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Abstract

Monitoring of pillar and roadway deformations is one of the most important issues in geotechnical engineering and mining practice. The use of 3D laser technology is ideal to monitor strata displacements in underground excavations enabling complex spatial data capture of the entire space around monitored pillars including all roof and rib deformation which occurs during the pillar excavation. This method based on repeated scans, can monitor the excavation surface movement ranging from a few mm to more than 600 mm. The 3D laser scanner was used to monitor the coal mine roadways and pillar stability in room and pillar panel trial in the Ostrava-Karvina coal basin (OKD Mines, Czech Republic). The 3D data analysis indicated rib movement that ranged from 250 mm to more than 600 mm, a large floor heave that was regularly brushed and practically no roof movement of very strong roof strata overlaying the whole panel area. All scanned results compared well to the results from the extensometry and other measuring instruments. The results further indicated that the mined roadway cross sectional area decreased between approximately 15-25% during the first 7 months of monitoring and stabilized at 5% after another 7 months. Further monitoring is planned to identify any long term creep in the room and pillar panel.

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Innovative Approach to Monitoring Coal Pillar Deformation and Roof Movement Using 3D Laser Technology

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Abstract

Monitoring of pillar and roadway deformations is one of the most important issues in geotechnical engineering and mining practice. The use of 3D laser technology is ideal to monitor strata displacements in underground excavations enabling complex spatial data capture of the entire space around monitored pillars including all roof and rib deformation which occurs during the pillar excavation. This method based on repeated scans, can monitor the excavation surface movement ranging from a few mm to more than 600 mm. The 3D laser scanner was used to monitor the coal mine roadways and pillar stability in room and pillar panel trial in the Ostrava-Karvina coal basin (OKD Mines, Czech Republic). The 3D data analysis indicated rib movement that ranged from 250 mm to more than 600 mm, a large floor heave that was regularly brushed and practically no roof movement of very strong roof strata overlaying the whole panel area. All scanned results compared well to the results from the extensometry and other measuring instruments. The results further indicated that the mined roadway cross sectional area decreased between approximately 15-25 % during the first 7 months of monitoring and stabilized at 5 % after another 7 months. Further monitoring is planned to identify any long term creep in the room and pillar panel.

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Keywords: 3D laser scanning; TLS; room and pillar; rib movement pillar deformation

1. Introduction

Although periodic convergence measurements cannot record continuous elastic and pseudo-plastic deformation of rock mass, 3D laser technology can be regarded as a solution for monitoring the floor heave and the roof and the rib side convergence of mine excavations.

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Laser scanning is becoming to be widely applied technology in a variety of industries. These systems excel in their ability to allow contactless determination of the spatial coordinates of any objects - buildings, structures, interior space, and ground with exceptional speed, accuracy, comprehensiveness and safety. The scanned objects are visualised in the form of point clouds which allows a wide variety of analytical tasks to be performed, and facilitate the generation of models of these objects [1, 2, 4, 9].

When scanning the selected objects, the principle of oscillating the laser beam is used with a selected density of spatially focused surface points on the object in interest. Based on the intensity of the reflected laser signal, it is also possible to quantify the distribution of material in the resulting point cloud. To cover the entire area of interest it is usually necessary to conduct scans from several scanning positions.

The main purpose of the laser scanning technology is to capture the entire *in situ* surface areas at various times. From these results, it is possible to determine the shape and size of excavations, displacements within the scanned area and position of mine supports [3]. Beyond these basic tasks it is also possible to frequently monitor displacements and fractures of coal pillars, rib movement and collapse of pillar corners. These tasks require repeated measurements that are compared with previous scans. Beyond these indisputable advantages the method of 3D laser scanning has its drawbacks which are more evident in the mining environment, including humidity, dust and inaccessible places.

2. Implementation of laser scanning

The compact pulsed terrestrial laser scanner Leica ScanStation C10 [6] was used for monitoring the of time dependent changes of coal pillar V2 in the OKD coal mine pillar panel. It is a device with a long range laser beam (up to 300 m), with accuracy of 4 mm/100 m and angular accuracy (60 micro-radian) and with high scanning speeds (up to 50,000 points/s).

Monitoring was done in nine separate surveys, eight of which are evaluated here. The first surveys were done at 5-6 week intervals. Subsequently, the scanning interval changed due to diminishing displacements of the coal pillar. The last three surveys were carried out at intervals of three to four months (see Table 1).

Table 1. Scanning surveys details.

Color ID	Survey	Number of position	Date	Days	Days total
■	1	6	10. 2. 2015		
■	2	8	17. 3. 2015	35	35
■	3	6	21. 4. 2015	35	70
■	4	7	4. 6. 2015	44	114
■	5	8	21. 7. 2015	47	161
■	6	8	3. 9. 2015	44	205
■	7	7	1.12. 2015	89	294
■	8	8	5.4. 2016	126	420

Within each survey, scanning was carried out from at least six positions. Each scan always captured roadway V300501 and the corresponding part of the roadway V3006 adjacent to the monitored pillar V2. At times the roadway V300502 and the corresponding part of the roadway V3005 was also scanned, thereby the complete coal pillar V2 was defined (see Fig. 1). Scanning was performed with a resolution of 1 cm/10 m, which ultimately leads to the identification of about 14,500,000 spatial points at each of the scanning positions [5].

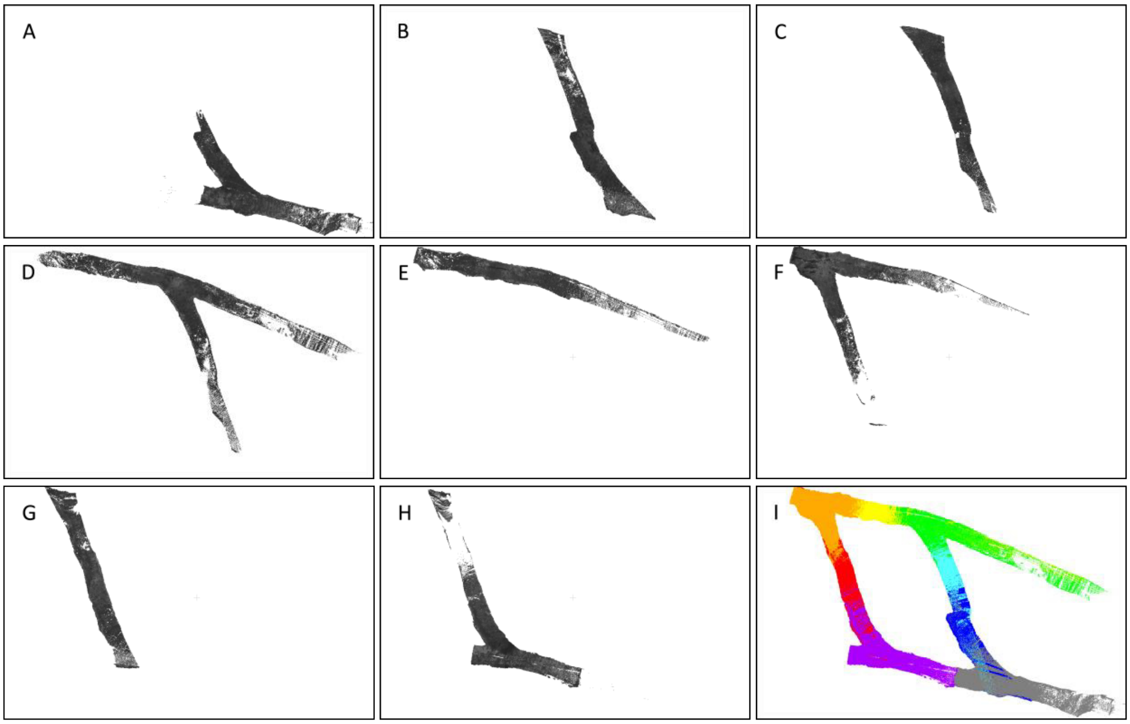

Fig. 1. Scanned roadway sections (A-H) in merged picture of the scanned roadways.

To merge the individual scan surveys together into a single image, several stable roof reference points in the scanned roadways were used. Extremely strong roof strata with no failure ensured that these reference points could be assumed to be stable with minimum displacements.

3. Practical outputs of laser scanning

The primary purpose of the 3D laser scanning within the pillar V locality was to monitor the time dependent in situ displacements of the roadway surfaces and rock bolt positions in the coal pillar V2 area. The coal rib displacements were compared to the extensometry results that were very close to those measured using the laser scanning. This comparison confirms the applicability of the 3D scanning technology for this type of work. Using the laser scanning technology complete picture of the pillar shape and its behavior in time was obtained. The main task of carrying out repeated scanning was to determine the extent of ongoing deformation with time [7, 8].

From the scan results, it was found that different degrees of deformation changes occurred across the whole pillar V2 profile. Significant coal pillar deformation was accompanied by a continuous rib movement in the surrounding roadways V3006, V300501 and V300502. When compared to the initial reference scan, a significant deformation of the monitored coal pillar occurred with rib movements reaching tens of centimeters on every side. This result compared well with the rib extensometers and convergence measurements. For a thorough evaluation of deformation at the central (conveyor belt) roadway V3005, not enough data has been processed to date. However, from the available data it can be inferred that the deformations in this roadway are lower than in other roadways.

To present rib displacements of the monitored data from the mine roadways surrounding the pillar V2, five locations of the 8 m partial length (Fig. 2) were used to calculate the rib movement.

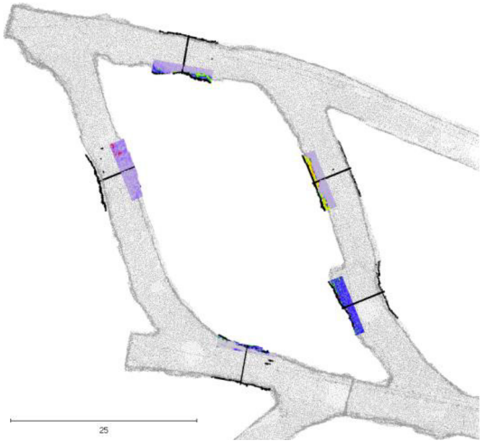

Fig. 2. Plan view showing locations of the cross-sections.

The cross-section displacements were calculated at the middle of each selected position while the 8 m rib section in plan view was also analysed. To limit the size of this paper, the only roadway V300501 cross-section 2 is presented here and shown in Figure 3.

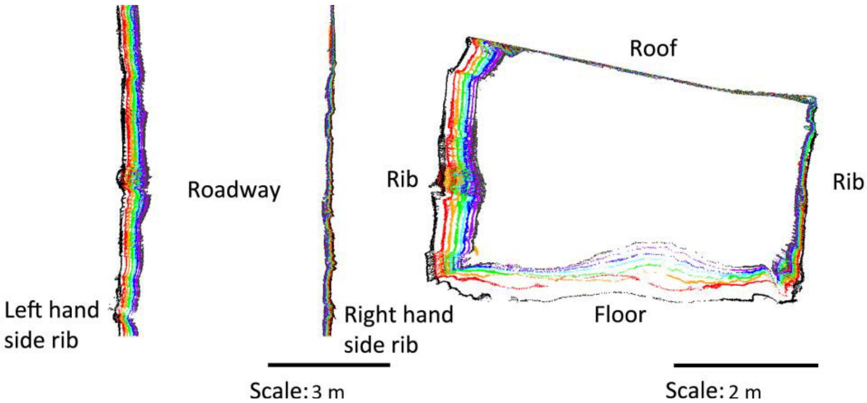

Fig. 3. Plan view of roadway and cross-sections at position 2, roadway V300501.

The individual positions have been chosen to represent the ongoing deformation changes of a coal pillar V2 shape and its surrounding area. The monitored pillar V2 was located on the left side of each cross-section. Each scan is presented in different color for easy identification (see color ID Table 1).

The roadway plan view (Figure 3) shows the measured changes of pillar V2 deformation. Vertical cross-sections describe the rib, roof and floor deformation changes (pillar V2 is on the left side). Significant pillar rib and floor deformations can be observed. The substantial floor heave that occurred during scanning was frequently removed by regular floor brushing.

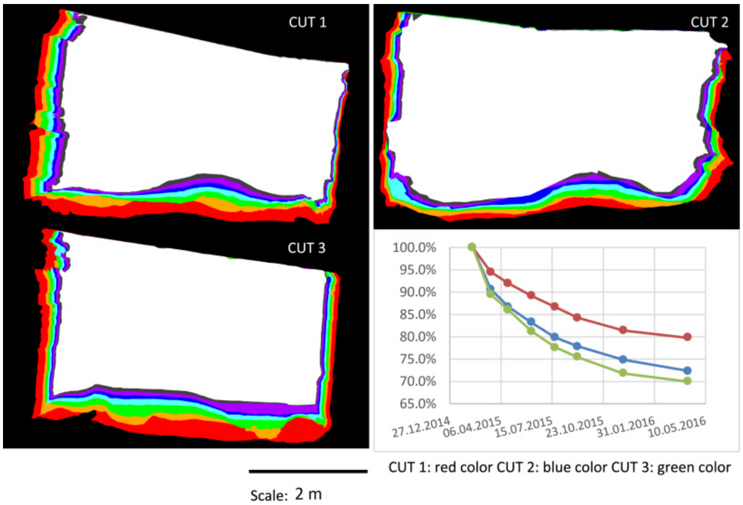

Fig. 4. Roadway cross-sections from laser scan analysis showing convergence at the sites No. 1, 2 and 3, including the summary of convergence plotted against time.

4. Spatio-temporal analysis of roadway convergence

Figure 4 presents cross-sections of the roadway convergence at locations No. 1, 2 and 3 adjacent to the monitored coal pillar V2 located on the left side of the roadway. Results from locations No. 4 and 5 were not presented due to an inadequate data set. The convergence graph plotted against time in Figure 4 shows an exponentially decreasing trend of deformation with time.

The data presented in Table 2 indicates that during the first seven-months after mining the original profile area of the mine roadways reduced by about 15 % in section 1, and by 22 % and 25 % in sections 2 and 3. In the following seven months (in the second half of the period under review), the rate of deformation slowed down with the subsequent roadway area reducing by an additional 5 % in each location. This correlates with the pillar extensometry measurements that indicated a gradual stabilization of coal pillars.

Table 2. Convergence analysis in selected locations.

	Cut 1		Cut 2		Cut 3	
Date	Profile [m^2]	Size	Profile [m^2]	Size	Profile [m^2]	Size
10.02.2015	17.1	100.0 %	15.1	100.0 %	14.8	100.0 %
17.03.2015	16.2	94.5 %	13.7	90.7 %	13.2	89.5 %
21.04.2015	15.7	91.9 %	13.1	86.7 %	12.7	86.0 %
04.06.2015	15.3	89.2 %	12.6	83.2 %	12.0	81.3 %
21.07.2015	14.8	86.7 %	12.1	79.9 %	11.5	77.6 %
03.09.2015	14.4	84.3 %	11.8	77.9 %	11.1	75.4 %
01.12.2015	13.9	81.4 %	11.3	74.9 %	10.6	71.8 %
05.04.2016	13.7	79.8 %	11.0	72.4 %	10.3	70.0 %

5. Coal pillar long term stability

The 3D laser scanning technology enables very detailed analyses to be performed to evaluate the long term coal pillar stability. An example of the survey output is shown in Fig. 5 displaying the deformation differences between the second and 8th survey. As seen here, the roof in the entire area is compact and stable, confirming the results from the dynamometers and vertical roof extensometer monitoring.

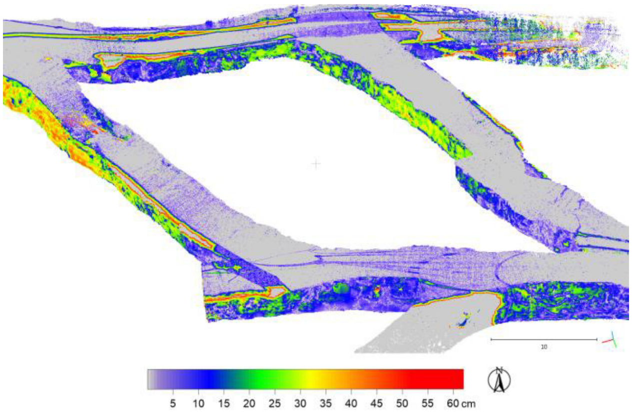

Fig. 5. The difference in deformation from the 2nd and 8th survey.

The laser scan surveys enabled monitoring of the coal pillar deformation with time. The rib displacement survey at five selected positions (see Fig. 6) present the 8 m long rib displacement sections scanned during the period of 14 months. The color scheme enables to determine the level of rib movement at a certain time. Through analysis of consecutive scans it is possible to deduce the speed of rib movement, which is closely correlated with the trend and rate of deformation changes measured by the extensometry.

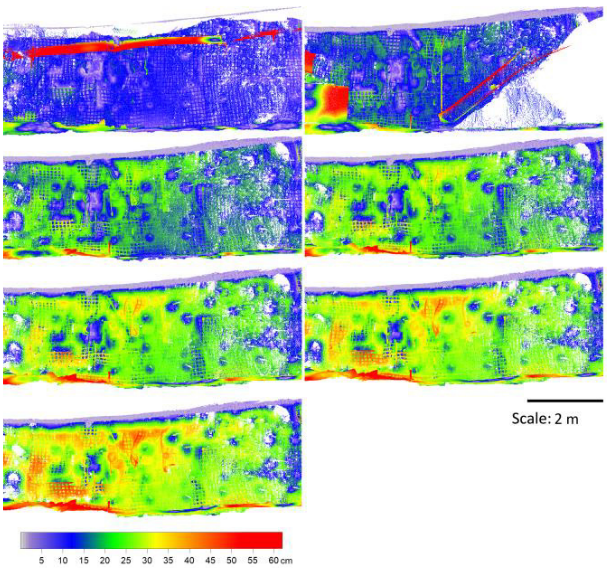

Fig. 6. Differential movement of pillar V2 rib at location 3 in the V3006 roadway.

6. Conclusions

The roadway roof, rib and the floor displacements were measured in great detail using eight laser scans over a period of 14 months. The scan results can determine the changing features of scanned workings including the shape and size of mine roadways and position of rockbolts. By performing spatio-temporal analysis it was possible to identify in detail the places of significant coal pillar rib movement with maximum displacements exceeding 600 mm. The results clearly show a noticeable difference between the rate of rib convergence including the rib bolts, which allows the performance of the installed reinforcement systems to be assessed. Deployment of 3D laser scanning technology enabled accurate and detailed measurements of coal pillar deformation over time.

The measured data indicate that during the first seven-months after mining the original profile area of the mine roadway was reduced by about 15 % in section 1, and by 22 % and 25 % in sections 2 and 3. In the following seven months (in the second half of the period under review), the rate of subsequent deformation decreased to about 5 % in each location, which correlates with the pillar extensometry measurements that also showed a gradual stabilization of coal pillars.

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