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VERIFICATION OF STRESS STATE MONITORING IN THE SURROUNDINGS OF THE ROADWAY AHEAD OF LONGWALL MINING BASED ON THE RESULTS OF 3D SCANNING OF ROADWAY DEFORMATION, BOGDANKA MINE, POLAND

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ABSTRACT: For designing precisely the reinforcement of mine tunnels and reinforcing underground structures in general, knowing stress and deformation states in the rock massive (hereinafter also referred to as the "RM") in the immediate vicinity of these mine works as precisely as possible is absolutely decisive. Stress is usually determined by interpreting deformation processes in the RM. These can be monitored and measured relatively exactly. Tunnels are loaded especially by longwall pressures. In addition, the distribution of stress is also influenced significantly by older mining activities, edges and pillars in the rock cover, or by seams mined through old-workings. All of these factors can influence significantly stress and thus also deformation manifestations in the surroundings of mine works. For the purpose of checking changes in the state of stress in the RM induced by mining, the monitoring of the state of stress in the RM in connection with mining seam 385 using longwall G6 in the black coal mine of LW Bogdanka in Poland was designed and carried out. The purpose of the monitoring carried out was to verify changes in the stress tensor during the mining process. For the purpose of verifying the monitoring of stress, the survey of the state of the tunnels was carried out using a pulse 3D scanner in the place of the geotechnical station (GS). The purpose was to capture deformation changes ahead of the advancing longwall face in the surroundings of the GS.

INTRODUCTION

To measure changes in the state of stress in the HM, the Compact Conical ended Borehole Monitoring method (CCBM) (Stas et al. 2005, 2011) was used. This method is based on the principles of the modified overcoring method. This is the so-called overcoring method using a compact conical probe developed at the Institute of Geonics of the Czech Academy of Sciences in cooperation with the Japanese Kumamoto university, with its original name Compact Conical ended Borehole Overcoring method (CCBO) (Sugawara and Obara 1999; Obara and Sugawara 2003). Modifying the overcoring method in such a way the lightening (drilling around) the core phase is skipped and the conical measurement probe is glued directly into the natural rock enables to monitor continuously and on a long-term basis changes in the stress that occur in the RM during mining processes and also as a result of natural changes in stress arrays.

The monitoring of the state of stress in the RM was designed as one geotechnical monitoring station in the entry tunnel of the longwall with the plough technology. The location of the GS was selected on the basis of the advances of the longwall so that there was a sufficient time reserve from the installation of all probes for carrying out measurement itself. Therefore, the geotechnical station was located in the longwall tunnel 4/VIII/385 at the stationing of 1,720 m in the analysed longwall G6. After the installation of all CCBM probes at the geotechnical station on 9 January 2021, the longwall face was at a distance of approx. 575 m from the mentioned station. The layout was designed not only with respect to the technical limits for installation limiting the maximum length of the installation hole and its incline but also with respect to the lithological development of the rock cover in the place of the monitoring station. For this reason, a prospect hole was drilled before installation itself and a qualitative evaluation of the RM was carried out. To verify stress monitoring, the survey of the state of the longwall tunnel was carried

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out using a pulse 3D scanner. The purpose was to capture deformation changes ahead of the advancing longwall face; specifically, at four stages in the ± 20 m section on each side from the GS.

METHODOLOGY OF MEASUREMENT

Methodology of stress state monitoring of rock mass

Development of the device was based on the experience of Sugawara and Obara from Kumamoto University. They were the first to develop and use the compact conical-ended borehole overcoring (CCBO) system (Sugawara and Obara 1999; Obara and Sugawara 2003). The conical shape of the CCBO probe provides a sufficient number of strain measurements in independent directions in one probe position in the borehole so that all values of the stress tensor can be determined. Two variants of the probe were developed at the Institute of Geonics: the first is equipped with a microprocessor for remote and wireless automatic recording of measured data in the probe's internal memory (CCBO), while the second can be connected to a data-logger and a power supply via a cable. The latter, called the 'compact conical ended borehole monitoring method' (CCBM) device, was used for long-term monitoring of stress tensor changes (Stas et al. 2005, 2011).

The CCBM method is based on similar principles to the CCBO method except for the 'destructive' overcoring phase, which is not performed. This method allows repeated measurement of strain on all sensors of the probe over a long period. In this case, however, only changes of the stress tensor in relation to the stress state at the time of probe installation can be determined. This is the principal difference between the CCBO and CCBM methods. The evaluation of measurements remains the same as in the case of the CCBO technique.

The dependence of corresponding deformations on the tensometers on the stress tensor was formulated by Sugawara and Obara (1999) and Obara and Sugawara (2003). For the CCBM, the following equation was formulated (Stas et al 2011):

$$[\varepsilon_{\Lambda}^{\Phi_j}(t_i) + \varepsilon_{\Lambda}^{\Phi_j}(\Delta t)] \times E = |\boldsymbol{A}(\Lambda;\mu;\Phi_j)| \times [\,|\boldsymbol{\sigma}_i| + |\boldsymbol{S}(\Delta t)|\,]$$

and the following was expressed using it:

$$\varepsilon_{\Lambda}^{\Phi_j}(\Delta t) \times E = |\boldsymbol{A}(\Lambda;\mu;\Phi_j)| \times |\boldsymbol{S}(\Delta t)|,$$

where $\varepsilon_{\Lambda}^{\Phi_j}(t_i)$ and $\varepsilon_{\Lambda}^{\Phi_j}(\Delta t)$ are the deformation $\varepsilon_{\Lambda}^{\Phi_j}$ at the time of the installation of the probe and the differential deformations related to the time of installation; $|\boldsymbol{\sigma}_i|$, $|\boldsymbol{S}(\Delta t)|$ are the tensors at the time of installation t_i and the induced stress tensor (stress changes at the time Δt after installation) related to the stress state $|\boldsymbol{\sigma}_i|$; E is Young's modulus and μ is Poisson's ratio. The optimum stress change tensor of the whole system can be calculated using the differences of all ("j-") pairs of the corresponding measurements ($\varepsilon_{\Lambda}^{\Phi_j}(\Delta t)$) and the ideal expected deformation ($\varepsilon_{\Lambda\Phi_j}(\Delta t) \equiv |\boldsymbol{A}(\Lambda;\mu;\Phi_j)| \times |\boldsymbol{S}(\Delta t)|/E$) can be calculated using the method of least squares.

The CCBM probe is designed for boreholes 76 mm in diameter. The waterproof probe body has a diameter of 55 mm. Six pairs of mutually perpendicular strain gauges are mounted onto the conical tip of the probe with an apical angle of 60°. The probe is glued directly in the conical shaped bottom of the borehole. The CCBM probe, which can be connected to an external control unit by cable, thus enables the observation of stress changes in the rock mass (induced, for example, by underground mining activities). Periodic manual reading of data can be done using a computer or data-logger. Periodic manual reading of data was carried out by Personal Digital Assistant (PDA). The data concerning stress changes in all three CCBM probes were read daily.

Methodology of measurement of tunnel deformations

Within scanning the longwall tunnel, Faro Focus S 350 and Z+F IMAGER 5010C pulse 3D scanners were used. This is a device with a long laser beam range, which is distinguished by its spatial, length and angle accuracies and its high scanning rate. The subject of scanning work was scanning longwall G6 tunnel No. 4/VIII/385 under the longwall, using the plough technology. The GS was installed in the tunnels concerned in the surroundings of which scanning works took place. The purpose was to capture deformation changes ahead of the advancing longwall face; specifically, in two steps in the ± 20 m section on each side of the geotechnical station. The subject of the first step was the initial initiation scanning at the time of the installation of the geotechnical station for the purpose of capturing the current state; additional steps were scanning this station at distances of 300, 150 and 80 m in front of the longwall face with the already possible detection of space-time changes.

With regard to the minimum blocking of the operational time in the tunnel concerned such resolution was selected that enables to capture the tunnel in sufficient detail, nevertheless respecting and considering mining operation. The chosen resolution was 1/4 (the detail level for the inside spaces up to max. 10 m to the point of interest) in quality 2x (43.7 mil. points within one position). Scanning itself with this resolution, including the time for setting the tripod, took 4-5 minutes at each station. With regard to the high humidity and temperature, scanning itself was preceded by waiting for approx. 30 minutes by reason of tempering the scanner optics because water vapours condensed on the surface of the rotating glass. The specified step between individual stations was 5 m, i.e. such distance that ensures the optimum coverage of the mine work from two consecutive stations. A necessary activity within 3D laser scanning is the registration of partial point clouds to create one unit. A condition of every successful registration is the detection of at least a pair of joint detection points (reference balls) within at least a pair of connected partial point clouds. To ensure that the processing and registration of partial scans are as precise as possible, reference balls with a diameter of 140 mm were used. When they were used, the achieved middle distance errors (registration errors) were in the order of up to 2 mm. A condition for problem-free registration is not only the visibility of the ground control points from one and more stations but also respecting the conditions for setting the reference balls resulting from the chosen resolution. For the purpose of aligning clouds, the reference balls had a fixed stated position (the reflective label on the reinforcement specifying unequivocally the position) at the border of the selected section to enable align mutually point clouds using these points. The details of all scanning campaigns are given clearly in **Table 1**.

Table 1: Overview of the scanning campaigns at the geotechnical station, *automatically generated cloud to cloud error from the TRW

Date	Device	Number of positions	Registration error	Number of captured points	Length of the captured section
08.01. 2021	Faro Focus S 350	6	1.0 mm	258,266,517	35 m
25. 02. 2021	Faro Focus S 350	8	1.38 mm	331,693,179	42 m
15. 03. 2021	Z+F IMAGER 5010C	5	32.9 mm *	221,284,995	64 m
23. 03. 2021	Z+F IMAGER 5010C	4	31.2 mm *	173,065,443	39 m

Scan registration itself took place in fully automated mode in the case of using reference balls. All captured partial point clouds were successfully connected to create one unit defined by the general united coordinate system based on the position of the scanner within one of the partial stations. The output of subsequent data processing in the Trimble Realworks (TRW) software is a continuous cloud of spatial points (hereinafter referred to as a "cloud"), describing in detail the scanned space. The results of partial scan registration are shown in **Figure 1.**

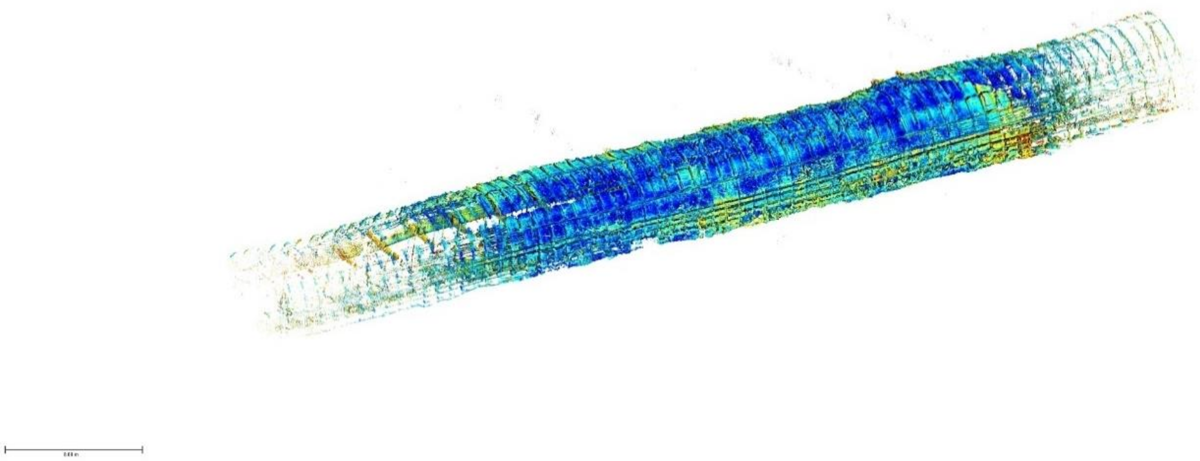

Figure 1: The section of tunnel No. 4/VIII/385 in the surroundings of the geotechnical station

An additional task following scan registration was to clean a point cloud so that the point cloud has no elements that complicate the mutual alignment of clouds. All visible mine technologies (conveyor belt, suspension track locomotive and others), cables, mine workers, and the like must be removed to ensure that only the tunnel floor ground, sides and roof remain. The clouds cleaned in this way will be compared with each other. A difference scan will then enable to show the places and sizes of the captured deformation changes.

Methodology of evaluation of rock mass geotechnical properties

A qualitative evaluation of the rock mass in the place where the monitoring of the stress state was carried out was carried out using the RQD (Rock Quality Designation) index. The RQD enables to describe the state of the drill core very easily using the measurement of the percentage of „qualitatively good" rocks in the selected length section of the core (Deere et al. 1967; Deere and Deere 1988; Deere 1989). The RQD parameter is defined as the percentage ratio of the sums of the lengths of the drill core intact pieces longer than 0.1 m to the total (selected) length of the core run. The methodology of the measurement of individual pieces of the drill core and the calculation of the RQD are clear from **Figure 2**. The RQD is currently used as standard as one of the basic parameters entering the calculation of rock mass quality using the RMR index classification systems (Bieniawski 1976, 1989) and Q (Barton et al. 1974).

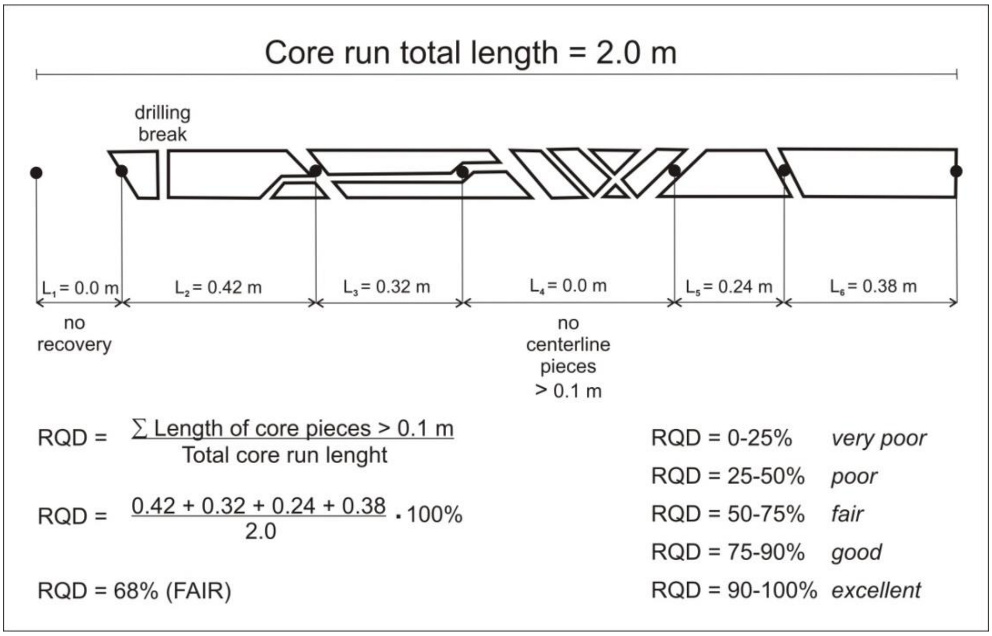

Figure 2: Methodology of the measurement and calculation of RQD (adapted according Deere et al. 1967; Deere and Deere 1988; Deere 1989)

The evaluation of the rock mass was carried out on the basis of the drill core of the prospect hole made in the area of the designed GS. It was hole BR59/20 with a length of 25 m in longwall tunnel 4/VIII/385. On the basis of the qualitative evaluation of the RM, the suitable installation positions of the probes were determined subsequently and the parameters of the installation holes were determined. A qualitative evaluation of the RM was also carried out in the last two meters of the installation holes, into which the CCBM probes were subsequently installed. The installation holes were drilled using a diameter of 76 mm. However, the installation holes were full hole drilled for time reasons; to obtain rock samples required for the determination of the physical and mechanical properties, only the last two meters of the installation holes were core drilled.

Gathering information about the qualitative parameters of the rocks in the rock cover of the seam 385 concerned, the basic physical and mechanical properties of the rocks captured by the prospect and installation holes were studied. Specifically, the simple (uniaxial) compression strength, modulus of deformability and Poisson's ratio were determined when the method of loading was standard. The modulus of deformability and Poisson's ratio are required parameters for converting the deformations measured using the probes (CCBM) to stress. For determination, cylindrical test specimens with an aspect ratio of approx. 2:1 (specimens approx. 122 mm high and with a diameter of approx. 61 mm) were used. The strength and deformation properties of the rocks were determined using the ZWICK 1494 deformation press with a cylindrical test chamber for measuring longitudinal and transversal deformations; the compression test was carried out in controlled deformation mode at a loading rate of 0.15 mm/min.

Design of monitoring of the stress state of the rock mass

The monitoring of the stress state of the rock mass in longwall G6 was designed as one monitoring geotechnical station with the location in tunnel 4/VIII/385 under the longwall at stationing 1,720 m. After the installation of all CCBM probes at the geotechnical station on 9 January 2021, the longwall face was at a distance of approx. 575 m from the mentioned station (see **Figure 3**). The monitoring of changes in the stress state of the RM was terminated on 7 April 2021, when the longwall face passed the geotechnical station.

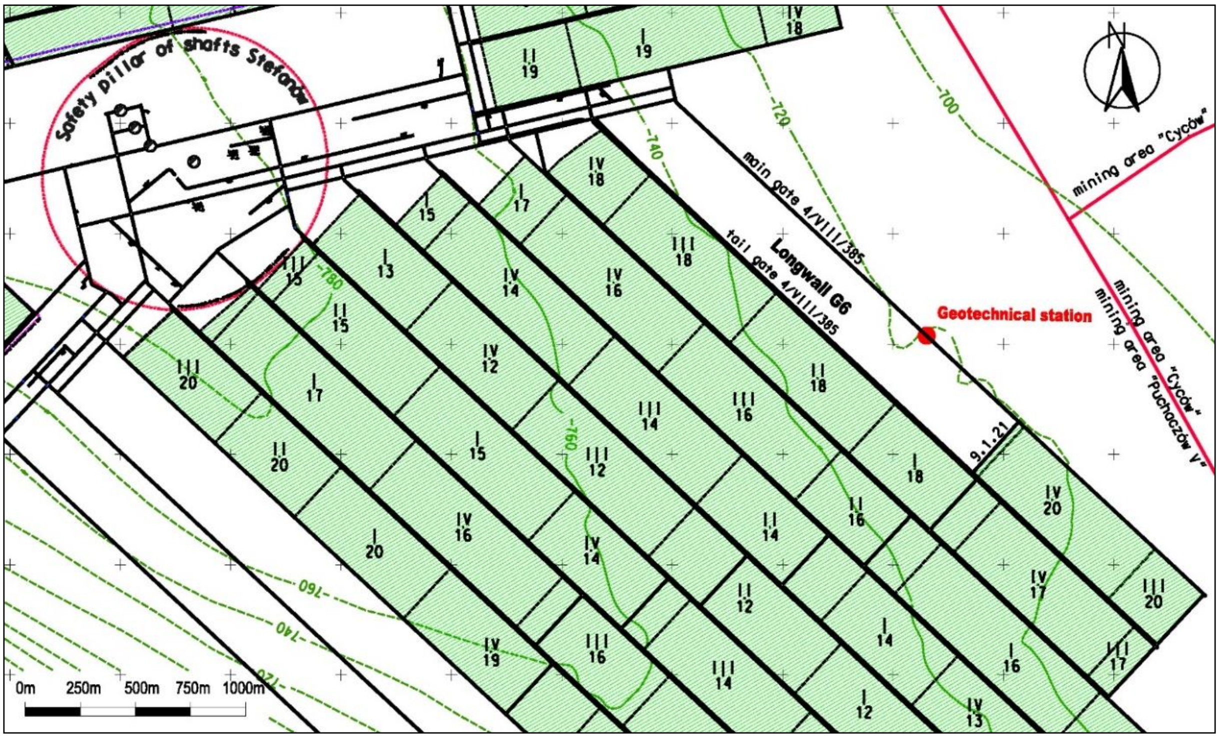

Figure 3: Location of geotechnical station GS1 in relation to longwall G6

Longwall G6, using the plough technology, was situated at a depth of 875 to 920 m under the surface. The total seam thickness ranged from 1.15 to 1.5 m. The location of the seam in the area concerned is subhorizontal. The incline of the layers is around 1° towards E. The lithological development in the surroundings of seam 385 is clear from **Figure 4**. In the rock cover of the seam siltstones with coal interstratified beds, up to 0.3 m thick, here and there prevail. The bed of seam 385 consists of claystone. The distribution of stress in the rock mass in the area of the installed geotechnical station GS1 is influenced especially by additional stresses induced by the advancing longwall. In the area of the influence there are no dug up longwalls and also in the rock cover of the longwall no exploitation was carried out in the past.

Three CCBM probes in total were placed in such a way that they monitor independently the stress state of the rock mass ahead of the longwall face of longwall G6 (CCBM 2, electronics No. 49 and CCBM 3, electronics No. 102) and above longwall tunnel 4/VIII/385 (CCBM 1, electronics No. 0). The location of the CCBM probes is clear from **Figure 4**. The layout was designed with respect to the technical limits for installation limiting the maximum length of the installation hole and its incline. On the basis of an analysis of the lithological development of the RM the parameters of the installation holes were designed and the places for the installation of the conical probes were selected. All conical probes were installed in the siltstone (locally with fine-grained sandstone interstratified beds), which showed "medium up to good" quality (the RQD in the range of 70 to 86 %; see **Figure 4**) on the basis of a quality evaluation of the RM in the core of prospect hole BR59/20 using the RQD index. The physical and mechanical properties of the siltstone are given in Chap. Result and discussion. For the purpose of installing the CCBM probes, three installation holes with a diameter of 76 mm were drilled. The installation holes were full hole drilled for time reasons; to obtain rock samples necessary for the determination of the physical and mechanical properties, only the last two meters of the installation holes were core drilled. The parameters of the installation holes are clear from **Table 2**.

Table 2: Parameters of the installation holes and CCBM probes installed in tunnel 4/VIII/385

Probe No.	Stationing [m]	Hole No.	Hole direction	Hole incline	Probe depth [m]	Electronics number	Date of installation
CCBM1	1,720.0	1	On the tunnel axis	+80°	19.6	0	09.01.2021
CCBM2	1,719.0	2	45° P.B.	+75°	20.1	49	07.01.2021
CCBM3	1,718.5	3	40° P.B.	+55°	17.5	102	08.01.2021

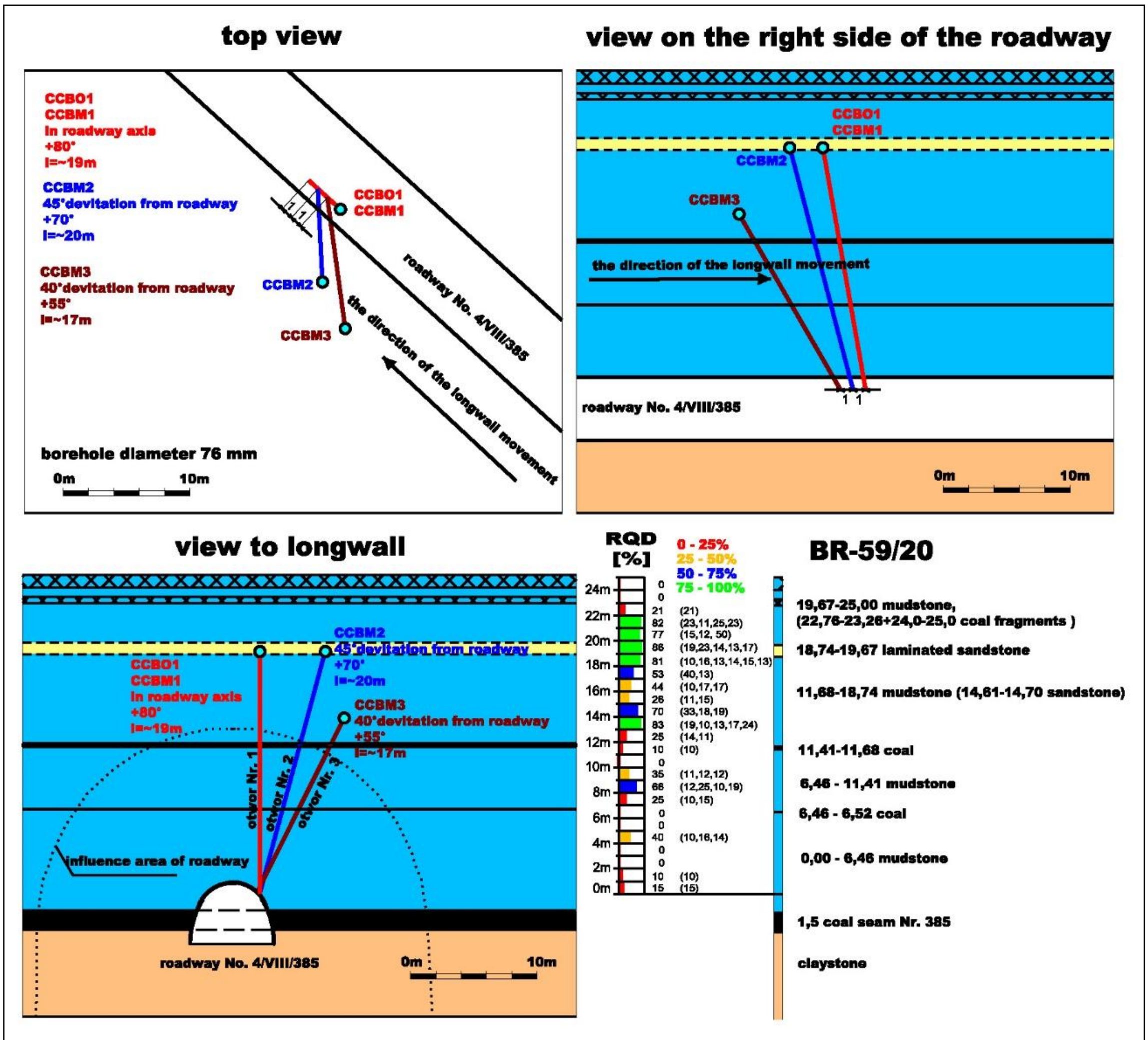

Figure 4: Positions of the CCBM probes and installation holes in relation to longwall tunnel 4/VIII/385

RESULTS AND DISCUSSION

Rock mass quality

The RQD index and lumpiness determined using the core of prospect hole BR59/20 are expressed in the form of the graphs below (see **Figures 5** and **6**). The hole profile is clear from **Figure 3**.

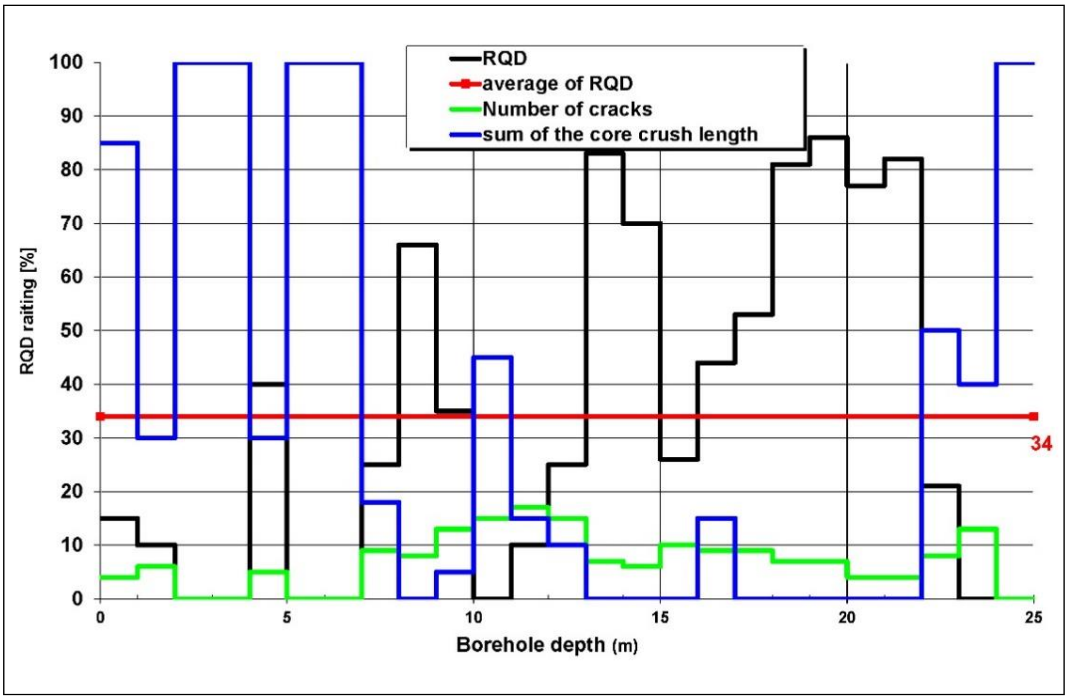

Figure 5: Evaluation of the RQD index from the drill core of hole BR59/20

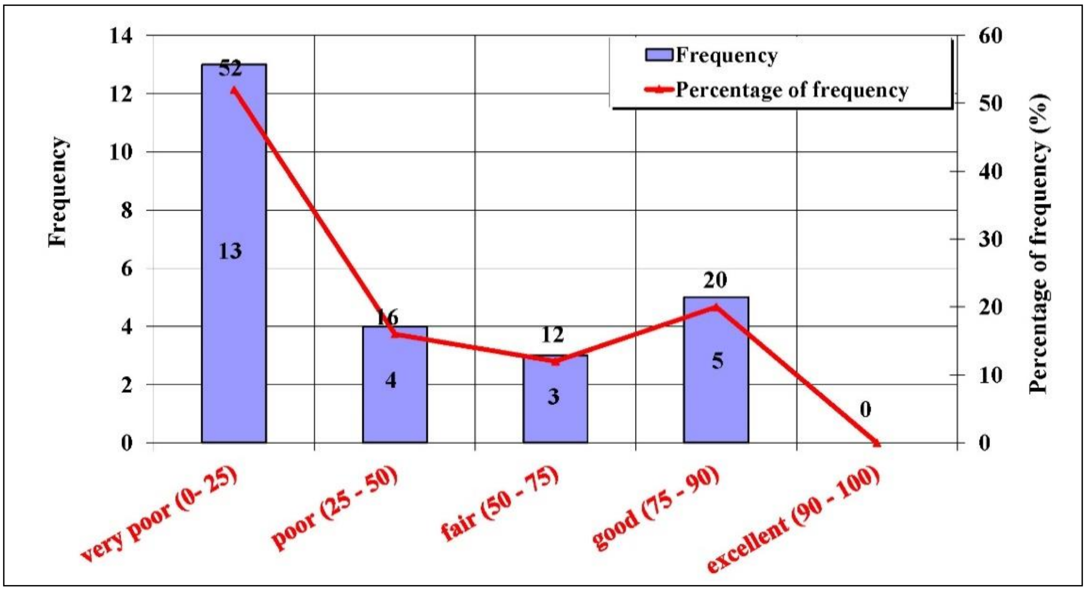

Figure 6: Quality class of the rocks according to the RQD parameter from the drill core of hole BR59/20

It follows from the results of the determination of the RQD parameter using the drill core of prospect hole BR59/20 presented in **Figures 4 and 5** that the rock mass above tunnel 4/VIII/385 can be generally put in the rock "poor" quality category within the intention of classification according to Deere and Deere (1988) and Deere (1989). The average value of the RQD, determined from the whole metrage of the hole, is 40 %. 16 % of the metrage of the hole is in detail in this rock "poor" quality category. Over one half of the metrage of the hole (52 %) is in the qualitative "very low" quality categories. Only 12 % resp. 20 % of the length of the core is in the "medium" resp. "good" quality category. However, it must be emphasised that the qualitative properties of the rock mass were influenced by induced stress due to the rock excavation of tunnel 4/VIII/385 at the time of drilling the prospect hole. The influence of the rock excavation of the tunnel is clear from the low RQD values up to a depth of 8 m, when the rock mass in the "very low" quality category is in this interval. The low RQD values were also registered in the areas with the development of coal interstratified beds.

Physical and mechanical properties of rocks

Considering the relatively low quality of the rock massive in the place of installation of the CCBM probes, five cylindrical test specimens with an aspect ratio of approximately 2:1 were successfully prepared. Specimens with registration numbers 16 914/1 and 16 914/2 from a depth of 19.3 and 19.5 m were prepared from the drill core of installation hole No. 1, specimen No. 16 915/2 from a depth of 17.2 m was prepared from hole No. 2, and specimens No. 16 916/1 and 16 916/2 from a depth of 16.1 and 16.4 m were prepared from hole No. 3. The characteristics of damage of the specimens are clear from **Figure 7**.

Figure 7: Test specimens before and after the test

Table 2: Values of the simple compression strength б$_{Pd}$, modulus of deformability E_{sec50} and Poisson's ratio μ_{sec50}

Specimen number	б$_{Pd}$ [MPa]	E_{sec50} [MPa]	μ_{sec50} [-]
16 914/1	111	32,043	0.13
16 914/2	63	18,187	0.09
16 915	59	20,062	0.09
16 916/1	32	19,976	0.17
16 916/2	47	22,242	0.11
Arithmetic mean	62	22,502	0.12
Standard deviation	27	4,941	0.03
Value used for converting deformation to stress	53	20,600	0.12

The tested undamaged specimens of siltstones and siltstones laminated with fine-grained sandstone can be put in the medium or high strength rock class in accordance with the known strength classifications (Bieniawski 1989). Also according to the classification by Hoek and Brown (1997), the tested siltstones belong not only to the "solid" rock group (the mean is 62 MPa) but also to the "medium strength" rock group (16 916). Specimen No. 16 914/1 was excluded from the assessment. This is a sample of compact sandstone with fine-grained structure, which outstrips markedly the other specimens from the viewpoint of its mechanical and deformation properties. Therefore, a modulus of deformability of 20,600 MPa and Poisson's ratio of 0.12 were used for the calculation of stress changes in probes CCBM2 and CCBM3.

Monitoring of stress changes ahead of longwall face

Mining in longwall G6 was started in quarter III 2021. As already mentioned, the monitoring of changes in stress ahead of the longwall was started on 9 January 2021, after the end of the installation of geotechnical station GS1. At that time the longwall face was situated at a distance of approx. 575 from station GS1. Currently, all probes are already in the collapse area of the longwall and the monitoring of stress was terminated on 7 April 2021. The monitoring of stress changes in all 3 probes was realized by daily data collection ensured by workers of LW Bogdanka (see Annex No. 3). The data were read by a pocket computer (PDA – Personal digital assistant). To present the results, stress changes detected on two probes (CCBM2 and CCBM3) ahead of the advancing longwall face were selected. Probably due to a break of the mass, probe CCBM1, which was installed above the tunnel under the longwall, ceased to provide data on 6 February 2021. The course of changes in the stress tensor components Sigma 1, Sigma 2 and Sigma 3 as the longwall face was getting closer to individual probes CCBM2 (el. No. 49) and CCBM3 (el. No. 102) is documented in **Figures 8** and **9**. The stress components are distinguished graphically in the figures.

Figure 8 shows the dependence of changes of the monitored stress tensor components (Sigma 1, Sigma 2 and Sigma 3) measured on probe CCBM 2. This probe was installed in the overlying rocks of the seam above the area of the longwall being mined (see **Figure 4**) at a distance of approx. 20 m from the roof of the mined seam 385. An increase in the significant stress changes at a distance of approx. 150 m from the edge of the longwall face is clear from the graph presented. The smallest stress component (Sigma 3) is decreasing. The medium stress component (Sigma 2) is around zero values with a gradual increase in the final phase of monitoring (from a distance of approx. 70 m ahead of the longwall face). By contrast, the maximum stress component (Sigma 1) is increasing and reaches its maximum (16 MPa) just in front of the edge of the longwall face (2.2 m on 3 April 2021). In the course of monitoring, an irregular cyclical increase in the load of the rock mass was recorded in the area of the installed probe, caused probably by breaking bigger rock blocks in the higher overlying stratum.

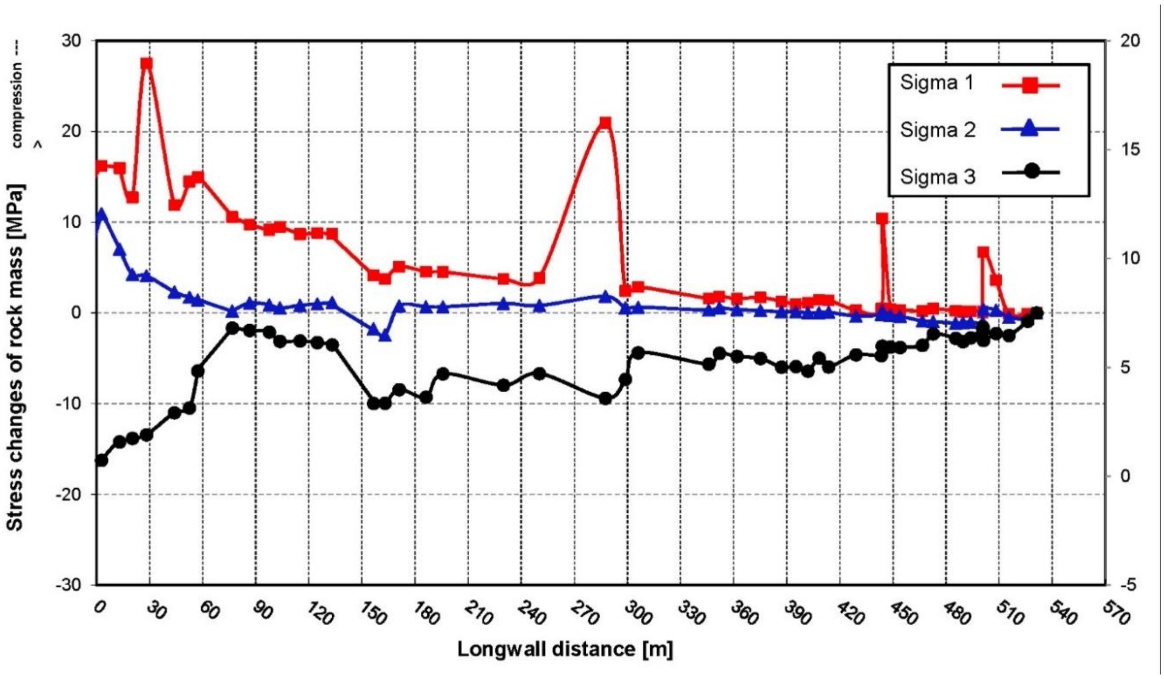

Figure 8: Changes in the stress tensor components (Sigma 1 – maximum, Sigma 2 – medium and Sigma 3 minimum) depending on the distance from the edge of the longwall face (probe CCBM 2)

Figure 9 shows the dependence of changes in the monitored stress tensor components (Sigma 1, Sigma 2 and Sigma 3) measured on probe CCBM 3. This probe was installed in the overlaying stratum rocks of the seam above the area of the longwall being mined at a distance of approx. 15 m from the roof of the seam 385 being mined. Due to the incline and direction of the installation hole, the probe provided data at a distance of 10 m from station GS1 and 5.5 m from the side of tunnel 4/VIII/385 (see **Figure 4**). An increase in significant stress changes at a distance of approx. 150 m from the edge of the longwall face is clear from the graph showed. The smallest stress component (Sigma 3) decreases with a marked decrease at the already mentioned distance of 150 m from the edge of the longwall face. In the case of the medium stress component (Sigma 2) a more marked decrease up to negative (tensile) values was recorded in the final phase of monitoring. The maximum stress component (Sigma 1) is increasing throughout monitoring slowly and reaches its maximum (6 MPa) just in front of the edge of the longwall face (8 m on 1 April 2021).

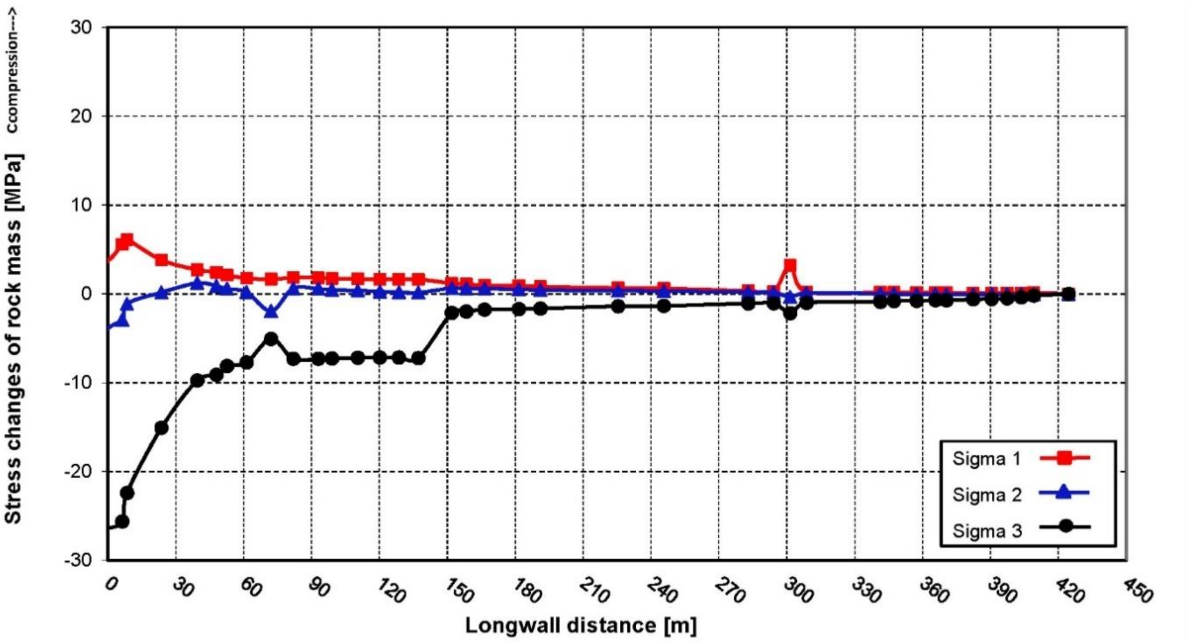

Figure 9: Changes in the stress tensor components (Sigma 1 – maximum, Sigma 2 – medium and Sigma 3 – minimum) depending on the distance from the edge of the longwall face (probe CCBM 3)

Deformation analysis by 3D laser scanning

As already described above, scanning in this tunnel took place in 4 cycles on 8 January 2021, 25 January 2021, 2 February 2021, 15 March 2021 and 23 March 2021. From the viewpoint of the distance from the longwall, point clouds were compared with each other at distances of 576 m, 302 m, 150 m and 80 m from the longwall. Mutual comparisons are clear from **Figures 10 to 14**.

Figure 10: View of the geotechnical station; comparison of changes 576 m x 302 m in front of the longwall

Figure 10 shows that there were no significant changes; the changes marked in green (0.001-0.03 m) mean changes on cable lines and piping. Deformations of the steel arch support are not visible.

It is clear from **Figure 11** that the changes that result from the comparison of campaigns 3 and 4 are of more significant nature, fully reflecting the influence of additional stresses ahead of the advancing longwall face. The green colour means changes in the order of 0.01 to 0.05 m and the dark green colour means changes of 0.12 m in the inter-week comparison. The yellow range means changes in the order of up to 0.18 m and the read scale from 0.18 m and above.

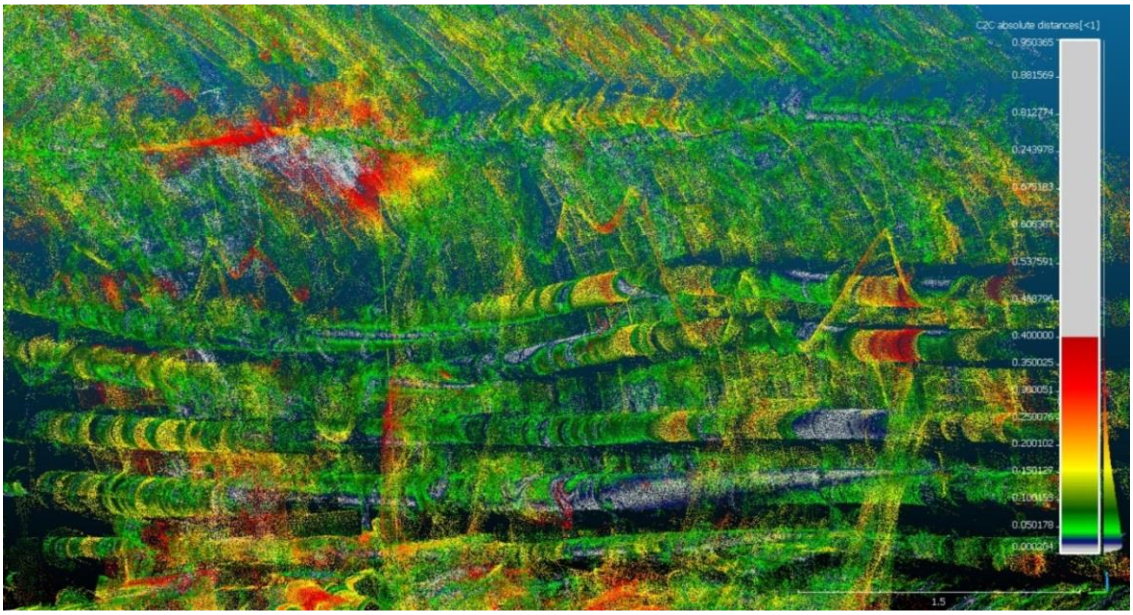

Figure 11: View of the geotechnical station; comparison of changes 150 m x 80 m in front of the longwall

The comparison in **Figures 12 and 13** show such changes where, according to the results provided by the CCBM probes, the initial and slow increase in stress should occur. The changes showed are not of essential nature; the prevailing green colour (changes of up to 0.06 m) shows rather the handling of the cable line and a small deviation of the pipe line. On the other hand, due to the possibility of showing at several angles of view, changes in the floor ground and sides of the tunnel behind the expanded metal are already captured. Extremes in the form of the red colour are differences caused by cleaning a cloud. The deformations of the TH reinforcement are not significant at this moment and therefore additional interpretation is not necessary.

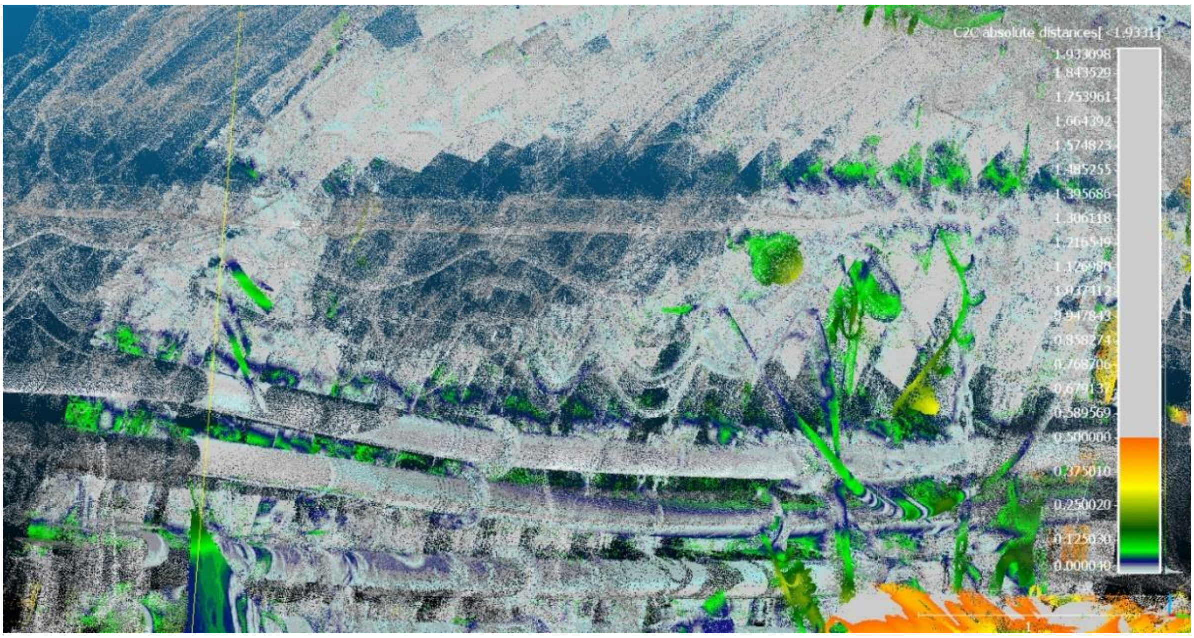

Figure 12: View of geotechnical station GS1; comparison of changes 576 m x 150 m from the longwall; view of the station opposite to the direction of the longwall

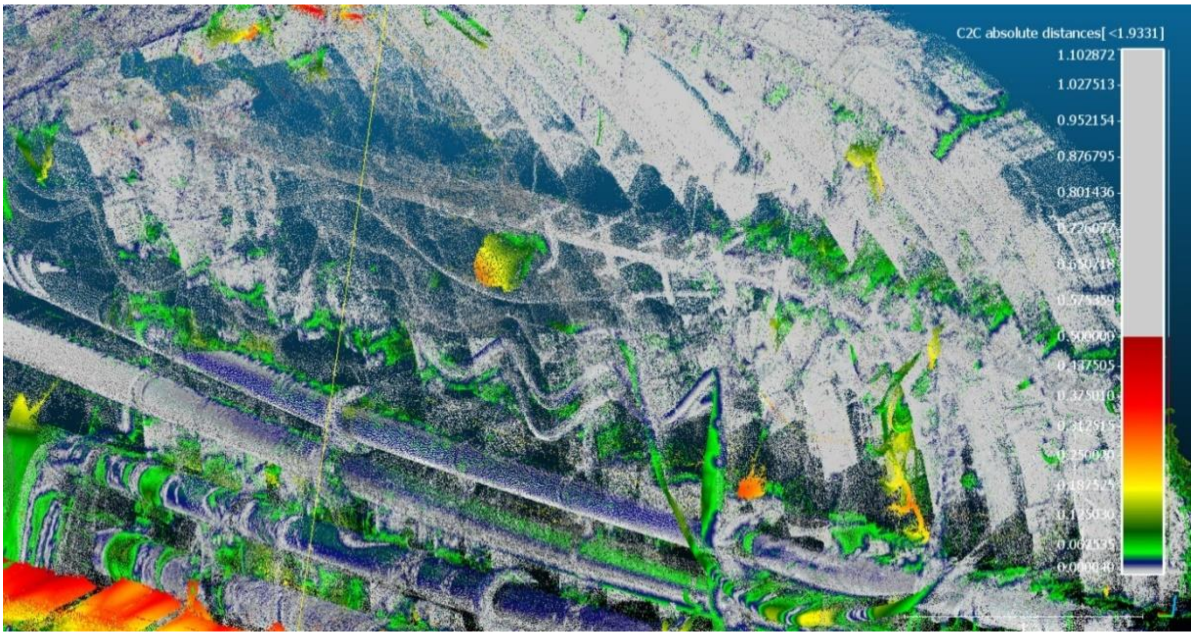

Figure 13: View of geotechnical station GS1; comparison of changes 576 m x 150 m from the longwall; view of the station in the direction of the longwall

Figure 14 shows the detected changes within the comparison of campaigns 1 and 4, i.e. distances of 576 m and 80 m from the longwall. The conclusions of the comparison are in full agreement with the conclusions for the comparison of campaigns 3 and 4 completed with the visible swelling of the floor ground in such parts of the profile where this is apparent. The swelling of the floor ground is in the order of 18-45 cm, with the maximums near the axis of the work and with the minimums at the legs of the TH reinforcement.

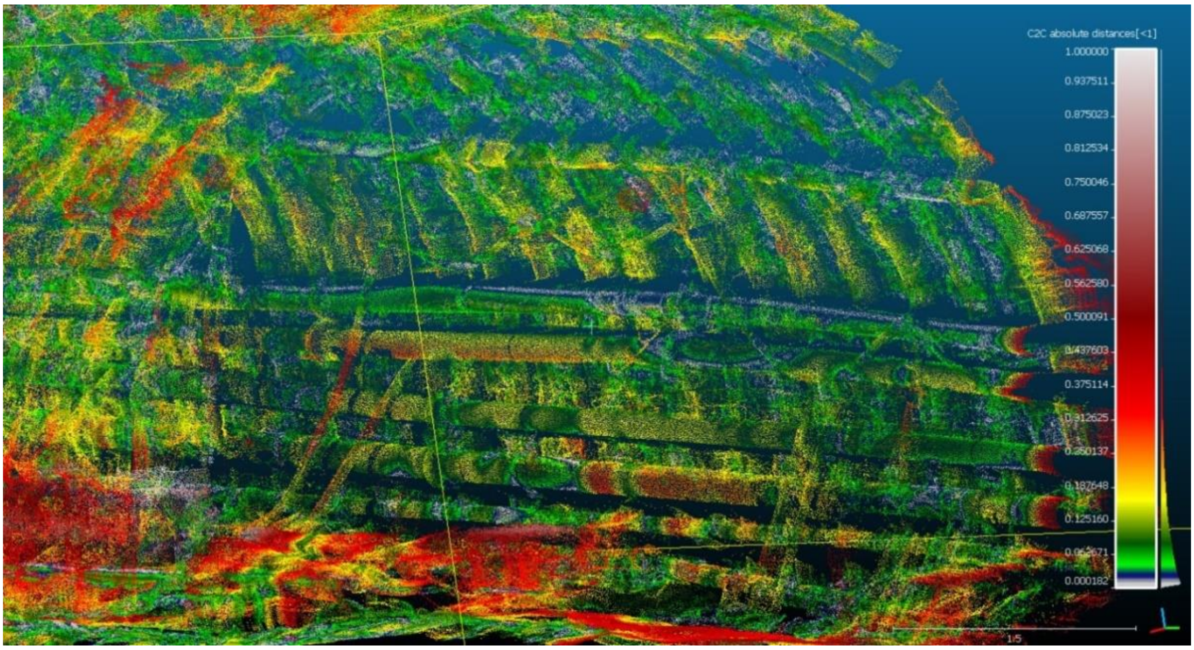

Figure 14: View of the geotechnical station; comparison of changes 576 m x 80 m from the longwall

SUMMARY AND CONCLUSIONS

The objective of monitoring carried out ahead of longwall G6 in tunnel 4/VIII/385 under the longwall was to check changes in the stress tensor depending on the course of mining. In this case changes in stress can be expected due to longwall pressures. Expected changes in stress due to loading by pressures in front of the longwall were recorded by the CCBM monitoring probes. The very low quality of the RM (RQD = 10-34 %) in the areas of the designed monitoring of changes in stress disabled to carry out any reliable measurement of the initial stress tensor using the overcoring method. An increase in significant changes in stress was recorded on the two installed probes (CCBM2 and CCBM3) already at a distance of approx. 150 m from the edge of the longwall face. Then a rapid increase in changes in stress was recorded subsequently at a distance of 75 m from the edge of the longwall face. The maximum changes in stress of up to 16 MPa were reached just in front of the edge of the longwall face. This captured trend in stress changes in front of the advancing longwall reflect deformation changes in tunnel 4/VIII/385 under the longwall analysed on the basis of measurement by a 3D laser scanner. On the basis of the comparison of the first measurement campaign (a distance of 575 m from the longwall) with the second campaign (a distance of 150 m from the longwall) deformation changes in the ground floor and sides of the tunnel after the expanded metal in the order of the first centimetres were evaluated. Deformation changes in the reinforcement and the ground floor of the tunnel in the order of the first centimetres (max. 45 cm in the ground floor) were then deducted from measurement carried out within the third campaign (a distance of 80 m from the longwall).

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