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*Review paper*

# APRIORI ACCURACY EVALUATION FOR THE CROSSCUT IN A HORIZONTAL PLANE BETWEEN THE VI HORIZON AND THE P2 SD ADIT OF THE "BLAGODAT" MINE

# APRIORI OCENA TAČNOSTI PROBOJA U HORIZONTALNOJ RAVNI IZMEĐU VI HORIZONTA I POTKOPA P2 SD JAME "BLAGODAT"

**Stoiljković Vladimir[1], Milutinović Aleksandar[2], Ganić Aleksandar[2], Mikanović Radenko[3]**

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**Abstract:** The construction of a crosscut in a sense of mine surveying is a hard and responsible job. This refers especially to the construction of longer crosscuts, considering the fact that, during its construction, there is no possibility for independent control of its execution. Therefore, in such cases, it is necessary to carry out prior analysis of the crosscut accuracy, where, based on all required elements, total standard tolerance of crosscut is to be calculated, and this must be less than default permitted tolerance. This paper shows a priori analysis of the crosscut accuracy that is to be executed with length of 1,192.43 m at the lead and zinc mine "Blagodat" for the purpose of ore transport.

**Key words:** mine surveyinig, crosscut, apriori accuracy evaluation

**Apstrakt:** Izrada proboja sa aspekta rudarskih merenja je težak i odgovoran posao. Ovo se pre svega odnosi na izradu dužih proboja, s obzirom da u toku njegove izrade ne postoji mogućnost nezavisne kontrole njegove realizacije. Zato je u ovakvim slučajevima neophodna prethodna analiza tačnosti proboja, gde se na osnovu svih potrebnih elemenata, računa ukupno standardno odstupanje proboja koje mora da bude manje od zadatog dozvoljenog odstupanja. U radu je prikazana apriori analiza tačnosti proboja koji treba da se realizuje u dužini od 1192,43 m u rudniku olova i cinka "Blagodat" radi transporta rude.

**Ključne reči:** rudarska merenja, proboj, apriori ocena tačnosti

[1] Lead and Zinc Mine "Grot"-Vranje, Kriva Feja bb, 17453 Kriva Feja, Serbia,
[2] University of Belgrade - Faculty of Mining and Geology, Djušina 7, 11000 Belgrade, Serbia,
e-mails: aleksandar.milutinovic@rgf.bg.ac.rs; aleksandar.ganic@rgf.bg.ac.rs
[3] Master Institut d.o.o., Dragana Bubića 19d, 78000 Banja Luka, Republic of Srpska, Bosnia and Herzegovina,
e-mail: mikanovic@gmail.com

## 1. INTRODUCTION

The crosscut is the name for the procedure of interconnection of two or more mine chambers. It is carried out upon the design for opening or development of a mine, field or a horizon, where crosscut direction is geometrically defined within horizontal and vertical plane (Patarić, 1990).

In terms of geometry, the difficulty and complexity of a crosscut depends on the case. Smaller crosscuts, easier for construction, donot require higher accuracy of measurement. However, there are also situations, where the design itself imposes such conditions for the accuracy of the crosscut's execution, that cannot be fulfilled.

Therefore, before the crosscut's construction starts, i.e. before marking starts, it is necessary to perform prior accuracy analysis.

The analysis of a crosscut accuracy defines types of instruments, measuring methods and marking accuracy, which must guarantee that the crosscut error is smaller than the default permissible deviation. The analysis includes:

- Standard deviations of geometrical basis on the terrain surface;
- Standard deviations of geometrical connection between the horizon and the terrain surface, and
- Standard deviations of measurement, i.e. of marking of points within the underground mine traverse.

If calculated standard deviation of a crosscut is larger than the default permissible deviation, the analysis is to be repeated with stricter critera for markings within the pit up to actually achiable limit for the instrument accuracy and measurement method. After that, adjustment of the technology of crosscut construction or adoption of higher values for permissible deviation must be made

## 2. ORE FIELD "BLAGODAT"

Lead and zinc ore deposit "Blagodat" is situated in the southeast of Serbia within the Serbian-Macedonian metalogenic province, on the southeast slope of the mountain summit Besna Kobila (H = 1,923 m). It was named after the first found and explored deposit. The deposit itsef is about 29 km by air away from Vranje to the east and 20 km away from Bosilegrad to the west. A road with length of 8 km leads to the "Blagodat" deposit, which departs from the main road Vranjska Banja - Kriva Feja - Bosilegrad at kilometer 28 not far away from the Kriva Feja settlement.

The mine is owned by the "Grot" Ltd. company, which extracts and processes polimetallic ores (Pb, Zn and Ag). Final product of the company is a concentrate of lead and zinc with silver, which is marketed on the domestic and foreign market.

The "Grot" mine was opened by the main haulage adit at H = 1,290 m, by service shaft, which was contructed from the adit level up to the surface (H = 1,741 m) and by a central ore conveying chute constructed also from the adit level up to the II horizon (H = 1,662 m). Apart from the central part of the deposit, which is to the maximum extentexcavated, the field "Bare - Đavolja vodenica I" ("Istočni revir I"), "Bare - Đavolja vodenica II" ("Istočni revir II") and "Vučkovo ležište" were also opened.

There are nine horizons at the mine. The ninth horizon, which is, at the same time, also the main transportation horizon, is located at the lowest elevation of 1,285 m and it connects Krava Feja, where flotation is located, with the haulage shaft and central ore corneying chutes 1 and 2. The first horizon is located at the elevation 1,713 m.

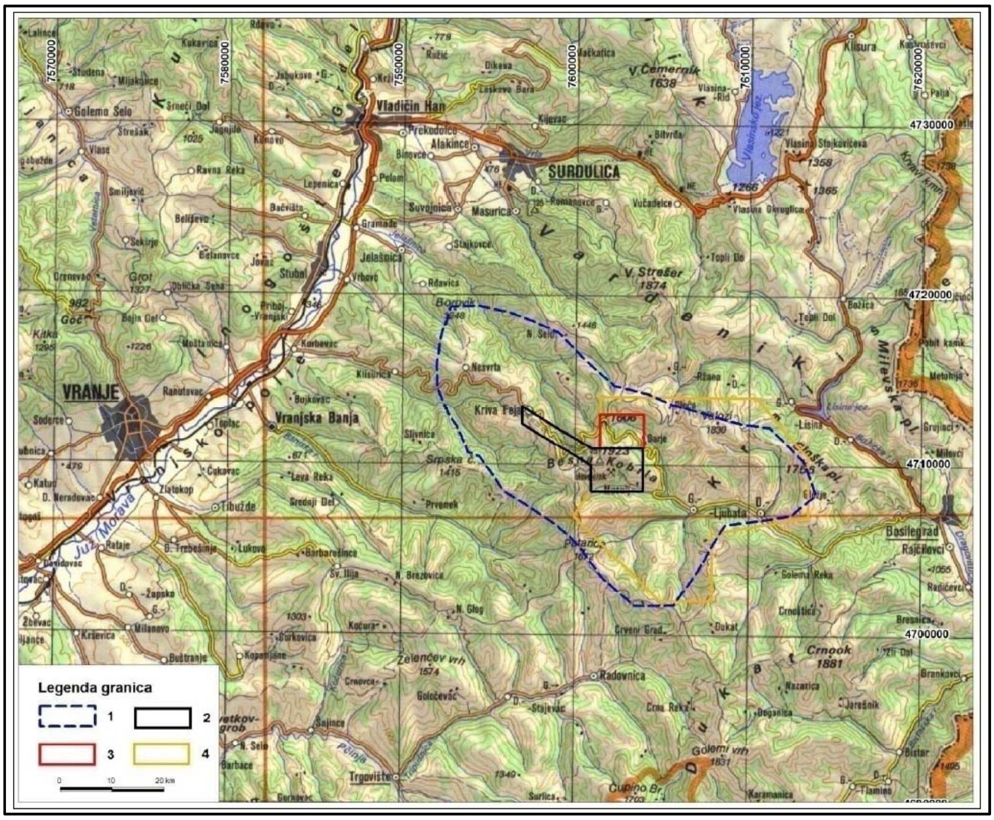


**Figure 1 -** Ore field "Blagodat": 1. Ore field "Blagodat"; 2. Mining field "Blagodat"; 3. Exploratory area "Kula"; 4. Exploratory area "Gornja Ljubata"

For the purposes of mining surveying at the terrain surface and for the purposes of connection of geometrical basis with the underground mine traverses, basic mining trigonometric network associated with the national trigonometric network is used.

## 3. CONSTRUCTION OF CROSSCUT BETWEEN THE VI MINE HORIZON AND THE P2 SD ADIT

Design specifications provide for to make crosscut between the VI horizon of the "Blagodat" mine and the P2 SD adit of the ore field "Blagodat" (Figure 2). In order to carry out the crosscut construction, i.e. the construction of mine chamber with the length of 1,192.43 m for the purposes of ore transportation, it is necessary to mark the direction of crosscut within the horizonal and vertical plane successively. In order to construct the crosscut within permissible deviation error, it is necessary to make a priori evaluation of crosscut accuracy, on the basis of which the type and class of the instrument, the measurement method and the accuracy, with which marking is to be carried out, are defined.

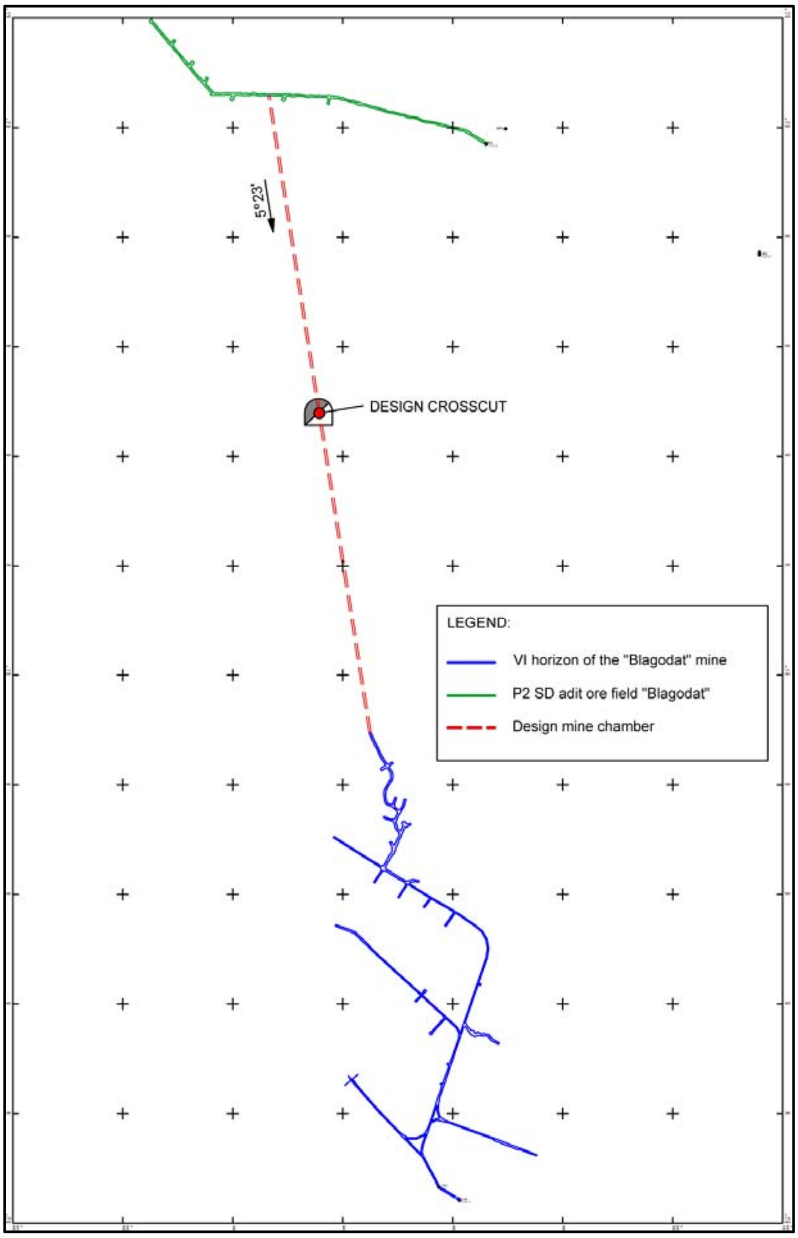


**Figure 2** - Design crosscut showed on the mine layout (S=1:2000)

It is designed to construct a crosscut between the existing points 38 from the direction of the VI horizon of the "Blagodat" mine and S23 from the directionof the P2 SD adit of the"Blagodat" ore field. The actual length of the crosscut is 1,192.43 m, and within the horizontal plane it is 1,187.20 m. It is designed that the opening point should be in the middle of this distance. Marking of 12 traverse points at each side of the crosscut (the twelfth point is the opening point) was planned by the analysis of the crosscut accuracy. The average horizontal length of traverse legs adopted by the analysis is 49.47 m, i.e. eleven legs at each side of the crosscut are 50 m each, and the last leg before opening point has the length of 43.60 m (Stoiljković, 2013).

Standard deviations of the position of points 38 and S23 are unknown, which disables the a priory evaluation of the crosscut accuracy. Moreover, positions of the existing points within underground mine traverses were not controlled since the time they were set. In order to detect possible deviations of the existing traverse points and in order to make analysis of the crosscut accuracy qualitatively, the analysis starts from the points on the surface of the terrain, in fact from the point 1/VI in the vicinity of the entrance to the VI horizon of the mine and point 8/P2 in the vicinity of the entrance to the P2 SD adit. This also means that the surveying department at the mine must previously carry out measurements within the existing traverses, in fact with the accuracy defined by the analysis, and only then proceed with marking of the design traverse points, i.e. crosscut. Figure 3 shows the outline for the crosscut plan.

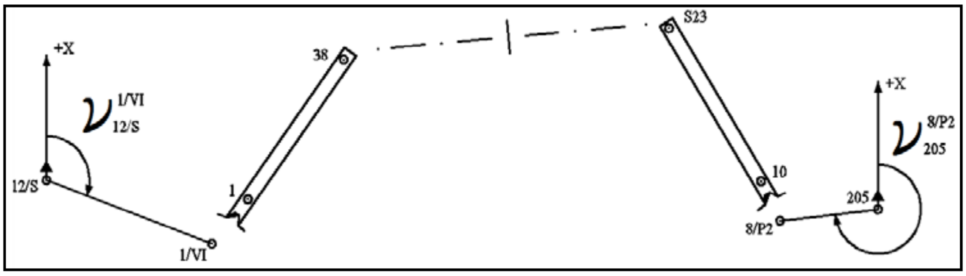


**Figure 3** - Outline for the crosscut plan

## 4. APRIORI EVALUATION OF THE CROSSCUT ACCURACY

The design width of the underground mine chamber to be constructed by the crosscut is 3.20 m. Since it is provided for to work with only half of the full profile immediately before opening, and pursuant to the Rule Book on the Method to Perform Mine Surveying, permissible error of the crosscut is 1/4 of the chamber width, i.e. in this case:

$$\Delta = \frac{3.20\text{m}}{4} = 0.80\text{m} \tag{1}$$

Standard deviation of the crosscut point marking for the probability of 95% is calculated upon the following equation:

$$\sigma = \frac{\Delta}{2} = 0.40\text{m} \tag{2}$$

The crosscut error is affected by given sizes, which are positioning errors of the starting point of the traverse (the error of traverse alignment) and the error of the starting grid bearing (the error of traverse orientation), as well as errors occurring during measurement, i.e. marking of traverse points in the form of errors when measuring refracted angles and errors of the measured lengths of traverse legs (Vulić and Uranjek, 2007).

The error of the position of starting traverse point, in accordance with the Rule Book on the Method to Perform Mine Surveying, is expressed in a form of permissible standard deviation of points within the mine network on the terrain surface, which amounts $\sigma_{y,x} = 0.3$ m. Presumed that such deviations of points are equal in the direction of coordinate axes, i.e. $\sigma_p = \sigma_y = \sigma_x$, then such standard deviations amount:

$$\sigma_{y,x} = \sqrt{\sigma_p^{\ 2} + \sigma_p^{\ 2}} = \sigma_p \sqrt{2} \tag{3}$$

i.e.:

$$\sigma_p = \frac{\sigma_{y,x}}{\sqrt{2}} = \frac{0.03m}{\sqrt{2}} = 0.0212\text{m} \tag{4}$$

## 4.1. Crosscut from the direction of the VI mine horizon "Blagodat"

Starting point for the construction of crosscut from the direction of the VI horizon is trigonometric point 1/VI at the entrance to the mine with coordinates:

$$y_{1/VI} = 7602612.80; \quad x_{1/VI} = 4710041.68$$

and with adopted standard deviations according to (4):

$$\sigma_{y_{1/VI}} = 0.0212\text{m}; \quad \sigma_{x_{1/VI}} = 0.0212\text{m}$$

Starting grid bearing was taken between 12/S and 1/VIpoints. Grid bearing and horizontal length between those points is:

$$\nu = 72^\circ 58' 30''; \quad d = 568.70m$$

Standard deviation of the starting grid bearing, apart from those given data, also depends on standard deviations of end points 12/S and 1/VI. It is to be calculated upon the equation:

$$\sigma_\nu = \sqrt{\left(\frac{\partial \nu}{\partial y_{1/VI}}\right)^2 \sigma_{y_{1/VI}}^2 + \left(\frac{\partial \nu}{\partial x_{1/VI}}\right)^2 \sigma_{x_{1/VI}}^2 + \left(\frac{\partial \nu}{\partial y_{12/S}}\right)^2 \sigma_{y_{12/S}}^2 + \left(\frac{\partial \nu}{\partial x_{po}}\right)^2 \sigma_{x_{12/S}}^2} \tag{5}$$

whereby partial derivatives are:

$$\frac{\partial \nu}{\partial y_{1/VI}} = \frac{\cos \nu}{d}; \qquad \frac{\partial \nu}{\partial x_{1/VI}} = -\frac{\sin \nu}{d}$$

$$\frac{\partial \nu}{\partial y_{12/S}} = -\frac{\cos \nu}{d}; \qquad \frac{\partial \nu}{\partial x_{12/S}} = \frac{\sin \nu}{d}$$

and the equation, which grid bearing is to be calculated upon, is:

$$\nu = \arctan \frac{y_{1/VI} - y_{12/S}}{x_{1/VI} - x_{12/S}} \tag{6}$$

As it was adopted that:

$$\sigma_{y_{1/VI}} = \sigma_{x_{1/VI}} = \sigma_{y_{12/S}} = \sigma_{x_{12/S}} = \sigma_p = 0.0212\text{m}$$

the equation (5) has the following form:

$$\sigma_\nu = \frac{\rho'' \cdot \sigma_p}{d}\sqrt{2\cos^2\nu + 2\sin^2\nu} = \frac{\rho'' \cdot \sigma_p}{d}\sqrt{2} \tag{7}$$

and the standard deviation of the starting grid bearing amounts:

$$\sigma_\nu = \frac{206265 \cdot 0.0212}{568.70}\sqrt{2} = 11''$$

The influence of the starting grid bearing onto the position of the last point of traverse, i.e. the opening point from the direction of the VI horizon is calculated upon the following equations:

$$\sigma_{y_\nu} = \frac{\sigma_\nu}{\rho''} \cdot R_x; \quad \sigma_{x_\nu} = \frac{\sigma_\nu}{\rho''} \cdot R_y \tag{8}$$

where $R_x$ and $R_y$ are distances between the first and the last point within the traverse on coordinate axes.

Deviation values of the opening point due to the error of the starting grid bearing are:

$$\sigma_{y_\nu} = \frac{11}{206265} \cdot 1429.37 = 0.0762\text{m}; \quad \sigma_{x_\nu} = \frac{11}{206265} \cdot 239.76 = 0.0128\text{m}$$

For the a priori evaluation of the crosscut accuracy, standard deviations of angle measurements within the traverse of $\sigma_\beta$= 10" and relative standard deviations for measurements of traverse legs' lengths of $\sigma_{drel}$ = 1:5,000 were adopted. The adopted standard deviations of the sizes measured affect standard deviation of the opening point according to the equations (Ganić et al. 1994):

$$\sigma_{y_\beta} = \frac{\sigma_\beta}{\rho''} \cdot \sqrt{\sum R_x^{\ 2}}; \quad \sigma_{x_\beta} = \frac{\sigma_\beta}{\rho''} \cdot \sqrt{\sum R_y^{\ 2}} \tag{9}$$

$$\sigma_{y_d} = \sigma_{d_{rel}} \cdot \sqrt{\sum \Delta y^2}; \quad \sigma_{x_d} = \sigma_{d_{rel}} \cdot \sqrt{\sum \Delta x^2} \tag{10}$$

So therefore, standard deviations of the opening point due to the influences of the sizes measured within the traverse are:

$$\sigma_{y_\beta} = \frac{10}{206265} \cdot \sqrt{31644362.03} = 0.2727\text{m}; \quad \sigma_{x_\beta} = \frac{10}{206265} \cdot \sqrt{1163743.90} = 0.0523\text{m}$$

$$\sigma_{y_d} = \frac{1}{5000} \cdot \sqrt{17451.26} = 0.0264\text{m}; \quad \sigma_{x_d} = \frac{1}{5000} \cdot \sqrt{77147.75} = 0.0556\text{m}$$

Values of sums of squares of deviation of traverse points from the opening point ($R_x$ and $R_y$), as well as sums of squares of coordinate differences ($\Delta y$ and $\Delta x$), are calculated in Table 1.

Total standard deviation of the opening point from the direction of the VI horizon on coordinate axes is:

$$\sigma_{y_{prl}} = \sqrt{\sigma^2_{y_{1/VI}} + \sigma^2_{y_\nu} + \sigma^2_{y_\beta} + \sigma^2_{y_d}} = \sqrt{0.0212^2 + 0.0762^2 + 0.2727^2 + 0.0264^2} = 0.2852\text{m}$$

$$\sigma_{x_{prl}} = \sqrt{\sigma^2_{x_{1/VI}} + \sigma^2_{x_\nu} + \sigma^2_{x_\beta} + \sigma^2_{x_d}} = \sqrt{0.0212^2 + 0.0128^2 + 0.0523^2 + 0.0556^2} = 0.0802\text{m}$$

**Table 1** - Elements for the analysis of crosscut from the direction of the VI horizon

| | **$\Delta y$** | **$\Delta x$** | **Ry** | **Rx** | **$\Delta y^2$** | **$\Delta x^2$** | **$Ry^2$** | **$Ry^2$** |
|---|---|---|---|---|---|---|---|---|
| 1/VI | -37.74 | 23.56 | -239.76 | 1429.37 | 1424.29 | 555.07 | 57483.70 | 2043094.10 |
| 1 | -29.28 | 55.62 | -202.02 | 1405.81 | 857.42 | 3093.96 | 40811.17 | 1976297.82 |
| 2 | -2.85 | 8.98 | -172.74 | 1350.19 | 8.12 | 80.62 | 29837.73 | 1823000.16 |
| 3 | 2.52 | 13.91 | -169.89 | 1341.21 | 6.35 | 193.59 | 28861.40 | 1798835.08 |
| 4 | 14.30 | 41.36 | -172.41 | 1327.29 | 204.47 | 1710.47 | 29724.20 | 1761706.86 |
| 5 | 58.48 | 169.96 | -186.71 | 1285.94 | 3419.88 | 28886.59 | 34859.23 | 1653629.41 |
| 7 | 16.83 | 48.85 | -245.19 | 1115.97 | 283.27 | 2386.52 | 60116.17 | 1245399.47 |
| 8 | 10.97 | 31.84 | -262.02 | 1067.12 | 120.36 | 1013.98 | 68652.71 | 1138750.78 |
| 9 | 17.32 | 50.30 | -272.99 | 1035.28 | 300.00 | 2530.24 | 74522.24 | 1071803.89 |
| PK | 2.66 | 16.19 | -290.31 | 984.98 | 7.08 | 262.21 | 84278.79 | 970181.88 |
| SK1 | -2.83 | 16.19 | -292.97 | 968.79 | 8.01 | 262.26 | 85830.58 | 938544.79 |
| SK2 | -8.24 | 14.69 | -290.14 | 952.59 | 67.87 | 215.71 | 84179.95 | 907429.15 |
| SK3 | -12.37 | 10.84 | -281.90 | 937.90 | 153.06 | 117.54 | 79467.27 | 879663.08 |
| KK | -59.01 | 36.73 | -269.53 | 927.06 | 3482.44 | 1349.20 | 72645.12 | 859443.83 |
| 10 | -77.54 | 48.77 | -210.52 | 890.33 | 6012.15 | 2378.41 | 44316.72 | 792688.35 |
| 11 | -9.38 | 6.48 | -132.98 | 841.56 | 87.97 | 41.99 | 17682.98 | 708225.72 |
| 12 | -11.19 | 6.19 | -123.60 | 835.08 | 125.26 | 38.33 | 15276.44 | 697361.65 |
| 13 | -9.57 | 7.76 | -112.41 | 828.89 | 91.57 | 60.21 | 12635.14 | 687059.99 |
| 14 | 3.68 | 5.57 | -102.84 | 821.13 | 13.56 | 31.06 | 10575.40 | 674256.66 |
| 15 | 7.92 | 13.45 | -106.52 | 815.56 | 62.74 | 180.94 | 11346.31 | 665134.66 |
| 16 | 4.61 | 8.24 | -114.44 | 802.11 | 21.24 | 67.87 | 13096.44 | 643375.09 |
| 17 | 1.94 | 8.25 | -119.05 | 793.87 | 3.77 | 68.14 | 14172.60 | 630226.89 |
| 18 | 5.68 | 10.75 | -120.99 | 785.61 | 32.27 | 115.59 | 14638.54 | 617188.50 |
| 20 | 4.82 | 9.15 | -126.67 | 774.86 | 23.22 | 83.69 | 16045.43 | 600411.06 |
| 21 | 2.23 | 7.22 | -131.49 | 765.71 | 4.98 | 52.18 | 17289.53 | 586317.34 |
| 24 | -7.53 | 10.88 | -133.72 | 758.49 | 56.69 | 118.34 | 17881.21 | 575307.54 |
| 25 | -1.57 | 15.13 | -126.19 | 747.61 | 2.46 | 228.88 | 15924.29 | 558923.19 |
| 26 | 7.68 | 11.70 | -124.62 | 732.48 | 59.02 | 136.98 | 15530.54 | 536531.20 |
| 27 | -11.01 | 10.20 | -132.30 | 720.78 | 121.24 | 104.06 | 17504.36 | 519522.46 |
| 30 | -13.01 | 7.00 | -121.29 | 710.58 | 169.18 | 48.98 | 14712.00 | 504921.37 |
| 31 | 15.98 | 9.27 | -108.29 | 703.58 | 255.25 | 85.89 | 11725.90 | 495024.74 |
| 32 | -14.14 | 23.55 | -124.26 | 694.31 | 199.96 | 554.65 | 15441.20 | 482069.16 |
| 33A | 8.71 | 12.01 | -110.12 | 670.76 | 75.91 | 144.32 | 12126.87 | 449920.45 |
| 34 | -1.13 | 10.37 | -118.83 | 658.75 | 1.28 | 107.51 | 14121.62 | 433948.61 |
| 35 | -1.96 | 5.56 | -117.70 | 648.38 | 3.85 | 30.96 | 13854.36 | 420395.51 |
| 36 | -16.87 | 23.97 | -115.74 | 642.81 | 284.57 | 574.50 | 13396.43 | 413210.84 |
| 37 | -15.76 | 31.09 | -98.87 | 618.85 | 248.43 | 966.79 | 9775.99 | 382970.38 |
| 38 | -7.00 | 49.51 | -83.11 | 587.75 | 49.01 | 2450.99 | 6907.58 | 345453.38 |
| P1 | -7.00 | 49.51 | -76.11 | 538.25 | 49.01 | 2450.99 | 5792.91 | 289708.05 |
| P2 | -7.00 | 49.51 | -69.11 | 488.74 | 49.01 | 2450.99 | 4776.26 | 238864.70 |
| P3 | -7.00 | 49.51 | -62.11 | 439.23 | 49.01 | 2450.99 | 3857.64 | 192923.32 |
| P4 | -7.00 | 49.51 | -55.11 | 389.72 | 49.01 | 2450.99 | 3037.02 | 151883.94 |
| P5 | -7.00 | 49.51 | -48.11 | 340.22 | 49.01 | 2450.99 | 2314.43 | 115746.53 |
| P6 | -7.00 | 49.51 | -41.11 | 290.71 | 49.01 | 2450.99 | 1689.86 | 84511.10 |
| P7 | -7.00 | 49.51 | -34.11 | 241.20 | 49.01 | 2450.99 | 1163.30 | 58177.66 |
| P8 | -7.00 | 49.51 | -27.11 | 191.69 | 49.01 | 2450.99 | 734.77 | 36746.19 |
| P9 | -7.00 | 49.51 | -20.11 | 142.19 | 49.01 | 2450.99 | 404.25 | 20216.71 |
| P10 | -7.00 | 49.51 | -13.11 | 92.68 | 49.01 | 2450.99 | 171.75 | 8589.21 |
| P11 | -6.10 | 43.17 | -6.10 | 43.17 | 37.27 | 1863.69 | 37.27 | 1863.69 |
| Proboj | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | **Σ** | **17451.26** | **77147.75** | **1163743.90** | **31644362.03** |

Position deviation of the opening point from the direction of the VI horizon of the "Blagodat" mine is:

$$\sigma_{y,x_{prI}} = \sqrt{\sigma_{y_{prI}}^2 + \sigma_{x_{prI}}^2} = \sqrt{0.2852^2 + 0.0802^2} = 0.2963\text{m} \tag{11}$$

## 4.2. Crosscut from the direction of the P2 SD adit of the "Blagodat" ore field

Starting point for the construction of crosscut from the direction of the P2 SD adit is trigonometric point 8/P2 at the entrance into the mine with the following coordinates:

$$y_{8/P2} = 7602696.12; \quad x_{8/P2} = 47111997.76$$

with adopted standard deviations according to (4)

$$\sigma_{y_{8/P2}} = 0.0212\text{m}; \quad \sigma_{x_{18/P2}} = 0.0212\text{m}$$

Starting grid bearing was set to be between points 205 and 8/P2. The grid bearing and horizontal length between those points is:

$$\nu = 296^\circ 29' 10''; \quad d = 515.54\text{m}$$

Standard deviation of the starting grid bearing according to (7) is:

$$\sigma_\nu = \frac{206265 \cdot 0.0212}{515.54}\sqrt{2} = 12''$$

The influence of the starting grid bearing onto the position of the last point of traverse according to (8) is:

$$\sigma_{y_\nu} = \frac{12}{206265} \cdot 526.75 = 0.0306\text{m}; \quad \sigma_{x_\nu} = \frac{12}{206265} \cdot 323.08 = 0.0188\text{m}$$

In view of previously adopted standard deviations for the measurement of angles and lengths, standard deviations of the opening point shall, due to the influence of measured sizes within the traverse, and in line with (9) and (10), be:

$$\sigma_{y_\beta} = \frac{10}{206265} \cdot \sqrt{4579304.61} = 0.1037\text{m}; \quad \sigma_{x_\beta} = \frac{10}{206265} \cdot \sqrt{373053.74} = 0.0296\text{m}$$

$$\sigma_{y_d} = \frac{1}{5000} \cdot \sqrt{19899.08} = 0.0282\text{m}; \quad \sigma_{x_d} = \frac{1}{5000} \cdot \sqrt{31009.61} = 0.0352\text{m}$$

Values of sums of squares of deviation of traverse points from the opening point, as well as sums of squares of coordinate differences were calculated in Table 2.

Total standard deviation of the opening point from the direction of the P2 SD adit on coordinate axes is:

$$\sigma_{y_{prII}} = \sqrt{\sigma_{y_{8/P2}}^2 + \sigma_{y_\nu}^2 + \sigma_{y_\beta}^2 + \sigma_{y_d}^2} = \sqrt{0.0212^2 + 0.0306^2 + 0.1037^2 + 0.0282^2} = 0.1138\text{m}$$

$$\sigma_{x_{prII}} = \sqrt{\sigma_{x_{8/P2}}^2 + \sigma_{x_\nu}^2 + \sigma_{x_\beta}^2 + \sigma_{x_d}^2} = \sqrt{0.0212^2 + 0.0188^2 + 0.0296^2 + 0.0352^2} = 0.0540\text{m}$$

Position deviation of the opening point from the direction of the P2 SD adit of the "Blagodat" ore field is:

$$\sigma_{y,x_{prII}} = \sqrt{\sigma_{y_{prII}}^2 + \sigma_{x_{prII}}^2} = \sqrt{0.1138^2 + 0.0540^2} = 0.1260\text{m} \tag{12}$$

**Table 2** - Elements for the analysis of crosscut from the direction of P2 SD adit

| | Δy | Δx | Ry | Rx | $\Delta y^2$ | $\Delta x^2$ | $Ry^2$ | $Ry^2$ |
|---|---|---|---|---|---|---|---|---|
| 8/P2 | -34.86 | -27.75 | -323.08 | -526.75 | 1215.41 | 770.18 | 104380.55 | 277462.13 |
| 10 | -38.49 | 24.06 | -288.22 | -498.99 | 1481.40 | 578.85 | 83069.03 | 248995.65 |
| S3 | -46.42 | 11.18 | -249.73 | -523.05 | 2155.06 | 125.00 | 62364.10 | 273585.51 |
| S7 | -22.71 | 5.87 | -203.31 | -534.23 | 515.90 | 34.47 | 41333.11 | 285406.58 |
| S8 | -82.07 | 21.99 | -180.59 | -540.11 | 6734.71 | 483.49 | 32613.44 | 291713.85 |
| S12 | -20.01 | 5.19 | -98.53 | -562.09 | 400.32 | 26.93 | 9707.50 | 315949.53 |
| S14 | -40.48 | 10.50 | -78.52 | -567.28 | 1638.66 | 110.25 | 6165.18 | 321810.34 |
| S18 | -27.82 | 7.21 | -38.04 | -577.78 | 774.00 | 51.99 | 1446.91 | 333833.47 |
| S20 | -41.56 | 1.22 | -10.22 | -584.99 | 1727.41 | 1.49 | 104.39 | 342217.19 |
| S22 | -51.77 | 1.54 | 31.34 | -586.21 | 2679.83 | 2.37 | 982.49 | 343645.85 |
| S23 | 7.00 | -49.51 | 83.11 | -587.75 | 49.01 | 2450.99 | 6907.58 | 345453.38 |
| P1 | 7.00 | -49.51 | 76.11 | -538.25 | 49.01 | 2450.99 | 5792.91 | 289708.05 |
| P2 | 7.00 | -49.51 | 69.11 | -488.74 | 49.01 | 2450.99 | 4776.26 | 238864.70 |
| P3 | 7.00 | -49.51 | 62.11 | -439.23 | 49.01 | 2450.99 | 3857.64 | 192923.32 |
| P4 | 7.00 | -49.51 | 55.11 | -389.72 | 49.01 | 2450.99 | 3037.02 | 151883.94 |
| P5 | 7.00 | -49.51 | 48.11 | -340.22 | 49.01 | 2450.99 | 2314.43 | 115746.53 |
| P6 | 7.00 | -49.51 | 41.11 | -290.71 | 49.01 | 2450.99 | 1689.86 | 84511.10 |
| P7 | 7.00 | -49.51 | 34.11 | -241.20 | 49.01 | 2450.99 | 1163.30 | 58177.66 |
| P8 | 7.00 | -49.51 | 27.11 | -191.69 | 49.01 | 2450.99 | 734.77 | 36746.19 |
| P9 | 7.00 | -49.51 | 20.11 | -142.19 | 49.01 | 2450.99 | 404.25 | 20216.71 |
| P10 | 7.00 | -49.51 | 13.11 | -92.68 | 49.01 | 2450.99 | 171.75 | 8589.21 |
| P11 | 6.10 | -43.17 | 6.10 | -43.17 | 37.27 | 1863.69 | 37.27 | 1863.69 |
| Proboj | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | Σ | **19899.08** | **31009.61** | **373053.74** | **4579304.61** |

### 4.3. Accumulated error of the crosscut

In order to calculate total deviation of the opening point, it is necessary to break down position deviations of the opening point from the direction of the VI horizon of the "Blagodat" mine and from the direction of the P2 SD adit of the "Blagodat" ore field onto the longitudinal and transversal errors in the direction of the crosscut.

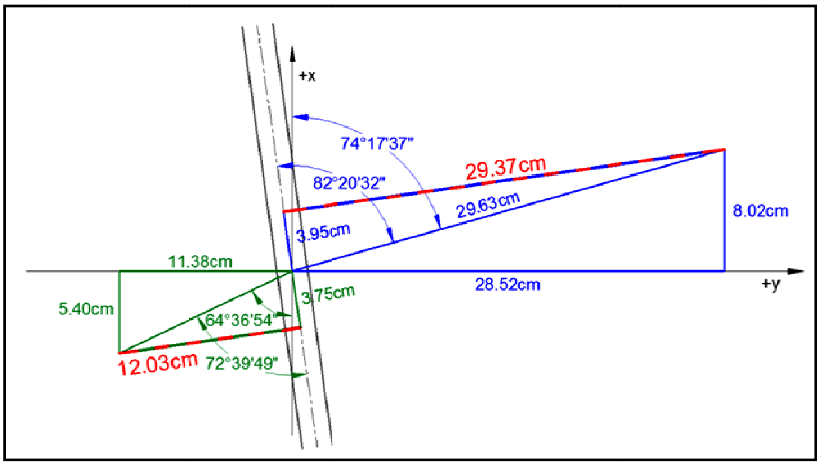


**Figure 4** - Longitudinal and transversal errors of the crosscut

The grid bearing of the resultant, i.e. of the positioning deviation of the opening point from the direction of the VI horizon is:

$$\nu_1 = \arctan \frac{\sigma_{y_{prI}}}{\sigma_{x_{prI}}} = \arctan \frac{0.2852}{0.0802} = 74^\circ 17' 37''$$

Angle $\Delta_1$ according to Figure 4 is:

$$\Delta_1 = 360^\circ - \left(\nu_{pr} - \nu_1\right) = 82^\circ 20' 32''$$

where $\nu_{pr}$ represents grid bearing of the last leg of the traverse toward the opening point, which amounts: $\nu_{pr} = 351°57'05''$.

The transversal and longitudinal standard deviation of the crosscut from the direction of the VI horizon of the "Blagodat" mine is:

$$\sigma_{pop_I} = \sigma_{y,x_{prI}} \cdot \sin \Delta_1 = 0.2937\text{m}$$

$$\sigma_{pod_I} = \sigma_{y,x_{prI}} \cdot \cos \Delta_1 = 0.0395\text{m}$$

The grid bearing of the positioning deviation of opening point from the direction of the P2 SD adit is:

$$\nu_2 = \arctan \frac{\sigma_{y_{prII}}}{\sigma_{x_{prII}}} = \arctan \frac{0.1138}{0.0540} = 64^\circ 36' 54''$$

Angle $\Delta_2$ is:

$$\Delta_2 = 360^\circ - \left(\nu_{pr} - \nu_2\right) = 72^\circ 39' 49''$$

Longitudinal and transversal standard deviation of the crosscut from the direction of the P2 SD adit of the "Blagodat" ore field is:

$$\sigma_{pop_{II}} = \sigma_{y,x_{prII}} \cdot \sin \Delta_2 = 0.1203\text{m}$$

$$\sigma_{pod_{II}} = \sigma_{y,x_{prII}} \cdot \cos \Delta_2 = 0.0375\text{m}$$

Total transversal standard deviation of the crosscut is:

$$\sigma_{pr} = \sqrt{\sigma^2_{pop_I} + \sigma^2_{pop_{II}}} = \sqrt{0.2937^2 + 0.1203^2} = 0.3174\text{m} \approx 32\text{cm}$$

## 5. CONCLUSION

When constructing double-sided tunnels and underground mine chambers, for the purpose of a priori evaluation of the crosscut accuracy, transversal standard deviation of the crosscut is of special significance due to small width of the chamber when compared with the length. Therefore shall a standard deviation calculated in such way be compared with standard deviation of marking of the opening point for the probability of 95% (σ). As $\sigma_{pr} < \sigma$ is, i.e. 32 cm < 40 cm, it follows that the achieved error of the crosscut is going to be smaller than maximum permissible value, if marking of horizontal angles is made with standard deviation of $\sigma_\beta$ = 10", and marking of the lengths of traverse legs is made with the relative standard deviation of $\sigma_{drel}$ = 1:5,000.

This means that marking of the crosscut may be made by using total station of common accuracy, which the "Grot" mine has at its disposal.

The analysis indicates that the influence of the marking accuracy of horizontal angles onto the standard deviation of crosscut is significantly larger than when marking lengths. The influence of angle marking from the direction of the VI horizon of the "Blagodat" mine is 4.5 times larger than the influence of marking the lengths, and from the direction of the P2 SD adit of the "Blagodat" ore field, this influence is 2.4 times larger.

If it is required that the influences of marking of angles and lengths within traverses are almost equal, it is necessary to increase the accuracy of angle marking, and to decrease the accuracy of length marking. Additional analysis has shown that, by increasing the accuracy of angle marking to 7", and by decreasing the accuracy of length marking to 1:3,000, those influences participate more uniformly in the total transverse deviation of the crosscut, which in this case shall be 25 cm.

This accuracy of crosscut marking may also be achieved by using total station of common accuracy along with marking of refracted angles in two telescope positions.

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