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Difficulties observed in operating powered roof support during work in lower range of its working height

Significant maintenance difficulties have recently been observed in terms of the proper maintenance of mining roofs during the operation of powered roof supports in their low section height range, which is characterized by a wide working range. These difficulties were also encountered in situations where the calculated load capacity index of the roof "g" reached favorable values. These phenomena occurred most often during extraction under gobs and when maintaining a protective roof carbon shelf of the required thickness. This paper presents the calculations and analyses aimed at clarifying and discussing these events.

Key words: *powered roof support, bearing capacity, forces, evaluation*

1. INTRODUCTION

Introduced for use in previous years, powered roof supports were equipped with legs of large diameters, enabling the development of significant forces due to the conditions of the designed extraction. The aim is to obtain wide ranges in the working span of the sections, as the mining companies want to apply universal roof supports that can be used in seams with different thicknesses. As a result, the created systems are characterized by larger sizes and load-bearing capacity levels than those used so far; therefore, they have led to problems and issues that have not been observed before. Increasing the size of a powered roof support results in the larger dimensions of an excavation, causes a greater load from the rock mass, and generates greater forces in the construction nodes. Consequently, it is essential to ensure the appropriate strength parameters of the roof support and good design of its kinematics, which in turn should ensure its correct cooperation with the rock mass, guaranteeing the fulfillment of the requirements arising from the geological and mining conditions of future areas of extraction.

This article presents the results of the calculations and analyses of the two types of powered roof support construction heights ranging from 2.4 to 4.6 m and internal diameters of the first stage legs reaching 320 mm (hereinafter referred to as OBUD-1 and OBUD-2, which are used in the Mysłowice-Wesoła Coal Mine in the floor layer of Seam 510 in Longwall 124 under the upper layer of the gobs). On the length of this longwall and on the part of the run (where the height of extraction was significantly reduced), there were difficulties in maintaining the roof and the correction of the position of the canopies, which was required due to the difficulty of parallelism with the floor bases. The two leg shields tended to set up with raised canopies in almost one line with legs. The results of the model calculations, drawings, and diagrams presented here are an attempt to find the reason for these events.

2. DESCRIPTION OF LONGWALL 124

Longwall 124 was carried in the floor layer of the 510 seam south of the Morga Fault and east of the Brzęczkowice Fault. After selecting the top layer, the remaining thickness of Seam 510 in this region ranged from about 3.0 m to 6.5 m. The seam was located at a depth of about 645–700 m, with an inclination of about 6° towards the southwest.

In the roof of Longwall 124 were gobs of the 510 seam's roof layers formed from sandstone layers, conglomerates, clay shales, and sandy slates. Seam 510 was located a distance of about 20–30 m above it. The floor was formed from a layer of shale.

Prior to the mining of the top layer of the seam, the roof had a compressive strength that ranged between 32–52 MPa, coal about 22 MPa, while the floor was about 31 MPa. The carried-out calculation of the gobs substitute strength conducted according to the GIG method developed as a result of the PROSAFECOAL 2007–2010 project [1] determined their value at slightly above 9 MPa, which is the average level of reconsolidation in the adopted classification (already close to weak <8 MPa) [2].

In the area of Longwall 124 (up to 160 m above the floor layers of Seam 510), the roof layer of the seam was extracted directly above Longwall 124 and Seam 405/2 located at a distance of 170 m. The seams located under the 510 seam have not been extracted yet.

The extraction of Longwall 124 was based on cave mining in the bilateral surroundings of the coal (in the floor layer) of up to 4.5 m, leaving a carbon shelf in the longwall. Its task was to isolate the gobs from the working space and provide a roof load index of $g \geq 0.8$. For this purpose, the minimum thickness was calculated, which should range between 0.6–1.0 m depending on the longwall run-out section and support type (five types of supports were used in the longwall).

At the first stage of the mining process, the longwall was 130 m long (which was increased to 225 m after about 325 m), and its run reached about 640 m.

On some supports of the runway, the height of the longwall was significantly reduced in relation to the maximum possible (4.5 m) due to the variable carbon layer remaining to be selected, the carbon thickness of the floor layer, and the need to leave a protective carbon shelf. At longwall heights lower than about 3.4 m, the shields were aligned with the raised canopy, and there were significant difficulties in correcting its position in order to ensure the correct geometry; i.e., to obtain parallelism between the canopies and the floor bases. Numerous damages were observed referring to the legs of the support cylinders and section shifters, which resulted in difficulties in maintaining the longwall and the need to replace the damaged elements. A broader description can be found in [3].

3. SELECTED GEOMETRY MODELS OF SECTIONS IN LONGWALL 124

On the basis of the ongoing observation and local vision carried out at the end of the longwall, characteristic cases of the geometry form of the OBUD-1 and OBUD-2 supports were determined on the sections of occurrence of difficulties during the liquidation.

It was found that, for each type of support, two cases of geometry models should be tested and analyzed for frequent heights in the front of the longwall (about 3.0 m and 3.5 m). The geometric dimensions of the support indicated that, in order to obtain the underground effect of the almost linear arrangement of the caving shield and the canopy, the lemniscate bars of OBUD-1 and OBUD-2 must be located at the same height (2.4 m and 2.7 m, respectively, with a horizontal canopy), while the inclination angles should reach about 8° and 12° [4].

The identification of the layout of the support was based on the method and software for the geometry analysis and distribution of the forces in the two leg shield nodes used in the Department of Extraction Technologies and Mining Support of the Central Mining Institute [5]. Four models of geometry for the variants described above are shown in Figures 1–4. The results of the force calculations for these models were compared with the model where the support canopy and base are in horizontal position and the working height is 4.5 m (Figs. 5 and 6).

Figures 1–6 present the subsurface representing a schematic distribution of the surface pressures during rock mass pressure impacting on the roof support and for the assumed coefficient of the friction between steel and rock of $\mu = 0.3$.

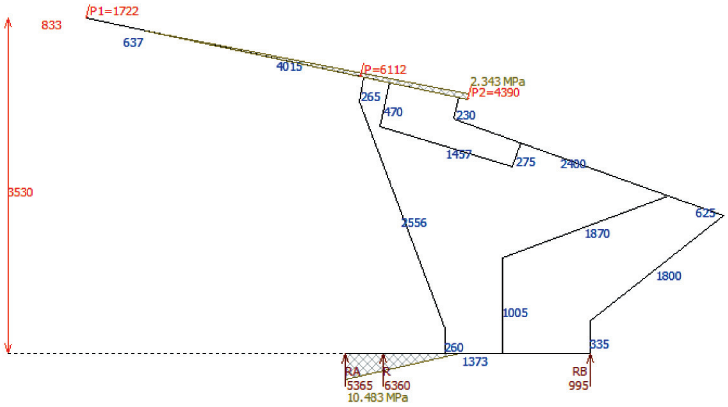

Fig. 1. Model 1 – OBUD-1, excavation height about 3.5 m, canopy raised at angle of 12°

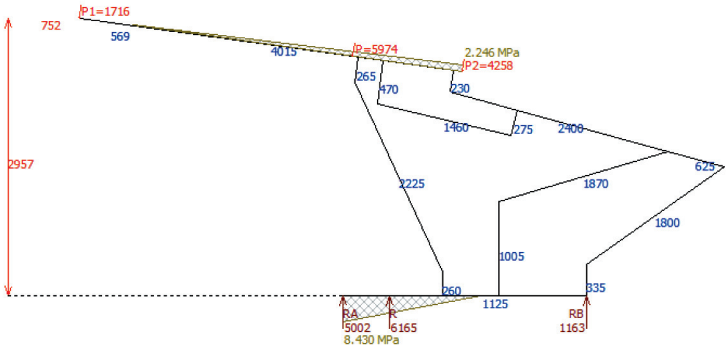

Fig. 2. Model 2 – OBUD-1, excavation height about 3.0 m, canopy raised at angle of 8°

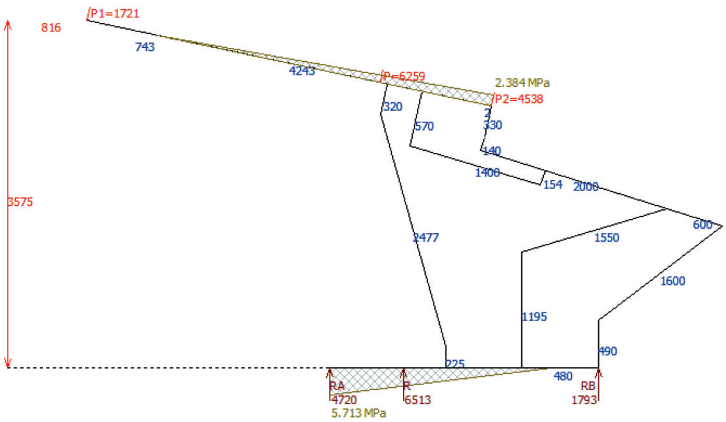

Fig. 3. Model 3 – OBUD-2, excavation height about 3.5 m, canopy raised at angle of 12°

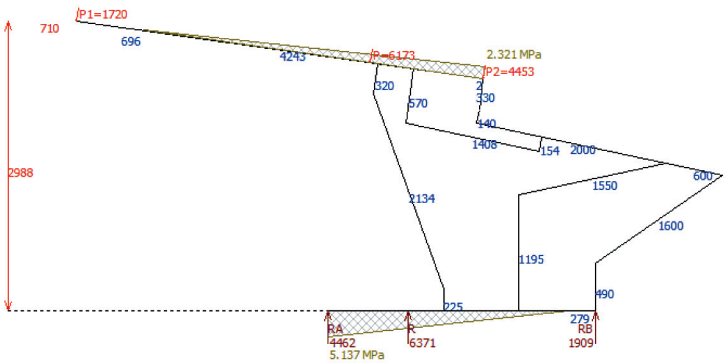

Fig. 4. Model 4 – OBUD-2, excavation height about 3.0 m, canopy raised at angle of 8°

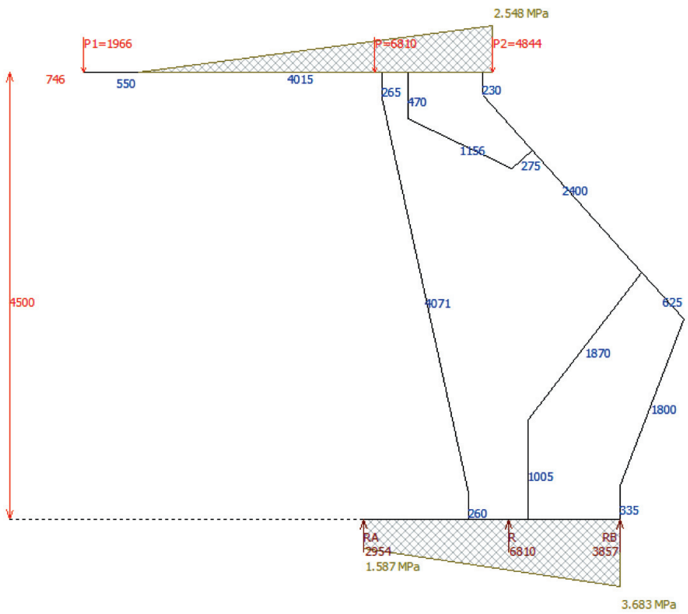

Fig. 5. Model 5 – OBUD-1, excavation height 4.5 m, horizontal canopy (angle 0°)

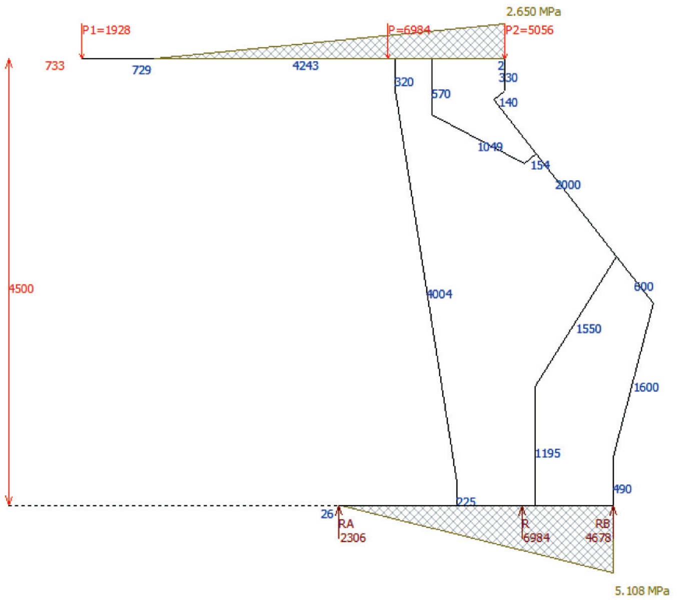

Fig. 6. Model 6 – OBUD-2, excavation height 4.5 m, horizontal canopy (angle 0°)

4. ANALYTICAL CALCULATION OF FORCE IN NODES OF SUPPORT WITH DIFFERENT LOAD OF CAVING SHIELD AND INCLINATION OF CANOPY

4.1. Section load at low working heights

The research team decided to include a simulation of the possibility of different load values impacting the caving shields in the calculations due to the caving debris that laid on the shields. The following variants of the load generated by the rock mass and impacting on OBUD-1 and OBUD-2 have been considered, as these two types of supports are often used during the analysis of the structure or operation of the powered roof support:

- no load impacting on the caving shield;
- load of 100 kN/m^2 – this value of the caving shield load was assumed in German mining and resulted from the stabilization condition of the joint of the canopy and caving shield [6] (this load corresponds to the weight of a 4.0 m high column), which was confirmed during the trial tests;
- point load of the caving shield with vertical force of 600 kN located in the middle of the length of the caving shield, which is used in the analyses performed by the constructors of the support.

The research team decided to compare the values of these loads with the results of other calculations; in this case, those carried out according to the method presented in [7].

Taking into account the dimensions of the OBUD-1 and OBUD-2 supports, the calculations performed showed that a load impacting on the caving shield with a relatively wide variability of approx. 300–950 kN can be expected depending on the assumed parameters, with the ratio of the load from the caving shield to the load of the canopy, while the support height decreases (depending on the conditions considered) may vary from approximately 41% to 73% for OBUD-1 and from approximately 30% to 58% for OBUD-2.

Therefore, the considered values of the loads are to a large extent comparable; nevertheless, they should be assessed with a certain approximation because the interpreted calculation scheme did not consider the loads for the inclined canopy.

4.2. Forces in structural nodes of powered roof supports

The values of the forces occurring in its structural nodes affecting the values of stresses and determining the durability of the whole structure or its specific elements fluctuate along with the change of the support's resistance.

In order to carry out the analysis of the forces in the structural nodes, a computational model was used that allowed for the calculation of the geometry and forces in the powered roof support according to the diagrams shown in Figures 7 and 8.

The computational model of a powered support developed in the Department of Extraction Technologies and Mining Support of GIG (included in the form of a computer program) allows for an analysis of its support in the function of many different parameters occurring during operation [5]. Calculations can be carried out for all types of supports used in Polish hard coal mines; i.e., backfilling or roof caving systems. The friction forces between the support and rock mass are included, which arise during the horizontal movement of the canopy on the lemniscate curve when the working height is changed. The actual conditions show that these forces should be taken into account in the static calculations carried out for the support, as they generate internal stresses in the elements and affect the stability (especially in the setting phase).

Calculations can be carried out for the parallel and inclined canopy with respect to the floor of the longwall excavation, and the direction of the external forces is perpendicular to the canopy. The dependencies are calculated as they are for rigid beams.

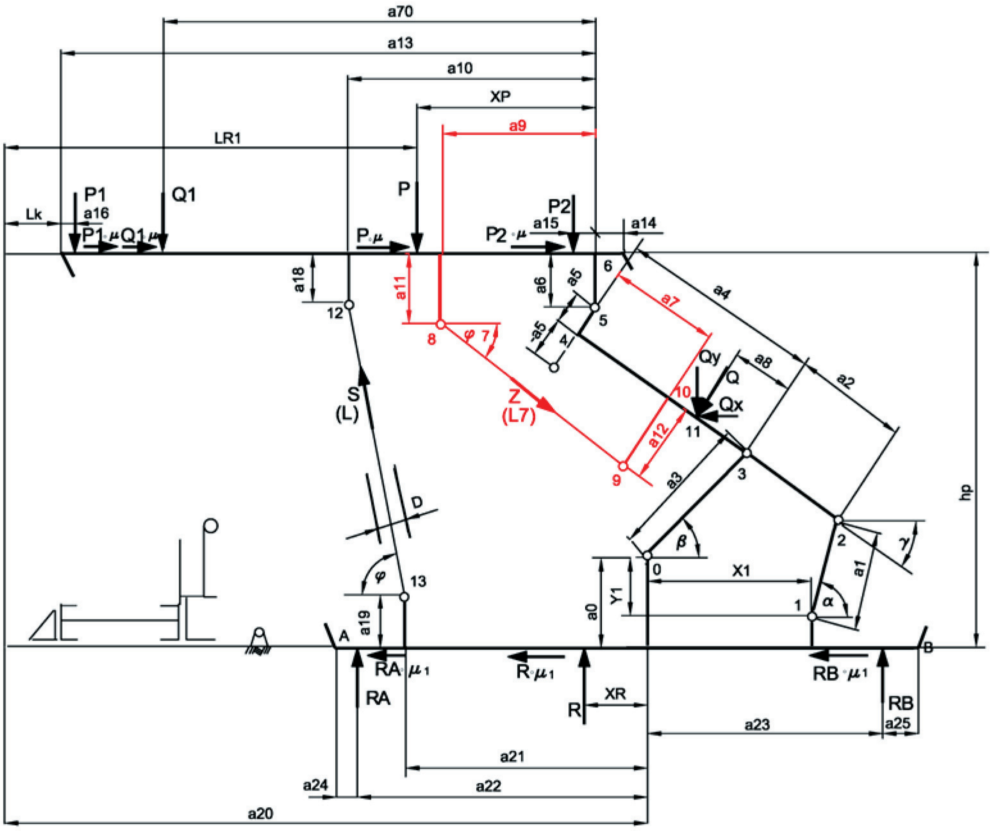

Fig. 7. Geometry scheme of powered roof support

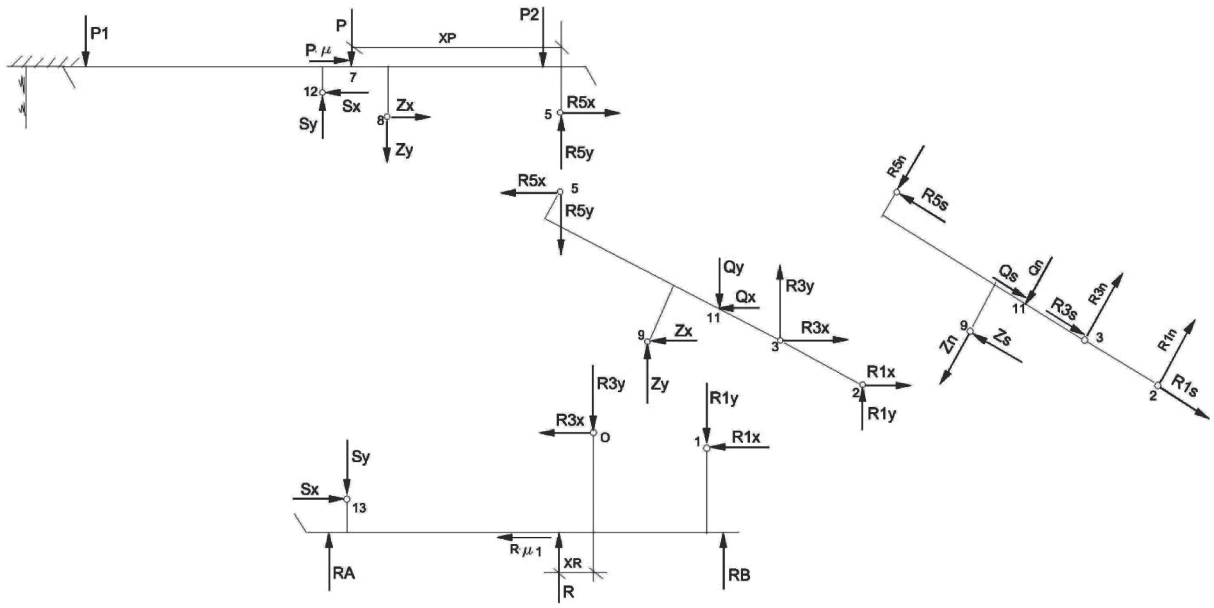

Fig. 8. Distribution of forces in nodes of powered roof support

Calculations of values can be carried out for forces:

- caused by the pressure of the rock mass impacting on the canopy (simulating the occurrence of additional external forces) and the pressure of the caving rocks on the caving shield, with the given load bearing capacity of the legs;
- occurring during the expansion of the roof support, with the initial load-bearing capacity resulting from the supply pressure of the legs, taking into account a change in the return of friction forces in this case.

The developed calculation model makes it possible to analyze the friction forces and compare them to the direction of the friction force resulting from the course of the lemniscate curve when the support's height is changed assuming the unchanged direction of the friction force when changing the height of the support.

The conclusions resulting from underground observations and the obtained geometry of the supports for the models shown in Figures 1–4 caused that particular attention was paid to the calculation of the following forces: R5x, R5y, R5n, and R5s, as the components of the R5 force. The R5 force is located at the joint between canopy and caving shield so has the decisive influence considering proper support geometry.

Calculations of the value of this force were made depending on the height of the working support for each of them and referred to these angles of the canopy: 0°, 8°, and 12° and for three load variants.

The results are presented in Tables 1 and 2 and in Figures 9 and 10.

Table 1

Values of force R5 [kN] in node of canopy's joint with caving shield for OBUD-1

Height of support (for lemniscate system) [m]	Inclination of canopy								
	0°			8°			12°		
	load of caving shield			load of caving shield			load of caving shield		
	0 kN	100 kN/m^2	600 kN	0 kN	100 kN/m^2	600 kN	0 kN	100 kN/m^2	600 kN
2.4	1276	1394	1454	1975	2046	2084	2302	2353	2381
2.7	816	944	1025	1587	1661	1708	1946	1998	2033
2.9	563	699	799	1371	1444	1499	1747	1797	1838
3.3	168	335	497	1027	1092	1167	1428	1471	1523
3.7	115	203	403	775	829	930	1194	1226	1293
4.1	332	321	449	584	625	761	1014	1038	1124
4.5	554	525	548	408	440	633	851	872	997

Table 2

Values of force R5 [kN] in node of canopy's joint with caving support for OBUD-2

Height of support (for lemniscate system) [m]	Inclination of canopy								
	0°			8°			12°		
	load of caving shield			load of caving shield			load of caving shield		
	0 kN	100 kN/m^2	600 kN	0 kN	100 kN/m^2	600 kN	0 kN	100 kN/m^2	600 kN
2.4	635	765	857	1370	1443	1503	1707	1761	1807
2.7	175	345	499	987	1067	1147	1358	1417	1476
2.9	72	216	394	776	858	955	1164	1222	1292
3.3	439	416	499	454	532	675	865	913	1007
3.7	668	639	680	244	309	520	669	700	821
4.1	816	795	810	109	151	446	544	558	707
4.5	1030	1024	932	30	30	396	424	427	643

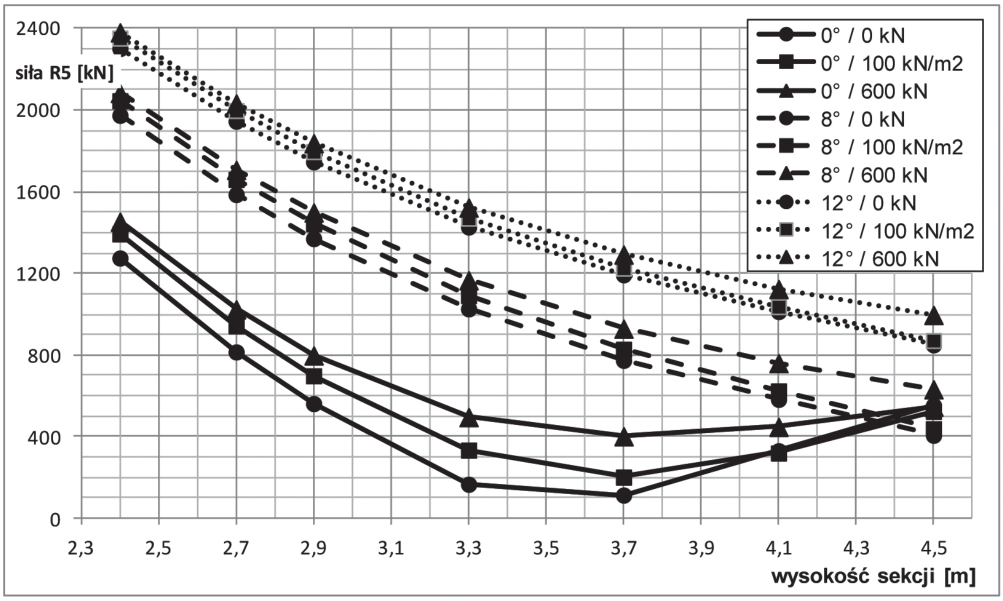

Fig. 9. Values of force R5 [kN] in node of canopy's joint with caving shield for OBUD-1

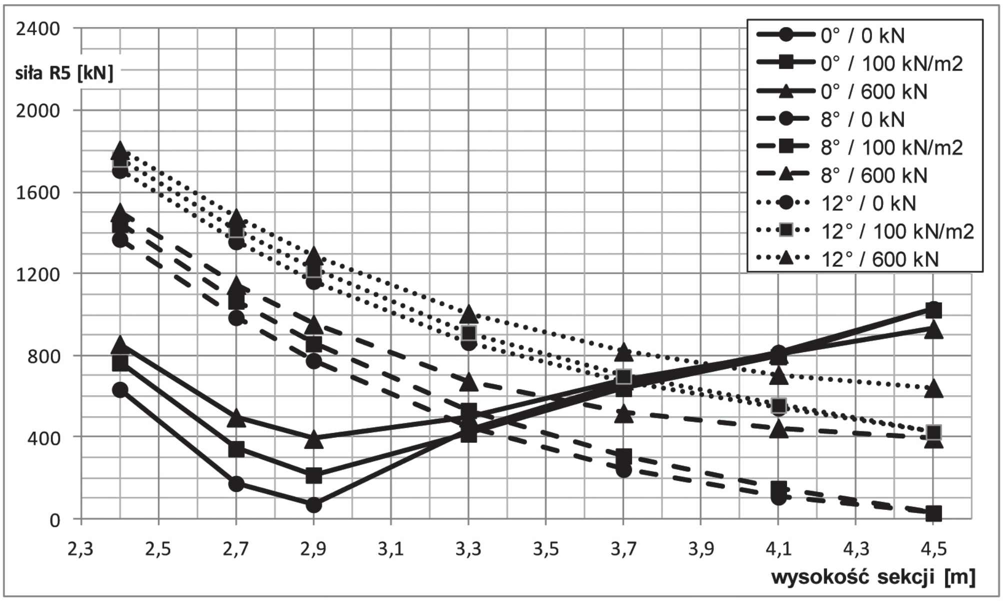

Fig. 10. Values of force R5 [kN] in node of canopy's joint with caving shield for OBUD-2

5. SUMMARY

On the basis of the analysis of the defined calculation models of the OBUD-1 and OBUD-2 support and variant load calculations, it can be stated that the force values in the construction nodes of these sections may differ significantly from the model typically adopted in the operation and maintenance manual for the maximum working and horizontal height.

The changes of the force value in the joint of the canopy with the caving shield (R5 in Fig. 8) based on the presented calculations and diagrams depend primarily on the particular form of the kinematics (geometric dimensions) of the support (in this case, OBUD-1 or OBUD-2), then from the inclination between the canopy and the floor base as well as the load impacting on the caving shield of the support.

In the case of the height of the lemniscate system of OBUD-1 and OBUD-2 (2.4 m and 2.7 m, respectively) and the angles of their canopies (8° and 12°, respectively), the values of force are clearly higher than the values calculated for the height of 4.5 m with a horizontal canopy. In the case of OBUD-1, they can be increased by up to 4.3 times, while they can be increased by about 1.8 times in the case of OBUD-2. Additional calculations have also shown that, when expanding the support, these forces can still increase significantly.

When laying the canopy and caving shield in almost one line, the inclination of Force R5 was often directed almost in the direction of Force component R5s (Fig. 8) and the line of the tilt cylinder. Considering the fact that the support was characterized by a maximum power of 588 kN under the piston or 703 kN above the piston, its changes could have a negligible effect on the possibility of correcting the position of the canopy. Under such conditions, the operation of the tilt cylinder was ineffective or even impossible, and the sections tended to form one plane from the canopy and the caving shield up to the position blocked by the stops and/or the maximum extension of the cylinders.

In the conditions of Longwall 124, this caused that the mining process was conducted while the canopy was raised and the roof was supported in a linear way, which led to the destruction of its structure and precipitation. In this particular case, the interruption of the continuity of the protective carbon shelf left in the roof of the excavation resulted in the roof falls and significant difficulties during operation.

It can be assumed that, in the case of maintaining these supports in a similar configuration but under a natural roof (where a carbon shelf is not required for insulating a weak layer in the direct roof; e.g., goafs), this intensity of falls may occur if there is a sufficient mechanical strength of the roof; nevertheless, the conditions for its "cutting" will still prevail as a result of the difficulties in correcting the positions of the canopies.

The diagrams presented in Figures 9 and 10 indicate that, for OBUD-1, the increase in Force R5 in the node joining the canopy with the caving shield is larger than the scale of the increase observed for OBUD-2; therefore, unfavorable phenomena may occur for the other higher support's heights than for OBUD-2. Practice has shown that the difficulties in Longwall 124 subsided while maintaining working heights greater than approximately 3.5 m.

The operation of the support with the wrong geometry (Figs. 1–4) also causes increased pressure in the front of the floor base, which can cause additional difficulties in the extraction process of the longwall in the case of working on weak floors.

The fact that the excessive accumulation of caving debris on the caving shields resulting from the small angles of their inclination and large surfaces of the covers (caused by relatively large lengths) can occur is another instance of unfavorable conditions.

The calculations carried out on the models show that, for OBUD-1 for Models 1 and 2 (Figs. 1, 2), these angles for longwall heights of approximately 3.5 and 3.0 m reached 19.8° and 15.3°, respectively. For comparison, with the correct support geometry and working heights of 3.0, 3.5, and 4.5 m, these angles obtain the following values: 24.1°, 31.2°, and 48.1°, respectively (Fig. 11). For OBUD 2 for Models 3 and 4 (Figs. 3, 4), the inclination angles of the caving shield towards the bottom of the excavation reached 17.4° and 11.9°, respectively. Similarly as before – for comparison, with the correct support geometry and working heights of 3.0, 3.5, and 4.5 m, these angles obtain the following values: 22.4°, 27.5°, and 51.9°, respectively (Fig. 11).

The small values of the angle of inclination of the caving shield at low working heights of the support may have a significant impact on the load of the supports and their proper cooperation with the rock mass aimed at ensuring the stability of the longwall working. Angles of inclination of the caving shield lower than about 30° are often too small to overcome the frictional force forming on the contact of the caving shield with the loose rocks coming from the caving [8] in the case of the possibility of slipping.

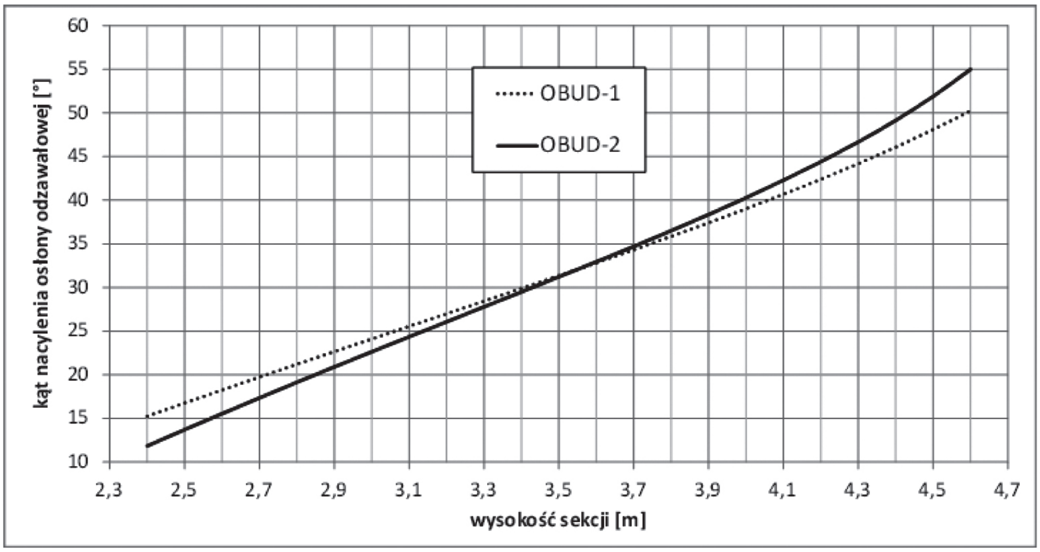

Fig. 11. Inclination angles of the caving shield in the OBUD-1 and OBUD-2 at the correct geometry

This leads to the excessive accumulation of caving debris on the section, which, in combination with the very large surface of the shield supports resulting from their length – determined mainly by the wide range of the working height of the section (2.4–4.5 m), causes both an additional significant load on the analyzed supports as well as an increase in the forces in the structural nodes.

In the case of low support heights and incorrect geometry (Models 1–4 – Figs. 1–4), load impacting on the caving shield may lead to a reduction of load-bearing capacity of up to 17.5% in relation to the conditions specified in the operation and maintenance manual for heights reaching 4.5 m with a horizontal canopy.

6. CONCLUSION

Based on the observations, calculations, and analyses carried out, the following conclusions can be made:

1. The main reason for the difficulties in ensuring the stability of the Longwall 124 excavation (formation of roof falls) in the case of maintaining the OBUD-1 and OBUD-2 supports in the lower range of the working heights was the improper geometry of the support, consisting of the formation of almost one plane between the caving shield and the canopy. In the specific case of Longwall 124, this caused a linear support of the roof resulting in damage, consequently leading to the breaking of the coal shelf and falling of the goafs.
2. The incorrect geometry of the support was the result of a significant increase in the forces in the canopy's joint with the caving shield, which could practically prevent the effective correction of the location of the canopy by means of a tilt cylinder.
3. In the case of the OBUD-1 and OBUD-2 supports, the values of the forces in the joint of the canopy and the caving shield depend in the analyzed cases on the low working heights, first of all from the geometric dimensions of the support, then from the angle of inclination between the canopy and the floor base and from the load impacting on the caving shield of the support.
4. The calculations indicate that the discussed difficulties for the analyzed supports are mainly related to the low heights of operation. Practice has shown that the difficulties in Longwall 124 have subsided while maintaining working heights greater than approximately 3.5 m.
5. The work of the section with the wrong geometry referred to in this article leads to very high-pressure values to be generated in the front of the floor base, which may also cause additional difficulties in extracting the longwall (even when working on weak floors).

Acknowledgement

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