Case Analysis of Damages to Control Hydraulics of the Leg in the Powered Roof Support Section

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Abstract. The article discusses a case of security hazard in a longwall equipped with a properly selected chock shield support with two legs, technically efficient, introduced to the market and for operation in compliance with the requirements covering Polish hard coal mining. As a cause of the hazard an accidental coincidence was indicated, such as the occurrence of a tremor at an area with unfavourable geometry for the operation of the support section and leg (including the shift of the double-telescopic leg from the 1st to the 2nd hydraulic stage) at the time of the mining process. Immediate safety measures were applied successfully. They were aimed at minimizing the conditions dangerous to the crew. The section was withdrawn and spragged again. As a result, the leg operated in full extension mode of the 1st hydraulic stage, obtaining the required strength and geometry of the section and leg. The presented case study will be additionally supplemented in the future with selected analytical and bench tests.

1 Introduction

The powered roof support was introduced to the market in compliance with the requirements resulting from the European Parliament Directives and the Polish standards correlated with them. The basic PN EN 1804 series standards that review mechanical requirements, exclude the case of their validity for operation in conditions of rock mass hazard. The Polish Minister of Energy Ordinance of November 23, 2016 is the supplement to Polish standards in the area regarding mining tremors (Dz. U. Nr 2017 poz. 1118 §523 ust. 1, pkt. 1). It introduces the requirement for the sections to be yielded for the conditions of mining tremors hazard. Section yielding is its adaptation to additional dynamic loads as a derivative of mining tremors. One of the important protection means is to introduce pressure limits in the under-piston space of the leg, up to permissible level set on the basis of mechanical strength of the structure. The pressure limitation is implemented by the use of hydraulic valves. Due to operational requirements (expectations), the valves are placed as high as possible above the floor, which considerably extends the path of liquid stream, from under the piston to the valve. In such cases, there are unfavourable phenomena related to the occurrence of water hammers in the leg's control systems, significantly increasing with the increase in the diameter of the leg and the values of flows [13]. As a result of water hammers, damage occurs to the elements of the control hydraulics of the leg, including valves, pressure gauges, as well

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as STECKO connectors. Damage to the elements of the control hydraulics significantly decreases safety in the mining area. In some cases it may lead to automatic and unintentional slip of the section. The article presents discussed this type of event.

2 Parameters of the analysed longwall

The exploited longwall was 246 m long and 3.1 m high, and was adjacent to goafs from one side. The thickness of the seam in the analysed area ranged from 1.2 to 3.2 m. The seam in the area of the longwall was located at an average depth of about 1010, it was inclined at an angle of up to 10°. The compressive strength of the coal of the seam and its surrounding rocks was about 32.0 MPa for the roof, about 14.0 MPa for the seam, and about 18.0 MPa for the floor. The longwall was equipped with a powered roof support, as presented in Fig. The basic technical parameters are listed in Table 1.

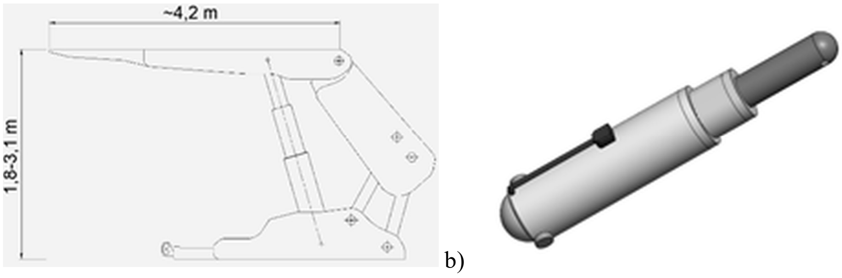
a)  b)

Fig. 1. The powered support section and leg applied in the case study.

Table 1. Basic technical parameters of the powered roof support.

Powered chock shield supports with two legs	
Geometric data	
- working height for seam where rock burst occurs	1.8 – 3.1 m
- section division	1.5 m
- step of the section	0.8 m
Bearing data	
- number of legs	2
- leg's diameter	Ø 0.3 / 0.23 m
- leg's initial bearing capacity	1.767 MN
- leg's working bearing capacity	2.686 MN
- supply pressure	25.0 MPa
- working pressure	38.0 MPa
- leg's length, min/max	1.365/2.91 m
- 1st/2nd level of a hydraulic jump	0.765/0.78 m
- control	remote local
- leg's protection	spring-loaded valve
- leg's overload coefficient	2.0

According to the method developed at GIG [4, 5], the support with the given parameters under the given geological and mining conditions ensured correct conditions for maintaining the roof (values of the load capacity index of the roof $g > 0.8$). The roof load index was calculated taking into account the forecasted maximum energy of a tremor with the value of $2 \cdot 10^6$J and included the load factor of the support $n_{tz}=1.22$ [1-3].

According to the assessment of flows of the safety system of the leg [9, 11, 12], the flow of the leg's safety system, Q=400 dm^3·min^{-1}, was assumed for calculations of the load of the powered roof support, at a pressure of 1.5 times the working load. Expected overloads for the above mentioned flows are shown in Fig. 2.

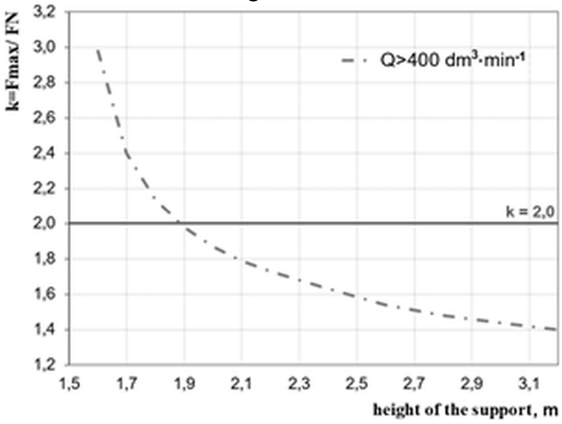


Fig. 2. Predicted overload of powered roof support's leg in the analysed case (for ntz =1.22 and application of hydraulic system with a flow of at least Q>400 dm3·min-1).

The results indicate that the powered roof support should be yielded from a height of 1.9 m, using a system with a minimum capacity of 400 dm^3·min^{-1}. This requires maintaining the liquid column under the first stage piston with a minimum height of 0.35 m, with the correct section geometry.

3 Description of effects

The geological and mining conditions of operation changed. Due to the thinning of the exploited seam, the height of the exploited longwall decreased gradually, to approx. 2.0 m, and the operating conditions deteriorated, which was manifested by roof falls in the face of the longwall area. In addition, at a guide height of 2.0 m, a tremor of energy not exceeding 2·10^{6}J (n_{tz}=1.22) occurred in the longwall, which caused dynamic load that impacted on the powered roof supports, which resulted in:

• damage to five pressure gauge systems (cutting off connection DN12 and damage to pressure gauges) – Photo 1, Fig. 3;
• damage to pressure limiting valves (loss of tightness, damaged seals) – Photo 2, Fig. 3;
• slip off two sections of the support due to damage to the pressure gauge systems (backrest of the canopies on the conveyor);
• roof rock fall.

The case described did not lead to any injury to the crew.

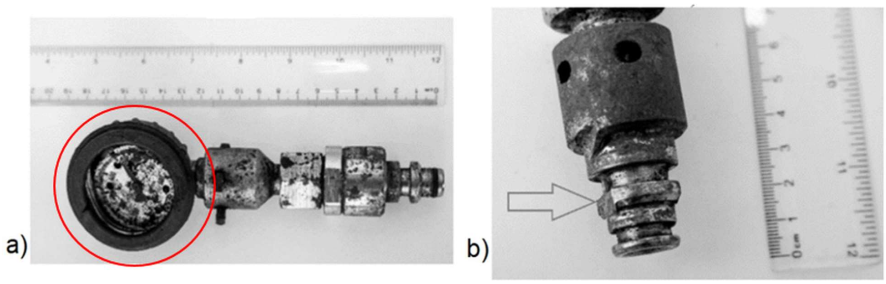


Photo. 1. Damaged manometers

Photo. 2. Damaged elements of valves

Fig. 3. Damages of the equipment.

4 Analysis of the causes of damage in the leg's control system

For a properly operated double-telescopic leg with a bottom valve, its load capacity is calculated from dependence [8]:

- initial bearing capacity: $$F_w = P_w \cdot S_1 \quad (1)$$
- working bearing capacity: $$F_r = P_r \cdot S_1 \quad (2)$$

where: P_w – initial pressure, P_r – working pressure, S_1 – surface of the leg at 1st stage position.

In the case of leg operating in the range of shifting from 1st to 2nd stage and clamping of the leg at 2nd stage, the relations given above change. The load-bearing capacity of the leg changes (due to the smaller surface of the second stage of the leg), its rigidity changes rapidly, which often leads to vibrations in the control system, as well as difficulties in maintaining the roof. Fig. 4 schematically shows the cases described.

As presented in Fig. 4, during the shift of the leg from 1st to 2nd stage, the work of the leg is unstable, which can be described by the following formulas:

$$F_r = S_2 \cdot P_r \text{ or } P_z \text{ (depending on the impact of the rock mass)} \quad (3)$$

$$F_w = S_1 \cdot P_w \quad (4)$$

where: P_w – initial pressure, P_r – working pressure, S_2 – surface of the leg at 2nd stage position.

After spragging the support due to the first and second stage rigidity, the bottom valve is opened (mechanical – displacement $1 \div 2 \cdot 10^{-2}$ m) and the pressure is set to the working pressure (P_r), which results in the leg's operating force to amount to:

$$F_r = S_2 \cdot P_r \quad (5)$$

For the analysed case, the initial load is respectively:

For leg at 1st stage

$$F_w=25\cdot 10^6\ (Pa)\cdot 0.07065=1.767\ MN \tag{6}$$

For leg at 2nd stage

$$F_w=25\cdot 10^6\ (Pa)\cdot 0.04153=1.04\ MN \tag{7}$$

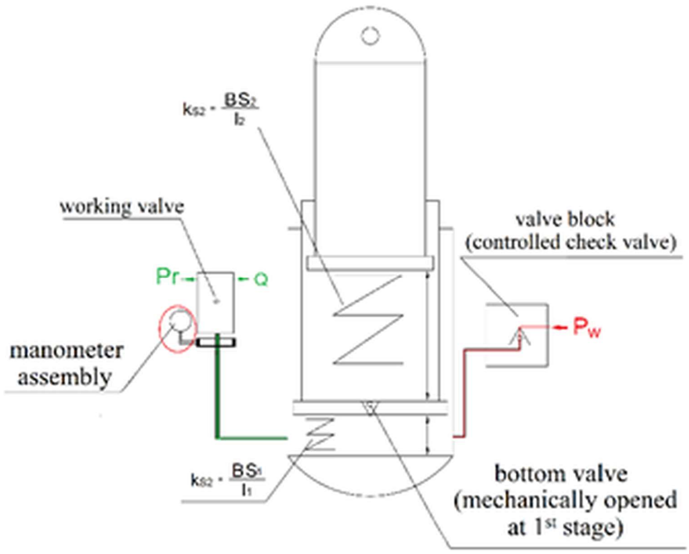


Fig. 4. Operation of the leg within the range of shifting from the 1st to the 2nd stage, where: k_{s1} – stiffness at the 1st stage, k_{s2} – stiffness at the 2nd stage, S_1 – surface of the 1st stage, S_2 – surface of the 2nd stage, l_1 – length of the 1st stage, l_2 – length of the 2nd stage, Q – capacity of the hydraulic system, B – compressibility of the hydraulic fluid.

The calculations presented indicate that the bearing capacity of the leg significantly decreased and corresponds to the load capacity of the leg with the diameter resulting from the second stage, which in the given case is ∅0.23 m. The reduced working load was taken into account in further analysis regarding the condition for the support to be yielded.

A back analysis of the condition of the section's positive state was made using a valve with a capacity of 400 $dm^3\cdot min^{-1}$, as shown in Fig. 5.

As can be seen in Figure 5, in the case of proper support (1st stage), it is compressed in the range from the height of 2.0 m, while maintaining the liquid column under piston at the 1st stage PT≥0.42 m. During incorrect operation (2nd stage) the support is yielded from the height of 2.35 m, which results from the diameter of the 2nd stage cylinder, while maintaining the height of the liquid column under the 2nd stage PT≥0.78 m. It should be noted, however, that in this case the height of the liquid column under the first stage piston is practically nil, in which case the leg is not working properly.

In addition, as shown in Figure 4, an area where dangerous phenomena may occur is formed during the shift from 1st to 2nd stage, i.e. at the height of support of 2.3 to 2.6 m. The research team estimates that the whole system excites within this range, which causes the occurrence of adverse phenomena in the form of impacts.

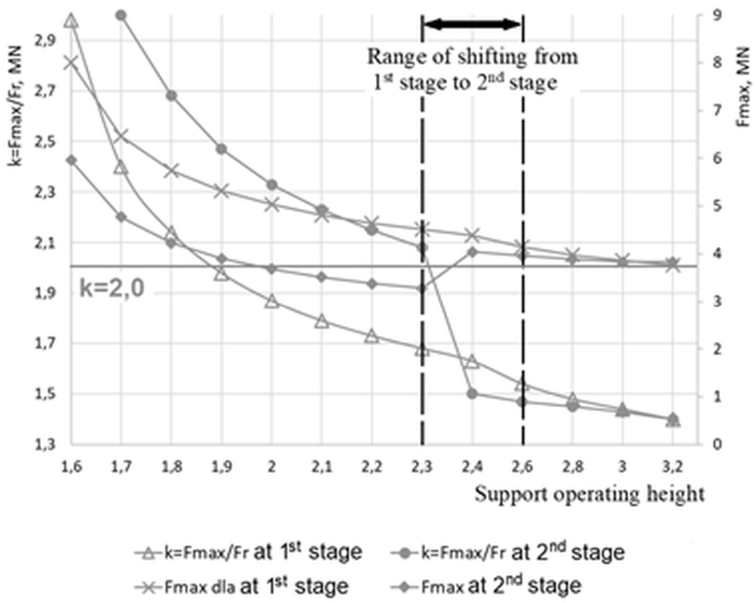


Fig. 5. Expected overload during operation of the hydraulic leg at 1st stage and during operation at the time of shift from 1st to 2nd stage.

The operation of the support at the 2nd stage also significantly affects the roof maintenance conditions, as shown in Fig. 6, using the load capacity index of the ceiling *g* according to the method developed at GIG [4, 5].

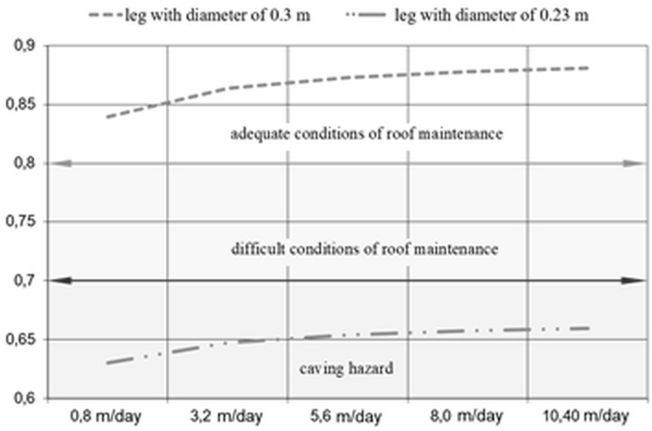


Fig. 6. Index of load-bearing capacity of the *g* roof during the operation of the leg at the 1st and 2nd stage.

The calculations indicate that when the operating parameters of the leg are correct, the bearing capacity of the roof support will be sufficient to protect the excavation against the dynamic impact of the rock mass, which largely depends on the diameter of the leg ∅0.30 m – the *g* factor ≥0.84. In the case when the load-bearing capacity of the operating support resulting from the diameter of the 2nd stage, the *g* indicator significantly decreases – *g* ≥0.63, and in accordance with the method developed at GIG, there is a risk of caving. This was confirmed in practice. The drop in the value of the *g* indicator in this case results mainly from the size of the 2nd stage cylinder's diameter, ∅0.23 m (too low bearing capacity of the support).

In addition, the reason for the difficulties when maintaining the longwall could be the failure to maintain the correct geometry of the support section (lack of parallelism between the canopy and the floor base – excessive lifting of the canopy). Supporting the roof with the entire surface of the canopy is extremely important, since the linear support (e.g. the end of the canopy) can lead to destruction of the structure of the roof rocks, and thus to impediments in the proper maintenance of the longwall.

The change of support parameters as a result of maintaining poor work geometry is shown in Table 2 [6, 7].

Table 2. Dependences of the canopy inclination angle in relation to the length and angle of the leg inclination.

Canopy inclination angle to the floor base [°]	The length of the leg in relation to the angle of inclination of the canopy [mm]	Leg inclination angle [°]	Distance between the end of the canopy and the floor [m]
0	1.787	23.38	2.000*)
5	1.862	22.28	2.364
10	1.935	21.10	2.724
15	2.005	19.80	3.077

*) height of section expansion with its correct geometry

5 Conclusion

This article analyses the operating conditions of a powered roof support (with a double-telescopic leg, 0.3 m diameter) adequately selected in terms of load-bearing capacity for the mining and geological conditions of the longwall. Despite the fact that the support was adequately selected in terms of resistance, it did not provide adequate work safety, due to its maintenance height.

As a result of the thinning of the deck, the height of the support operating area was successively lowered, which led to its operation on the 2nd stage of extension of the leg, without maintaining the appropriate column of liquid under the piston at 1st stage position. The tests results indicate that in this case the support does not have adequate bearing capacity and operates in the *hazardous area* in which the entire system is excited and, consequently, adverse effects occur in the form of water hammers in the control system.

Immediate safety measures were applied successfully. They were aimed at minimizing the conditions dangerous to the crew. The section was withdrawn and spragged again. As a result, the leg operated in full extension mode of the 1st hydraulic stage, obtaining the required strength and geometry of the section and the leg.

Difficulties described in the article are significant in terms of safety of the crew and the continuity of the production process, therefore, research which include bench tests of the leg to characterize its work and a numerical analysis of flows in the leg's valve block will further describe the phenomenon.

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