 m</td>
</tr>
<tr>
<td>$h$</td>
<td>2.83 m</td>
</tr>
<tr>
<td>$R_t$</td>
<td>11.8083 MPa</td>
</tr>
<tr>
<td>$n$</td>
<td>1.3</td>
</tr>
<tr>
<td>$H$</td>
<td>44.4+20 m</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.0227 MN/m$^3$</td>
</tr>
</tbody>
</table>

Determination of pillars lifetime produced from previous formula:

$$t = \left(\frac{8.96}{R_t - 7.04}\right)^{5/3} - 1$$
By checking calculation results the pillars current strength make \( R_t = 11.81 \text{ MPa} \). Calculated \( t \) equal tree month showed real behaviour of rock dump subsidence, which occurred during this time period.

**The technology of rock dump formation above excavated area**

Rock dump development above 13 chamber block has served reason of the overburden thickness partial subsidence in the right semi-block. Than the rock dumping has stoped the situation in 13 chamber semi-block stabilized, that confirms opportunity develop rock dump by small platform to achieve uniform subsidence on calculated critical area.

![Figure 2. Rock dump above chamber block 13](image)

The purpose of this project was technological develop of safe parameters and methods for loading rock dump loading on a basis of surface stability to provide safety subsidence. The pillar load depends on the width of the mining block, so the concept of the critical width is to be used. The critical width is the greatest width that the rock above the mine can span before its failure, or, if there are pillars, the width we must mine before the pillars accept the full weight of the overlying materials. For Estonian oil shale mines it is presented by the following formula [4, 5]:

\[
L \geq 1.2H + 10
\]  

(5)

Where \( L \) – critical width, m; \( H \) – thickness of the overburden rocks, m.

Using the formula (5) was received critical area for rock dump formation. Embank of rock dump realize by small platforms. Monthly volumes of rock waste on small platforms
total 40 000 m$^3$. After the calculation of pillars long-term bearing capacity using empirical formulas (1-4) were received safety parameters of allowable rock dump volume. The calculated area of small platforms is 75 x 80 m with height 20 m will guaranty stability during three month and after this period the platform must be finished and enclosed. On enclosed area the period of massive movement and surface subsidence begins. At the moment of rock dump further development the subsidence must totally complete and the next floor is formed on a top of the first floor with the stable ground.

**Estimation of safety parameters and management for mining block control subsidence**

The period of dangerous deformations lasts 1-1.5 months and occurs very actively - speed of ground surface subsidence 110 mm per day. Subsidence during the next 2 - 3 months makes 30 mm. These additional subsidences occur non-uniformly, on separate sites non-uniformity is close to critical, that can adversely affect ground constructions. Observation of pillars at the moment of destruction beginning from collection drift in chamber block 13 was made after the two month of rock dump formation. The square pillars cross-sectional area was 36 m$^2$ with distance between them about 7 m. After loading increasing on mining block the pillars parts exfoliation are formed. The roof on the collection drift has a lot of tectonic joints supported by converted timber. In the left semi-block located under rock dump strong deformation of sights is observed. Destruction of parts up to 1.5 m is observed on all perimeters of pillars. The greatest destructions were observed in the middle of pillars side.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_k$</td>
<td>3.0 m</td>
<td>Sediments</td>
</tr>
<tr>
<td>$H_k$</td>
<td>41.3 m</td>
<td>Carbonate rock thickness</td>
</tr>
<tr>
<td>$h$</td>
<td>2.83 m</td>
<td>Height of pillar</td>
</tr>
<tr>
<td>$\phi$</td>
<td>50$^\circ$</td>
<td>Sediments movement angle</td>
</tr>
<tr>
<td>$\delta$</td>
<td>70$^\circ$</td>
<td>Carbonate rock movement angle</td>
</tr>
<tr>
<td>$B$</td>
<td>5 m</td>
<td>Safety berm width</td>
</tr>
<tr>
<td>$a$</td>
<td>37$^\circ$</td>
<td>Rock dump movement angle</td>
</tr>
</tbody>
</table>

Dangerous zone borders influence of underground developments on a surface are determined concerning a line external security (barrier) of pillars row on corners of movement in carbonate rock and sediments. In the chamber block safety zone border are determined by lines of crossing layer with the planes drown under movement angels through borders of the protected area. Around of rock dump, through its angular points, is frame the rectangular which sides arranged in a direction of mining developments borders, in parallel the sides of the received rectangular is frame safety berm (the reserve area) which external borders are borders of the protected area [3].
Minimally admissible distance from object up to border protected zones (top view) is determined under the following formula (6). For reviewed rock dump condition minimally admissible distance equal 23.6 m (Figure 3)

\[ D = h_k \cot \varphi + (H_k + h) \times \cot \delta + B \]  

(6)

Figure 3. Scheme of minimally admissible distance from mining block up to border rock dump.

Underground development under rock dump protection from working developments by the concrete constructions prevent from distribution of an air shock wave roof caving. Constructions are represented by the strengthened concrete barricade and strong metal gates.

**Conclusion**

By way of checking calculations were received critical pillars bearing capacity which will guarantee control collapse and uniform subsidence. By the practical way determined stable rock dump height, volume and area for avoidance unexpected deformation. These practical experiments allow assuming that a pillars property in the mining block with normal condition has no significant changes during 22 years and laboratory test confirm empirical formula of the long-term rock strength of Ordovician rocks in conditions of the Baltic Oil Shale Basin.

**References**


