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NUMERICAL ESTIMATION OF EFFECTIVENESS OF FAULT ZONES PROTECTION IN LONGWALL

1. Introduction

The occurrence of a geological dislocation, and faulting in particular, has always caused serious difficulty in mining. On the other hand, expectations of production growth as well as work safety during simultaneous and reasonable deposit management, have made the mining industry look for methods to cross fault zones on longwall excavations. At present, crossing a fault of a throw lower than the height of a wall with a longwall, does not cause any serious problems. The faults of a throw larger than the height of a wall and their unidentified faults prior to exploitation can still cause serious problems in order to run the walls correctly, in order to achieve the planned rate of production. Problems connected with the issue of maintaining headings and run exploitation in more and more difficult mining-geological conditions, impose the necessity of useing more effective protective methods.

In the present article, the possibilities of making use of roof bolting and injection agents to protect fault zones during exploitation heading are presented, on the grounds of numerical analysis. Such methods are a very interesting alternative to conventional methods used to protect side walls and roof-rock in tectonic disturbance regions.

2. Fault zones — characteristics

Fault zones are tectonic disturbance zones which formed as result of rock mass destruction and its dislocation along the surface or cutting down zone, which causes a disturbance in the deposition of the strata geometry. Such faults which are a loosening or cracked zone, which does not accumulate high stresses [7]. Whereas the neighboring fault zone is characterized by heightened strength parameters. This results from the compaction and porosity of

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rocks in this zone, and thus an increase in their strength features. Occurrence of faults indicates the presence of tectonic stresses in given areas. Fault zones are also the source of water outflow and gas migration.

3. Exploitation in fault zone areas

When crossing the fault zone with a longwall, constraints and appropriate adjustment of exploitation technology are necessary. It is important, as far as possible, to determine the parameters of the fault just before the start of exploitation. It is then, possible to adjust the direction of the exploitation and place the working face accordingly to the run, slope and throw of fault. Geological conditions of the bed and the surrounding rocks should be taken into consideration, including all zones of structural weakening, such as cleavage or rock cleavage. While crossing fault zones with an exploitation heading, some preparations should be made early enough to direct the wall in such a way that the remaining coal staff is in close contact with the underlayer, and the least amount is left in the near-by-superstratum. When leaving the near-by-superstratum of the coal staff, the fall of the roof undergoes crushing, and increases the risk of endogenous fire in the abandoned workings. Some actions should also be taken to minimize the possibility of roof rock stripping in the mining zone, as this can consequently lead to a technological standstill connected with work to protect the breach in the floor. The decrease in wall advance increases the probability in the development of the coal self-heating process in the fall of the roof in the abandoned workings ventilation zone.

An exploitation carried out next to a fault results in the occurrence of high stresses, which, in headings and exploitation headings is manifested by a significant pressure growth on the lining, roof rock strippings and side wall drift. An exploitation next to, or crossing fault zones constrains the use of additional reinforcements and technological protections for both, roof-rocks as well as for side walls. Such actions lead to a 'down-time' of the wall run. A lack of proper protection may result in roof rock strippings and a technological standstill connected with it. The decrease or stoppage of the development of the exploitation frontage is conductive to accumulation of stresses and their drift towards exploitation edge. Such a stoppage repeatedly causes loss of roof and side wall stability, and causes problems in order to keep crossings with close-by-wall headings, particularly in situations of necessity which keep them directly close to abandoned workings. In such conditions, near-by-wall headings, show a significant increase in pressure on the lining and in such cases floor heave can be observed, which necessitates using additional strengthening. The accumulation of stresses also increases the risk of abrupt geodynamic events, which are a real danger for a team working in a given area. The decrease in wall advance leads to the growth of the coal self-heating process caused as a result of long periods of air migration through the abandoned working zone.

Problems connected with the issue of running exploitations in difficult mining and geological conditions impose the necessity for improving agents and techniques for the immediate strengthening and sealing of the rock mass and using effective preventive methods in relation to natural hazards.

4. Methods of rock mass strengthening in fault zones

An exploitation close to a fault zone or crossing one causes constrains in the usage of additional strengthening and technological protection of the floor and side walls. Protective and strengthening actions undertaken should be adjusted to the range of disturbances occurring. Many methods used to protect floor and side walls have been elaborated in the Polish mining industry. Generally rock mass strengthening can be divided into two groups. The first group comprises of conventional methods of floor and side wall protection in exploitation headings in a run in a tectonic disturbance zone. In this group, it should be mentioned: in the event of considerable throw of a fault and range, sufficient protection will decrease the roof opening by means of pushing a mechanized lining section closer to the side wall directly behind mining heading machine. In the event of a roof rock fall off or loosening of side the wall, preliminary roof protection is carried out by means of building wooden roof-bars perpendicular to the side wall, and making an astel. Alternatively, wooden stretcher bars are used, which are spread between the lining section and side wall. When a loosening of a side wall occurs at a considerable depth, forward piloting with steel bars is used. When the roof fall off reaches a considerable depth, the building of wooden or steel roof-bars is used. When a loosening of the side wall reaches more than 1meter and a roof rock fall off occurs, ahead steel roof-bars are built out of roof-bar section. Additionally, an astel can be used. In the event of a side wall loosening at a considerable depth, building wooden or steel props spread between the floor and the roof-bar is additionally used. Additional protection in the fall off zone can be made by introducing rails min S24 or straight connections V into the pockets made in the side wall. After introducing rails S24 or straight connections into the pockets, their tips at the side of the wall should be gradually underpinned with roof-bars from the mechanized lining section.

When conventional methods are insufficient, or the occurrence of difficult roof conditions are predicted, in order to protect against roof rock fall off and side wall loosening, it is advisable to roof--bolt the weakening zones by means of bolts and chemical agents permissible for use in mining plants. In the event of problems with side wall stability, strengthening by means of mineable bolts can be used. Linking roof bolting with the injection of properly chosen chemical agents produces very good results. In this group of methods of roof and side wall protection, the following can be listed:
1) Side wall bolting with the use of mineable bars,
2) Bolting with self-drilling bars,
3) Bolting with self-drilling and mineable bars,
4) Protection of cavities after roof rock fall off in walls,
5) Rock mass strengthening by means of the injection of chemical agents method.

5. Numerical analysis of fault zones protection in wall headings

5.1. Introduction

Numerical calculations were carried out in order to determine the effectiveness of roof rock strengthening by means of roof bolting and the injection of chemical agents, while

crossing the fault zone with an exploitation heading. For this purpose, numerical simulations were conducted with the use of the Finite-Difference Method FLAC. Calculations were done in flat state of strain (FLAC 2D), as well as by means of three-dimensional models (FLAC 3D). Numerical simulation was conducted for conditions similar to real situations, which have occurred in coal mines.

5.2. Geological-mining conditions in a wall and the use of fault zone strengthening

The wall analysed was the second exploitation heading run in the analysed bed. The planned length of the longwall reached 1320 m, and the width 310 m. In the field under consideration, the exploitation carried out with the longwall system on one layer with a fall of roof was used, in a variation reaching the cross-bar at the height of 3,5–4,0 m. In the roof of the longwall, due to safety conditions, the coal layer of a thickness of up to 0.4 m was left, whereas in the floor of the longwall it was up to 0.3 m. One year after, commencement the longwall drove into the fault zone with the throw of fault approx. $h = 0.7$–$2,8$ m (Fig. 1) and as a result of a significant deterioration in geological-mining conditions was stopped. During the 8 month period, the longwall made 6% of the planned advance, which was due to the frequent standstills caused by the occurrence of roof rock fall and loosening of roof rock, as well as by time-consuming technological protection.
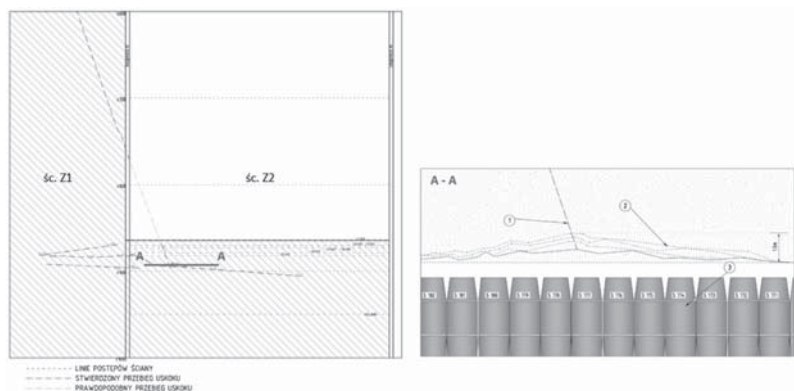

Fig. 1. Faults in the area of analyzed wall

On the grounds of observations made during mining and, in particular, while drilling holes in the side wall in the dislocated zone, it was found out that within the range of depth from 0.5 m to 1.5 m, cracks of rock mass (inconsiderable voids of the size of a few centimeters) occur.

Because of the significant range of rock mass destruction in the fault zone and the local decrease in rock strength in the area of the exploitation heading, the use of conventional protection methods showed to the exceptionally low in effectiveness. Moreover, they were

extremely time-consuming. Because of the frontal advance, an accumulation in rock mass pressure occurred on the edge of exploitation heading, which was caused by additionally (opening) knocking out the side wall to accommodate depths (up to 3.0 m).

To improve the mechanical characteristics of the rock mass in the section under research, it was designed to take injections of polyurethane resins and a bolting of the consolidated zone by means of self-drilling bolts built of injection rods with a bolting-gluing effect. On the grounds of the strength parameters of the roof rock and side wall in the dislocated zone, bolts with a diameter of R25 were chosen, which have characteristics are presented in table 1. The determined range of the crack zone reached 3.5 m, therefore, the length of the bolt chosen was 5.0 m, which guarantee the fastening of weak rocks into a strong layer.

TABLE 1
Parameters of the bolt

Technical data	unit	R25
Outside diameter	mm	25
Minimal diameter of rod hole	mm	14
Cross-section field	mm^2	290
Ripping load	kN	200
Load of plastic strain	kN	150
Calculation ability	kN	100
Strength limit R_m	MPa	690
Plasticity limit R_e	MPa	520
Mass	kg/m	2.3

Taking into consideration the geometry of the dislocation, divisibility and mechanical properties of the rocks and the parameters of the bolts, the appointed mine project team chose their lay-out in a horizontal row located in the side wall, at a distance of about 0.2 m under the roof, with a spacing of 0.75 m. The bolts were drilled perpendicular to the side wall, at an angle of about 30° inclination upwards in relation to the horizontal plane. Because of the limited possibilities for using pneumatic to drill holes, in the wall, for enabling the use of bolts, hydraulic drills were used by means of drilling rods and diamond with a tipped bit with drilling fluid. Then, the bolts were inserted.

The choice of injection agents was made according to their physical-mechanical parameters and the conditions occurring in the region under research. The basic parameters were: time of injection set, strength after bounding, foaming index and the influence of hydro-geological conditions. While choosing the kind of polyurethane glue for fastening the bolts and the consolidation of the cracked zone, the project team accepted the pessimistic assumption that a cracked rock mass zone might reach beyond the designed length of the bolts. The expected reaction time for the glue agents should be chosen in such a way that its penetration range in the rock mass should be larger than 0.5 m. To minimize possible losses of the glue

used resulting from possible effluents in the cracked zone, its bounding time should not exceed 60 sec. The expansion of the injection in the rock mass should be chosen in such a way that after its grouting in the zones of voids, slackness and fissures, further delamination should be eliminated. Finally, glue of the following parameters was used:
— reaction starting period: approx. 40 sec,
— reaction end approx. 85 sec,
— foaming approx. 2.5 times,
— compression strength approx. 60 < [MPa] [1],
— bending strength approx. 55 < [MPa] [1].

Taking into consideration the foaming of the chosen glue (volume growth during bond reaction) and the degree of degradation in the rock medium, a maximum strength 12 kg/glue for 1 running meter of the bolt was accepted, which means 60 kg glue for 5.0 m of the bolt.

5.3. The choice of a theoretical model for the analysis of different alternative designs to protect the wall front in fault zones

The modelling of the geo-mechanical phenomena in the fault is an issue of high complexity. It is caused, among others, by an occurrence of materials of different mechanical properties as well as by a complicated mechanism in the cooperation between the lining and the rock mass [2, 3]. Therefore, just at the very beginning of the simulation calculations, it is very important to choose a proper model of the rock medium. In the analysis under research for the numerical modelling, three constitutive models were used [4–6]:
— Elastic model was used for modeling the fall of roof zones in the three-dimensional model. In this model the increas in strain generates an increase in the stresses in accordance with the linear and invertible Hooke's law:

$$\Delta\sigma_{ij} = 2G \cdot \Delta_{ij} + \alpha_2 \cdot \Delta\varepsilon_{kk} \cdot \delta_{ij} \tag{1}$$

Where a summation is done in Einstein's convention, δ_{ij} is the Kronecker delta, and α_2 is the material constant dependent on the volumetric modulus of elasticity K and form modulus G:

$$\alpha_2 = K - \frac{2}{3}G \tag{2}$$

New stresses are received from the dependence:

$$\sigma_{ij}^N = \sigma_{ij} + \Delta\sigma_{ij} \tag{3}$$

— The elastic-plastic model by Coulomb-Mohr (Mohr-Coulomb model) was used for modeling the majority of the rock layers. It is the most popular model used in numerical

calculations of elastic-plastic problems referring to geo-engineering and geo-mechanics. The popularity of this model results from, among others, clearly defined and relatively easy to determine strength parameters, or their indirect determination.

— The elastic-plastic model Coulomb-Mohr with discontinuity planes (Ubiquitous model) was used for modeling the coal superstratum and carbonaceous shale, and also the cracked side wall layers. It enabled consideration to be given to the cracks and planes of the weakening of particular medium, which were and are still being observed in the area of faults. This model assumes that an occurrence of the planes of weakening in Coulomb-Mohr model. The destruction criterion of the planes of weakening, in which the orientation is strictly determined, is based on the Coulomb-Mohr criterion. In numerical implementation, at first, general destruction is detected and then the appropriate plastic corrections are taken into consideration. Next new stresses are analysed in relation to destruction on the planes of weakening.

5.4. Numerical calculations for the estimation of the effectiveness of the designed protection of fault zone

The calculations were done by means of using a two-dimensional model, with the assumption of the Plane State of Strain (FLAC 2D v.6.0), and also the three-dimensional (FLAC 3D) [4–6], making use of the differences in the calculation possibilities of the tools used for the analysis of the different alternatives for the strengthening of fault zones.

5.4.1. The results of numerical calculations (2D)

The calculation model of the dimension 300×130 m was comprised of horizontally surged geological layers (Fig. 2) the mechanical properties of which are presented in table 2. In the layer of *sandstone_01a* there is a rectangular opening with the dimensions of 6×4 m. In the roof of the opening there is a zone of weakening of horizontal deposition, modeled with a Ubiquitous medium (Table 3). The remaining layers are described using the Coulomb-Mohr model. On the left side of the heading, a heap zone was modeled of significantly lowered values of deformational parameters (Table 4).

In the first calculation step boundary conditions were assumed in the form of zero horizontal dislocations on the side edges of the model, and zero vertical dislocations on the bottom edge of the model. To the upper edge of the model, vertical stress with a value of 12.45 was applied, resulting from pressure coming from the overlay layers. Simultaneously, a prime state of stress in the form of $\sigma_{xx} = \sigma_{yy} = 0.5 \cdot \sigma_{zz}$ was assigned for the particular layers. Such a prepared model was solved (owing to defined stresses in the rock mass), the convergence was already obtained in the second step of the calculations.

In the next step, the fall of a roof zone with a 12 m thickness was introduced and the model was solved again. Up to this stage, the occurrence of the vertical stress concentration was indentified in the neighboring undisturbed soil, which reaches a value of approx. 36 MPa,
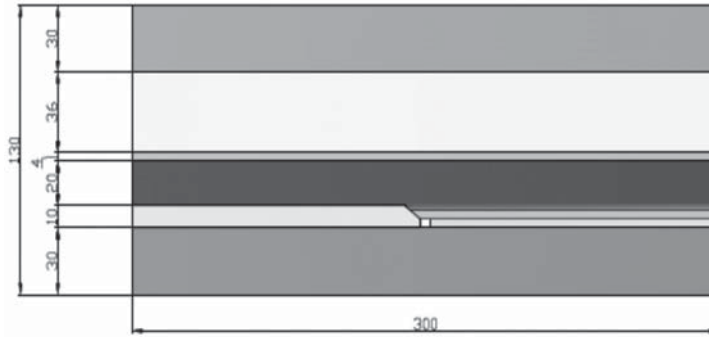
Fig. 2. Geological structure of the model

TABLE 2

The parameters of Coulomb-Mohr model

Geotechnical layers		Thickness of the layer	Density	E modulus	G modulus	Angle of internal friction	Cohesion	Tensile strength
		[m]	[kg/m³]	[GPa]	[GPa]	[°]	[kPa]	[kPa]
sandstone_01		30	2 300	8.390	3.846	35.7	513.5	250
sandstone_01a		4	2 300	2.500	1.154	36.9	177.7	75
coal_01		4	1 300	1.667	0.769	35.7	411	200
mudstone_02		2	2 500	0.833	0.385	36.3	440.4	200
sandstone_02		20	2 300	2.500	1.154	36.9	177.7	75
coal_02		4	1 300	1.667	0.769	35.7	411.05	200
Sandstone _03		36	2 300	4.167	1.923	36.9	177.7	75
overlay		30	2 500	4.167	1.923	30.3	656.5	500

TABLE 3

The parameters of Ubiquitous model

Geotechnical layers		Thickness of the layer	Angle of internal friction	Cohesion	Tensile strength
		[m]	[°]	[kPa]	[kPa]
mudstone_02		2	25	20	20
coal_02		4	25	40	20

TABLE 4

The parameters of elastic model for fall of roof zone

Geotechnical layers		Volume of layer	Thickness	E modulus	G modulus
		[m]	[kg/m³]	[GPa]	[GPa]
Fall of roof zone		12	2200	0.266	0.100

which constitutes approx. 240% of the value of the prime vertical stress. Although this stage does not show any real situation of exploitation, it is a good starting point for the next stage of the calculations, because of the preliminary elastic recovery of the rock mass behind the mechanized lining.

In the next step, a situation for making an opening with the dimensions of 6×4 m was modeled. This stage was divided into three alternatives which are marked: w3a, w3b and w3c. In w3a alternative, a situation without using the protection of the fault zone was modeled. In w3b alternative, strengthening of the roof-rock was taken into consideration by means of two rows of roof bolting and its properties are presented in table 5. In the next w3c alternative, strengthening of the rock by means of using an injection agent in the neighboring area of the bolt was taken into consideration. The range of strengthening is of a cylindrical shape with a radius of $r = 1.5$ m. The injected area was modeled with the Coulomb-Mohr agent of the following parameters: friction 36.9°, cohesion 178 kPa, tensile strength 75 kPa.

TABLE 5
The characteristics of roof bolting

Angle of inclination of injection bolts	α	30°
Bolt spacing	d	1 m
Length of bolts	l	5 m
Location concerning the fault	β	0°
Number of bolts in area of cross-cut of wall front with edge of fall	n	2
Outside diameter of bolt	d_z	38 mm
Cross-sectional area	A	8.506 cm²
Young's modulus	E	200 GPa
Poisson's ratio	v	0.25
Plasticity force	F	400 kPa
Polar moment of inertia	J	$1.919 \cdot 10^{-7}$ m²
Second moment of area of bolt in relation to axis y	I_y	$9.596 \cdot 10^{-8}$ m²
Second moment of area of bolt in relation to axis z	I_z	$9.596 \cdot 10^{-8}$ m²
Normal stiffness on contact	k_n	20 MPa/m
Shear stiffness on contact	k_s	20 MPa/m

Comparing pictures 3, 4 and 5 it can be clearly seen that smaller displacements occur for the alternative with bolting (w3b) than with the alternative without bolting (w3a). For the model without the protection of the fault zone, the displacement reaches 55 cm (Fig. 3), in the event of using strengthening by means of roof bolting, the displacements reach 36 cm (Fig 4). A much higher dicrease in the value of the displacements occurs with the assumption of an injected strengthened zone (Fig. 5). Maximum displacements for the alternative reach below 31 cm.
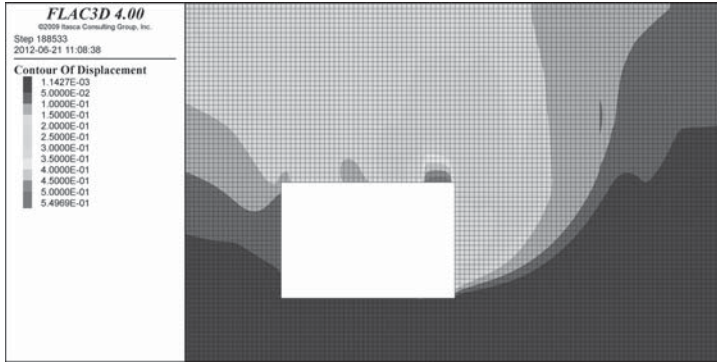
Fig. 3. The map of the contour displacements around the opening outline for alternative w3a, maximum dislocations reach 55 cm
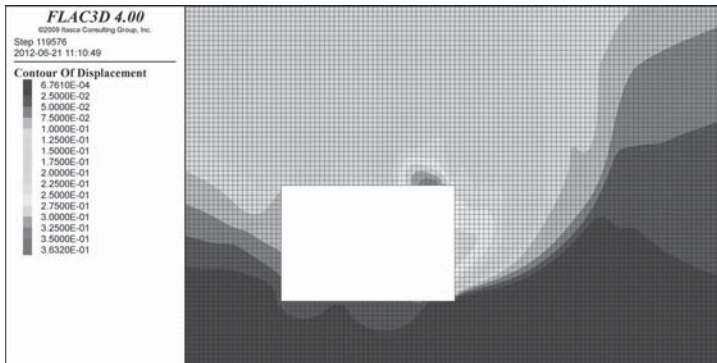

Fig. 4. The map of the contour of displacement around the opening for alternative w3b, maximum displacements reach 36 cm
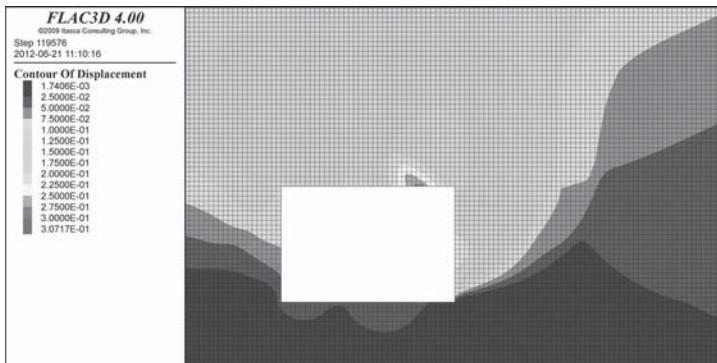

Fig. 5. The map of displacements around the opening for alternative w3c, maximum displacements reach 31 cm

Comparing pictures 3, 4 and 5 it can be clearly seen that smaller displacements occur for the alternative with bolting (w3b) than with the alternative without bolting (w3a). For the model without the protection of the fault zone, the displacement reaches 55 cm (Fig.

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5.4.2. The results of three-dimensional calculations (3D)

Three-dimensional calculations were done in order to determine the forces acting on the bolts at the moment of leaving the section of lining. This manoeuvre requires leaving a section, which causes the roof of the opening not to be protected. In such a case, due to the three-dimensional character of the problem, it cannot be modeled in two-dimensional calculations.

For modeling the problem mentioned above, a three-dimensional model was constructed with dimensions of $300 \times 130 \times 30$ m consisting of a horizontal deposition of strata (Fig. 6) with mechanical values presented in table 2. In the layer of sandstone_01a there is a rectangular opening with dimensions of 6×4 m. In the roof of the opening there is a weakness zone of horizontal deposition modeled with a Ubiquitous medium (Table 3). The remaining layers are described by means of a Coulomb-Mohr model. On the left side of the opening, the fall of the roof zone was modeled with significantly decreased values of deformational parameters (Table 4).

The analysis was done by means of the FLAC 3D v.4.0 program, based on the Finite--Difference Method with an assumption of Two-Dimensional State of Strain. A mesh was added to the model under discussion, which was gradually thickened in such a way that the thickest zone occurred in the area surrounding the front of the longwall (Fig. 6). The total number of elements in 3D model amounted to1 346 760.
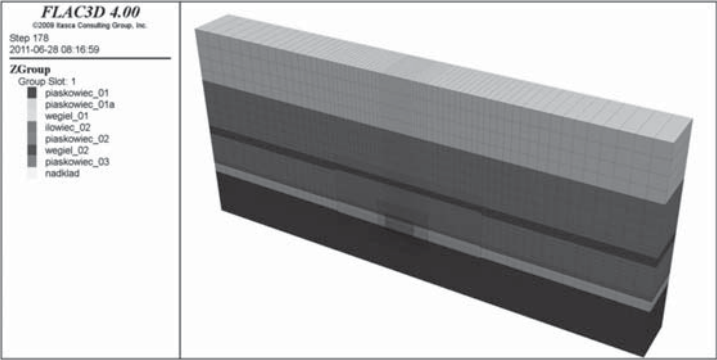

Fig. 6. Geometry of the model

In the first step of the calculations, edge conditions were assumed in the form of zero horizontal displacements on the side edges of the model and zero horizontal displacements on the bottom edge of the model. To the top edge of the model, vertical stress was applied to the

value of 12.45 MPa presenting pressure coming from the layers of overlay. Simultaneously, the prime state of stress was attributed to particular layers in the form of $\sigma_{xx} = \sigma_{yy} = 0.5 \cdot \sigma_{zz}$.

In the next step, the fall of the roof with a thickness of 12 m was introduced into the model and the model was solved again. Then, the opening was modeled with dimensions 6×4 m and the lining of the elements of a type of *shell* was introduced and the model was solved again.

In the next step of the calculations, the bolts were assumed in the form of structural elements of a *pile* type, and then one section of the lining with a width of 1.5 m was removed. This stage complies with such a situation when the lining movement to the wall of the opening occurs. Analysing the values of axial forces in the bolts after doing that calculation step, it was found out that there is a significant influence around the removed lining section on the values of the forces in the bolts — in the central part of the model, in the place where the lining was removed, the values of the forces reach more than 40 kN (Fig. 7). Therefore, a conclusion can be made that installing bolts to the parameters assumed in the model, protects the roof of the opening at the moment of leaving the section in a significant way in order to its displacement.
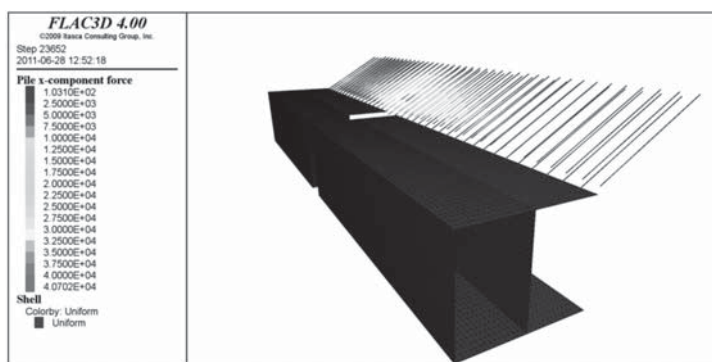

Fig. 7. Axial forces in the bolts after leaving the section of the lining

5.4.3. Analysis and making the detailed conclusions resulting from the calculations

The numerical calculations were carried out with the aim of estimating the effectiveness of the designed strengthening of the fault zone occurring in the area of an opening. To achieve that numerical calculations simulation were made by means of the Finite-Difference Method FLAC 2D v.6.0 and FLAC 3D v.4.0.

The calculations done by means of the two-dimensional models showed the significant influence of bolting in the area of cracked rock mass on the stability of the roof in the longwall. The analysis of the axial forces in the bolts shows the significant values of the tensile forces in the bolts, and their good interaction with the rock mass. Comparing the displacements shown in figures 3, 4 and 5, a significant decrease in vertical displacement together

with the use of the bolts is seen, and give consideration to the injection bonding the rock mass. The influence of the injection is quite significant, and it confirms the effectiveness and the principle of using such solutions in real conditions. Based on this it information can be concluded that the choice of an injection agent with a significant strength and also a good adherence to the rock material, significantly influences improvements in the conditions of roof stability. In the two-dimensional calculations, the bolts were assembled right after making the opening, therefore significant axial forces occur. Actually, the forces will be less due to the fact that assembly of the bolts is done with a certain delay.

The aim of calculations carried out with the use of three-dimensional models were to show the influence of bolting on the roof protection in the fault area while leaving the lining section aiming at its displacement towards the wall of the exploitation heading. In figure 7 axial forces were presented after leaving a single lining section. The influence of leaving the lining on the values of the forces, which reach more than 40 kN, is clearly seen. Because of the way the modeling was carried out, these forces should be recognized more as a force increase in the bolting resulting from leaving the section, than the total forces occurring in it. When leaving out consecutive segments of the lining, part of the forces will sum up and lead to significantly higher values of tensile forces in the bolts.

The numerical calculations carried out confirm the effectiveness of the designed strengthening of the fault zone by means of bolting. There is also clear influence caused by the compaction of deformed rocks while applying injections of chemical agents. The effectiveness is also seen in a sore situation, which occurs at the moment of moving the mechanised lining towards the wall of the longwall. This manoeuvre forces the lowering of the lining, and in such a situation the roof is left without protection. The situation was analysed as a three--dimensional problem. The significant growth of the shearing forces was show in the event of leaving the section of the mechanized lining.

6. Summary

Running the exploitation headings in an area of tectonic dislocations forces the appropriate adjustment of the exploitation technology, as well as undertaking preventive actions based on strengthening and giving protection against the front of the longwall. These actions aim to provide for the continuity of the mining and work safety. In particular, they have to be the protection against:
— the possibility of the rock sidle of roof rocks in the mining zone,
— the possibility of knocking out the side wall,
— leaving the layer of disintegrated coal in abandoned workings.

In the protection used, two groups of methods can be distinguished. The first one is the protection of the fault zones and side wall rocks by means of conventional methods. In this group of methods, among others, an astel with pillar halves or wooden stretcher bars spread between the lining section and the side wall was used. In more difficult conditions, for protection of the roof by piloting with steel bars is used, or by building roof-bars, etc. The second

group consists of methods that give consideration to the use of bolting and injection agents. Matching the bolting with the injection of appropriately chosen chemical agents brings very good effects. This group of methods becomes an alternative to conventional methods, in particular, in difficult geological-mining conditions. In the real example presented the use of appropriately chosen bolting matched with the injection of chemical agents allowed for crossing the fault area with the exploitation heading.

On the grounds of the numerical calculations presented for conditions close to those occurring in wall 2 in the mine X, the effectiveness of solutions used were tested. The influence of the use of bolting and chemical agents is particularly clear as seen on the grounds of the analyses of the displacements for the three alternatives of the calculations without strengthening (Fig. 3), with the use of bolts (Fig. 4) and with the use of injection agents (Fig. 5). In the three-dimensional simulations carried out, the role of bolting was presented in order to keep the stability of the roof while moving a section of mechanized lining (Fig. 7). The numerical calculations were carried out to confirm the effectiveness of the strengthening of roof rocks by means of bolting. There is very clear and visible influence in the compaction of deformed rocks when injections of chemical agents are carried out. The applied bolting enables maintaining the stability of rocks in the fault zone while moving the mechanized lining towards the side wall of the wall heading.

It can be stated that in the series of numerical calculations carried out bolting together with the injection of chemical agents, particularly in difficult conditions, can be an effective alternative to conventional methods for the protection of fault zones.

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