Oil Shale, 2022, Vol. 39, No. 2, pp. 142–149
doi: https://doi.org/10.3176/oil.2022.2.04

Long-term stability of pillars in an underground oil shale mine

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Received 20 April 2021, accepted 22 April 2022, available online 10 June 2022

Abstract. *A method was developed to predict the collapse of underground rooms in a previously mined area. This methodology is necessary to assess the condition of the excavated areas in the case of an additional load of buildings and supporting pillars weakening. As an example, the ground stability of the Estonia mine under the waste dump has been calculated.*

Keywords: *oil shale, underground mining, long term stability of rooms, collapses, land cover conditions.*

1. Introduction

Oil shale reserves in Estonia exist in the form of a shallow sheet deposit. The room-and-pillar mining method is used in the depth range of 30–70 m. The pillars are designed to last either throughout the duration of oil shale extraction or for a longer period. The proposed durability depends on the objects above the mine, such as buildings, fields, forests, or other mineral deposits. At the end of the designed lifetime of the pillars, the entity of rooms may collapse and the ground sink. In fact, the time limit for land subsidence is indefinite. Short-lived pillars last longer than expected. On the other hand, several rooms have collapsed before the end of the designed operating time. In total, more than a hundred rooms have collapsed, which forms a significant part of the underground mined area. Thus, the condition of the greater part of the underground mined area is indeterminate, quasi-stable. The uncertainty of the future condition of the land of exhausted mines creates problems for the spatial planning of the oil shale deposit territory.

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2. Background

The stability and risk of collapsed rooms has been a relevant topic for a long time. The principle has been to assess the probable life of load-bearing structures (supporting pillars and the roof of rooms). The aim of this study is to determine the long-term compressive strength of the oil shale sequence and the bearing capacity of pillars.

In the 1970s it was hypothesized that the compressive strength of oil shale would decrease over time, but not indefinitely. After 2–3 years, the creeping of pillars practically stops. The final strength is 44% of the original value. This hypothesis is based on observations in the mines. Hereafter, it is called the VNIMI hypothesis or formula [1]. According to this formula, the average uncertainty of instantaneous strength is 12% and the maximum confidence limit is 30%. The probability of exceeding these limits is 0.16 in the first case and 0.01 in the second, respectively.

A second hypothesis was set up in 1980, according to which the weakening of pillars does not cease. This hypothesis is based on the theory of kinetic strength of rocks and data from oil shale mines. Here it is called the TUT hypothesis [2]. The article describing the TUT hypothesis does not set out confidence limits for it.

The bearing capacity of pillars depends on their size, which is very indeterminate. The size of the columns and rooms depends on the quality of the miners' work, but also on geological factors. Therefore, although the average cross-sectional area of the columns corresponds to the mining plan, their dimensions may differ significantly from the average.

Sometimes in practice, larger pillars have been made if rock pressure has increased during excavation. This has led some researchers to assume that if the size of the pillars is not described by normal distribution, the rooms will not collapse [3]. This is true if the distribution of the cross-sectional area of pillars has a positive skewness. A negative skewness indicates that some pillars are smaller than average. A collapse may start forming above small pillars.

3. Methods for predicting collapses

Prediction of collapses during mining is possible by measuring rock movement. By measuring roof-to-floor convergence, it is possible to predict the collapse with an accuracy of a few days. The measurement method is applicable when the pillars are designed for a short lifetime [4].

If the pillars are designed to withstand for a long time, at some point the rooms will be abandoned and measurements become impossible in such a situation. In this case, hypothetical methods of collapse prediction can be used. The stochastic approach to the problem was explained by Reinsalu [5] by the fact that the weakening of pillars in mined-out areas continues, and the probability of collapses of rooms and pillars remains. This study also showed that the occurrence of collapse depends on the safety factor used for designing the load-bearing capacity of the pillars.

The process of collapse formation has also been simulated with computer modelling on the basis of the parameters of registered collapses. This so-called Monte-Carlo method makes it possible to determine the probability of collapse and fracturing of pillars. The method is suitable for analysing the stability of rooms and predicting their collapse if the dimensions of the rooms and pillars and the safety factor are known from the design mining plan [6].

All sources refer to rooms where a collapse occurred no later than 15 years (180 months) after excavating. No long-term study has been performed on this topic.

4. A case study

For the case study, the enrichment waste of Estonia mine is placed in a quasi-stable area.

Oil shale was extracted in this area during 1973–1974, more than 45 years (550 months) ago. Mining took place at the depth of 60 m. The thickness of the waste dump will be up to 60 m (Fig. 1). The specific pressure of the dump on the ground has a maximum of 100 t/m^2 (1 MPa). Pressure increases loading on the pillars. The total load increases the probability of the pillars breaking up under the dump. The resulting collapse of the underground rooms can cause a dangerous air wave in the mine.

5. Calculations

The pressure in a pillar (*M*) is proportional to the total load and inversely proportional to the size of the pillar:

$$M = (\gamma_1 H_1 + \gamma_2 H_2)g/\delta \text{, Pa,} \tag{1}$$

where

γ_1 – the average bulk density of the overburden rock, kg/m^3;
H_1 – thickness of the overburden, m;
γ_2 – average bulk density of the dump material, kg/m^3;
H_2 – thickness of the dump, m;
g – acceleration of gravity, 9.81 m/s^2;
δ – the ratio of the sum cross-sectional area of the group of pillars to the exhausted area (rooms, drifts and pillars).

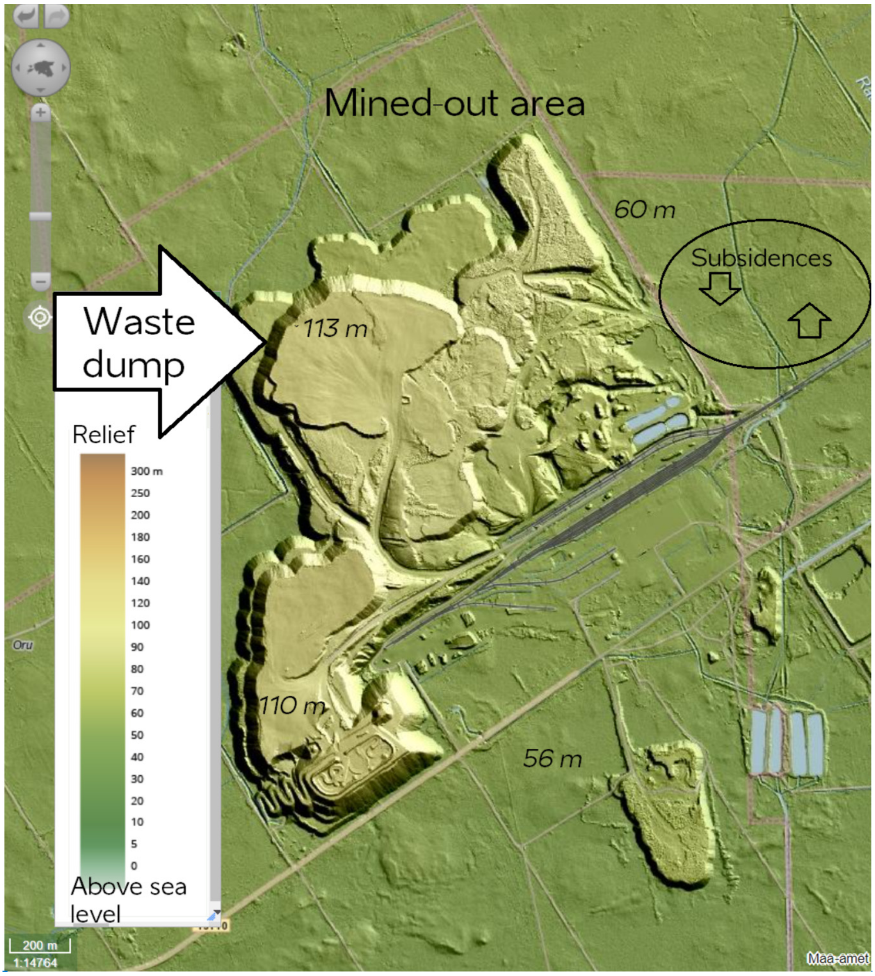

Fig. 1. Enrichment waste dump of Estonia mine on the mined-out area. The level of the mine horizon is from −10 to +10 m above sea level. Source: https://xgis.maaamet.ee/maps/XGis?app_id=UU82A&user_id=at&LANG=2&WIDTH=1182&HEIGHT=851&zlevel=7,693695.3125,6567830.078125&setlegend=SHYBR_ALUS01_82A=0,SHYBR_ALUS11_82A=1

In practice, where the unit of bulk density is t/m^3, the equation can be simplified:

$$M \approx 0.01(\gamma_1 H_1 + \gamma_2 H_2)/\delta, \text{ MPa}. \quad (2)$$

To find out the area of the most pressurized pillars is a problem. A method has been developed for the underground surveying of pillars [7]. However, if the exhausted rooms underlying the dumps area are dangerous, the decaying pillars cannot be overestimated. In other words, the actual size of the pillars 40–50 years after their formation is uncertain. Therefore, the exhausted area can only be analysed on the basis of old mining maps. The freeware QGIS was used for mapping the pillars. The maps were processed using the procedure “Contour Lines”, which is more productive than the “sliding rectangle method” formerly used [3, 4, 6]. Isobars were considered in 1 MPa increments (Fig. 2).

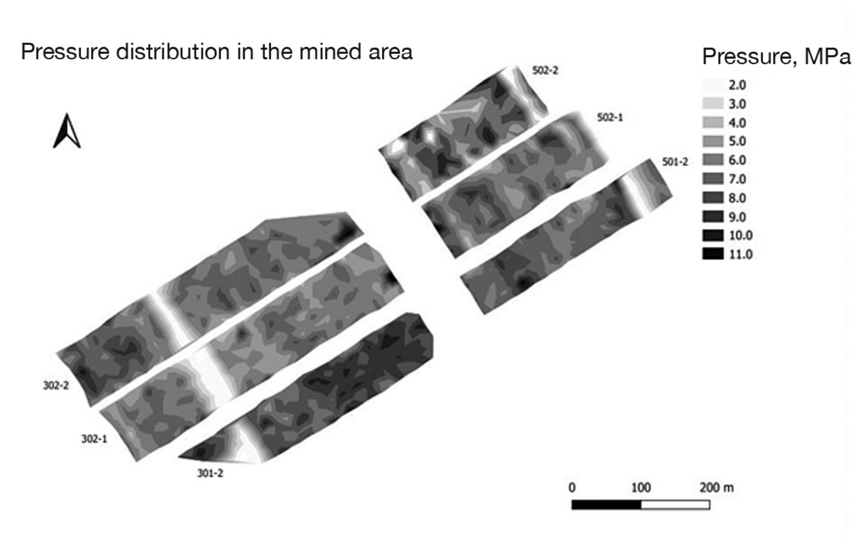

Fig. 2. Mapped distribution of pressure in the pillars (as an example). The darker is the colour, the higher is the pressure in the pillar.

Areas under higher pressure were separated in the rooms. These “critical-areas” group of decaying pillars had an area of 2500–7000 m^2. There were 20 to 60 pillars in each area. Making a selection of critical areas requires adequate competence, i.e. the researcher should have professional qualification in mining and experience of working underground.

Pressure distribution in the pillars of the critical area was determined (Fig. 3). The mean, standard deviations and variance of statistical parameters were calculated.

These pillars break where the pressure is greater than their bearing capacity. In other words, a pillar breaks up if the pressure (M) is greater than the current strength of oil shale inside the pillar (R_{600}).

Within each critical-pressure area, the following was examined:

1. What is the probability for some pillars being smaller than average and therefore under greater pressure?

2. What is the probability for the bearing capacity of these pillars to be lower than average?

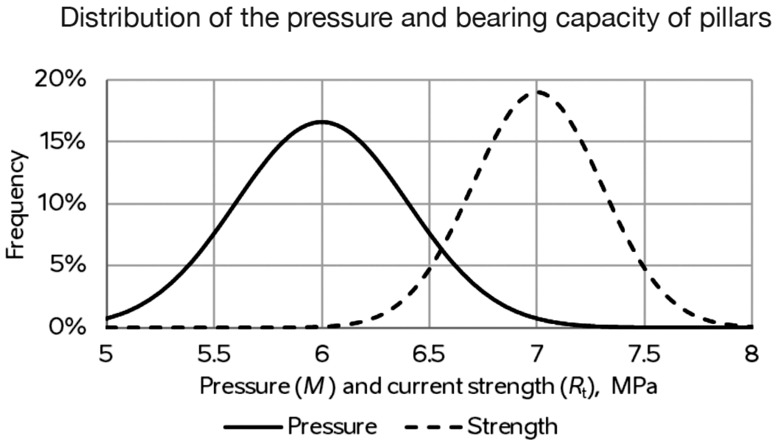

Fig. 3. Distribution of pressure in pillars and their strength (illustrative).

The key to the second question is: how much have the pillars weakened during 45 years?

Figure 4 illustrates the two weakening hypotheses mentioned above. According to the VNIMI hypothesis, the final strength (R_{600}) of 600-month-old pillars is 44% of the original (R_o). According to the TUT hypothesis, the current strength of the pillars after 600 months (R_{600}) is lower than the final state by VNIMI ($R_{600} < R_\infty$). Both hypotheses fit within the confidence limits. The following calculations are based on the TUT hypothesis.

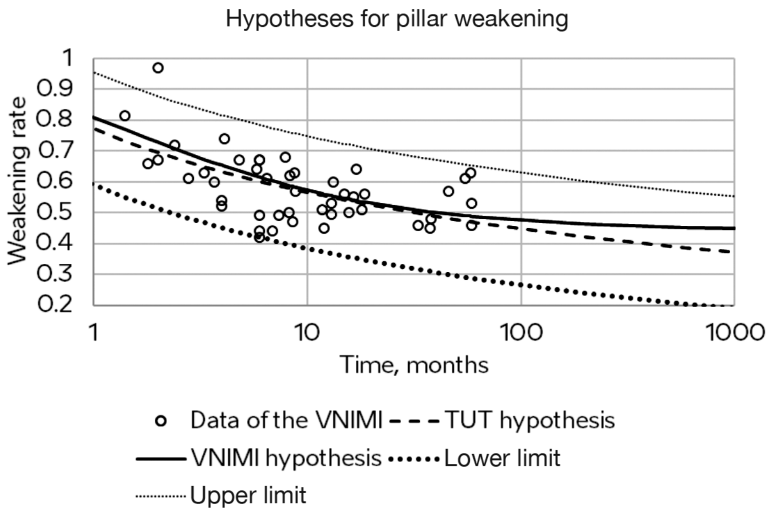

Fig. 4. Two hypotheses for the weakening of pillars as a result of oil shale creep.

The statistics of approximations in the formulas can be used for assessing the probability of the pressure on the pillars being greater than their load-bearing capacity.

The probability of a collapse is calculated using the Excel procedure:

$$P\,(M - R_{600} > 0), \tag{3}$$

where

M – pressure, MPa, (Eq. (2));

R_{600} – current strength of the pillars after 600 months, MPa.

The statistics required for calculating the probability can be obtained by examining the pressure and strength of the selected set of pillars.

Figure 5 depicts diagrams of the height of the dump and probable collapse.

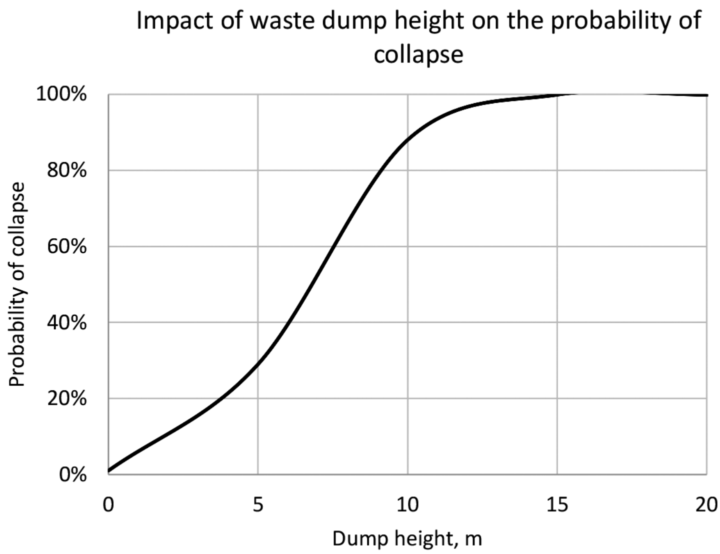

Fig. 5. Impact of the waste dump height on the probability of rooms collapse (illustrative).

4. Summary

A methodology for assessing the probability of collapse was established. The safety of quasi-stable land was predicted. The developed method is suitable for assessing the condition of the surface of old oil shale mines.

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