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MONITORING OF STAND-AND-ROOF-BOLTING SUPPORT: DESIGN OPTIMIZATION

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ABSTRACT

Assuring the stability of underground headings in order to fulfill their technical functions without any disturbance and provide a safe workplace for mining staff seems to be a fundamental issue in mining activity. In recent years, rockbolts: bar or cable have been most frequently applied as a means of reinforcement. Such a construction is often referred to as a stand-and-roof-bolting support. The paper presents sample results of monitoring stand-and-roof-bolting support systems selected from numerous research projects carried out by the authors. The results discussed below are based on the measurements of the strength parameters of rocks in the laboratory and *in-situ* research, convergence of underground excavations, forces in rockbolts, separation of roof rock strata tested with extensometric probes, telltales and endoscopes, as well as steel yielding support frames load tested with dynamometers. The complex measurements of stand-and-roof-bolting supports along with specifications of geological, mining and geomechanical conditions allowed to formulate a proper evaluation of support behavior and its effectiveness for particular conditions.

KEYWORDS: stability of underground roadways, support monitoring, stand-and-roof bolting support, support design

1. INTRODUCTION

Assuring the stability of underground roadways in order to fulfill their technical functions without any disturbance and provide a safe workplace for mining staff seems to be a fundamental issue in mining activity. Roadways are usually protected with steel yielding support, which can be additionally reinforced in difficult geological conditions or changing mining conditions. In recent years, steel rockbolts or cable bolts have been most frequently applied as a means of reinforcement. Such a construction, combining steel arches and rockbolts is often referred to as a stand-and-roof-bolting support.

A chronological analysis of roadway reinforcement in support systems reveals that in the 1990s Polish hard-coal mines applied steel rockbolts mostly in order to fix roof-arches into the roof rocks or, to a lesser degree, as the individual rockbolt systems. As a matter of fact, since the beginning of the 21st century an intensive increase of cable bolt application has been observed alongside with an almost complete resignation from the use of individual rockbolt systems or a limited use of steel bolts.

Stand-and-roof-bolting supports are constructed in many variants or versions as there are numerous types of frames and infinite numbers of possible systems of rockbolt distribution. Regarding the varied options of steel yielding support with roof bolting, a proper selection of support systems for particular geological and mining conditions appears to be highly problematic (Majcherczyk et al., 2011). Although the effectiveness of such a solution seems to be well documented with numerous practical experiments, such research is most often based only on visual evaluation of the state of roadways and support systems, which definitely fails to provide a sound basis for estimating the behavior of support and surrounding rock mass over a longer period of time or in changeable mining conditions. Therefore, the only way to optimize the support system for particular conditions is the proper monitoring of stand-and-roof-bolting support carried out in natural conditions (Layer, 1996), (Bawden and Tod, 2002), (Majcherczyk et al., 2006), (Bigby et al., 2010). Such a method allows one to obtain a work specification of particular elements of support, which can verify the appropriateness of the applied. In most cases, support monitoring makes it possible to determine optimal conditions, in which number of rockbolts, their length and frame size can be minimized, whereas frame spacing can be increased. As a result, such monitoring procedures offer numerous benefits, such as: an increase in the safety potential offered by the applied solutions, facilitating an on-going search for more innovative support systems, entailing cost minimization of exploitation and providing optimal protection of headings with an ideal adjustment of support system to dynamic requirements.

What seems to be the crucial element of coal-mine measurements is the possibility to utilize their results in numerical modeling (Procházka and Trčková, 2008), (Małkowski et al., 2008). The application of so-called reverse analysis allows the researchers to formulate a proper selection of rock mass models, their properties and rate of strata influence on the support. A model calibrated in this way can serve as a basis for designing underground roadways with the use of numerical methods. The support parameters can be optimized then.

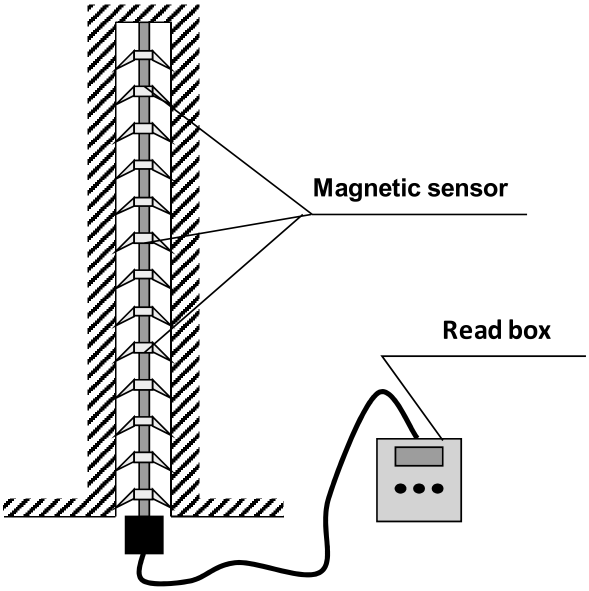

Fig. 1 The scheme of extensometric probe.

Fig. 2 The borehole endoscope.

The paper presents sample results of monitored stand-and-roof-bolting support systems selected from numerous research projects carried out by the authors. The results discussed below are based on the measurements of the strength parameters of rocks in laboratory and *in-situ* research, the convergence of underground excavations, forces in rockbolts, separation of surrounding rock strata tested with extensometric probes, telltales and endoscopes, as well as frame loading tests with dynamometers. Complex measurements of stand-and-roof-bolting support alongside with specifications of geological, mining and geomechanical conditions allowed for the formulation of a proper evaluation of support behavior and its effectiveness for particular conditions.

2. MONITORING METHODS OF SUPPORT BEHAVIOR IN UNDERGROUND HEADINGS

The monitoring of underground workings is usually carried out in the three areas specified below (Majcherczyk et al., 2006): measurements of changes in rock mass, measurements of loading in particular support elements, measurements of excavation geometry change.

The most frequently applied research in the first area mentioned above includes measurements of roof and floor strata separation. The tests are carried out, *inter alia*, with the use of such devices as: telltales, extensometric probes, endoscopic cameras, aerometric probes and stress sensors. All these devices possess some undisputable advantages. Cable telltales, for example, offer an instant visual evaluation of the long-term roof strata displacement. In such a case, no extra reading devices are necessary. Extensometric probes consist of several or even a dozen or so measurement bases (Fig. 1), hence such measurements are far more precise in terms of localizing on-going changes and their values (with the precision of 0.2 mm). Such a solution additionally allows the researchers to carry out remote readings in a given time interval. Endoscopic measurements seem to be most effective in terms of the obtaining results (Fig. 2), as the endoscopes allow for the precise determination of location and volume of roof or floor strata separation based on observations of borehole walls (Małkowski et al., 2008b), (Sosna et al., 2009). What seems to be of crucial importance in this case is that such a method allows for the evaluation of the initial state of strata separation, which is impossible with the measurements carried out using telltales and extensometers. On the other hand, it should be stated clearly that endoscopic measurements are time-consuming and require insertion of the device into a borehole for every single test.

Aerometric probe offers advantages similar to endoscopes as it allows for the determination of rock fissure rate in consecutive sections of boreholes on the basis of pressure changes of air pumped into the boreholes (Kabiesz and Patyńska, 2009). In this case, however, the researchers cannot ascertain the precise character of the fissures but they can only estimate their total capacity. Stress sensors allow to determination in the stress field around a particular heading as well as its changes. Nonetheless, the device is relatively rarely used in Polish coal-mining industry due to its high cost.

The measurements of loading in particular elements of support are carried out with the use of the following devices: instrumented bolts, hydraulic and tensometric dynamometers, tensometers and pressure cushions.

The application of hydraulic dynamometers (Figs. 3 and 4) or tensometric dynamometers allows for the researchers to determine the loading of particular elements of steel arch supports. Dynamometers are installed in the roof between rock

Fig. 3 Hydraulic dynamometer.

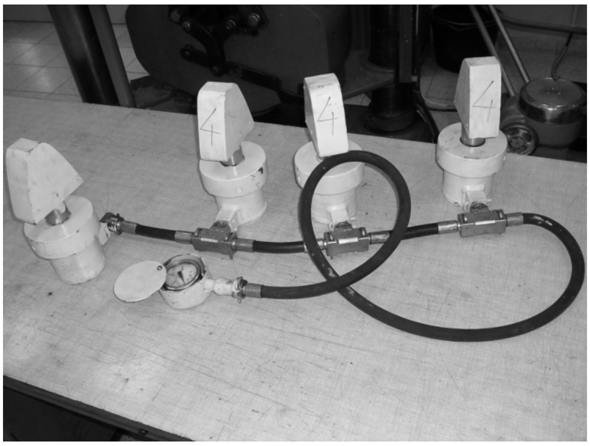

Fig. 4 Hydraulic series dynamometer.

mass and support frames to estimate the loading coming from the rock mass. In order to determine the axial forces in wall arches, the dynamometers can be installed under the arches instead of support footings. In the case of using close support sets, dynamometers can also be built-in between the floor arch and the rock mass. A series dynamometer allows for the measurement of support loadings on its perimeter (Fig. 4).

The evaluation of forces acting on standing support arch yokes can be also made with appropriate actuators (Prusek et al., 2011). In order to determine the value of a support loading, pressure cushions or tensometers can also be applied, though to a significantly lesser degree (Dolinar et al., 2009). Paradoxically, their low popularity results from their higher technical advancement making them less resistant to damage in coal-mine conditions (Majcherczyk et al., 2007).

Instrumented bolts most often consist of tensometers installed in selected points of steel bars, which allows for the determination of the value of a rockbolt loading at different points. Apart from the value of forces, it is also possible to measure the value of bending moments owing to the installation of two pairs of tensometers in each point. Depending on the sensor type applied in instrumented bolts, the measurement can be taken automatically, though usually it is made manually.

Measurement of convergence indicating visual changes at cross sections of underground headings are the last but not least element of the monitoring (Majcherczyk et al., 2006), (Majcherczyk et al., 2007), (Majcherczyk et al., 2008), (Duży, 2009), (Prusek, 2008). The test can be carried out with the use of bench-marks installed in the rock mass, usually in the roof, walls or floor. Convergence measurement can also be realized in the stabilized points in steel frames, but then the total rate of strata displacement around the analyzed heading is not taken under consideration. In such a case, only relative change of heading profile is described. Convergence measurements are often complemented with the change of yoke positions between roof and wall arches (steel frame sliding).

3. SELECTED APPLICATIONS OF SUPPORT REINFORCEMENT IN UNDERGROUND HEADINGS AND THEIR STABILITY EVALUATION

As it was pointed out in the introduction, there are a plentitude of possible systems of stand-and-roof-bolting support. The following section presents results of monitoring carried out in three selected underground roadways with varied systems of support, located in different mining and geological conditions. Various types of measurement devices were used in order to evaluate the stability of standing supports with anchored roof bars, reinforced with roof bolting between arches, reinforced with strand bolts between steel frames and reinforced with support beams anchored with strand bolts.

3.1. THE TYPICAL SUPPORT OF POLISH DEVELOPMENT WORKINGS

The base and typical support of developments in polish hard coal mines is a steel yielding support. The polish symbol of it is ŁP, which means "yielding arch". The number after the support abbreviation means the arch size (a width and a height) and the next symbol – the size of the arch section. For example symbol ŁP9/V29 means the steel yielding support with the height of 3.5 m, width 5.0 m and a V-section arch, which weight is 29 kg per 1 m of length. The only profile used in polish coal mines is a V-section profile (Fig. 5). The dimensions of V29 are: K = 150.5 ± 1 mm,

N = 116.5 ± 0.5 mm, D = 16 ± 0.6 mm, H = 124 ± 1 mm. The sizes of shearer loaders and conveyors electric drives require ŁP8 – ŁP12 support, it means with the width 4.7 ÷ 6.1 m, the height 3.3 ÷ 4.225 m. Regarding high overburden loads mining engineers in Poland prefer V-sections no 29 or 32. There are sections 25 and 36 used also at the mines, but rather rarely. The all technical data one can find on the website (www.hutalab.com.pl).

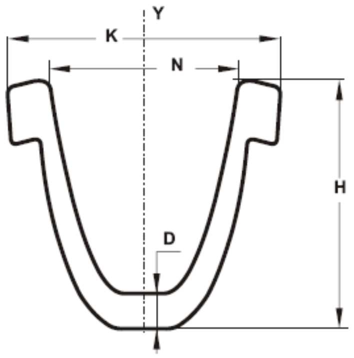

Fig. 5 Profile type V of steel arch support.

3.2. STANDING SUPPORT REINFORCED WITH ROOF BARS

The measurements were carried out in the inclined drift Izn in the seam 358/1 at the depth of approx. 900 m. The coal seam height was in the range of 2.3-2.9 m with the inclination of up to 6^0. The direct roof of the working consisted of claystone and mudstone, above which sandstone occurred. Locally, sandstone also appeared in the direct roof. The compressive strength of the rock mass was set by the penetrometer. This gauge allows to evaluate the strength of rocks directly in the boreholes, even 10 m long (Nierobisz, 2010). The average penetrometric compressive strength amounted to 46 MPa. The floor in the analyzed area consisted of claystone and mudstone. The working was not influenced by any exploitation pressures and faults; the distance to the nearest parallel working was approx. 50 m.

The analyzed section of the inclined drift Izn was 250 meters long. The primary research objective was to estimate the potential influence of support spacings on the working's stability (Majcherczyk et al., 2006). Therefore, two support systems were applied:

- System I: ŁP9/V29-type support with frame spacing of 1.2 m reinforced with two pairs of rockbolts with the total length of 2.5 m (Fig. 6);
- System II: the same support type with frame spacing increased to 1.5 m.

The system of measurement stations is presented in Figure 7.

The analysis of average values of height change in time for particular sections of the working with frame spacing of 1.2 m (Fig. 8) indicates that in the first period of measurements (i.e. up to the 159th day) systematic vertical convergence of the working occurred (up to the value of –52 mm). After this period, a slight increase in the oscillating range -50 mm ÷ -70 mm was observed. A significantly larger decrease of height was observed in the working's section with support system II (Fig. 8). In this case, the height decreased systematically during the period of 11 months (i.e. by -81 mm in total). Later, at the end of measure, a modest increase of height by 80 mm was recorded.

Differences in the horizontal convergence of the working can also be observed and analyzed in relation to the applied support type (Fig. 9). In the section with System I, the width practically decreased regularly

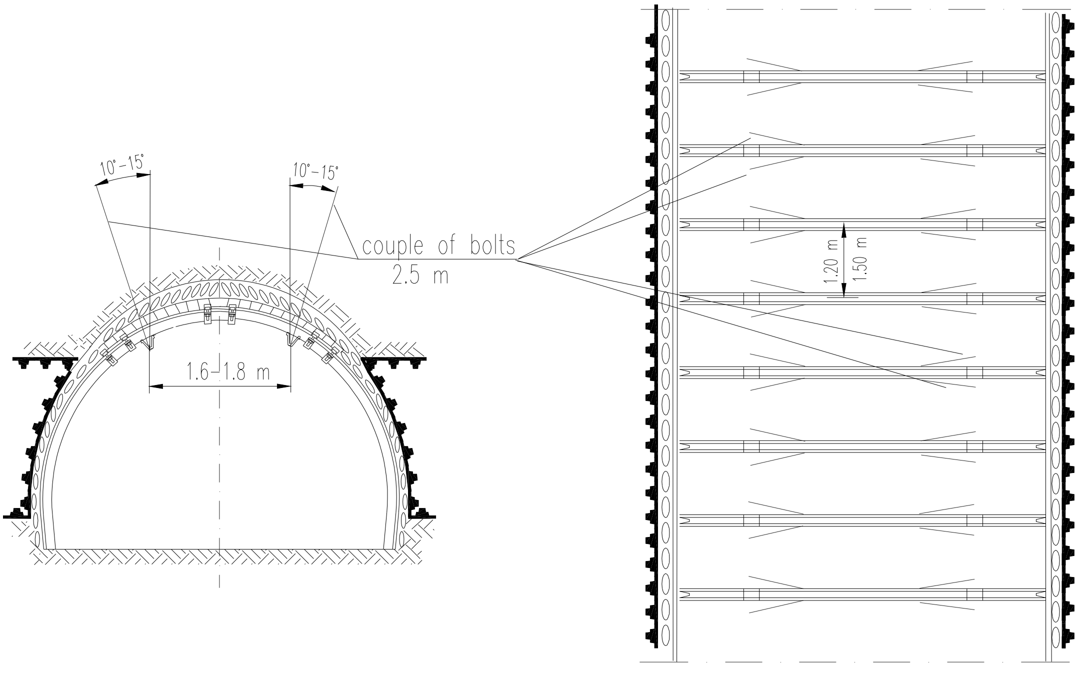

Fig. 6 Support system in the drift Izn (seam 358/1).

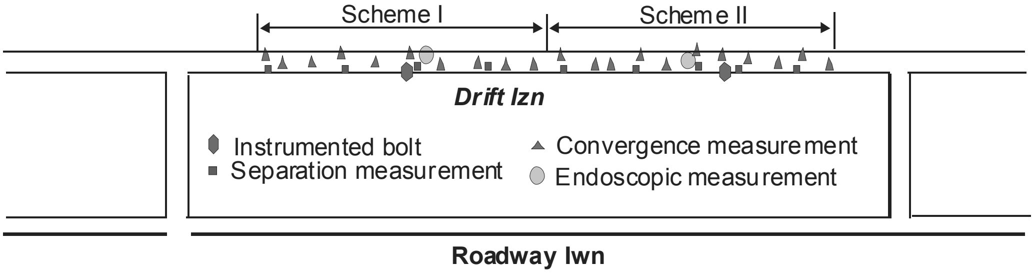

Fig. 7 Distribution of measurement stations in the inclined drift Izn (seam 358/1).

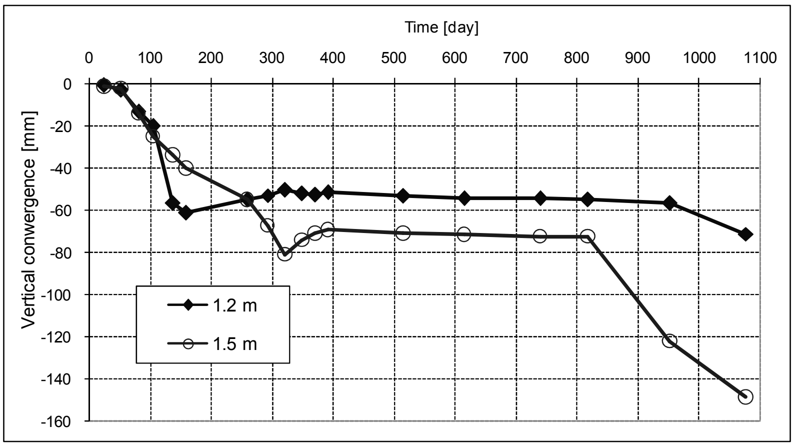

Fig. 8 Vertical convergence in time.

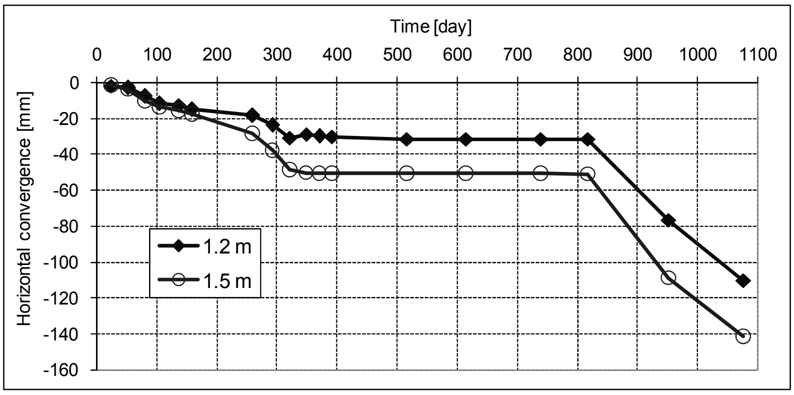

Fig. 9 Horizontal convergence in time.

reaching the maximum value of -31 mm. The same character of changes was observed in the measurement section with System II, but the maximum value was more significant in this case and reached as much as -51 mm. Both diagrams presented below indicate some stabilization of horizontal dislocations.

Endoscopic measurements carried out in the inclined drift Izn for the borehole located in the working section with 1.2-meter-spacing of steel frames indicate that the range of fractured zone between the initial and the final measurement changed only insignificantly from 0.45 m to 0.90 m (Fig. 10). The number of fractures also increased unimportantly (i.e. from 4 to 7) over a period of about a year and the total separation amounted to 18 mm. In the section with steel frame spacing of 1.5 m separation the rate was more significant and in the final phase of measurements reached 41 mm with the range of fractured zone of 4.4 m (Fig. 11).

Steel rib bolts anchoring the roof arches to the strata constituted crucial elements of the analyzed support system. The test results presented in Figures 12 and 13 clearly indicate the increased rockbolt loading in the section with the changing of steel framing to 1.5 m. In this case, however, roof bolting works in its nominal range (i.e. approx. 70÷80 % of its bearing capacity). A rather insignificant rockbolt loading in the section with a frame spacing of 1.2 m suggests a load transfer mainly by support frames.

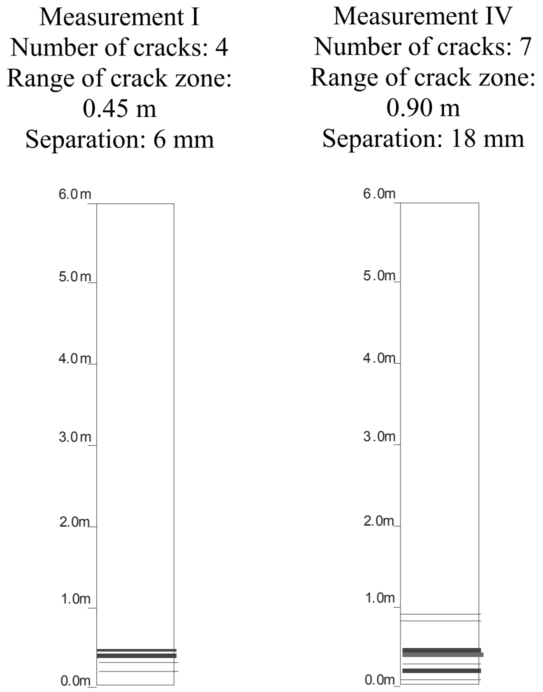

Fig. 10 Endoscopic observations - support with frame spacing of 1.2 m.

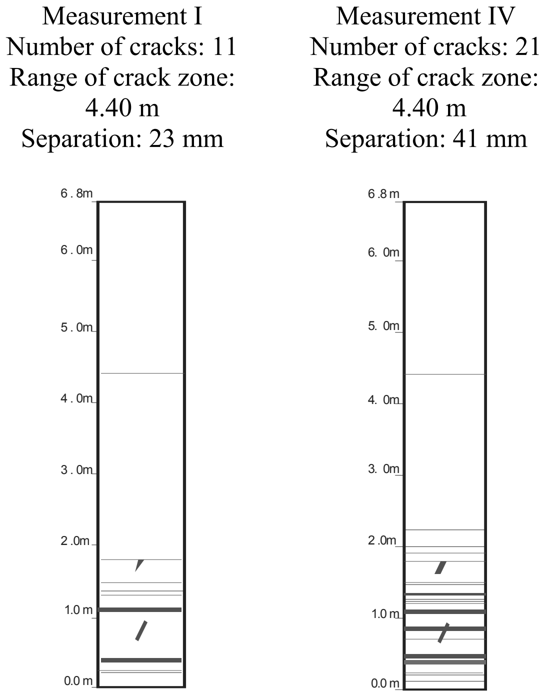

Fig. 11 Endoscopic observations - support with frame spacing of 1.5 m.

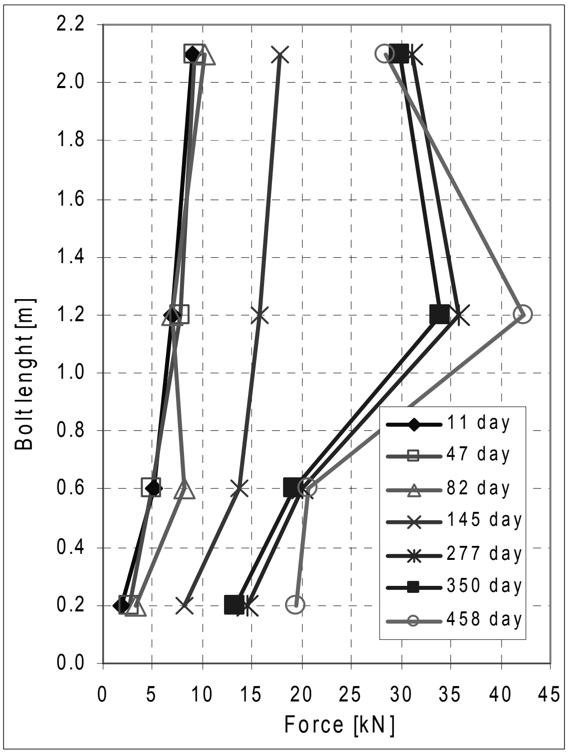

Fig. 12 Axial forces in the rockbolt located in the section with frame spacing of 1.2 m.

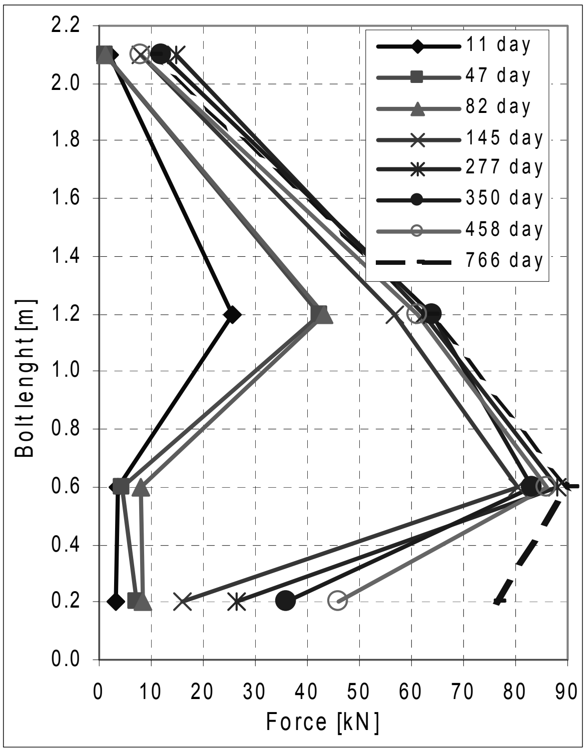

Fig. 13 Axial forces in the rockbolt located in the section with frame spacing of 1.5 m.

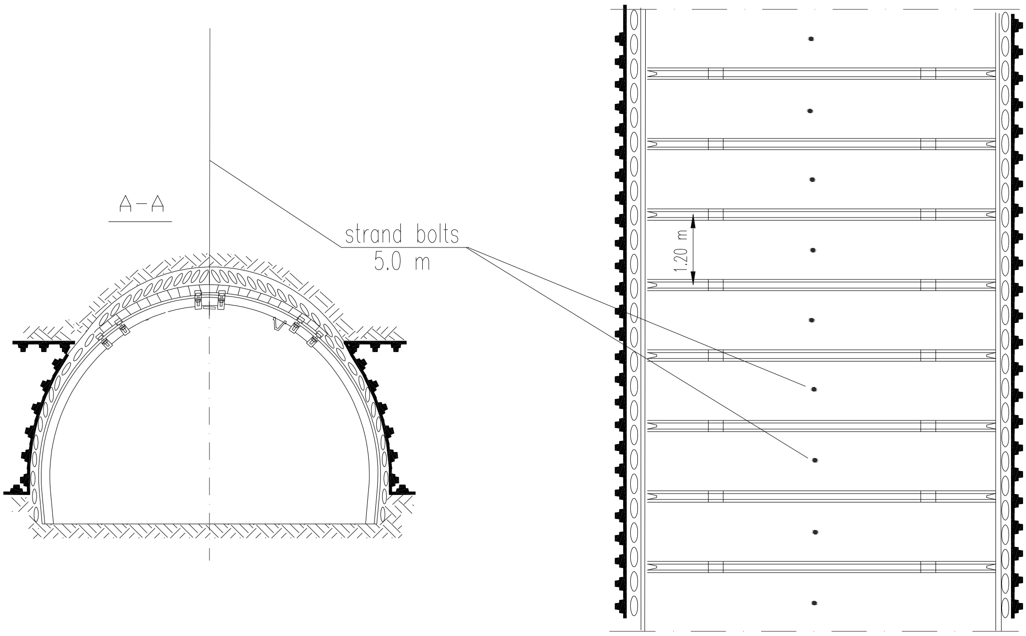

Fig. 14 Support system in the connecting roadway Z3 (seam 510/2).

In general, the measurements indicate that although an increase in frame spacing resulted in a larger convergence of the working and caused more separation in roof strata, the measured volumes, however, did not cause any disturbance in the working's functioning. Hence, in the case of high strength of rocks and the lack of exploitation pressure influence, it is possible to increase frame spacing to 1.2 m and still provide safety in workings. The research also indicates that it is possible to increase frame spacing even further to 1.5 m, but in this case the support should be additionally reinforced with roofbolts. In such a solution rockbolts act properly and fulfill their function well, which was also proven by the coal-mine research.

3.3. SUPPORT REINFORCED WITH STRAND FLEXIBLE BOLTS BETWEEN FRAMES

Coal-mine tests of standing supports reinforced with strand flexible bolts between steel frames were carried out in the connecting roadway Z-3 of the seam 510/2 łd. In the analyzed area the seam is located at a depth of approx. 900 m and its thickness ranges are 1.5÷2.8 m. The roof of the seam 510/2 łd consists of a 30-meter layer of sandstone with varied graininess and with a penetrometric compressive strength of 50÷60 MPa. In the floor there is mudstone, which in some places turns into fine-grained or medium-grained sandstone with a total thickness of above 40 meters.

In the selected section of the working in the connecting roadway Z3, the ŁP9/V36/4-type support was used with a frame spacing of 1.2 m (Majcherczyk et al. 2008 – Fig. 14). Rock mass was reinforced with one strand bolt with a total length of 5.0 m in every second frame. In the analyzed working, the measurements of convergence, separation (telltales), range of fractured zone (endoscope) and steel frame loading (dynamometers) were carried out.

Low telltales were installed in the working's roof in order to determine the changes in the immediate roof strata packet with a thickness of 3.0 m, whereas high telltales were to perform a similar role in the roof strata packet with a thickness of 6.0 m. During almost 700 days of measurements, only a minimal dislocation (separation) of roof strata towards the working was observed (i.e. reaching only 7 mm) in the roof packet with a thickness ranging between 3 and 6 m (Fig. 15).

The endoscopic observations in testing boreholes carried out with an infra-red camera confirmed the measurement results as they indicated only single fractures, which developed from a depth of 0.7 m to 1.1 m after 4 months of monitoring. The total separation in this time increased from 14 to 22 mm, which is a higher value than the one recorded with telltales. This seems to confirm the reservations expressed earlier pertaining to the differences in measurement results of the same parameter caused by the diverse research methods applied.

The results of convergence measurements corroborate a proper interaction between the support and the rock mass. The maximum values of height change and width change reached approx. 2 cm after 550 days, which seems to be an extremely low and unimportant rate in terms of providing stability of the working (Fig. 16). In the case of width change, the measurements were carried out over almost 3 years. It has shown that a width change increase to -87 mm and the slide of clamps, connected with the roof and side arches, reached a value of 34 mm. The analysis of the overall dimension changes in the connection roadway Z3 carried out during a period of almost 1500 days

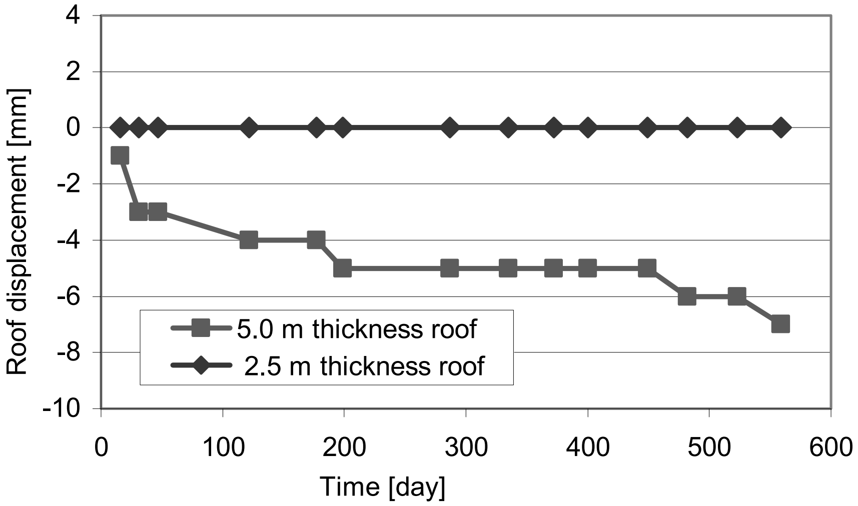

Fig. 15 Convergence in the connection roadway Z3.

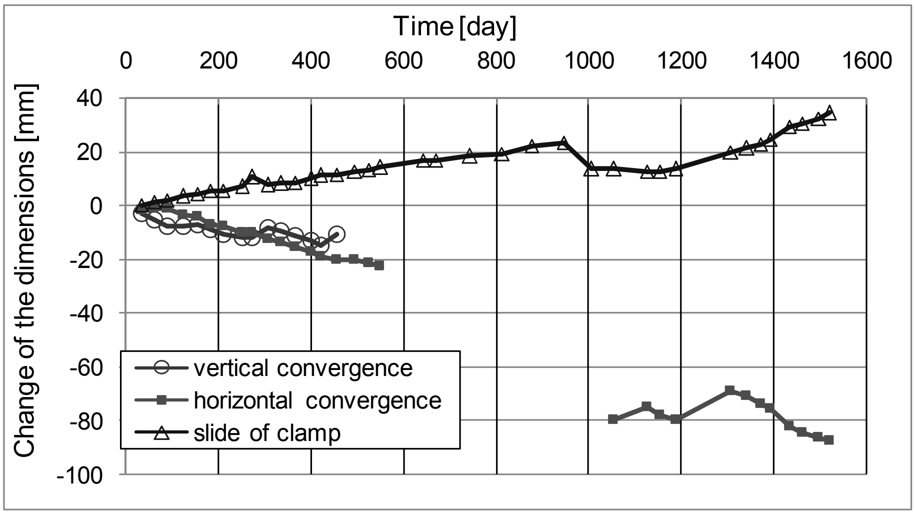

Fig. 16 Convergence in the connection roadway Z3.

indicated that the changes occurred continually. The curvature of trend between width change and time is approximate to the linear function.

The measurements thus indicate that in the case of a sandstone roof, the application of flexible strand bolts and the rarifying of steel frames do not cause any further convergence of the working. The behavior of the anchored roof is proper and the support transmits rock-mass loading completely. This observation is additionally confirmed by the measurements carried out with a series hydraulic dynamometer at the 374th running meter of the roadway.

Tests results obtained in the connecting roadway Z3 suggest that the ŁP9/V36-type support with a frame spacing of 1.2 m and with strand bolts anchored in the roof is only insignificantly loaded by roof forces. After less than two months, the force between the support and the rock mass was approx. 31 kN, and after a consecutive 18 months it raised only up to 38 kN (Fig. 17). The insignificant force decrease in the initial period of measurements might have been related to a decompression or a slight slip. With reference to bearing capacity of the applied steel frames of 0.255 MPa, it may be concluded that the recorded loading is insignificant and it is related mainly to the kind of roof strata (i.e. thick layer of sandstone) as well as to the type of applied roof reinforcement (i.e. rockbolts).

The effectiveness of the tested support was additionally confirmed by its resistance to mining tremors, as the analyzed area was located near a rock burst in the strata only 30 m above the analyzed working (Małkowski et al., 2009). The horizontal distance from the tremor epicenter was evaluated at approx. 300 m. The rock burst occurred after about 4 months from the commencement of loading measurements with the use of dynamometer and its energy increased 4×10^5 J. During the period neither an increased loading nor a step change of transversal dimensions was observed. Thus, in the analyzed case, both the favorable geological conditions (thick layer

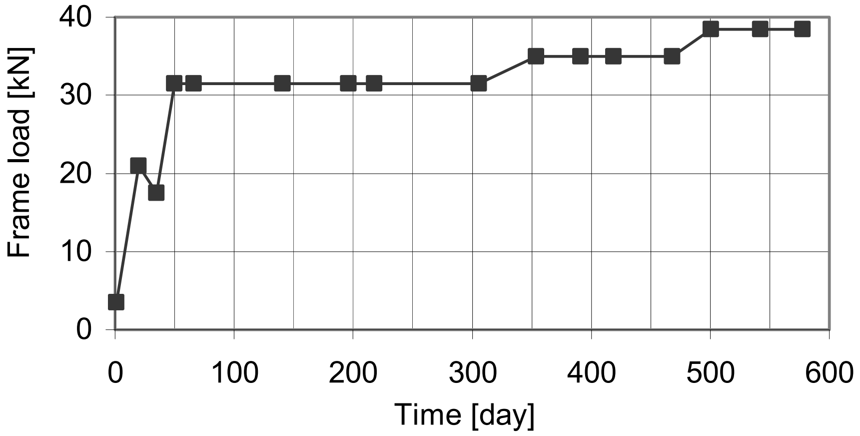

Fig. 17 Distribution of forces in series dynamometer.

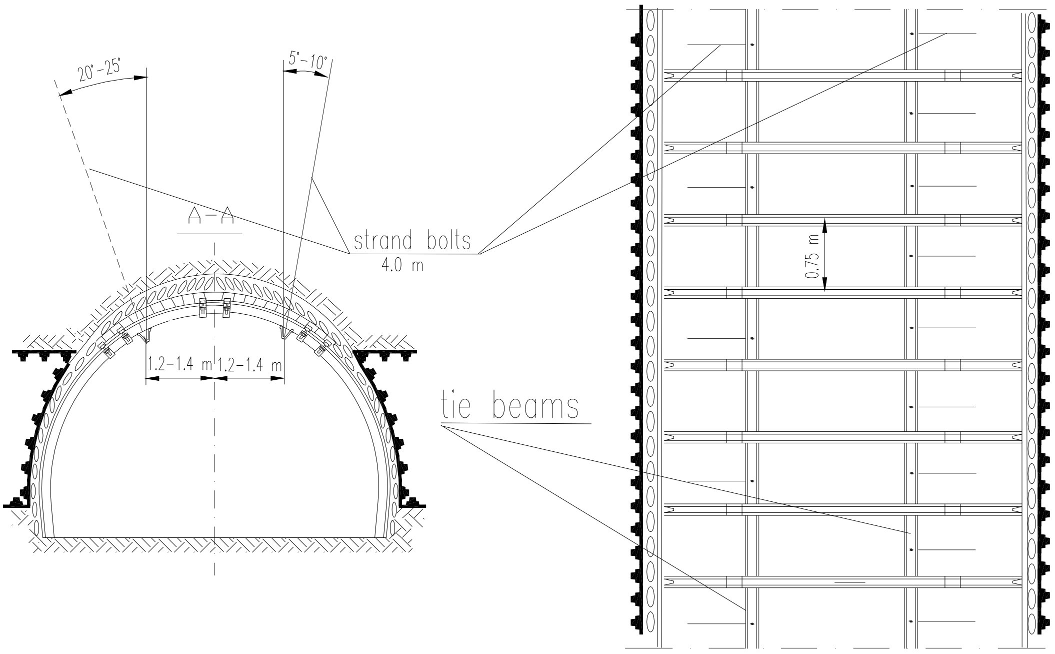

Fig. 18 Support system in the roadway B-7 (seam 403/3) in the testing section.

of sandstone) and the support reinforced with cable bolts allowed for complete stability of the working despite additional seismic-induced loading.

3.4. STEEL YIELDING SUPPORT REINFORCED WITH STRAND FLEXIBLE BOLTS BY MEANS OF TIE BEAMS

Research on the behavior of standing supports reinforced with strand flexible bolts by means of tie beams was carried out in the roadway B-7 in the seam 403/3. The analyzed working was located at a depth of approx. 800 m. The thickness of the seam 403/3 in the discussed area ranged between 1.42 m and 1.81 m. The inclination of the deposit was insignificant and maximally reached 5^0 in northbound direction.

Mainly claystone occurred above the seam 403/3 in part ‘B’. In the test section roof there was sandstone with the thickness of up to 10.9 m with penetrometric compressive strength of 60 MPa, above which claystone occurred. At a distance of approx. 17÷19 m, the seam 403/1 was located (the distance, however, locally decreased to 12 m). The floor consisted also of claystones with a thickness of approx. 1.25 m, below which mudstones occurred with a thickness ranging between 2.0-2.2 m. Next, a layer of sandstone occurred with a thickness of approx 4.5 m. Further on, claystones and mudstones appeared. Above the testing section there were exploitation edges of longwall panels at a distance of 19 m, 35 m, 80 m and 120 m respectively.

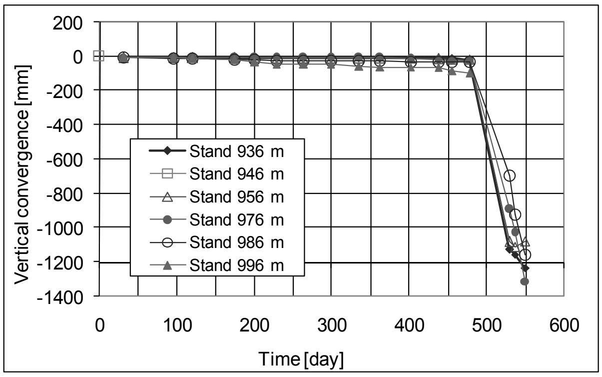

Fig. 19 Vertical convergence in the roadway B-7.

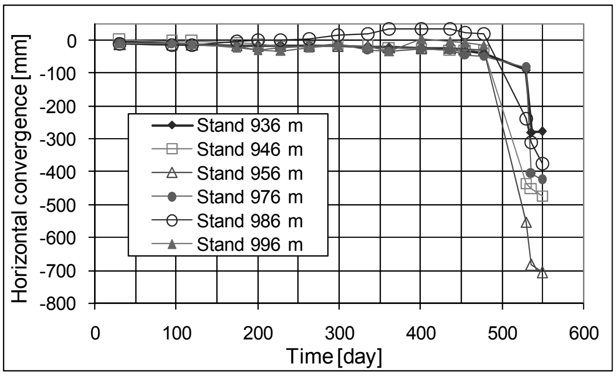

Fig. 20 Horizontal convergence in the roadway B-7.

The analyzed roadway was a longwall, subject to the influence of an active exploitation face during the period of research (Majcherczyk et al., 2008). The ŁP9/V29-type steel frames with a spacing of 0.75 m were applied. The support was reinforced with two rows of V25-type steel tie beams anchored to the roof by means of strand bolts with the total length of 4.0 m (Fig. 18). The following tests were carried out in the roadway B-7: endoscopic observations of the fractured zone range and penetrometric measurements, measurements of convergence with the use of extensometric probes, measurements of convergence and rockbolt loading by means of the Istrumented bolt.

Convergence measurements indicated that the values were insignificant and did not exceed several centimeters until the influence of the working face was revealed (Figs. 19 and 20). The only passage of the face resulted in step vertical convergence reaching 1.3 m and horizontal convergence reaching 0.7 m. Although the obtained values of convergence were significant, it was possible to re-use the roadway for the neighboring longwall panel.

Figure 21 presents measurement results of roof strata dislocations. The tests were carried out when the extensometric probe was approx. 170 m away from the longwall face. The analysis indicated that the application of anchored tie beams caused the roof to initially move towards the working while later it was subject to compression. Only close above the working (approx. to 0.5 m) regular roof strata separation occurred (dislocation towards the working). Maximum values of dislocations reached approx. +80 mm and –20 mm. From the perspective of working stability, values of dislocation ranging from 2-8 cm in the roof are not problematic in providing stability of the working. It could be also observed that the longwall face, which had been 170 m ahead of the measurement station, did not generate any changes in rock mass in the area of test section. Such results were additionally confirmed by endoscopic research, which indicated that fracture occurred up to the height of 1.4 m from the roof after 18 months.

In order to estimate the values of forces acting on the bolts, the additional measurements of roof strata loading were carried out with the use of an instrumented bolt (Fig. 22). The measurements indicated that the bolt's compression occurred only in the initial section (0.05 m – black solid rhombs) after about 3 months. The phenomenon might have been a result of leaning of rock strata on the support and the occurrence of compression forces of -200 kN. In the remaining part of bolt's length there appeared tension, but the maximum values (i.e. 143 kN and 157 kN) were recorded at the levels of 0.49 m and 1.81 m respectively. In the remaining sections of the instrumented bolt, the values of tension forces did not exceed 22 kN. The diagram shows that a roof reinforced with strand flexible bolts is subject to some separation, whereas the bolts can be locally subjected to a relatively strong loading with both compression and tension forces. Hence, the analyzed system of stand-and-roof-bolting support can successfully provide roadway stability as it offers an active work of rockbolts used.

4. CONCLUSIONS

Stability monitoring of selected headings with reinforced steel frames allows for the formulation of the following practical conclusions:

1. Additionally reinforced steel yielding support proves its usefulness in various mining and geological conditions. In particular, the system should be adjusted to the roof conditions, whereas the potential influence of exploitation on a working should be calculated into the support design.
2. In the case of high strength parameters of rock mass and lack of influence from serious mining factors (e.g. the influence of goafs or the influence of the running longwall face), a standard frame spacing of the support (i.e. 0.75÷1.0 m) can be increased up to 1.5 m. Obviously, in such a case it is absolutely necessary to properly reinforce the rock mass with rockbolts. In the analyzed case, the effective use of rockbolts' capacity at the level of 70-80 %

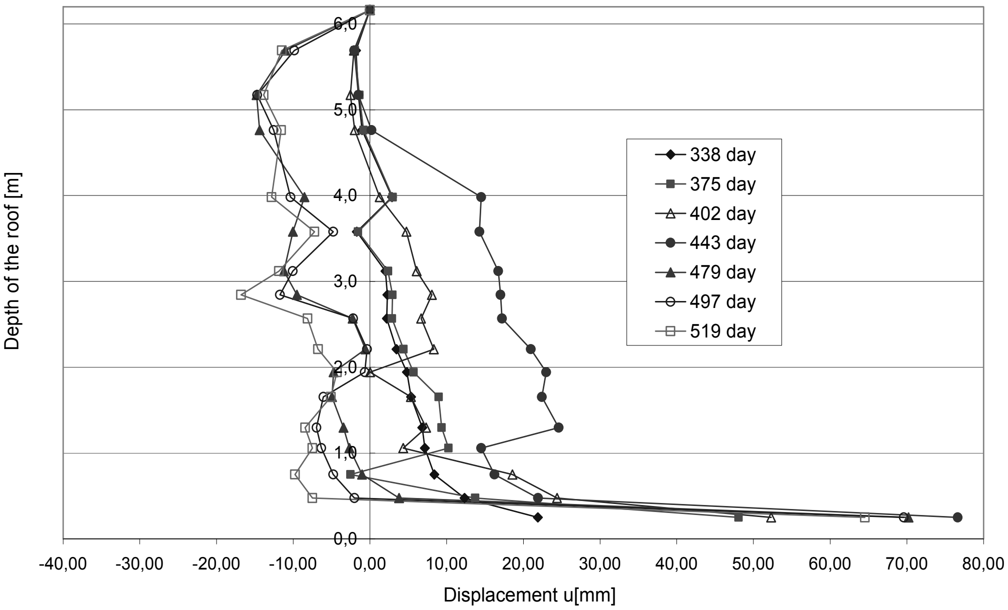

Fig. 21 Roof strata dislocation in the roadway B-7.

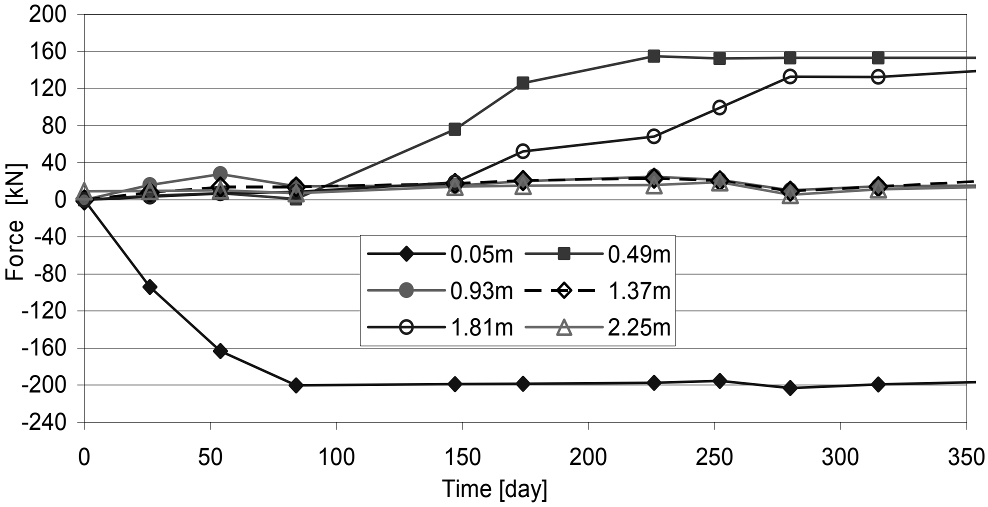

Fig. 22 Rockbolt loading in the roadway B-7.

performs when the spacing of yielding support is 1.5 m.

3. As the research shows, the application of long strand flexible bolts is also effective in seismic hazard conditions owing mainly to their bearing capacity exceeding 400 kN and large deformation resistance. The expertise gathered during the research indicates that rockbolts with their potential to absorb elastic strain energy in certain ranges can successfully counteract roof separation. The measurements carried out as part of the present research did not reveal any changes in the analyzed working after the occurrence of a rock burst in the surrounding rock mass.
4. In favorable roof conditions in a gateroad (σ_c of roof > 60 MPa), the applied reinforcement of steel yielding support by means of two tie beams anchored with strand flexible bolts can provide suitable working stability. Until exploitation influence was revealed, a working convergence and range of the fractured zone around the roadway were insignificant, whereas large dislocations and loading of support occurred only with the approach of the mining face. Such technology of support reinforcement, however, allows for the re-use of the gateroad for the next longwall panel.

It should be also pointed out that long-term coal-mine research illustrates the evolution in the range of applied rockbolts. During the last two decades, there have been spectacular changes in the types and lengths of implemented rockbolts. Initially, bar bolts with the length of approx. 2.0 m and bearing capacity ranging 120÷200 kN were used. Then, cable bolts appeared with the length of approx. 6.0 m. Currently, longer strand flexible bolts are applied in order to reinforce the workings in mines: their usual length ranges between 6 and 10 m but sometimes reaches up to 12÷15 m, with a bearing capacity of more than 420 kN. On the one hand, such a rate of progress was enforced by the increasing dimensions of workings and the appearance of larger influences acting on rock mass. On the other hand, the development was made possible by the implementation of more advanced technologies and innovative materials in bolting.

The instances of monitoring the stability of roadways discussed in this paper suggest that coal-mine tests allow the researchers to make a precise evaluation of the behavior of rock mass surrounding the working and particular elements of its support. The measurements of similar parameters with the use of varied methods (e.g. estimating roof strata separation with endoscope and extensometric probes) often produce completely different results. For instance, dislocations of the roof strata recorded with extensometric probes do not always refer to rock separation, which has been proven by endoscopic observations in testing boreholes. The values obtained in monitoring are strictly related to the properties of rocks and the type of applied support system. In the case of high strength parameters, no changes in the working occur that could be determined with a method based on visual analysis. Leading to precise measurements, allowing the researchers to record even tiny changes in rock mass can optimize the design and application of support systems and, if necessary, provide additional reinforcement.

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