UNDERGROUND MINING ENGINEERING 46 (2025) 175-188 UDK 62
UNIVERSITY OF BELGRADE - FACULTY OF MINING AND GEOLOGY eISSN 2560-3337

*Original scientific paper*

# A-PRIORI ACCURACY ASSESSMENT OF TRACING THE CUT-TROUGH IN THE VERTICAL PLANE DURING THE CONSTRUCTION OF THE HAULAGE DRIFT IN THE "GROT" MINE

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**Received:** June 17, 2025 **Accepted:** June 28, 2025

**Abstract:** Mining projects for the exploitation of the grade ores encompass specific technical and technological solutions that are a consequence of the characteristic spatial position and geometry of the ore deposit, existing mining works, natural and artificial objects, and terrain relief. To realize the mining project, a series of mining and surveying tasks must be carried out in the pre-project and project phases of exploitation, as well as during the construction of mine facilities and the excavation of mineral materials. Among the various mining and surveying tasks that follow project implementation, the tracing of the cut-through or cross-cuts, between existing mine tasks is often a crucial step. For the successful execution of these tasks, it is necessary to perform an *a priori* assessment of the accuracy of the cut-through in order to define the required precision for the measurement/monitoring process, and based on that, determine the appropriate equipment and measurement method. This paper presents a *priori* assessment of the accuracy of marking the cut-through in the vertical plane during the construction of the haulage drift on the IX horizon of the "Grot" lead and zinc mine.

**Keywords:** underground exploitation, lead and zinc mine, mining measurements, a priori accuracy assessment

## 1 INTRODUCTION

The assessment of the accuracy of the marking of large and significant infrastructure facilities, as well as facilities that may pose potential risks to human health and safety, include an *a priori* evaluation. The purpose of *a priori* accuracy assessment is to define the necessary level of precision in measuring and marking angles, lengths, and height differences, which will ensure the accuracy of the marking of the designed points or object in accordance with project or previously established standards. The quality of the measured quantities can be *a priori* standardized based on the principle of equal or

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nonequal influence. An *a priori* accuracy assessment guided by the principle of equal influence ensures that each measured quantity has an equal impact on the overall standard deviation of the marking of the designed object. Conversely, in the case of nonequal influence, individual measured quantities may have a greater or lower influence on the standard deviation of the marking (Wolf and Ghilani, 1997).

On the other hand, *a priori* accuracy assessment can be performed in accordance with the projected or previously defined standard deviation of tracing, ensuring a 68.27% (1s) probability that the specified standard deviation will be achieved. However, for large and significant infrastructure facilities and works, the standard deviation of marking can be devided by 2, establishing more strict criteria for *a priori* accuracy assessment and necessitating greater precision in the measured/marked quantities. In this case, the probability of achieving the given standard deviation increases to 95.45% (2s). To attain even greater certainty in the realization of marking, the standard deviation of object marking can be reduced by a factor of three, which will ensure a 99.73% (3s) probability of tracing precision, but will also require a significantly higher accuracy of field measurements (Ganić, 2008; Schofield and Breach, 2007).

This study presents an *a priori* evaluation of the accuracy in the execution and tracing of cut-through in the vertical plane, using the construction of a haulage drift in the "Grot" mine as a case study. Given the relatively short length and simple geometry of the cut-through, for the *a priori* accuracy assessment was adopted to the 1s standard and the principle of equal influence of the measured variables on the overall error of the cut-through.

## 2 GEOGRAPHICAL SETTING OF THE "GROT" MINE

The "Grot" lead and zinc ore deposit is situated in the Pčinja district of southeastern Serbia, on the southeastern slope of Besna Kobila mountain (height k+1923 m). The "Grot" mine's ore field exhibits the characteristic features of a high-altitude region. It is bordered by the Vardenika mountain massif to the north, the Glok mountain to the east, the Dukat mountain to the southeast, the Patarice mountain and Srpska Čuka to the south, and the Borovik peak to the northwest (Figure 1).


**Figure 1** Geographical setting of the "Grot" mine

The deposit is situated approximately 29 kilometres east of Vranje and 20 kilometres west of Bosilegrad. An 8 kilometer road leads to the "Grot" mine, branching off from the main Vranjska Banja-Bosilegrad road at the 28th kilometre, near the village of Kriva Feja. The mine's exploitation and exploration field falls under the jurisdiction of the city municipalities of Vranjska Banja and Bosilegrad, as well as the cadastral municipalities of Kriva Feja and Musulj.

## 3 "GROT" MINE

The first exploration activities in the "Blagodat" (nowaday "Grot") deposit commenced in 1903. These tasks were undertaken by Italian researchers in the eastern and southern parts of the deposit. The exploration continued until 1911, when excavation has been started. The Italian researchers primarily focused on extracting the richest sections of the ore bodies, which were accessible at the open levels of 1565 m, 1585 m, 1606 m, 1608 m, and 1621 m. During this period, a facility for ore preparation was also established. From 1948 to 1953, the research was reactivated, firstly by the "Mačkatica" molybdenum mine, and subsequently by the "Trepča" combine. In late 1956, following a comprehensive study by the Institute for Geological and Geophysical Research from Belgrade, a research program and project were developed, which have been implemented since 1958. Since 1963, the "Trepča" combine has overseen the research and financing. Notably, during the period of 1959-1964, more than 10 km of exploratory mining rooms and approximately 4 km of drill holes were created within the deposit. Regular exploitation started in September 1974.

Based on the limited resources remaining from the "Blagodat" mine, social company lead and zinc mine "Grot" was established on December 19, 2000. as a newly founded mining company, started exploitation in 2001. After the mine's establishment, the necessary production settings of the mining facilities and the establishing of conditions for the starting of preparation and excavation activities were carried out. During the period from 2001 to 2007, a total of 612,850 tons of Pb-Zn ore was extracted, with an average content of 3.00% Pb and 3.84% Zn.

According to Decision BD 146657/2007 issued by the Agency for Business Registers on 07.12.2007, the official data for the business entity was changed to lead and zinc mine "Grot" a.d., which remains the name under which it currently operates.

The "Grot" lead and zinc mine exploits ore from the Grot deposit, which is situated within an area whose coordinates are presented in Table 1 and in Figure 2 (The primary mining project for the extraction of lead and zinc deposits "Grot" - Kriva Feja, 2011.).

**Table 1** Coordinates of the boundary points of the mining area "Grot"

| Point | Coordinates | |
|---|---|---|
| Number | Y [m] | X [m] |
| 1 | 7 597 000 | 4 713 500 |
| 2 | 7 601 000 | 4 711 000 |
| 3 | 7 604 000 | 4 711 000 |
| 4 | 7 604 000 | 4 708 500 |
| 5 | 7 601 000 | 4 708 500 |
| 6 | 7 601 000 | 4 710 000 |
| 7 | 7 597 000 | 4 712 500 |

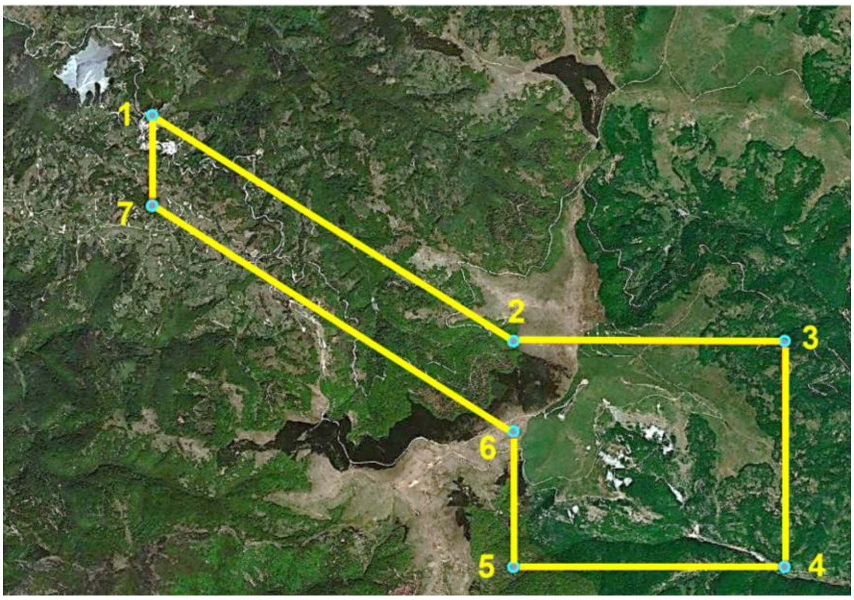


**Figure 2** Exploitation field of the "Grot" mine

Until the 1960s, mining activities were confined to the extraction of exposed ore deposits through shallow adits and the declines directly from the terrain surface. Exploration efforts carried out until 1967 led to the identification of ore reserves categorized as A+B+C1 in the "Blagodat" (Table 2) deposit, which were certified by the Commission for Ore Reserves in same year.

**Table 2** Certified deposit reserves from 1967.

| Reserve category | Ore Reserves [t] | The metal content Pb [%] | Zn [%] |
|---|---|---|---|
| A+B+$C_1$ | 4 766,241 | 4.16 | 4.24 |

Within the mine drift, ore deposits are delineated into designated mining districts, which are then further subdivided into individual ore bodies:

- Mining district "Bare-Đavolja vodenica-Istočni revir I",
- Mining district "Vučkovo",
- East Mining district II, currently under exploration.

East Mining district I contains several notable ore bodies, including RT-10, RT-10a, and RT-11, which were formed at the contact between gneiss and schists (Technical mining project of the ore deposit extraction "Istočni revir I", 2016.). The physical characteristics and spatial distribution of these ore bodies are presented in Figures 3, 4, and 5. Additionally, the Vučkovo mine district hosts a primary lenticular ore body, RT-1, in the form of an elongated lens situated along a steeply dipping ore structure (slope≈70°), within a sequence of biotite-sericite schists (Figure 6).

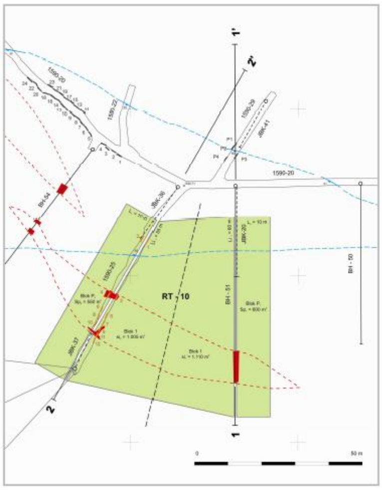


**Figure 3** Ore body RT-10

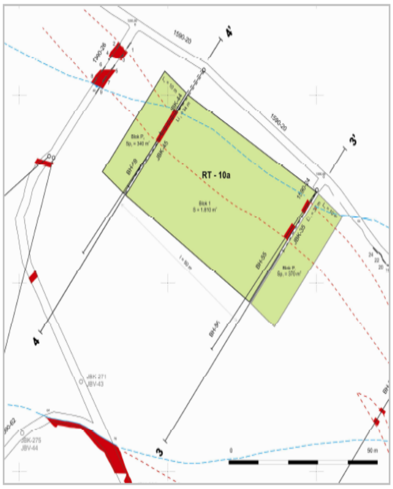


**Figure 4** Ore body RT-10a

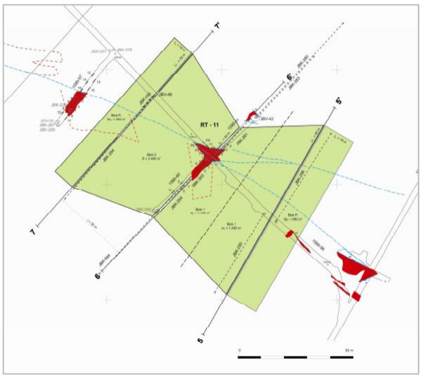

**Figure 5** Ore body RT-11

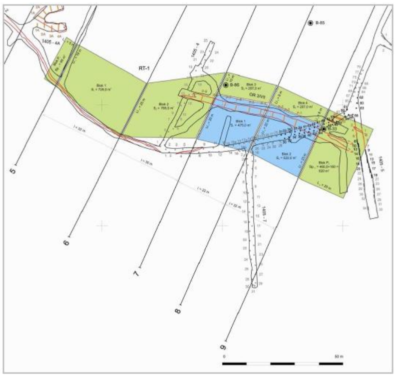

**Figure 6** Ore body RT-1

Alongside the primary ore structure, a secondary wire ore deposit, designated as RT-2, was formed spanning approximately 30 meters, situated at the interface between gneissic and biotite-sericite schist lithologies, Figure 7.

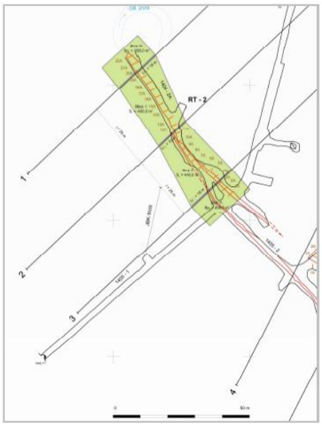


**Figure 7** Ore body RT-2

The RT-3 ore deposit, unlike the preceding two previous deposits, exhibits a gentler inclination, typically up to 30 degrees, and originated at the interface between gneisses and biotite-sericite schists, Figure 8.

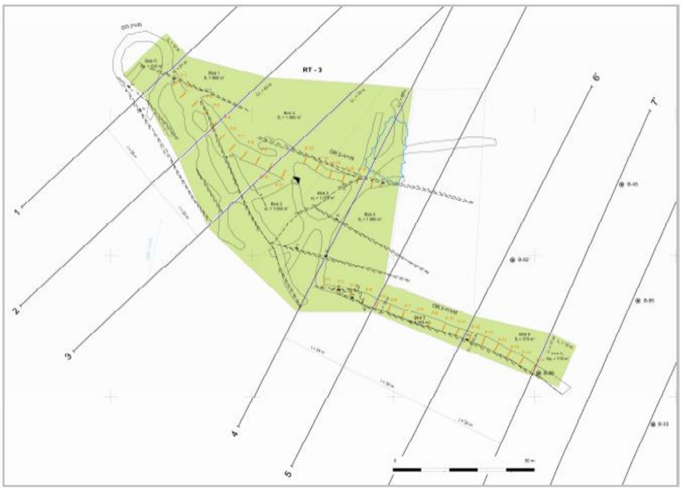


**Figure 8** Ore body RT-3

Based on the contract for the development of project documentation between the Lead and Zinc Mine "Grot" a.d. (registration number 152-20-10, dated 04.12.2010) and the company "Geo Consulting Studio" in Belgrade, a study was conducted on the lead and zinc reserves in the ore bed Grot: encompassing the Bare - Đavolja Vodenica and Vučkovo deposits, as presented in Table 3.

**Table 3** Ore reserves certified in the 2010 study

| Mining district | Category | Deposit reserves | Average content [%] | | Ore reserves [t] | |
|---|---|---|---|---|---|---|
| | | [t] | Pb | Zn | Pb | Zn |
| Bare - Đavola Vodenica | $C_1$ | 133,492.80 | 2.98 | 4.40 | 3,983.48 | 5,867.83 |
| Vučkovo | $B+C_1$ | 344,739.82 | 3.99 | 5.42 | 13,764.25 | 18,689.35 |

## 4 PROJECT ASSIGNMENT FOR THE DEVELOPMENT OF THE CUT-THROUGH AT THE IX HORIZON LEVEL IN THE EXPLOITATION FIELD OF THE LEAD AND ZINC MINE "GROT"

The project assignment involves constructing a haulage drift (TH) parallel to the existing main haulage drift (GTH), extending from the surface to the IX horizon level (Figure 9). Designed haulage drift TH is 494.54 meters (horizontal distance) long and primarily intended for the transport of dirt and deposit materials. By creating this additional haulage drift, the length of exporting and transporting dirt and deposit materials will be reduced. Furthermore, the establishment of this new haulage drift will facilitate more detailed exploration of the zone at the IX horizon level and the levels below, potentially leading to an increase in the exploitation field's deposit reserves and the formation of new mining works.

The dimensions of the cross-section of the current GTH system, measuring 2.5 m x 2.5 m, constrain the utilization of mechanized equipment for loading and transportation. Consequently, the designed TH haulage drift will be constructed through a single access point, directly from the surface.

Construction of the TH is planned to commence at point 1 on the field's surface and proceed towards the designated breakthrough site at point 11. The haulage drift will be built with an incline ($\boldsymbol{\delta = 0°49'42''}$) and a specific bearing ($\boldsymbol{\nu = 15°}$). The overall, actual length of the TH is 494.59 meters, with a cross section measuring 3.5 meters by 3.0 meters.

The initial point 1 on the field's surface will be marked from the existing trigonometric point T4, known as Orlov kamen. The table 4 provides the coordinates and heights of the trigonometric point, as well as the start point 1 and end point 11 of the haulage drift (Đorđević, 2020).

**Table 4** Coordinates and heights of the important points

| Point | Y [m] | X [m] | H [m] |
|---|---|---|---|
| T4 – Orlov kamen | 7 602 866.97 | 4 709 281.68 | 1,354.38 |
| 1 | 7 602 730.15 | 4 709 415.23 | 1,298.84 |
| 11 | 7 602 861.88 | 4 709 891.90 | 1,305.99 |

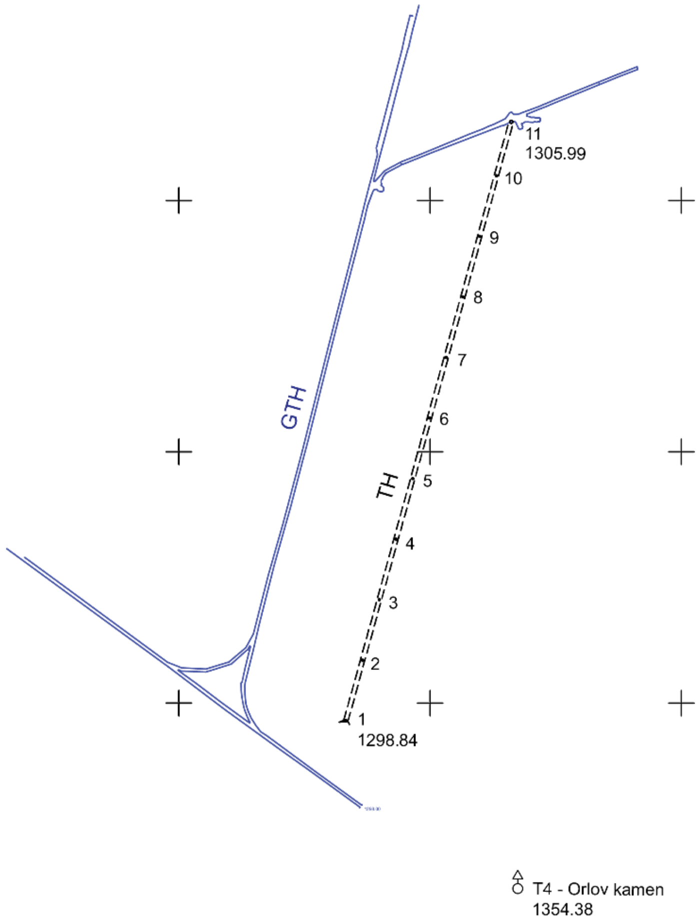


**Figure 9** Designed haulage drift TH

## 4.1. *A priori* accuracy assessment of the cut-through in the vertical plane

To establish the cut-through in acordance with the project and within the maximum adopted error, it is necessary to make a *a priori* accuracy assessment before starting of the cut-through. The *a priori* accuracy assessment determines the standard deviations of all measured parameters, including the method and precision of marking, as well as the class of instruments that will achieve required cut-through accuracy. This paper will present *a priori* accuracy assessment of the specified cut-through on level of the IX horizon of the "Grot" mine in the vertical plane.

The project assignment does not specify the permitted error for the vertical alignment of the haulage drift markings. Following the construction of the haulage drift at the level of the IX horizon, mining operations will continue, and the permitted error for vertical plane markings is adopted as the acceptable margin of error for measuring height differences within the underground mine rooms. This error was adopted based on the Rulebook on the methodology for conducting mining surveyings (Službeni glasnik RS, 1997), and for the leveling on the primary horizon calculates the error according to the equation:

$$\varDelta = 25\sqrt{L} \tag{1}$$

Where, L - the overall distance of the traverse in kilometers, and error $\Delta$ in milimeters.

In this case, the vertical plane markings during the projected haulage drift construction will start from the existing trigonometric point T4 - Orlov kamen. This will enable the marking of point 1 at the future haulage drift entrance, followed by the demarcation of the breakthrough as per the design specifications. The vertical plane cut-through markings should be executed with a total standard deviation of

$$\varDelta = \sigma_{max} = 25\sqrt{(0.49454 + 0.19120)} = 20.7\,mm \tag{2}$$

From the trigonometric point T4 - Orlov kamen to the cut-through point, a total of 11 height differences are planned to be staked out: one to determine the height of point 1 on the terrain surface, and 10 height differences during the construction of the cut-through, i.e., the haulage drift. Assuming all elevation measurements will be taken with the same standard deviations, the following can be inferred:

$$11 \cdot \sigma_{\Delta h}^2 = 20.7\,mm \tag{3}$$

regarding:

$$11 \cdot \sigma_{\Delta h}^2 = 428.29 \rightarrow \sigma_{\Delta h}^2 = 38.95 \rightarrow \sigma_{\Delta h} = \pm 6.2\,mm \tag{4}$$

The method of trigonometric leveling will be employed to stakeout height differences in accordance with the following equation:

$$\Delta h = d_k \cdot cosz \pm i \mp l \tag{5}$$

whereas:

$d_k$ - slope distance between end points;

$z$ - zenith angle;

$i$ - instrument height;

$l$ - marker height.

The mathematical operations of addition or subtraction indicated in the equation are dependent on the vertical positioning of the marked points, whether they are situated on the floor or roof of the haulage drift.

In the *a priori* evaluation of accuracy, the principle of equal influence of the measured variables is commonly applied. This implies, in this case, each of the four measured variables when determining height differences, must have an equivalent impact on the standard deviation of the height difference from $\pm 6.2mm$. According to the law of error propagation, the error of the function (height differences determined by method of the trigonometric levelling) is:

$$\sigma_{\Delta h}^2 = k_d^2 \cdot \sigma_d^2 + k_z^2 \cdot \sigma_z^2 + k_i^2 \cdot \sigma_i^2 + k_l^2 \cdot \sigma_l^2 \tag{6}$$

whereas:
$k_d, k_z, k_i, k_l$ - partial derivatives of the function with respect to the corresponding measured parameters;
$\sigma_d, \sigma_z, \sigma_i, \sigma_l$ - standard deviations of the measured parameters.

Assuming the principle of equal influence has been adopted, it is then:

$$k_d^2 \cdot \sigma_d^2 = k_z^2 \cdot \sigma_z^2 = k_i^2 \cdot \sigma_i^2 = k_l^2 \cdot \sigma_l^2 = k^2 \cdot \sigma^2 \tag{7}$$

follows:

$$\sigma_{\Delta h}^2 = 4k^2\sigma^2 \rightarrow 38.95 = 4k^2\sigma^2 \rightarrow k\sigma = 3.1\ mm \tag{8}$$

Partial derivatives of the function with respect to the corresponding measured parameters are:

$$k_d = \frac{\partial \Delta h}{\partial d_k} = \cos z \tag{9a}$$

$$k_z = \frac{\partial \Delta h}{\partial z} = -d_k \cdot \sin z \tag{9b}$$

$$k_i = \frac{\partial \Delta h}{\partial i} = \pm 1 \tag{9c}$$

$$k_l = \frac{\partial \Delta h}{\partial l} = \mp 1 \tag{9d}$$

For the first height difference between T4 and 1 values for the slope distance and zenith angle are: $d_k = 199.10\ m$ i $z = 106°11'51''$. Values of the partial derivatives are: $k_d = -0.278949$, respectively, $k_z = -191.196893\ m$.

Standard deviation of the measuring slope distance between points T4 and 1 is:

$$k_d\sigma_d = 3.1 \text{ mm} \quad \rightarrow \quad 0.278949\sigma_d = 3.1 \text{ mm} \quad \rightarrow \quad \sigma_d = \pm 11.1 \text{ mm}$$

Standard deviation of the measuring zenith angle between points T4 and 1 is:

$$k_z\sigma_z = 3.1\text{ mm} \rightarrow 191.196893\ m \cdot \frac{\sigma_z}{\rho''} = 0.0031\ m \rightarrow \sigma_z = \pm 3.3''$$

Standard deviation of the measuring instrument height and marker during surveying between points T4 and 1 is:

$$k_i\sigma_i = k_l\sigma_l = 3.1\text{ mm} \quad \rightarrow \quad 1 \cdot \sigma_i = 1 \cdot \sigma_l = 3.1\text{ mm} \quad \rightarrow \quad \sigma_i = \sigma_l = \pm 3.1\text{ mm}$$

When marking the cut-through the vertical plane, equidistant slope distances between the points were adopted, $d_k = 49.46\ m$ and zenith angle from the designed cut-through, $z = 89°10'18''$. In that case, the partial derivative values are: $k_d = +0.014457$ and $k_z = -49.454831\ m$.

Standard deviation of the measuring slope distances when marking the cut-through the vertical plane correspond to:

$$k_d\sigma_d = 3.1\text{ mm} \quad \rightarrow \quad 0.014457\sigma_d = 3.1\text{ mm} \quad \rightarrow \quad \sigma_d = \pm 214.4\text{ mm}$$

Standard deviation of the measuring zenith angles when marking the cut-through the vertical plane correspond to:

$$k_z\sigma_z = 3.1\text{ mm} \quad \rightarrow \quad 49.454831\ m \cdot \frac{\sigma_z}{\rho''} = 0.0031\ m \quad \rightarrow \quad \sigma_z = \pm 12.9''$$

## 5 CONCLUSION

An *a priori* accuracy assessment in measuring and marking the cut-through in the vertical plane during construction of the haulage drift on the IX horizon level of the "Grot" mine, following data has been obtained:

- The project specifications for the construction of the haulage drift does not define the acceptable error in the vertical plane. Therefore, the standard deviation of the height differences within the underground mine was adopted, which in this case is $\sigma_{max} = 20.7$ mm
- Measuring and marking height differences
- When employing the trigonometric levelling technique to determine the height differences between points T4 and 1 on the terrain surface, the length must be measured with the standard deviation $\sigma_d = \pm 11.1$ mm, zenith angle sa $\sigma_z = \pm 3.3''$, instrument height and marker height $\sigma_i = \sigma_l = \pm 3.1$ mm. These standard deviations require the lengths to be measured through three to four repeated trials with re-sighting, and the angle in the vertical plane to be assessed in two faces and by sighting with all three horizontal reticle lines.
- When employing the trigonometric technique to determine the distance between points T4 and 1 on the terrain surface, the length must be measured with the standard deviation $\sigma_d = \pm 214.4$ mm, zenith angle $\sigma_z = \pm 12.9''$, instrument height and marker height $\sigma_i = \sigma_l = \pm 3.1$ mm. These standard deviations are relatively straightforward to achieve, allowing the measurement and marking of angles to be performed using a simple method. This involves positioning in a single orientation and aligning the reticle's central thread. It is advisable that the instrument be thoroughly tested and calibrated before use. Additionally, lengths

can be measured with a standard steel tape, given the known standard deviation.

A priori accuracy assesment has shown that the measurements and markings can be achieved using the total station equipment operated by the surveying service of the "Grot" mine.

Standard devation of the height of the starting trigonometric point T4 - Orlov kamen is $\sigma_{H_{T4}} = \pm 15.0$ mm, the standard deviation of the height of the point is 11, with regard to the adopted standard deviation of the measurement and marking of the height differences is: $\sigma_{H_{11}} = \pm 25.4$ mm with the reliability of 68%. The reliability and standard deviation of the height at point 11 provide the quality execution of all future mining activities in the vertical plane at the IX horizon level of the mine.

*A priori* accuracy assessment was conducted using the principle of equitable influeces of all measured values on the standard deviation of height differences. The standard deviation of measurement or marking of slope distances within the projected haulage drift was evaluated from $\sigma_d = \pm 214.4$ mm is extremely large. It is reasonable to expect when measuring or marking lengths, the standard deviation would be notably low, abouth $\pm 50$ mm, representing a relative standard deviation of $\sigma_{rel} = 1{:}\,1000$, and therefore the standard deviation of the height of point 11 will be lower than the values previously reported$\sigma_{H_{11}} = \pm 25.4$ mm.

**ACKNOWLEDGMENT**

The research presented in this paper was conducted with the financial support of the Ministry of Science, Technology, and Innovation of the Republic of Serbia, within the framework of funding for scientific research at the University of Belgrade, Faculty of Mining and Geology in Belgrade, under contract number 451-03-65/2024-03/ 200126.

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