Dependence of Land Stability on Applied Mining Technology

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***Abstract* – Oil shale is obtained in Estonia with open cast or underground mining. In case of open cast method the area stabilizes within a few years and a new forest is planted on the site. The result of underground mining is undermined land. There are different types of undermined land: steady land, stable land, quasistable land, and subsided land. There exists a number of methods for undermined land evaluation. The first condition for choosing an evaluation method is the information about time, location and method of mining. When the condition is fulfilled, one has to select a suitable evaluation method for a concrete study area. Considering the aforementioned, Department of Mining in Tallinn University of Technology has developed a method and a computer program to evaluate the undermined land areas and to describe the mining impact area. The method and program enable to evaluate the state of undermined land and the risks as well as to plan land utilization and construction works.**

I. Introduction

The principal mining regions of Estonia are: Lääne-Harju (Vasalemma, Padise, Harku, etc. deposits), Ida-Harju (Lasnamäe, Väo, Maardu, etc. deposits), Kunda-Rakvere (Toolse, Ubja, Aru, etc. deposits) and Ida-Viru (Estonian oil shale deposit, peat deposit of Puhatu and many locations for mining building material). The greatest number of problems is faced in old mining regions, while the region is being developed according to the “State plan for utilization of oil shale, 2008-2015”, as it is difficult to predict the behaviour of the land in the construction areas utilized according to the plan. On the other hand, the plan contains a design for the development of sustainable mining environment in these regions. Mining environment is understood as the entity of resources (deposits and groundwater), land (agricultural and housing land), engineering, and technology.

In order to ensure the stability and safety of constructions, the results of investigations for detailed planning must provide the input for the designation of primary risk factors and for efficient and economical realisation of planned construction works (building and civil engineering works) [1].

In Estonia oil shale is obtained with open cast or underground mining. When the oil shale area is excavated with open cast method, it stabilizes within a few years and a new forest is planted on the site. Undermined land and surrounding land can be described in following ways: steady land, stable land, quasistable land, and subsided land [7].

Steady land is located on mining claims but is unmined because of protective or remnant pillars. The area of the steady land is always smaller than the area of the pillar.

Stable land is located in pillar-protected areas. Stable land covers the rooms which pillars were not mined before abandoning and where the thickness of the hard roof remains in the range of 10...35 m. Secondary subsidences may occur in the areas with thinner limestone cover.

Quasistable land and area emerges in places where pillars were solid during mining but may break afterwards. All the unstable room-and-pillar mining area is quasistable. Quasistable areas also occur near the sides of mined longwall mining areas, above drifts, adits, and rooms in low-depth mining area.

Subsided land is located above the hand-mined area where advancing and retreating mining and longwall mining with double-unit-face areas were used. The relief of subsided land depends on the roof structure as well as the quantity and quality of the filling material.

Underground mined areas are complex and it is difficult to predict their stability – a problem faced not only in Estonia, but in the whole world [5]. Stability of underground mined areas depends on many factors (extraction time, technology, the thickness of oil shale and many others), some of which are known and some of which are very difficult to identify or even remain unknown [5].

Determination of land stability conditions in Estonian underground mined areas for road construction or other building purposes is quite complicated as different segments of the area were mined at different times, using different mining methods. The difficulty of determining land stability is connected with various parameters of multiple mining methods (e.g. thickness of the seam, type of support etc.) applied in the area.

The problem of land stability has been studied at various sites. The studies are important because a large part of Ida-Viru county is undermined, and developers need the information about the sites and conditions of construction. The main questions of the studies are: How much does the earth sink in the mined areas? How much space remains in oil shale seams? How can describe the undermined land stability?

II. Methods

There exists a number of methods for undermined land evaluation. The first condition for choosing an evaluation method is the information about time, location and method of mining. When the condition is fulfilled, one has to choose a suitable evaluation method for a concrete study area.

Such information can be obtained from old mining plans. To describe the situation in undermined areas, maps of old mining operations have been digitised (with scale 1:10000 and 1:5000), also showing the used mining method (TABLE III).

A. *Digitalisation of Old Mining Plans*

The old mine plans have been drawn by surveyors on paper with application of the local coordinate system. Firstly, it is necessary to establish the plan of what mine it is and its xy coordinates, which will enable to georeference the plan in the map software. The old plans have been scanned and changed into digital files (image files) and opened in map processing software (such as MapInfo Professional). Knowing the coordinates of the scanned map, then digital map is created (Fig. 1.). These plans (with scale 1:10000 and 1:5000) do not give accurate results. The research group has found out that to obtain better results the old mining plans have to be digitalized with scale of 1:2000. The old plans with the scale of 1:1000 and 1:500 would yield even better results but unfortunately many of them have not been preserved. Scanned mining plans enable to identify the location, time and method of mining (see Fig. 1.) as well as the extension of steady, stable, quasistable, and subsided land in the area (Fig. 2.,Fig. 3.).

Fig. 1. Scanned mining plans, digitized mining plan and ortophoto.

B. *The Calculation Method of the Mining Impact Areas*

Department of Mining has developed methods and computer programs to assess and describe the undermined areas and their risks for planned land use and building activities [3]. To draw the mining impact areas, it is first necessary to create a regular grid of thickness or absolute altitude of different soils (see Table). The program uses the algorithm to calculate the mining impact areas (steady, stable, quasistable, and subsided land) [1],[3]. When the grid is ready, the values must be inserted in the contour of the undermined area's block.

TABLE I

EXAMPLE OF BOREHOLE DATA FOR MAKING GRIDS

Borehole number	Ground Surface, m	Quaternary thickness, m	Oil shale bed, m
2545	55	2	40,5
6584	52,5	2,1	41,3
4752	54	2,6	40

NB! Values are indicative

TABLE II

ANGLES FOR DESCRIPTION

Angle	Ground cover (Quaternary)	Limestone
Ultimate angle – angle, which is characterized by the greatest extent of effects of underground mining overhanging terrain coatings	50 °	60 °
Sliding angle – angle, which characterizes the extent of coverage for underground mining dangerous overhanging terrain coatings	50 °	70 °
Breakage angle – angle, which is characterized by tearing off coatings under the influence of underground mining	75 °	75 °

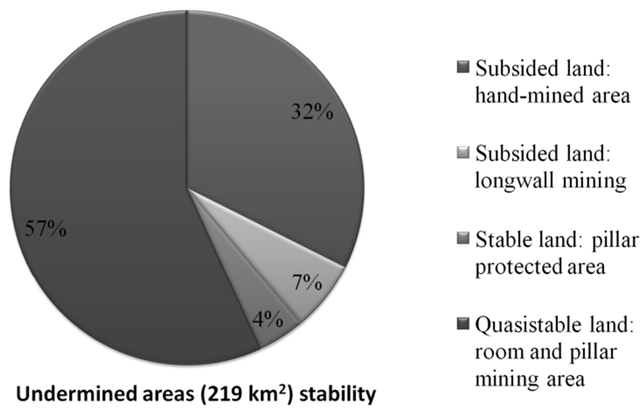


Fig. 2. Undermined areas stability in oil shale deposit.

The impact mining area's extention outside the undermined block's border can be calculated according to the formula:

$$\sum[\, h_i * \tan(90-n_i)], \qquad (1)$$

Where: h_i – layer thickness

n_i – layer ultimate, sliding or breakage angle

The described method provides a basis for further expert assessment including extraction time, movement of the faces, applied technology and equipment. The drawing method of mining impact areas (steady, stable, quasistable, and subsided land) is shown in Fig. 3.

The image of the drawn mining impact areas can be changed, e.g., the areas can be marked with different colours for better understanding. It is not recommended to build anything on quasistable land as it has not yet fully sunk.

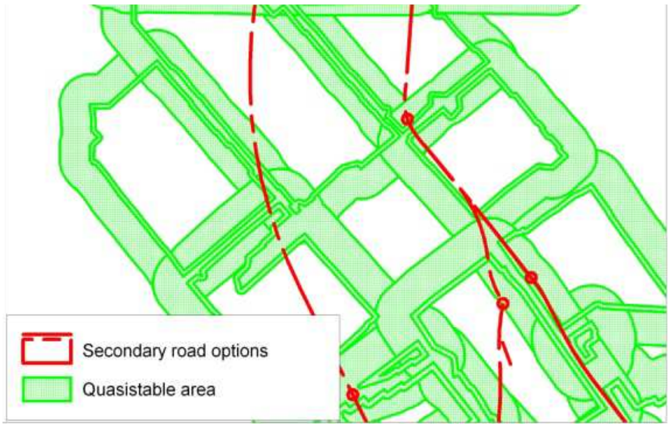


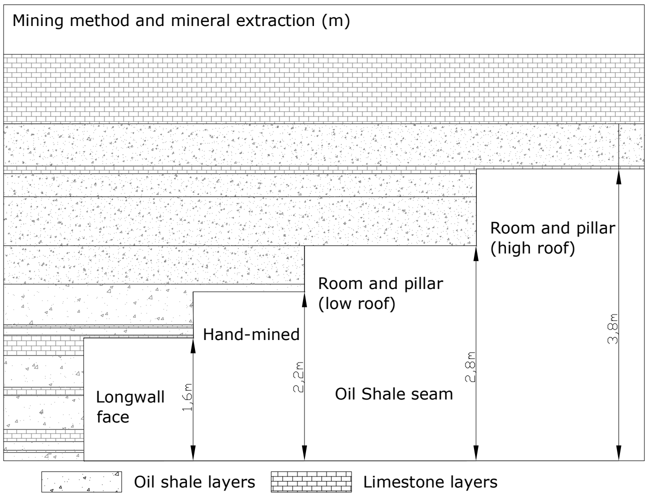
Fig. 3. Drawing method of impact areas.

III. RESULTS

During the ninety years different mining technologies have been used in the oil shale deposit. The price of the extracted oil shale depends on the applied mining technology (see TABLE III). The evaluation method and results of land stability assessment also depend on the mining technology. The calculation method described above is employed to calculate the stability areas (steady, stable, quasistable, subsided).

TABLE III

USED MINING METHODS AND WORKING HEIGHT IN OIL SHALE SEAM



Using the results of the calculation method, it can be said that the undermined area in Kukruse-Tammiku secondary road region is mostly quasistable – it means the limestone layer and elements of the support were not broken during the extraction, but it may happen later [2].

The possible maximum land subsidence is different and depends on the applied mining method. Land subsidence ranges 0,90…1,84m (see TABLE IV) and causes cracking of rock, which in its turn generates additional empty spaces, depending on the thickness of the overburden and mined oil shale seam (see TABLE V).

The following are the study results of the Mine no 4 area. Using the aerial photograph and the altitude data (known as LIDAR data) it has been found out that the longwall areas have sunk. On the basis of the analysis of longwall subsidence it can be said that the subsidence of the land is 0.50 ... 0.70 m. Such subsidence encourages the formation of wetlands, and water filled old mine shafts as the area had originally been quite marshy (Fig. 4).

TABLE IV

MAXIMUM LAND SUBSIDENCE DEPENDING ON MINING TECHNOLOGY

Mining technology	**Land subsidence, m**
Hand-mined	1.32
Room and pillar	1.84
Longwall face	0.90

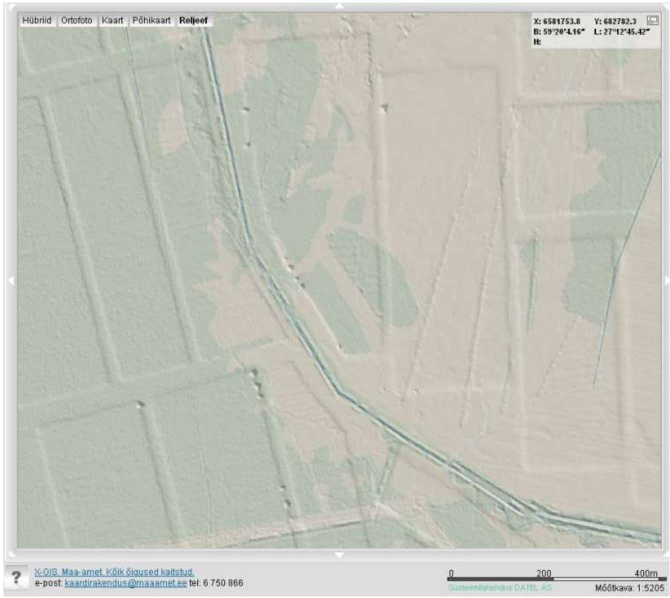


Fig. 4. Subsidences in undermined area.

IV. DISCUSSION

The undermined areas can be easily mapped with the help of the devised method and programs. Studies have shown that oil shale room and pillar mining area is stable if mining depth was less than 35...40 meters. In the old mining fields with drifts in the mines the friable overburden may collapse, where its thickness is less than 10...12 meters. Quasistable land initially behaves like the stable, but various types of dangerous earth movements occur later and the collapse causes the appearance of holes in the area’s land.

Undermined land’s quasistability is one of the major problems caused by mining, which is difficult to assess. A more extensive use of mining plans with the scale of 1:1000 and 1:500, application of LIDAR and 3D scan data enables a more exact evaluation of the undermined areas and a better understanding of rock and sediment layers’ behaviour as well as the stress areas linked to it.

TABLE V

MINED AREA

Options	**Kukruse**	**Mine no 2**	**Käva**	**Käva 2**	**Mine no 4**	**Tammiku**	**Sompa**	**Kohtla**	**Ahtme**	**Viru**	**Estonia**
Mine opening	1921	1949	1924	1924	1953	1951	1948	1937	1948	1964	1972
Mine closing	1967	1973	1972	1972	1975	1999	1999	2001	2001		
Working time, year	46	24	48	48	22	48	51	64	53		
Field area, km^2	13.20	12.30	3.47	14.05	12.70	40.00	33.60	18.30	43.30	41.70	141.10
Mined field area, km^2	15.13	8.57	1.84	11.72	10.43	19.26	18.14	12.14	26.36	25.49	62.77
Not mined area, km^2	-1.93	3.73	1.63	2.33	2.27	20.74	15.46	6.16	16.94	16.21	78.33
Thickness of overburden, m	11	13	21	10	12	23	23	15	37	42	57
Thickness of oil shale seam, m	2.83	2.81	2.83	2.82	2.8	2.8	2.77	2.76	2.79	2.75	2.71
Geological space in oil shale seam, mln m^3	**42.82**	**24.08**	**5.22**	**33.05**	**29.20**	**53.92**	**50.24**	**33.52**	**73.53**	**70.09**	**170.11**
Mined oil shale seam thickness, m											
Hand-mined face	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Hand- mined rooms	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Room and pillar	2.83	2.81	2.83	2.82	2.8	2.8	2.77	2.76	2.79	2.75	2.71
Drifts	2.83	2.81	2.83	2.82	2.8	2.8	2.77	2.76	2.79	2.75	2.71
Longwall face	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Mined field area, km^2											
Hand-mined face	11.28	6.87		9.16	7.71	4.36	12.70	3.80	6.33	0	0
Hand- mined rooms	3.50	0.00	1.84	1.73	0	0	0.06	1.36	0.05	0	0
Room and pillar	0.29	1.70		0.79	1.08	11.81	1.86	0.55	19.22	25.38	61.49
Drifts	0.06	0.00	0.00	0.04	0.69	0.36	0.00	0.02	0.30	0.11	1.26
Longwall face	0	0		0	0.95	2.74	3.52	6.41	0.46	0	0.02
Total mined area	15.13	8.57	1.84	11.72	10.43	19.26	18.14	12.14	26.36	25.49	62.77

V. CONCLUSIONS

The main questions of the studies were: How much does the earth sink in the mined areas? How much space remains in oil shale seams? How can describe the undermined land stability? Scientists have a set of methods to predict the subsidence and to evaluate its parameters, though it is difficult to forecast the exact time of its occurrence. There are also measures to prevent and mitigate flooding. To get better results the collapsing areas at undermined sites should be assessed. Specifying the collapse locations, their mining methods, geological conditions and other parameters can enable a better evaluation of the extend of the collapse influence area. The aforementioned data will enable construction specialists to assess the safety conditions of the roads to be built and expenditures linked to it.

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