Connecting Surveys and Orientation Measurements in Čsa 2 and Mír 5 Shafts

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Summary

Connecting surveys and orientation measurements in the ČSA 2 and Mír 5 shafts were carried out in order to determine their positions in relation to each other and the positions of these two underground mining works in relation to structures situated on the surface. The measurements were carried out during the completion of the connecting underground crosscut between the Karviná and Darkov Mines, with an anticipated length of 3,100 metres. This is a very complex issue involving the most precise measurement and calculation techniques in mine surveying, especially as to achieving the necessary accuracy, which is mostly defined by the longitudinal and transverse deviations of the "cut-through" or "breakthrough". The project engineer determined the required accuracy as a maximum deviation (longitudinal, transverse) of 0.250 metres for all cut-through options (special accuracy). The entire measurement process included surface measurements, depth measurements of both connected horizons (Mír 5: level 9, ČSA 2: level 11), connecting surveys and orientation measurements (using an MVT-2 gyrotheodolite), in accordance with Regulation of the Czech Mining Authority No. 435/1992 Coll. By analyzing the accuracy of the measurements, it was verified that the accuracy specified by Regulation of the Czech Mining Authority No. 435/1992 Coll. and required by the project had been achieved at all measurement stages. On 12 December 2012, both operating mines were connected underground at a depth of 870 metres, with positional accuracy of $m_{x,y}$=0.011 m and height accuracy of m_h=0.003 m.

Keywords: GNSS-technology, orientation measurement, CSA 2 shaft, Mir 5 shaft

1. Introduction

Connecting surveys and orientation measurements of mining and underground works are some of the most important activities of mine surveyors. This is a very complex issue involving the most precise measurement and calculation methods in mine surveying, especially as regards achieving the required accuracy, which is mostly defined by the longitudinal and transverse deviations of the "cut-through" or "breakthrough".

Connecting surveys and orientation measurements are aimed at determining the positions of underground mining works in relation to structures situated on the surface and/or in relation to other underground mining works situated on other levels of the mine or "horizons", i.e. to determine their relative positions. The determination of relative positions is required during the preparation of mining facility projects for mine shafts, exploration and ventilation wells and other underground mining works on various levels of the mine. This is also related to the necessity of taking essential safety measures to protect surface structures from the harmful effects of mining operations as well as the necessity of protecting underground mining works from harmful effects on the surface such as the inflow of water from the surface into a mine.

2. Measurement stages

Connecting surveys and orientation measurements in the ČSA 2 and Mír 5 shafts were carried out during the completion of the planned connecting crosscut between the Karviná and Darkov Mines.

The measurements were carried out in June and July 2011 and were done in several stages.

1. Determination of the coordinates of reference points on the surface using GNSS technology.
2. Measurement of the traverse oriented on both ends on the surface.
3. Measurement of the levelling line using very accurate levelling methods.
4. Depth measurement for connecting the horizons of both underground mining works.

5. Connecting survey in the ČSA 2 and Mír 5 shafts.
6. Orientation measurement using an MVT-2 gyrotheodolite.

3. Analysis of accuracy prior to measuring

An analysis of accuracy was conducted prior to measuring to achieve the necessary accuracy determined by the project engineer, which was set as the maximum deviation of 0.250 metres for all cut-through options.

The other deviation values and values of maximum mean errors in individual measurement stages were set in accordance with Regulation of the Czech Mining Authority No. 435/1992 Coll., as amended (hereinafter referred to as the "**Regulation**"), as "special accuracy" pursuant to [6]. The work assignment documentation further specified that the measurements should be carried out and the documentation should be prepared using the Datum of Uniform Trigonometric Cadastral Network ("S-JTSK") and the elevations should be determined in the Baltic Vertical Datum after adjustment.

1. The deviation in the direction of the last measured side of the traverse oriented on both ends and conducted on the surface is as follows pursuant to Section 2.3 of Annex 2 of the Regulation:

   $$U = \pm 10'' \sqrt{n} \tag{1}$$

   where n is the number of traverse points
   Assuming the number of traverse points is $n = 12$, the result is as follows:

   $U = 15.07 \cdot 10^{-5} \, rad = 9.6 \cdot 10^{-3} \, gon$.

2. The deviation in the position of the terminal point of the traverse oriented on both ends and conducted on the surface is as follows pursuant to Section 3.2 of Annex 2 of the Regulation:

   $$D_{x,y} = \pm 10^{-3} \sqrt{8L + 0.04[RR]} \tag{2}$$

   where L... is the sum of the lengths of the measured traverse sides, and $[RR]$ is the sum of the squares of direct distances between individual points of the traverse from its terminal point in metres.

3. The deviation in the levelling measurement there and back on the surface is defined as follows pursuant to Section 9.2.2 of Annex 2 of the Regulation:

   $$\Delta \nu = \pm 5 \cdot 10^{-3} \sqrt{L} \quad [\mathrm{m}] \tag{3}$$

   which is L 0.017 metres for the assumed length of the traverse.

4. The deviation of the bearing of the side which was determined twice by independent measurements using a gyrotheodolite, is defined as follows:

   $$\Delta \sigma_G = \pm 2 \sigma_{\Psi_{G0}} \sqrt{2} \tag{4}$$

   The $\Delta \sigma_G$ deviation was calculated on the basis of the accuracy of the $\sigma_{\Psi_{G0}}$ gyro-compass used, and its resulting value is

   $\Delta \sigma_G = 2.35 \cdot 10^{-5} \, rad = 1.5 \cdot 10^{-3} \, gon$.

5. The deviation of the depth measurement between two independent measurements is as follows pursuant to Section 5.3.2 of Annex 1 of the Regulation:

   $$D_H = \pm 2 \cdot 10^{-3} \sqrt{20 + \frac{2}{15} h} \tag{5}$$

   where h is the depth measured in metres.
   As determined for:
   - Mír 5 shaft, h=745 m, D_H= 0.021 m,
   - ČSA 2 shaft, h=930 m, D_H= 0.024 m.

6. The accuracy of the connecting survey and orientation measurement is defined by the allowable deviation of the projection of the point position pursuant to Section 4.2.1.1 of Annex 1 of the Regulation:

   $D_{x,y} = 7 \cdot 10^{-3} \, m$,

7. The measured lengths were adjusted by reductions for elevation and atmospheric conditions. The elevation reductions were calculated using the following formula:

   $$\Delta s = -S \frac{H}{R} \tag{6}$$

   where:
   H... – is the average elevation [m],
   R... – is mean radius of curvature (R=6381·10³ m),
   S... – is the distance measured [m].

   H_{povrch} = 230 m (Bpv)
   – then $\Delta s = -S \cdot 3.6 \cdot 10^{-5} \, m$,
   $H_{ČSA}$ = –692 m (Bpv)
   – then $\Delta s = -S \cdot (-10.8) \cdot 10^{-5} \, m$,
   $H_{Mír}$ = –507 m (Bpv)
   – then $\Delta s = -S \cdot (-7.9) \cdot 10^{-5} \, m$.

4. Positional and height measurement on the surface

The coordinates of the reference points on the surface were determined using GNSS technology and Leica System 1200 on the basis of the fast static method with a 20-minute observation time. The vectors were calculated in relation to a virtual reference station (VRS) generated using the CZEPOS network service (Czech Network of Permanent Stations for Positioning), approximately in the centre of gravity of the relevant locations.

For the purposes of converting the coordinates into the S-JTSK binding reference system, we used a local transformation key derived from identical points in the ETRS89 and S-JTSK systems (using the ETRF2000 reference framework). The point coordinates were converted from the ETRS89 system into the S-JTSK system based on congruent transformation, and the coordinates so determined were verified by means of a checking calculation in relation to the VSBO reference station (included in the CZEPOS network). The impact of certain site dependent factors when using GNSS technology is described, for example, in [3] and [5].

The traverse oriented on both ends was measured twice (independent measurements) and the horizontal angles at the traverse points were measured in two groups. The lengths of traverse sides were measured in both directions and adjusted by atmospheric corrections and elevation reductions. The coordinates of the traverse points were calculated in the local coordinate system and subsequently converted into the S-JTSK system based on congruent transformation using the identical points determined by GNSS technology.

The following table illustrates the coordinate corrections of the congruent transformation on identical points (see Table 1).

Table 1: Values of coordinate corrections on identical points

Tabela 1. Wartości współrzędnych korekty dla identycznych punktów

Point	v_Y [m]	v_X [m]
11	-0.018	0.018
12	-0.028	0.038
13	-0.037	0.007
27	0.045	0.032
23	0.038	-0.031
Mean coordinate error of the transformation key m_0=0.037 m		

The accuracy achieved in the determination of the coordinates of the traverse points was assessed based on the deviation in the direction of the last measured side (see Chapter 3, Section 1) and based on the deviation in the position of the terminal point of the traverse oriented on both ends (see Chapter 3, Section 2). The prescribed deviations were met in both cases. The calculation of the allowable deviations is described in the final report on the measurement of the Karviná Mine – Darkov Mine connecting crosscut.

To determine the control height difference between levelling signs 137 (ČSA 2 shaft) and 219 (Mír 5 shaft), we conducted very accurate geometrical levelling using LEICA DNA 03 electronic levelling equipment and invar bars. As a basis, we used the elevation of 234.019 metres (Bpv) at levelling

Fig. 1. Scheme for determination of the reference points using GNSS technology

Rys. 1. Schemat określenia punktów odniesienia z wykorzystaniem technologii GNSS sign 137 at the ČSA shaft, which was determined by mine levelling in 2008. The length of the levelling traverse was 3.2 kilometres and the $D_s = 0.0005\,m$ deviation achieved in the there-and-back measurement met the accuracy criteria for conducting the levelling traverse on the surface pursuant to Regulation of the Czech Mining Authority No. 435/1992 Coll., as amended.

5. Depth measurement for connecting the horizons of both underground mining works

To determine the elevations of the levelling signs and points on basic orientation lines of the connected horizons of both underground mining works, we conducted a depth measurement using a depth tape with a length of 1,000 metres. The depth tape was marked in millimetres along its entire length and was weighted with a 5-kg weight during measurement. The other technical parameters of the depth tape are given in Table 2.

The comparation of the tape was carried out under the following conditions:

- Weight of the weight during comparation $Q_0 = 5$ kg,
- Temperature $t_0 = 20$°C.

To reflect the systemic temperature error, we measured the temperatures at fixed intervals during the slow descent of the mine cage to the connected horizon. The difference between the temperatures on the surface and in the connected horizon was 4°C in the ČSA 2 shaft and 7°C in the Mír 5 shaft.

During the depth measurement, we used a Leica DNA 03 levelling instrument and invar bars. We performed a total of 5 independent measurements, in each case by moving the tape by a distance not known in advance.

The deviation achieved between two independent measurements was as follows:

- ČSA 2 shaft: $\Delta_s = 0.0003$ m,
- Mír 5 shaft: $\Delta_s = 0.0002$ m.

The allowable deviation in the case of the ČSA 2 shaft was calculated (see Chapter 3, Section 5) as $D_H = 0.0024$ m and in the case of the Mír 5 shaft as $D_H = 0.0021$ m.

The accuracy of the depth measurement set by Regulation of the Czech Mining Authority No. 435/1992 Coll., as amended, was thus met.

6. Connecting survey and orientation measurement

The connecting survey and orientation measurement of the horizons of both underground mining works (level 11 of the Karviná Mine, level 9 of the Darkov Mine) were carried out in the manner laid down by Regulation of the Czech Mining Authority No. 435/1992 Coll., Annex 1, Section 4.1.2.4, namely by the connection and orientation of the horizon, with a traverse which runs from the point projected by one shaft and a line oriented by a gyrotheodolite.

The connecting survey was carried out using one plummet in each shaft. To connect the projected plummets on the surface, we used points in the pit bank of the ČSA 2 or Mír 5 shaft, whose coordinates

Table 2. Technical parameters of the depth tape

Tabela 2. Parametry odniesienia taśmy głębokości

Technical parameters	
Thermal expansivity coefficient	$\alpha = 0.0000102$
Standard temperature	$t_0 = 20$ °C
Cross-section of the tape	$f = 0.026 \cdot 10^{-4}$ m^2
Elastic modulus	$E = 2\,100 \cdot 10^8$ Pa
Weight of 1 m of tape	G = 0.01976 kg
Weight of the weight during comparation	5 kg
Weight of the weight during measurement	5 kg

Table 3. Corrections of the depth tape section in the ČSA 2 shaft

Tabela 3. Korekta sekcji taśmy głębokości w szybie CSA 2

Corrections of the depth tape section	
Temperature correction	-0.0061 m
Elongation correction	+0.1586 m
Comparation correction	+0.0518 m
Total correction	+0.2043 m
Corrected section of the depth tape	**929.9155 m**

were determined by means of a surface traverse. On the connected horizon of both underground mining works we determined, in the local coordinate system, the positions of the points on the basic orientation line, including the positions of the control points. The plummet position in the plumb line was determined by observing the swings. The observation of swings, necessary for the purposes of determining the accurate position of the plummet in the plumb line, was performed from one point on the basic orientation line using a robotized electronic tacheometer and a plummet with an omnidirectional prism coaxially inserted in its suspension wire. The plummet swung around its plumb line and its individual positions were continuously calculated from the data measured by the tacheometer in the local coordinate system, which was referenced to points on the basic orientation line on the connected horizon. On the basis of the calculated coordinates of the plummet positions in the swing, we could determine the coordinates of the plummet positions in the plumb line and, based on such data, we could determine the length and direction to a point on the basic orientation line. On the basis of the bearing determined by the gyrotheodolite on the basic orientation line and the calculated values, we determined the coordinates of the points on the basic orientation line in the valid coordinate system.

Lengths of the projected plummets:

- ČSA 2 shaft: 950 m,
- Mír 5 shaft: 760 m,
- Weight of the weight: 180 kg.

The measurements on the surface were conducted by means of a Leica TCRP 1201 device and on the connected horizons by means of a robotized universal measuring instrument, Leica TS 30, using a tripod system for the signalling of points on the basic orientation line. All measured values were adjusted by atmospheric corrections and elevation corrections. The adverse effect of the refraction on the estimate of the geodetic networks parameters and other effects are described in [1] and [2]. When the plummet was lowered, suspension was regularly checked in order to prevent it from snagging on the shaft equipment. Another technology which can be used for measuring underground gas storage facilities is described in [4].

7. Accuracy achieved by the connecting survey

The assessment of the accuracy achieved was based on the fact that the size of the tested set for the calculation of mean error of the measurement will always be small. The conducted measurement was tested on the basis of the required accuracy of the projected point or, more precisely, by the value of the mean error in the $\overline{m}_x$ point projection, determined pursuant to Regulation of the Czech Mining Authority No. 435/1992 Coll., as amended.

In three measurements based on the average values of three positions of the projected plummet, we compared the value of the mean random error with its maximum permitted value. In a pair of measurements, we compared their maximum permitted difference according to the formula for the mean random error

$$\overline{s}_x = \sqrt{\frac{\sum vv}{n(n-1)}}, \tag{7}$$

where $\sum vv$ is the sum of the squares of the most probable errors, or rather corrections, and n is the number of measurements.

Furthermore, we verified the fulfilment of the condition between the $\overline{s}_x$ mean random error and the $\overline{s}_{xmet}$ maximum permitted mean random error

$$\overline{s}_x \leq \overline{s}_{xmet}, \tag{8}$$

where:

$$\overline{s}_{xmet} = \overline{m}_x \left(1 + \sqrt{\frac{2}{n-1}}\right). \tag{9}$$

The maximum difference between pairs of measurements was calculated on the basis of the following formula:

$$\Delta_{met} = \overline{m}_x t \sqrt{2}, \tag{10}$$

where t is the confidence coefficient determining the width of the reliability interval.

As it was not possible to eliminate all systematic errors affecting the measurement, we chose a t=2.5 confidence coefficient.

Based on the accuracy analysis carried out after the measurement, we verified that the required accuracy for point projection pursuant to Regulation of the Czech Mining Authority No. 435/1992 Coll., as amended, was achieved in both cases of the connecting survey.

We matched the resulting values of the centre positions of swings with the coordinates of the individual positions of the projected plummets on the surface, and calculated the coordinates of the points from which the plummet swings were observed.

The resulting coordinate values of the G 43 point, from which swings were observed, in the JTSK system (see Figure 2).

The resulting coordinate values of the G 38 point, from which swings were observed, in the JTSK system (see Figure 3).

Table 4. Swing centre positions: Darkov Mine, Site 2 – Stonava, Mír 5 shaft, level 9

Tabela 4. Pozycja środka obrotu: Kopalnia Darkov, Oddział 2 – Stonava, szyb Mír 5, poziom 9

Suspension	Tested value	Maximum permitted value	Result
1st position	$s_{\bar{x}} = 0.004\,\mathrm{m}$	0.013 m	achieved
2nd position	$s_{\bar{x}} = 0.003\,\mathrm{m}$	0.013 m	achieved
3rd position	$s_{\bar{x}} = 0.006\,\mathrm{m}$	0.013 m	achieved

Y = 453218.787 m, X = 1103677.379 m

Mean error of the position average value **m = ± 0.002 m**

error ellipse parameters: a = 0.004 m, b = 0.002 m, $\sigma_a = 98.6^g$

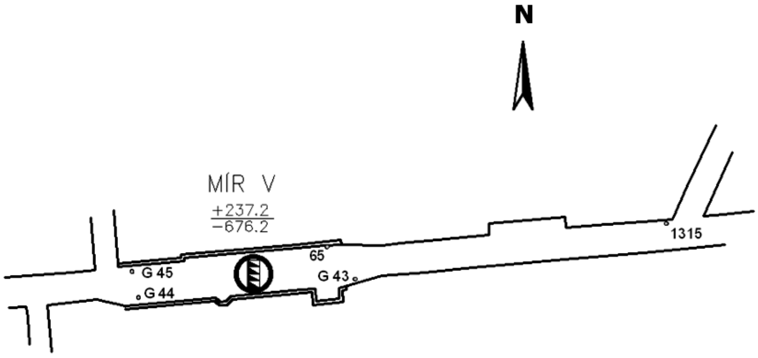

Fig. 2. Situation – level 9, Mír 5 shaft, Darkov Mine, Site 2 – Stonava

Rys. 2. Sytuacja – poziom 9, szyb Mir 5, Kopalnia Darkov, Oddział 2 – Stonava

Table 5. Swing centre positions: Karviná Mine, ČSA Site, shaft no. 2, level 11

Tabela 5. Pozycja środka obrotu: Kopalnia Karvina, Oddział CSA , szyb nr 2, poziom 11

Suspension	Tested value	Maximum permitted value	Result
1st position	$s_{\bar{x}} = 0.003\,\mathrm{m}$	0.014 m	achieved
2nd position	$s_{\bar{x}} = 0.006\,\mathrm{m}$	0.014 m	achieved
3rd position	$s_{\bar{x}} = 0.025\,\mathrm{m}$	0.025 m	achieved

Y = 455291.115 m, X = 1101842.348 m

Mean error of the position average value **m = ± 0.013 m**

error ellipse parameters: a = 0.034 m, b = 0.008 m, $\sigma_a = 68.3^g$

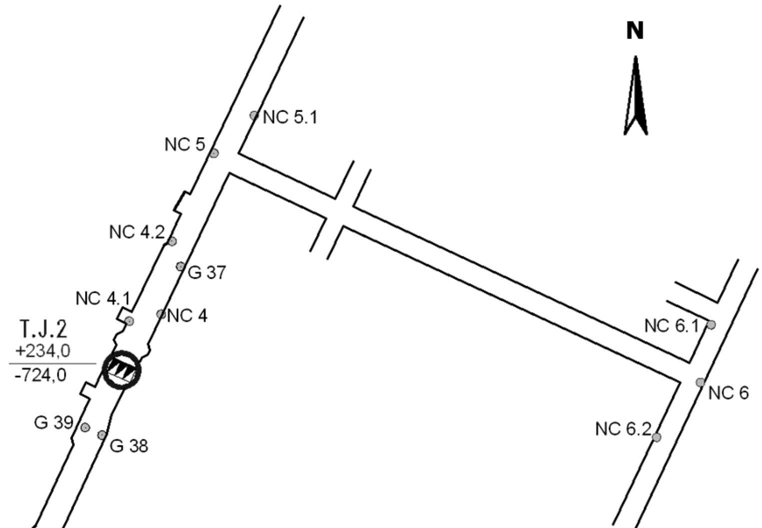

Fig. 3. Situation – level 11 of the Karviná Mine, ČSA Site

Rys. 3. Sytuacja – poziom 11, Kopalnia Karvina, Oddział CSA

8. Orientation measurement

Based on the orientation measurement conducted by the MVT-2 gyrotheodolite, we defined the bearing of the basic orientation line and, by means of the bearing so defined and the measured length; we calculated the coordinates of the points on the basic orientation line in the JTSK coordinate system. The gyroscopic orientation measurement uses the mechanical properties of a balance wheel, which rotates rapidly in the gravitational field of the Earth. The principle behind such measurement is to determine the astronomical azimuth on a known line on the surface, whose position is calculated in a valid coordinate system, and on a measured line in a mine, and subsequently to calculate the φ angle, i.e. the angle of the orientation of lines against each other, from the azimuth difference:

$$\varphi = \alpha_d - \alpha_p \, . \tag{11}$$

In the aforesaid formula, α_d is the astronomical azimuth in the mine and α_p is the astronomical azimuth on the surface.

The geodetic azimuth of the measured underground line is then calculated as follows:

$$\sigma_d = \sigma_p + \varphi \, . \tag{12}$$

The gyroscopic orientation was determined by means of one gyrotheodolite; we first measured the astronomical azimuth on the surface line and subsequently on the oriented line on the connected horizons, and completed the measurement again on the surface line.

The basic initial surface orientation line was the line at Báňská měřická základna in Ostrava-Poruba, in the Johann Palisa Planetarium.

The prescribed maximum measurement values for the given type of gyro-compass were maintained and the resulting value of the bearing in the S-JTSK system was determined with the mean error of arithmetic average $1.88 \cdot 10^{-5} \, rsd = 1.2 \cdot 10^{-3} \, gon$.

9. Conclusion

At the end of 2012, at precisely 12 noon on 12 December 2012, the Darkov and Karviná Mines were connected at a depth of 870 metres. By cutting through, the connection of all operating mines of the Karviná part of the Ostrava-Karviná Coal District was completed. The 3,031 m long connecting crosscut (see Figure 4) will be used to haul all coal produced at the ČSA-Karviná Mine to the Darkov coal preparation plant and it will also serve as a transport channel for the two-way transportation of material, equipment and persons. Besides its length, the new underground structure is also unique in its cross-section and the

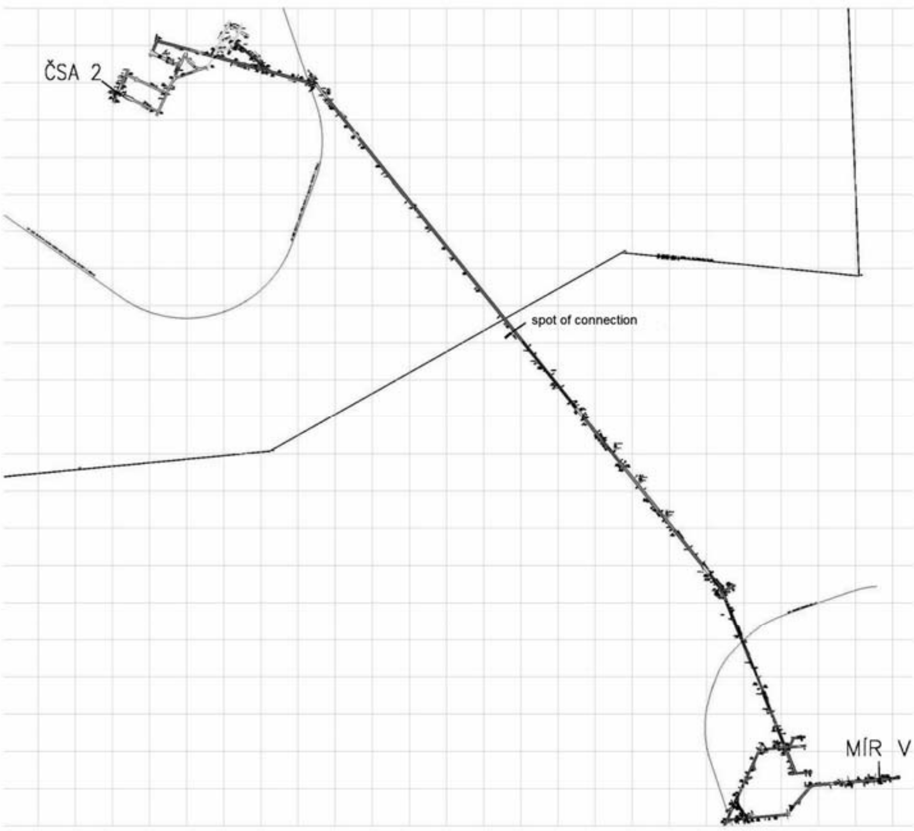

Fig. 4. Basic mining plans (crosscut plans)

Rys. 4. Podstawowe plany wydobywcze (przekroje poprzeczne) development technology applied. Its minimum width is 6.7 metres with a height of 4.5 metres. At its maximum cross-section it widens to 8.7 metres and has a height of 5.5 metres. Similar structures were built in the past using tunnelling machines; this crosscut was created by standard drilling and blasting techniques.

Boring activities began in April 2011 and were conducted from both sides, from the Karviná and Darkov Mines. The cut-through was completed by counter-excavations with a gradient of 6°, approximately in the centre of the underground mining works, at a length of 1.750 m and with a difference in elevation of 196 m. The achieved deviations in the point of connection were $m_{x,y}$ = 0.011 m in position and m_h= 0.005 m in height.

For the purposes of comparison: The longest Czech road tunnel is the Panenská Tunnel on the final section of the D8 Motorway from Trmice to the border with Germany. It is 2.130 metres in length. The second longest tunnel is the Klimkovice Tunnel on the D1 Motorway. The lengths of individual tubes of the tunnel are 1.077 metres (in the Brno-Ostrava direction) and 1.088 metres (in the Ostrava-Brno direction). The longest Czech railway tunnel is the Březenský Tunnel near Chomutov, which is 1.758 metres long. The second longest railway tunnel is the Špičácký Tunnel on the Plzeň – Železná Ruda railway track, which is 1.747 metres in length. The following entities cooperated in the development of this longest underground crosscut in the Czech Republic: VŠB – Technical University of Ostrava, the Institute of Geodesy and Mine Surveying, whose workers performed connecting surveys and depth measurement, mine surveyors of the Karviná and Darkov Mines, who were in charge of the management of boring activities, and surveyors of VOKD, a.s., DMG, who conducted orientation measurements.

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6 *Regulation of the Czech Mining Authority No. 435/1992 Coll., on Mine Survey Documentation for Mining Activities and Certain Other Activities Performed in Mining, as amended (In Czech: Vyhláška ČBÚ 435/1992 Sb., o důlně měřické dokumentaci při hornických činnostech a některých činnostech prováděných hornickým způsobem, ve znění pozdějších předpisů)*

Pomiary połączenia i pomiary kierunkowe w szybach Čsa 2 i Mír 5

Pomiary połączenia i pomiary kierunkowe w szybach Čsa 2 i Mír 5 zostały przeprowadzone w celu określenia ich położenia względem siebie oraz położenia tych dwóch podziemnych obiektów względem struktur na powierzchni. Pomiary przeprowadzono w okresie zakończenia projektu łączenia podziemnego przekopu pomiędzy kopalniami Karviná i Darkov o długości 3100 m. Jest to bardzo złożony problem obejmujący najbardziej precyzyjny pomiar i techniki obliczeniowe w miernictwie górniczym, głównie ze względu na potrzebę osiągnięcia wymaganej dokładności, która jest głównie określona przez wzdłużne i poprzeczne odchylenia przekopu i przecinki. Inżynier projektu określił wymaganą dokładność jako maksymalne odchylenie (wzdłużne, poprzeczne) równe 0,250 m dla wszystkich przekopów (dokładność specjalna). Cały proces pomiaru składał się z pomiaru powierzchni, pomiaru głębokości dwóch połączonych szybów (Mír 5: poziom 9, ČSA 2: poziom 11), pomiarów połączenia oraz pomiarów kierunkowe (przy użyciu giroteodolitu MVT-2) przeprowadzonych zgodnie z rozporządzeniem Czeskiego Urzędu Górniczego nr 435/1992. Poprzez analizę dokładności pomiarów potwierdzono, że dokładność określona w rozporządzeniu Czeskiego Urzędu Górniczego nr 435/1992 oraz ta wymagana w projekcie zostały osiągnięte we wszystkich etapach pomiarów. W dniu 12 grudnia 2012 obie kopalnie zostały połączone podziemnym tunelem o długości 870 m z dokładnością pozycyjną równą $m_{x,y}$ *= 0,011 m oraz dokładnością wysokości równą* m_h *= 0,003 m.*

Słowa kluczowe: Technologia GNSS, pomiary kierunkowe, szyb CSA2, szyb Mir 5