Mine surveying works for the purpose of excavating the remaining reserves of bauxite in the deposit of "Podbracan"

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Abstract

Mining projects for mineral resource mining contain in certain cases specific technical and technological solutions, these being the result of the mine's characteristic spatial position and the geometry of the ore deposit, existing mining works, structures, and terrain relief etc. For the purpose of completion of the mining project, it is necessary to carry out a series of mining and surveying tasks during the pre-project and project stage of mining, as well as during the construction of mining facilities and excavation of mineral resources. Specific features of the project concerning excavation of the remaining reserves of bauxite in the deposit of "Podbracan", and in this way the forthcoming mining and surveying works, are displayed by the integration of the underground mining project into the existing mine chambers, infrastructure structures on the terrain surface and into the open pit. Large number of mining and surveying works will follow the completion of this project, but in the meantime, this paper shows the a priory accuracy assessment of the spatial position of the point, it being the exit point to the existing bench of the open pit at the elevation +420m.

keywords: underground mining, bauxite mine, mine surveying, a priori accuracy assessment.

1. Introduction

The bauxite deposit "Podbracan" is located on northwestern slopes of the Javor and Susica mountains in the territory of the municipality Milici – Bosnia and Herzegovina (The Republic of Srpska). The ore reserves of the bauxite deposit of "Podbracan" were excavated till 2010 by using the open pit method of mining at the central and northern part of the deposit up to the +410m. Above this level, in the southern part, 1,120,000t of ore reserves remained. A feasibility study on the possible expansion of open pit established that open pit mining of this part of the deposit was not economically justified at the moment. In view of these facts, it was decided to excavate the remaining reserves by using an underground method of mining. For the purpose of this, the Main Mining Design was elaborated (Faculty of Mining and Geology, 2008), whose technical and technological solutions were conditioned by the spatial position and geometry of the open pit including appertaining structures, underground mine chambers constructed in the seventies within the underground production system at that time, as well as by spatial position and geometry of the bauxite deposit (Qiang *et. alli.* 2005) (Figure 1).

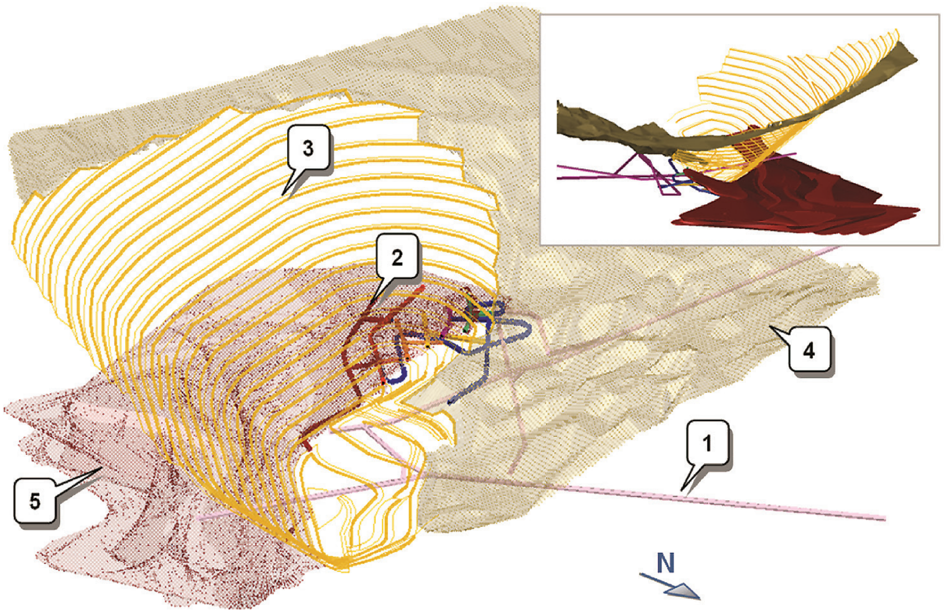

Figure 1
(1) Spatial position of mining and geological structures at the location "Podbracan" existing and
(2) newly designed mine chambers,
(3) open pit ,
(4) terrain ,
(5)bauxite ore body

2. Geology of the "podbracan" bauxite deposit

Bauxite deposit "Podbracan" has a surface of approximately 523,000m^2 and is classified as the first group of red bauxite deposits by its structure-morphological type and economic importance. The ore body was created during the continental phase of development between the upper Triassic and older upper Cretaceous period, most likely during the lower Cretaceous. Due to the typical filling of paleo relief cavities, the ore body thickness varies from several centimetres up to 37m, discordantly lying over the floor. The thickest is the central deposit area bauxite. The ore body is irregularly layered, sinking toward the SSE by 20°. These are mostly oolitic-pisolitic bauxites of dark red colour, where the basic bauxite mass dominates over oolites and pisolites. The oolites and pisolites are mainly evenly distributed within the basic mass, making on average 30% of the overall bauxite mass. The highest areas of the ore body are made of the light red, multi-coloured, predominantly kaolinitic bauxites with higher SiO_2 and Al_2O_3 content in comparison to the Fe_2O_3 content. The pre-deposited bauxite, mixed with the red clays is also located in this area.

The ore body lies over Triassic light-grey crystalline and massive underlying limestones with numerous Karst occurrences (sinkholes, chasms, blind valleys). These limestones are occurring along the rim of the deposit.

The overlying beds are made of the upper Cretaceous and Neogene deposits. The upper Cretaceous sediments were discovered furthest to the southeast of the deposit, spreading to the east outside of the deposit. They are represented by marlstones, marly limestones and sandstones with thickness up to 70m. These sediments are moved over the Neogene deposits along the low-angle reverse fault. The longevity of the movement and the dip angle of the reverse faults are not determined, since it is predominantly located outside of the explored deposit.

The Neogene sediments are vastly spread both horizontally and vertically (approximately 300m in thickness) and discordantly lies over the older beds. They are consisted of sandy and gravelly clays, clayly and ironaceus quartz sands and semi-consolidated sandstones, laterally and vertically shifting on the bauxite-limestone base. The increased iron content in most of the Neogene sediments is originated partly from the deposed bauxitic material, and partly from the deposed Triassic ironaceus sandstones.

3. Characteristics of the existing structures

The open pit is of a deep type with 10m high levels, with 8m-10m wide bedding planes, the angle of inclination of slopes 55°-65° and a general end slope of 33°. Bauxite is being excavated up to the flooring so that the stope slope is milder in the northwestern part and there are roads for the bauxite transport located. The stope is open from level +410m to the terrain surface, while to the southeast, the stope is formed up to the level +710m, which means that the total depth of mine is 300m. In the nineteen seventies, the concept for the underground exploitation of this deposit was designed. In the course of this, the following capital objects were constructed: the adit Jadar with length of over 2km; the main ventilation downcast; drifts H-484 and H-448; power substation chamber at level +448m.

4. Selection of opening and development solutions

The opening, development and excavation concept is conditioned by the natural conditions of the deposit and by its technical and technological conditions. Figure 2 shows the mine layout with the existing and newly designed mine chambers for the purpose of the design documentation of the Main Mining Design for Underground Mining.

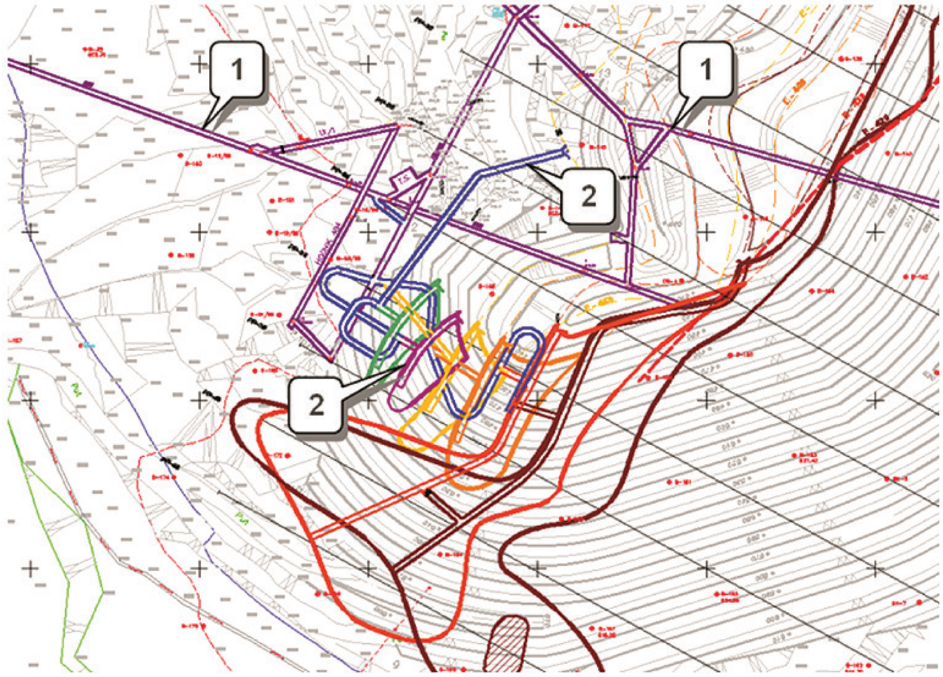

Figure 2
(1) Mine layout with the existing and (2) newly designed mine chambers

During the opening stage at levels +470m and +460m, haulage drift TH-470 and TH-460 are constructed for the purpose of determining the floor part of the bauxite ore. The basic layout of the development is to construct haulage drift (TH) from haul downcast for E-470 level to the level E-420 up to the ore body level (Figure 3).

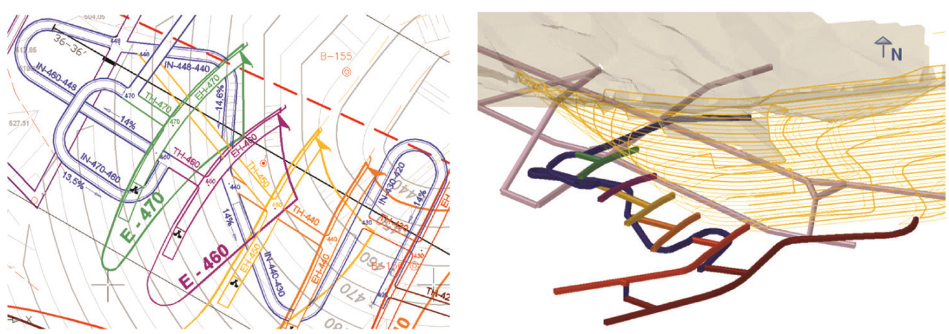

Figure 3
Newly designed mine chambers; the opening, development and excavation concept

After the haulage drift reaches the ore body, bench drift EH is constructed along the floor part of ore body to the exit into the open pit, and to the opposite side till the deposit excavation limit. Bench drifts have multiple purposes: preparation for the construction of excavation drifts and for the ore excavation, supplying fresh air, and as emergency exit from the pit. The adopted altitude difference between excavation levels is 10m, the same as the height of the benches at open pit, for the purpose of using the benches of the mine for communication (Figure 4).

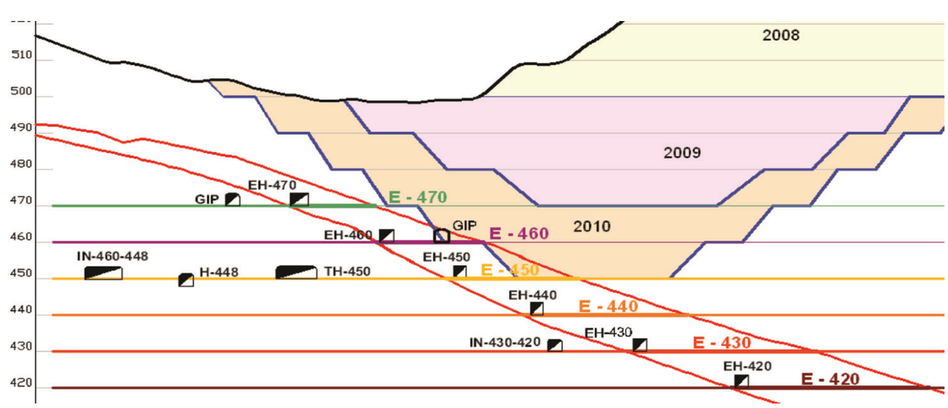

Figure 4
Geological cross section 36-36'with mine chambers

4.1. Mining method

The applied mining method, named the sublevel caving excavation method in crosswise direction, was chosen based on the relevant mining-geological parameters, mining conditions and other technical-technological factors influencing the mining. Basically, the ore body is made of separate mining fields divided by height to levels with the height difference of 10m. By this method, mining starts at the end of bench drift (EH) and generally progresses toward the opening location of the level, i.e. the haulage drift (TH). Excavation dimensions of the bench drift (EH) are 3.5m×3.5m. The stope is made of the over pit part with overall height at 6.5m and the pillar next to the excavation drift, 4.0m wide. The mining of bauxite is performed backwards, in retreat towards the level gallery, by rock drilling of mining holes in the shape of semi-fan and blasting ("semi-fan"). Angle of blasting surface is 60°, while the internal distance between the semi-fans is 1.8m, which is the least resistance line at the same time. The transport and hauling of the ore is realized by the diesel-powered loading-hauling and dump (LHD) equipment and pit truck. The loading and transport of the blasted ore from the stope to the appropriate loading place to the pit truck is realized by the LHD machine. The ore is transported by the pit truck through the main haulage adit (GIP) to the surface, and afterwards with the same truck to the ore dump location.

A special feature of this project requires an analytical and systematic approach when defining the existing spatial position and geometry, and setting out structures designed at and under the terrain surface (Kessler *et alli*. 2008). The tasks set shall be completed by mining and surveying works, whose extent, type and special positioning must observe the progress of the project.

5. Mine surveying works

Mining and surveying works are present at the pre-extraction and extraction stage of the underground deposit mining project.

Pre-extraction activity in view of mine surveying includes:

- Analysis of the existing geometric base on the terrain surface, stabilization of new geodetic points and determination of their spatial coordinates;
- Connection of geometric grid on the terrain surface with mine traverses and determination of spatial coordinates of points in the pit;
- Detailed scanning of the open pit levels (Figure 5), which are interactive with the designed bench drifts for the purposes of geomechanical analysis of the stability;
- Detailed scanning of the existing mine chambers.

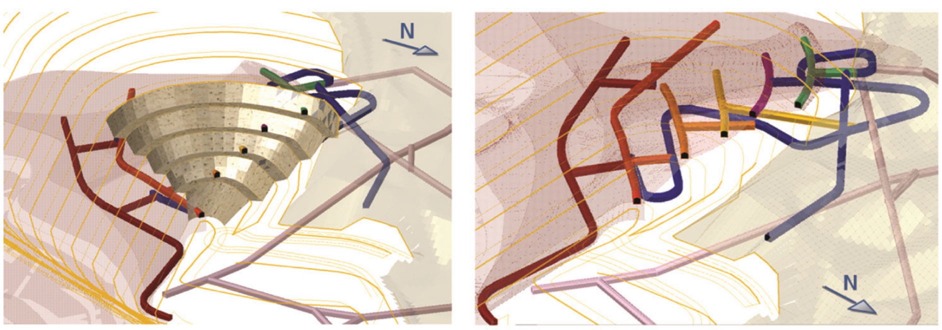

Figure 5
Parts of open pit benches in interaction with bench drifts

The extraction activity in view of mine surveying includes: a priori accuracy assessment of geometry elements for setting out the mine chambers designed and the setting and scanning of the as-built condition.

6. A priori accuracy assessment for setting out the mine chambers projected

Within the extraction activities, and immediately before setting out the mine chambers projected, it is necessary to carry out the a priori accuracy assessment of the geometric elements to be used for setting out. In this stage, the a priori accuracy assessment is the most important task in view of mine surveying, because this analysis defines the setting out method, the type of surveying instruments and their class, as well as the accuracy itself and the number of repetitions in performing the setting out of the geometric elements for the project.

As aforementioned, this project provides for a unilateral construction of mine chambers, from the main haulage adit to the existing benches of the open pit. At the first stage of the project, the lowest bench, planned to be exited to, is located at the level +420m. This is the longest complex of the designed underground chambers, whose spatial length is d_k=743.52m, and total horizontal length is d=739.73m. The total of 54 points is designed in those chambers; those points are to represent the future mine continuing series of levels, and they need to be set out while carrying out mining works. Mine traverse is to include 54 traverse legs, or levelling distances with average length of 13.70m. Only two distances are longer than 50m (the longest one is 95.38m long), and even 36 distances are shorter than 10m (the shortest one is only 1.70m long). Those facts have caused to carry out, within the project to set out the designed mine chambers, the *a priory* accuracy assessment within the horizontal and vertical planes.

6.1. A priori accuracy assessment for setting out of the designed mine chambers within the horizontal plane

The setting out of the designed mine chambers within the horizontal plane is to be carried out by using a polar method to set out characteristic points by means of horizontal angles and lengths. The characteristic points of the designed mine chambers represent, at the same time, the traverse points of the future mine traverse. This means that each characteristic (traverse) point is to be set out from the previous, already set out, traverse point. The future mine traverse through mine chambers designed shall be from the point GIP in front of the main haul adit up to the point E420-10 representing the exit of the bench drift onto the bench at level +420m. The coordinates of the traverse points set out on the traverse are to be calculated by using the known equations (Boershch-Komponiets *et alli*. 1989):

(1)
$$N_i = N_{i-1} + \Delta N^i_{i-1} = N_{i-1} + d^i_{i-1} \cdot \cos\nu^i_{i-1} = N_{i-1} + d^i_{i-1} \cdot \cos\left(\nu^{i-1}_{i-2} + \beta_{i-1} \pm 180^\circ\right)$$
$$E_i = E_{i-1} + \Delta E^i_{i-1} = E_{i-1} + d^i_{i-1} \cdot \sin\nu^i_{i-1} = E_{i-1} + d^i_{i-1} \cdot \sin\left(\nu^{i-1}_{i-2} + \beta_{i-1} \pm 180^\circ\right)$$

Whereby: N_i, E_i - coordinates of the last traverse point set out;

N_{i-1}, E_{i-1} - coordinates of the previously set out traverse point;

$\Delta N^i_{i-1}, \Delta E^i_{i-1}$ - coordinates of the difference between the traverse points;

d^i_{i-1} - horizontal length between traverse points (element to be set out);

ν^i_{i-1} - grid bearing between traverse points;

β_{i-1} - direction angle (element to be set out).

The coordinates of the starting connecting point GIP of the designed mine traverse are determined by using the static GPS method and they are: E_{GIP}=5917.60m i N_{GIP}=1648.12m. The tolerance of the GIP point within the horizontal plane is $\sigma_{E_{GIP}} = \sigma_{N_{GIP}} = \pm 0.01\text{m}$

The coordinates of the starting orientation point OR of the designed mine traverse are also determined by using static GPS method and they are: E_{OR}=6215.61m i N_{OR}=1914.61m, with the standard tolerance of $\sigma_{E_{OR}} = \sigma_{N_{OR}} = \pm 0.01\text{m}$.

The bearing and the horizontal length between starting orientation and starting connecting point are:

$$\nu^{GIP}_{OR} = 228^\circ 11' 44''; \; d = 399.79\text{m}$$

On the basis of those values, the standard tolerance of the initial grid bearing between starting orientation and starting connecting point was calculated (Stoiljkovic *et al*. 2013):

(2)
$$\sigma_\nu = \frac{\rho'' \cdot \sigma_p}{d}\sqrt{2\cos^2\nu + 2\sin^2\nu} = \frac{\rho'' \cdot \sigma_p}{d}\sqrt{2} = \pm 7.3'' \approx \pm 8''$$

Whereby: $\sigma_p = \sigma_{E_{GIP}} = \sigma_{N_{GIP}} = \sigma_{E_{OR}} = \sigma_{N_{OR}}$

The designed coordinates for the point E_{420-10} of the exit of bench drift onto the bench at level +420m are: $E_{E420-10}$= 6022.70m and $N_{E420-10}$= 1581.30m.

The designed width of the bench drift is 3.40m. According to the Rulebook on the Method for Executing of Mine Surveying (The Government of the Republic of Serbia, 1997), the permissible transversal error of the last point E420-10 is 1/4 of the chamber width, i.e. in this case Δ = 0.85m.

The maximum allowable standard deviation for setting out the last point E420-10 within the horizontal plane, for the probability of 95% is to be calculated by using the following equation:

(3)
$$\sigma_{\max} = \frac{\Delta}{2} = \pm 0.425\text{m} \approx \pm 0.40\text{m}$$

The standard deviation of the setting out of the last point E420-10 within the horizontal plane is affected by the given dimensions:

- Standard deviation of the position of starting point in traverse $\sigma_{E_{GIP}} = \sigma_{N_{GIP}} = \pm 0.01\text{m}$;

- Standard deviation of the starting grid bearing ($\sigma_\nu = \pm 8''$); as well as the errors occurring during measuring, i.e. during setting out of traverse points in form of errors in setting out direction angles and error in setting out lengths of traverse legs.

The environment enables the use of total station when setting out the designed mine chambers, i.e. of the mine traverse. When carrying out the *a priori* accuracy assessment, the standard deviation for setting out direction angles $\sigma_\beta = \pm 20''$ and standard deviation for setting out length $\sigma_d = \pm 0.01$m were adopted.

Based on the standard deviations for given dimensions and adopted standard deviations of dimensions to be set out, and in accordance with (1), by implementing the General Law on the Propagation of Errors (Chandra, 2005), the variance-covariance matrix for standard deviations of coordinate differences was established:

(4)
$$K_{\Delta N,\Delta E} = A \cdot K \cdot A^T = \begin{bmatrix} \frac{\partial \Delta N}{\partial d} & \frac{\partial \Delta N}{\partial \nu} \\ \frac{\partial \Delta E}{\partial d} & \frac{\partial \Delta E}{\partial \nu} \end{bmatrix} \cdot \begin{bmatrix} \sigma_d^2 & 0 \\ 0 & \sigma_\nu^2 \end{bmatrix} \cdot \begin{bmatrix} \frac{\partial \Delta N}{\partial d} & \frac{\partial \Delta E}{\partial d} \\ \frac{\partial \Delta N}{\partial \nu} & \frac{\partial \Delta E}{\partial \nu} \end{bmatrix} = \begin{bmatrix} \sigma_{\Delta N}^2 & \sigma_{\Delta N,\Delta E} \\ \sigma_{\Delta N,\Delta E} & \sigma_{\Delta E}^2 \end{bmatrix}$$

Whereby: A - the coefficient matrix (Jacobian matrix) that represents matrix of partial derivatives when compared with the variables;

K - variance-covariance measurement matrix;

Where partial derivations are:

$$\frac{\partial \Delta N}{\partial d} = \cos\nu; \quad \frac{\partial \Delta N}{\partial \nu} = -d \cdot \sin\nu; \quad \frac{\partial \Delta E}{\partial d} = \sin\nu; \quad \frac{\partial \Delta E}{\partial \nu} = d \cdot \cos\nu$$

In the covariance measurement matrix K, members outside the main diagonal are zeros, because the measurements are independent from each other. Standard deviation of the traverse leg inclination is to be calculated according to the equation:

$$\sigma_{\nu_{i-1}^{i}} = \sqrt{\sigma_{\nu_{i-2}^{i-1}}^{2} + \sigma_{\beta_{i-1}}^{2}} \tag{5}$$

Whereby:

$\sigma_{\nu_{i-2}^{i-1}}$ - standard deviation of the grid bearing of previous traverse leg;

$\sigma_{\beta_{i-1}}$ - standard deviation for setting out the corresponding direction angle within the traverse.

Standard deviation of the traverse point position is calculated according to the equation:

$$\sigma_{N,E} = \sqrt{\sigma_{N_i}^{2} + \sigma_{E_i}^{2}} = \sqrt{\left(\sigma_{N_{i-1}}^{2} + \sigma_{\Delta N_{i-1}^{i}}^{2}\right) + \left(\sigma_{E_{i-1}}^{2} + \sigma_{\Delta E_{i-1}^{i}}^{2}\right)} \tag{6}$$

Whereby:

σ_{N_i} - standard deviation of traverse point in the direction of x-axis;

σ_{E_i} - standard deviation of traverse point in the direction of y-axis;

$\sigma_{N_{i-1}}$ - standard deviation of the previous traverse point in the direction of x-axis;

$\sigma_{E_{i-1}}$ - standard deviation of the previous traverse point in the direction of y-axis;

$\sigma_{\Delta N_{i-1}^{i}}, \sigma_{\Delta E_{i-1}^{i}}$ - standard deviation of coordinate differences calculated according to the equation (4).

Based on the above equation, calculated the standard deviation of the position of the last point in the traverse E420-17, which is $\sigma_{N,E} = \pm\,0.100\text{m}$.

6.2. A priori accuracy assessment for setting out of the designed mine chambers within the vertical plane

Setting out the mine chambers designed within the vertical plane is to be carried out by using trigonometric leveling of reference points by means of vertical angle (zenith distance). The reference points representing traverse points are to represent, at the same time, leveling points (benchmarks) of the future mine traverse, as well. This means that, similar to the case of setting out within the horizontal plane, setting out of each point within the vertical plane ist to be set out by using the previous already set out point. The levels of the mine traverse points set out are to be calculated by using the known equations (Schofield & Breach, 2007):

$$H_i = H_{i-1} + \Delta H_{i-1}^{i} = H_{i-1} + \frac{d_{i-1}^{i}}{\tan z_{i-1}^{i}} + i - l \tag{7}$$

Whereby:

$\boldsymbol{H_i}$ - the level of the last point set out;

$\boldsymbol{H_{i-1}}$ - the level of the previously set out point;

$\boldsymbol{\Delta H_{i-1}^{i}}$ - the altitude difference between points;

$\boldsymbol{d_{i-1}^{i}}$ - the horizontal length between points (element to be set out);

$\boldsymbol{z_{i-1}^{i}}$ - zenith distance between points (element to be set out);

i - height of the instrument;

l - altitude of the signal.

The GIP point level of the mine traverse designed was determined by static GPS method and it is H_{GIP}=460.36m with standard deviation $\sigma_{H_{GIP}} = \pm 0.02\text{m}$.

The E420-10 level of the point projected at the bench drift exit at level +420m is HE420-10=420.07m.

The design specifies to construct the adit from the GIP point upwards at the length of 151.63m, with inclination of 6.4% up to the point 2, which should be at the level H_2=470.00m. Through the haul downcast, transport drifts and bench drift, descend mine chambers up to the designed point E420-10 at the level 420.07m, which represents average drop of 8.5%.

It is normal that allowable tolerances within the vertical plane, while carrying out crosscut, i.e. when setting out points within undergroud traverses, are 2.5 times smaller in comparison with permissible lateral tolerances. Therefore, maximum allowable standard deviation for setting out of the last point E420-10 within the vertical plane, for the probability of 95% in this case, is $\sigma_{H_{max}} = \pm 0.16\text{m}$.

Setting out of the designed mine chambers within the vertical plane shall also be carried out by using total station and it is to be carried out at the same time as setting out within the horizontal plane. While making the a priori accuracy assessment, the standard deviation for setting out zenith distances $\sigma_z = \pm 15''$ was adopted, as well as standard deviations for measuring the instrument height and the altitude of signal of $\sigma_i = \sigma_l = \pm 0.01$m.

In accordance with (8), and by implementing the General Law on Propagation of Variances (Wolf & Ghilani, 1997), standard deviations for elevation differences are to be calculated as follows:

$$\sigma_{\Delta H} = \sqrt{\left(\frac{\partial \Delta H}{\partial d}\right)^{2} \cdot \sigma_d^{2} + \left(\frac{\partial \Delta H}{\partial z}\right)^{2} \cdot \sigma_z^{2} + \left(\frac{\partial \Delta H}{\partial i}\right)^{2} \cdot \sigma_i^{2} + \left(\frac{\partial \Delta H}{\partial l}\right)^{2} \cdot \sigma_l^{2}} \tag{8}$$

Whereby partial derivatives are:

$$\frac{\partial \Delta H}{\partial d} = \cot z \,; \quad \frac{\partial \Delta H}{\partial z} = -\frac{d}{\sin^2 z} \,; \quad \frac{\partial \Delta H}{\partial i} = +1; \quad \frac{\partial \Delta H}{\partial l} = -1$$

Standard deviation for the level of the point set out is to be calculated by using the following equation:

$$\sigma_{H_i} = \sqrt{\sigma_{H_{i-1}}^{\;2} + \sigma_{\Delta H_{i-1}^{i}}^{\;2}} \tag{9}$$

Whereby:

$\sigma_{H_{i-1}}$ - standard deviation of the level of the point previously set out;

$\sigma_{\Delta H_{i-1}^{i}}$ - standard deviation of elevation differences calculated by using the equation (10).

Calculate the standard deviation of elevation points E420-10 is $\sigma_{H_{E420-17}}$ = 0.107m.

7. Conclusion

Standard deviations of given parameters and a priori adopted standard deviations for setting out of direction angles and horizontal lengths cause the standard deviation for the position of the last point E420-10 within the horizontal plane to be $\sigma_{N,E}$ = ± 0.10m, which is 4 times smaller than the maximum allowable tolerance. Therefore, this value, which is obtained by using the a priori accuracy assessment method, does not need to be broken down to longitudinal and lateral components.

The additional analysis of standard deviation for the position of the last point E420-10 in terms of adopted tolerances for parameters to be set out, indicate:

- that standard deviation for setting out direction angles of σ_{β} = ± 20" causes standard deviation for the position of the last point of $\sigma_{N,E_{(\beta)}} = \pm 0.067\text{m}$;

- that standard deviation for setting out lengths of σ_d = ± 0.01m causes standard deviation for the position of the last point of $\sigma_{N,E_{(d)}} = \pm 0.073\text{m}$..

These values show that the adopted standard deviations of parameters to be set out not only satisfy the accuracy prerequisites laid down, but they also satisfy the prerequisite of equal impact of setting out angles and lengths onto the standard deviation for the position of the last point E420-10.

The deviation of the last point E420-10 within the vertical plane, obtained by the *a priori* accuracy assessment, is $\sigma_{H_{E\,240-10}} = 0.107\text{m}$, which is approximately 1/3 smaller than the maximum allowable tolerance. The impact of setting out the zenith distance onto the standard deviation for the position of the last point E420-10 within the vertical plane is negligible. The analysis has shown that, if standard deviation of zenith distances would be 30"instead of the adopted 15", the standard deviation of the last point would be 0.108m (it would remain the same). The largest impact onto the standard deviation of the last point's position within the vertical plane is the result of measuring the instrument height and the altitude of signal. If standard deviations of these measured altitudes would be 0.02m, the standard deviation of the last point would also be almost 2 times larger than the value obtained by the analysis (0.209m).

All of this indicates that the completion of this project in terms of mine surveying may be carried out by using total station of common accuracy, that setting out of direction angles and zenith distances may be carried out with only one position of scope (it is required that the total station be previously tested and rectified), and that while carrying out of those operations, one must not strictly look at the alignment of instrument and signal, due to the fact that the lengths of sides are short, but one must also look at the quality of measurement of the instrument height and altitude of signal.

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