Displacement of mined ground as a consequence of the exploitation of Pb-Zn ore in the mine Crnac

Pomik podkopanega terena kot posledica pridobivanja rude Pb-Zn v jami Crnac

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Abstract: Underground exploitation of mineral raw materials and the construction of sub-surface facilities cause changes on the ground surface. These changes on the ground surface are practically manifested as specific displacements and deformations on the surface of the mined ground. The objective of this Paper is to determine a safe working depth and to make an assessment of a prospective deformation hazard and subsidence of the ground over the mining zones of Pb-Zn ore veins in the Mine Crnac. A high-quality determination, forecasting of deformations and subsidence of a terrain is very important for the safety of underground mine workings and the protection of facilities on the surface of the ground.

Izvleček: Podzemno pridobivanje mineralnih surovin, kot tudi gradnja podzemnih objektov povzročata spremembe na površini. Praktično se te spremembe na površini izražajo kot pomiki in deformacije na območju odkopa. Cilj članka je določanje varne globine odkopavanja ter ocena potencialne nevarnosti zaradi deformacij in ugrezanja nad območji pridobivanja Pb-Zn rudnih žil v jami Crnac. Kakovostno določanje, napovedovanje deformacij in ugreznin terena je zelo pomembno za varnost podzemnih jamskih prostorov ter zaščito objektov na površini.

Original scientific paper

Key words: working environment, underground works, displacement of the ground, deformation, angular parameters, analytic dependence
Ključne besede: delovno okolje, podzemna dela, pomik terena, deformacija, vplivni koti, analitična odvisnost

Introduction

The extraction of lead-zinc ore (Pb-Zn) in the mine Crnac has been made intensively since 1967, year which is taken as the beginning of the modern exploitation.

By investigation mining at the height of 862 m there were over 20 Pb-Zn ore veins identified, with thickness from 1 m to 3.5 m. Depending on the physical and mechanical characteristics of ore and accompanying rocks of ore veins, extraction methods for each ore vein are applied separately. For the extraction of ore veins the following methods are applied: extraction with back-filling of cavities, caving method and sublevel open stope mining method.[6]

This paper shows the impact of Pb-Zn ore exploitation in the mine Crnac on the displacement of mined ground in the exploitation by open stope method on the example of the ore vein No. 3.

Characteristics of a working environment

In a geological environment of a deposit the following lithologic members are involved: amphibolites, Palaeozoic shales, serpentinites, diabases, diabase-hornstone series and tertiary effusives with their pyroclastites. Tertiary magmatic activity was manifested by the formation of significant masses of effusive rocks and a number of changes in the active rocks. The same magmatism gave rise to dumping of the Pb-Zn mineralization in the form of ore veins with 1–3.5 m thickness and 60–90^0 angles of occurrence (dipping) and with coefficients of solid ore and accompanying rocks (*f* 5–15) according to Protodjakonov.

Impact of underground works on the surface of the ground

As a consequence of the underground mineral deposit exploitation, it comes to roof caving above the working cavity, which can frequently be manifested on the surface of the ground.[9] The first signs of ground subsidence are manifested by deflections of the terrain, subsidence or caving of a stope roof. Moreover, the subsidence is reflected by an increased pressure in the roof and sidewall.[8]

The underground mining leads to vertical and significantly mere horizontal displacements and deformations on the surface of the terrain. The shape, size and the process of terrain deformations depend on a number of factors where the main are the following:[5]

- Structure of the characteristic of a rock massif (fissuring, bedding),
- Physical and mechanical characteristics of rocks which constitute the ore massif,
- Dipping conditions of ore bodies and accompanying rocks,
- The shape and the size of ore bodies, their thickness, ratio between the size of the working cavity and the depth of works,
- Mining system,
- Damage degree of rocks,
- Terrain relief.

The above factors in each individual case define particularities of the displacement and deformation processes of the massif, by enabling the application of analytic, graphic and numerical and analogue methods for defining and studying the processes of deformation of massif and the terrain surface.[10]

The Figure 1 shows the diagram of displacement and deformation zones on the surface of the mined ground and angular parameters and displacement assessment.

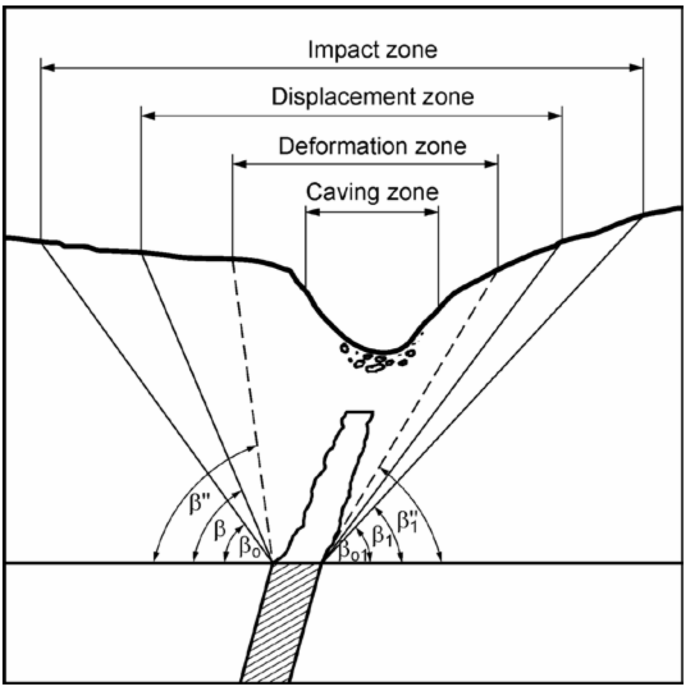

Figure 1. Diagram of displacement and deformation zones on the surface of the mined terrain

The first researches related to the impact of underground works on the surface of the terrain were from the late 19^{th} century. These issues were dealt by a number of researchers who gave their indisputable contribution to the scientific thought in this field and served as an instrument for developing new theories in the contemporary mining, based on the mathematical processing of a large number of collected data.[1], [2], [11]

CRITERIA FOR DETERMINING ANGULAR PARAMETERS Β ACCORDING TO I. N. KISIMOV

Applying the theory of probability and mathematical statistics methods, and on the basis of measurements completed, analytical dependencies and criteria for determining angular parameters were proposed (Figure 1.) when resolving problems related to displacements of a mined terrain due to the impact of mining works. The basic criteria for a forecast calculation of displacements and deformations of a mined terrain and angular parameters of the displacement process were given by the author I. N. KISIMOV:[3]

- Impact of the inclination angle of an ore body α,
- Impact of the strength of accompanying rocks f,
- Impact of the actual thickness of an ore body m,
- Impact of the depth of mining works H.

Impact of the inclination angle of an ore body *α*

For the open stope method (caving method and sublevel open stope mining method) it is found that the inclination angle α of an ore body is the factor which influences the most on the angle β of the deformation impact zone:

$\beta = -37.27 + 1.37\ \alpha$ ($\eta = 0.881$; $\mu_\eta = 9.68$),

$\beta_1 = 0.002\ \alpha^2 + 0.296\ \alpha + 35.572$ ($\eta = 0.682$; $\mu_\eta = 6.89$),

$\beta'' = -0.052\ \alpha^2 + 8.53\ \alpha - 264.898$ ($\eta = 0.596$; $\mu_\eta = 6.47$),

$\beta''_1 = 0.004\ \alpha^2 - 0.070^\alpha + 57.572$ ($\eta = 0.675$; $\mu_\eta = 10.55$).

Impact of the strength of accompanying rocks *f*

Impact of the coefficient f on the angle β is significant and is considered as the approximate to the impact of an ore body dip α, is given in the form of the expression for open stope methods:

$\beta = -17.07 + 0.97\ \alpha + 0.93\ f$ ($R = 0.896$; $\mu_R = 11.23$),

$\beta_1 = -79.03 + 1.63\ \alpha + 1.62\ f$ ($R = 0.847$; $\mu_R = 7.30$),

$\beta'' = 0.024\ f^2 - 0.086\ f + 76.955$ ($\eta = 0.484$; $\mu_\eta = 39.2$ with $f = 6–18$),

$\beta''_1 = -0.087\ f^2 - 2.456\ f + 63.031(\eta = 0.589;\ \mu_\eta = 7.96$ with $f = 8–18)$.

Impact of the actual thickness of an ore body *m*

Impact of the thickness *m* on the angle *β* is certain to the itself impact of the coefficient *f*:

$\beta = 67 - 0{,}42\ m + 0{,}81\ f$ (with $R = 0.375$ and $\mu_R = 3{,}59$ for $m = (1{:}3\text{m})$

Impact *m* to the factor *α*:

$\beta = 28.01 + 0.55\ \alpha + 0.29$ ($R = 0.509$; $\mu_R = 4.28$)

Impact *m* to the factor *H*:

$\beta_1 = 66.52 + 0.04\ H + 0.83\ m$ ($R = 0.529$ and $\mu_R = 5.04$

$\beta'' = 77.6 + 0.19\ m + 0.38\ f$ ($R = 0.329$ and $\mu_R = 3.09$).

Impact of the depth of mining works *H*

The change in the angle *β* depending on the depth *H* is typical for the decrease in value *β* at depths from 50 m to 150 m and the increase in the angle *β* in the interval from 150 m to 300 m; therefore the dependency of the impact *H* and *f* on the angle *β* is determined:

$\beta = 7.148 + 0.33\ f - 0.004\ H$

with $f = 6–18$ and $H = 100–400$ m

$\beta_1 = 0.0003\ H^2 - 0.094\ H + 76.71$ ($\eta = 0.784$ and $\mu_\eta = 13.63$) and value $H = 15–400$ m

$\beta'' = 74.25 + 0.74\ f - 0.02\ H$ with $R = 0.368$ and $\mu_R = 3.38$

$\beta''_1 = -\ 0.0005\ H^2 + 0.152\ H + 68.162$

Determining the stability of the terrain surface due to the impact of mining works in Mine Crnac

Previous mining activities in the pit of Crnac Mine, more ore veins were excavated above the horizon $H = 862$ m (Figure 2). Extraction methods which were applied to ore mining in particular ore veins of different thickness (from 1–3.5 m) and dipping angle of ore veins from $60–90^0$, were not adapted to mining conditions, and therefore it led to displacements of terrain surface above working cavities. Figure 3 shows a longitude cross-section of the stope in the ore vein No. 3 and its relation to the terrain surface where there was the displacement of the terrain surface (Figure 4.).

In order to prevent displacements of the terrain surface above the working cavity it is necessary to determine the impact of mining on the surface. In case that mining works have impact on the surface, it is necessary to define

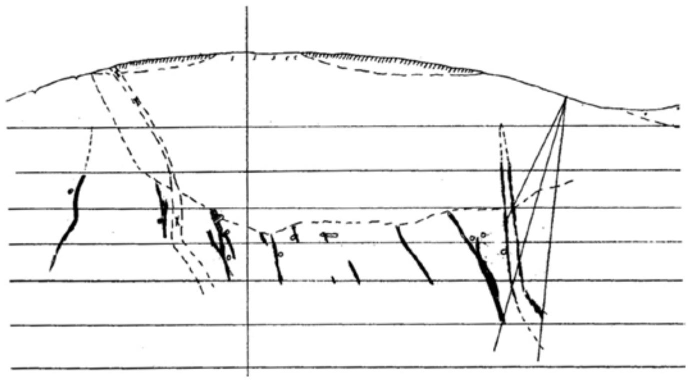

Figure 2. A geological profile of ore veins above the horizon H = 862 m

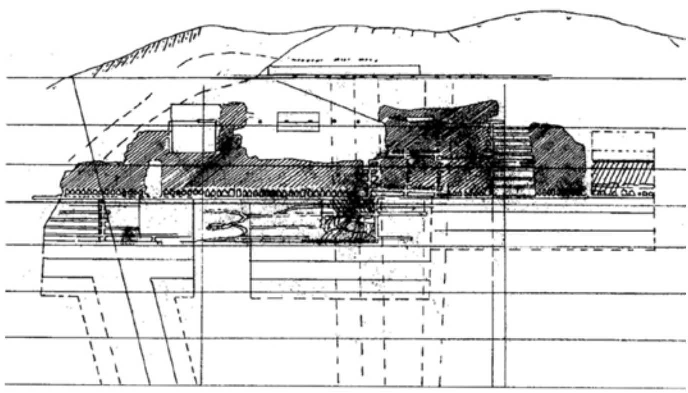

Figure 3. Longitude cross-section of a stope in the ore vein No. 3 and its relation to the terrain surface

Figure 4. Displacement of the terrain surface

zones of displacements and caving and a possibility of creating a safe depth, and when there are not any, it is important to know if there are stable areas directly above mining works.[4], [7]

The stability of surfaces directly above mining works depends on the rock excavation method and natural and technical conditions, such as: occurrence angle of the ore body α, and the strength coefficient of accompanying rocks f, mining lengths at the dip L, with mining thickness m, depth to the upper border of exploitation H, lengths of excavation in the direction of strike N, with the thickness of covering detritus h_1, the thickness of covering main rocks h_2.

According to KISIMOV there is a directly proportional interdependence between the surface stability and the parameters α, H, f, h_1, h_2 and L, m, N respectively.

The impact of these parameters may be determined when necessary data are analyzed and expressed through empirical mathematical dependencies. Certainly, the stability of the surface in mining is influenced also by fissuration of accompanying rocks, considering that all the rocks are fissured to a small or large extent, it can be accepted that the fissuration takes part through the value of empiric coefficients.

Patterns for minimal extraction depths where there are no displacements on the surface of a working cavity, bearing in mind the thickness of the ore body m, strength coefficient of roof beds f and excavated length at strike N, for the conditions of the Mine Crnac are given as follows:

- Impact of the excavated thickness:

$$H_m \geq \frac{25{,}4 \cdot (L \cdot \cos\alpha + m \cdot \sin\alpha)}{(L \cdot \cos\alpha + m \cdot \sin\alpha) + 3{,}6 \cdot m} \cdot m$$

$$H_m \geq \frac{25{,}4 \cdot (125 \cdot 0{,}174 + 3 \cdot 0{,}985)}{(125 \cdot 0{,}174 + 3 \cdot 0{,}985) + 3{,}6 \cdot 3} \cdot 3$$

$$H_m \geq 53{,}02m$$

- Impact of the strength coefficient:

$$H_f \geq \frac{5.6 \cdot (L \cdot \cos\alpha + m \cdot \sin\alpha)}{(L \cdot \cos\alpha + m \cdot \sin\alpha) + 1.9 \cdot f} \cdot f$$

$$H_m \geq \frac{5{,}6 \cdot (125 \cdot 0{,}174 + 3 \cdot 0{,}985)}{(125 \cdot 0{,}174 + 3 \cdot 0{,}985) + 1{,}9 \cdot 8} \cdot 8$$

$$H_f \geq 27{,}7m$$

- Impact of the excavated length at strike:

$$H_N \geq \frac{9.3 \cdot (L \cdot \cos\alpha + m \cdot \sin\alpha)}{(L \cdot \cos\alpha + m \cdot \sin\alpha) + 5 \cdot n} \cdot n$$

$$H_m \geq \frac{9{,}3 \cdot (125 \cdot 0{,}174 + 3 \cdot 0{,}985)}{(125 \cdot 0{,}174 + 3 \cdot 0{,}985) + 5 \cdot 600} \cdot 600$$

$$H_N \geq 45{,}57m$$

On the basis of these calculations, we obtained three different values for a minimal extraction depth, the maximum value is adapted, which is the dislocation due to the impact of the strength of the ore vein No. 3 of the Crnac Mine.

CONCLUSION

Applying the KISIMOV's pattern along with introducing local parameters of the deposit, gave real, approximate values for determining a safe exploitation depth or the possibility of the appearance of falling-in on the surface of the terrain.

Under the conditions in the Mine Crnac we obtained the results which indisputably show that a safe mining depth had not been defined, so the works on the ore extraction on the example of the ore vein No. 3 had caused the displacement of the terrain surface.

Bearing in mind that the ore exploitation above horizon N^0 : 862 m in the mine Crnac and further open stope mining method, it is necessary to define the impact of extraction on the surface of the terrain for each ore vein separately.

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