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The impact of selected structural and operational factors on load bearing capacity of the powered roof support

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Abstract. This paper presents a short analysis of the state of knowledge regarding the selection criteria of the powered roof support unit parameters for specific geological and mining conditions. The study exhibited that the theoretical models and selection methods applied so far do not allow to determine the impact of structural and operational factors on the load bearing capacity of the powered roof support unit. The authors have proposed a research procedure which uses the developed load model of the powered roof support unit in the longwall heading, allowing the prediction of roof stability conditions by determining convergence of the heading for given parameters of the support unit or selection of technical parameters and initial load bearing capacity to achieve the planned convergence of the heading. Thanks to this method it is possible to determine the characteristic relating the load bearing capacity of support unit with the convergence of the heading, the measure of which is the inclination angle of the roof part of rock mass, and further analysis of the impact of structural and operational factors on the load bearing capacity of the support unit.

1. Introduction

The continuous progress in the improvement of the technical equipment used in longwalls leads to an increase of investment capital and the related increase of the risk of considerable losses incurred by the mining plant in case of interruption of the longwall exploitation. The assurance of high availability of machines and good exploration of the deposit do not guarantee achieving a specific technical goal. The "sine qua non" condition for that is, among others, ensuring proper interaction of the powered roof support unit with the rock mass. Therefore, it is an important research problem to determine the impact of structural and operational factors on the load bearing capacity of the powered roof support units [1, 2]. The knowledge in this area is necessary for proper selection of the powered roof support unit for given geological and mining conditions.

2. The models used in selection of operating parameters of the powered roof support unit

A number of models have been developed for the purpose of selecting the parameters of the powered support unit for specific geological and mining conditions. One of the first was the Wilson model [3] developed in the 1970s, in which the external load exerted on the powered roof support unit was the weight of the roof part of rock mass (figure 1). As a result of exploitation, a gob appears due to separation of rocks forming the direct roof. According to this model, the support units would take over the entire weight of the roof part of the rock mass. The dimensions and the weight of the rock mass are conditioned by increase in volume of rocks forming the direct roof, which is related to the degree of

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loosening of the blocks. This approach only provided for the balance of forces, without taking the convergence of the heading into account.

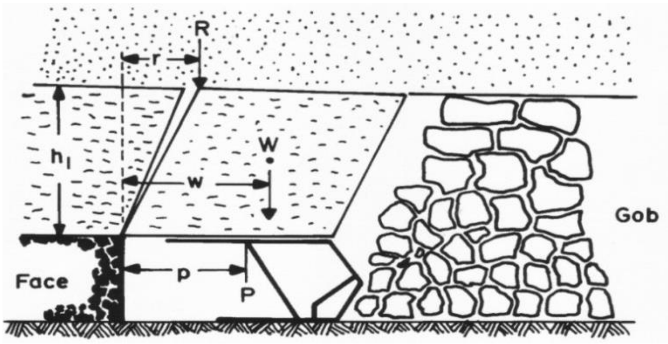

Figure 1. External load exerted on the powered roof support unit according to the Wilson model [3].

Another model, which better described the roof support, was developed by Smart in the 1980s [4], it was based on the idea that powered roof support units are one of the three yielding supports that counteract the displacement of the direct roof in the form of a unilaterally fixed beam and the main roof maintaining the form of a self-supporting beam. The other supports include: the coal seam in the face area and goafs behind the longwall (figure 2). It was the first model in which the roof subsidence, dependent on stiffness of the supporting elements, was taken as a measure of correctness of roof support.

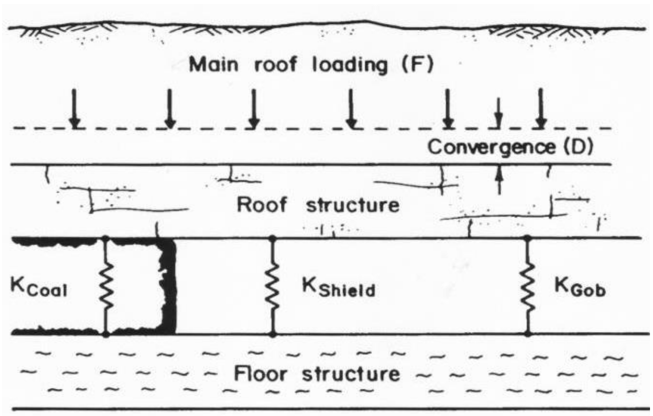

Figure 2. Model of roof support according to Smart [4].

The method of permissible roof deflection developed by A. Biliński [5] approximately 30 years ago combines the features of both of the above models. The essence of this method is to assume that the relaxed roof part of rock mass, the range and shape of which depends on the type of roof rocks, is kept in balance by powered roof support units, coal seam, and a chaotic caving after the displacement, which is measured by rotation of this mass. Above thr relaxed rock mass, a disturbed rock mass is present with layers that exhibit a high self-load bearing capacity (figure 3).

In this method, the equilibrium conditions were not specified in an explicit manner and the relation between the loading moment of the support unit by the weight of the rock mass and the support moment by the support unit at a given rotation of the mass was determined based on field research in the form of empirical relations.

The method of selection of powered roof support on the basis permissible roof deflection used nowadays in our country, was developed in research carried out for slow daily wall progress of up to

4.5 m. Observations and underground tests were carried out only in about 20% of cases for longwalls with powered roof support, and the vast majority consisted of measurements and observations on the walls with individual articulated steel supports (built into a triangle and a line).

The method of permissible roof deflection allows for checking the impact of parameters of the powered roof support unit on the roof support condition due to the prevention of gobs or roof collapses. Based on the analysis of underground test results, it was found that proper roof maintenance in the aspect of non-occurrence of gobs can be achieved when the roof load indicator g, dependent on the relation of individual roof inclination to the roof inclination limit, is greater than or equal to 0.8 [6].

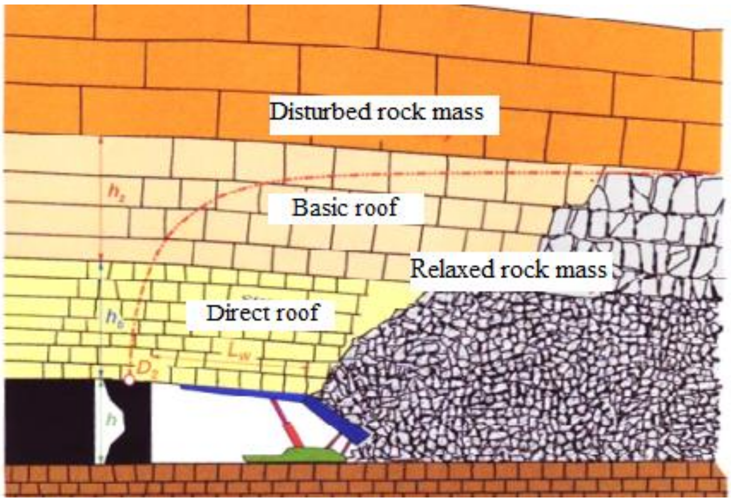

Figure 3. Schematic drawing of disturbed rock mass [5].

The empirical relations used in this method of selecting the powered roof support unit do not currently include the progress achieved by high-efficiency walls [7], and the way of determining the load bearing capacity of the support unit does not take into account the structural features of caving shield units [8].

For the purpose of selecting a powered roof support unit, manufacturers develop characteristics of the powered roof support units that describe e.g. [8]:

- the relation of the working load bearing capacity of the powered roof support unit to the height of unit use (figure 4),
- the relation of the distance of the resultant load bearing capacity of the powered roof support unit from the end of the roof-bar at the side of the goaf area as a function of the height of the unit operation (figure 5).

These characteristics make it possible to correctly determine the working load bearing capacity of the unit and the resultant moment of the unit's load bearing capacity for a given height of the longwall, they do not, however, take the impact of convergence of the heading into account.

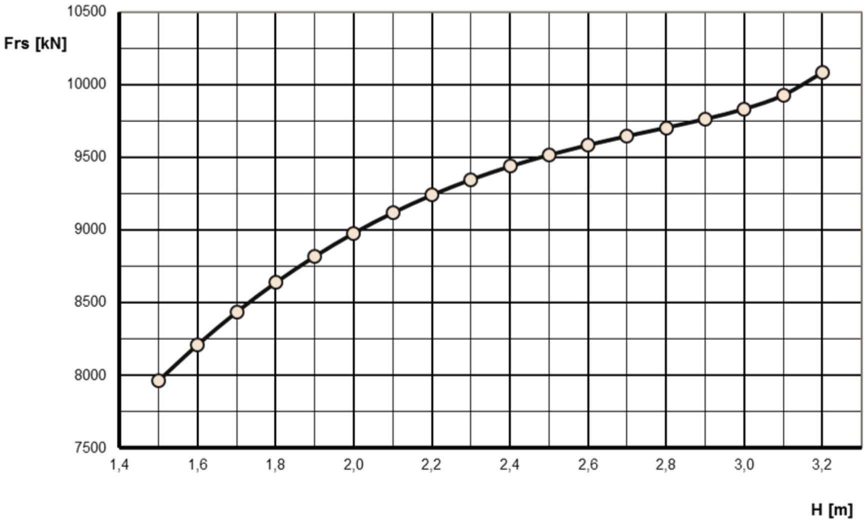

Figure 4. The relation of the working load bearing capacity of the unit to the height of the unit [8].

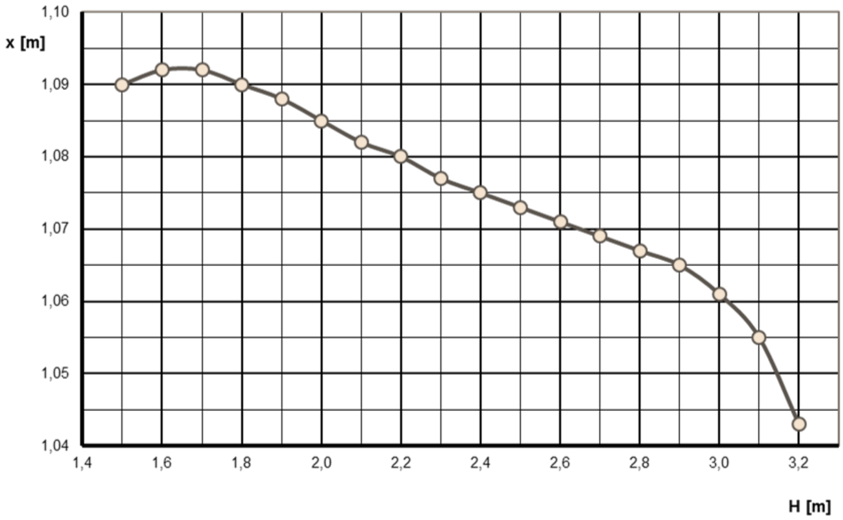

Figure 5. The relation of the coordinate of the position of the resultant working load bearing capacity of a unit in relation to the rear edge of the roof-bar and the height of the unit [8].

The presented analysis of the state of knowledge shows that the currently used theoretical models of interactions of the supports with the rock mass do not take into account the yielding capacity of the unit, and its impact is modelled only in the form of concentrated force exerting pressure on the roof [9]. In the method used in Poland to select the support of longwall exploitation headings, the value of initial load bearing capacity and working load bearing capacity of the support unit is not determined and the impact of both parameters on the support condition of the longwall roof is only estimated on the basis of the roof load capacity indicator g.

Therefore, the impact of all design features of the used caving shield unit, as well as the factors related to its use, are not taken into account in the process of selecting the powered roof support for specific geological and mining conditions. In addition, in the currently used models of the load exerted of the support units, when determining the load bearing capacity characteristics, the load impact of the caving shield is not taken into account, considering that load only as an additional factor in the strength analysis of the main elements of the unit.

The load bearing capacity characteristics used nowadays only include the relation between the initial load bearing capacity and the working load bearing capacity of the powered roof support unit as well as the height of the longwall. In order to determine the conditions for maintaining the roof, however, it is necessary to know the characteristics that relate the support unit's load bearing capacity with the convergence of the heading, the measure of which is the inclination angle of the rock mass. Thanks to the method that allows to determine such characteristics, it is possible to analyse the structural and operational factors affecting the load bearing capacity of the powered roof support units.

In view of the above, the issue of the interaction of the powered roof support unit with its surroundings has been addressed in this paper, taking into account the above-mentioned issues relevant from the cognitive point of view.

3. Analysis of selected factors affecting the load bearing capacity of the powered roof support units

Structural factors significantly affecting the load bearing capacity of the powered roof support units include the geometrical features of the unit, in particular the structural form of the props, which determines yielding capacity of the entire unit. The operational factors, on the other hand, include: the load exerted on the caving shield by the rocks forming the chaotic caving, the initial load bearing capacity, and the variability of the props’ expansion in the unit and the adjacent units.

The assessment regarding the impact of selected factors of structural nature and factors related to the use of the powered roof support units in longwalls with caving was carried out in [2]. Due to the fact that the models used so far do not make it possible to determine the impact of all these factors, a model of external load exerted on the powered roof support unit was developed. The model provided for the support of the roof part of rock mass by: the unit F_N, the coal seam R_A, the rocks forming the chaotic caving R_{01V}, and regular caving R_{01H} (figure 6). In this model, the powered roof support unit is loaded with the weight of the roof part of rock mass Q_1 and the caving debris Q.

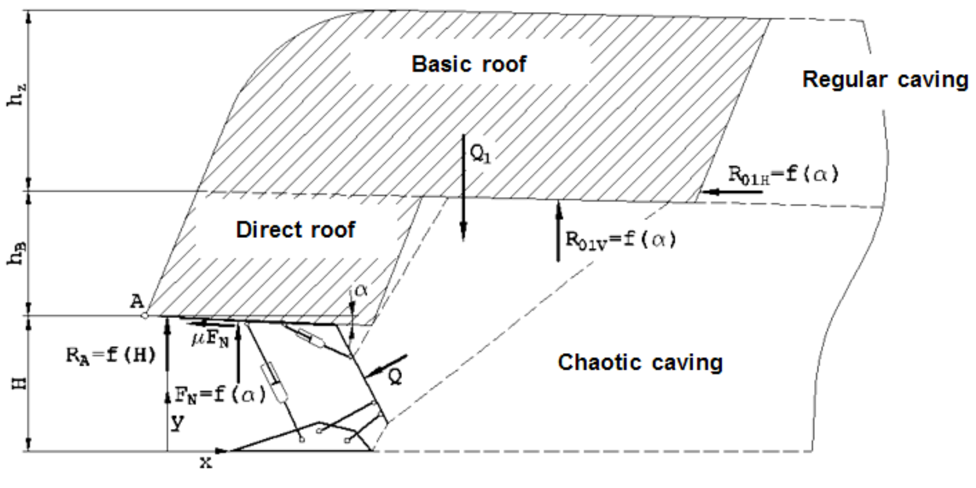

Figure 6. The model of load exerted on a powered roof support in a longwall with caving [1,2].

The research procedure proposed in [2] (figure 7) using the developed model allows for prediction of the roof part of rock mass equilibrium conditions by determining the convergence of the heading for given parameters of the support unit or the selection of technical parameters and initial load bearing capacity in order to achieve the assumed convergence of the heading.

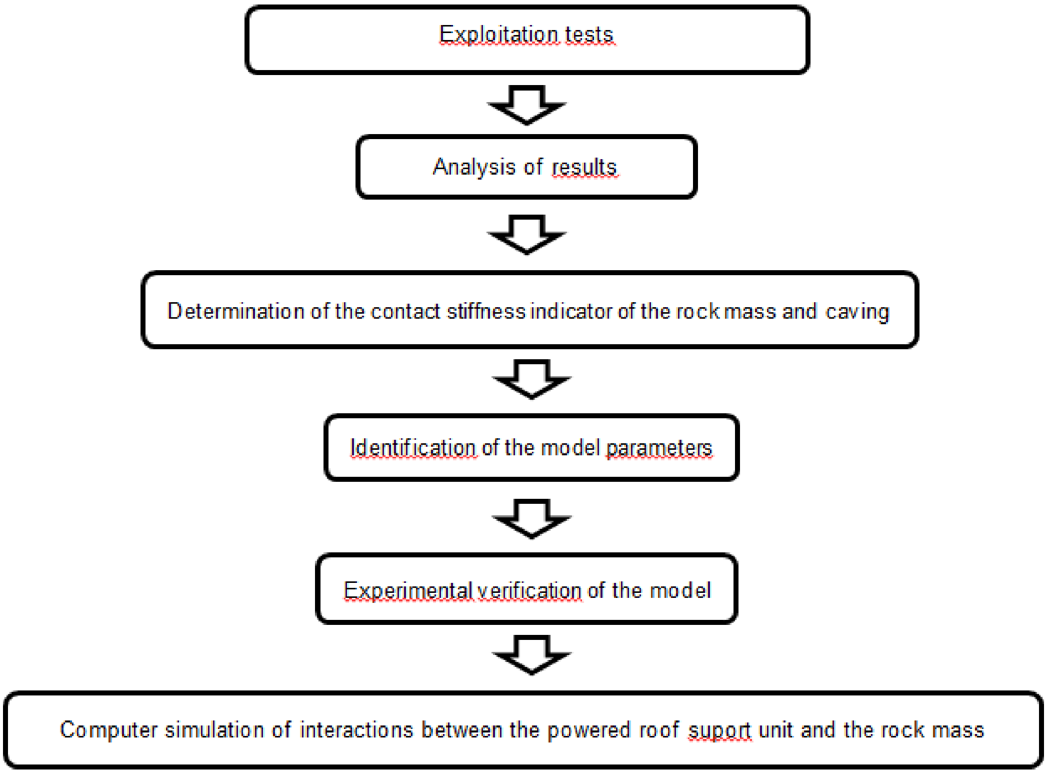

Figure 7. The test procedure for determining the yield capacity of the support unit with consideration given to the horizontal component of the goaf reaction [1,2].

This is possible due to the introduction of the horizontal component of the goaf reaction, dependent on the convergence, to the roof part of rock mass equilibrium conditions, and achieving the load bearing capacity characteristics of the unit that relates the load bearing capacity with the inclination of the roof part of rock mass [2].

Based on the conducted exploitation tests in which the pressures of the under-piston part of the load bearing system actuators, the position of the roof-bar, springer, and caving shield were measured in time, a procedure was developed for determining the stiffness of the support of roof part of the rock mass by rocks forming the regular caving.

For each work cycle of the unit adopted for the analysis the stiffness indicator was determined for the contact between the roof rock mass and the rocks forming the regular caving, assuming the linear relation of the horizontal reaction to the convergence of the heading. After verifying the stiffness indicator distribution, average value was adopted as a parameter enabling the determination of the horizontal component of the goaf reaction in the model of external load exerted on the powered roof support unit, which allowed to determine the required load bearing capacity of the powered support unit necessary to ensure the stability of the roof part of rock mass. Relation of the required load bearing capacity of the support unit to the convergence of the heading obtained in this way is the equivalent of a fragment of GRC corresponding to the conditions of reinforcement of the roof part of rock mass due to the presence of the horizontal component of the goaf reaction.

GRC (Ground Response Curves) is a recently developed concept that allows to determine the required load bearing capacity of the support unit based on the relation of load exerted on the unit to convergence of the heading (figure 8) ensuring maintenance of equilibrium of the roof part of rock mass [10, 11, 12, 13]. The curves were obtained by an analysis of the exploitation test results and constitute a tool that allows for graphical analysis of the interaction of the rock mass and the powered roof support unit.

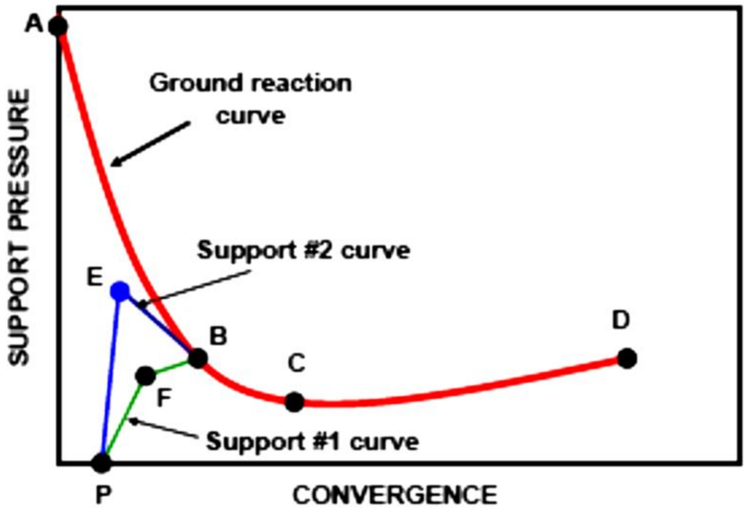

Figure 8. Conceptual illustration of interaction of the powered roof support unit with a rock mass using the GRC [10].

Before commencing the exploitation, a pressure resulting from the overburden height (point A) occurs at the location of the future contour of the heading. As a result of the exploitation, the contour of the heading decreases and the load bearing capacity of the support unit necessary to ensure the equilibrium conditions is reduced due to a self-supporting layer being formed and fortified as a result of displacement of layers located directly above the heading (point B). This phenomenon occurs until there is a loosening of the contact between rocks deposited in one layer as a result of, for example, destruction of the rock structure (point C), which results in the necessity to increase the support's load bearing capacity caused by the loss of self-supporting features of the roof layers (point D). The equilibrium state is achieved at the intersection of the rock mass reaction curve with load bearing capacity characteristics of the support unit (point B).

The observations conducted in exploitation conditions confirm the validity of the adopted approach. It was found that increasing the initial load bearing capacity improves the maintenance of the roof due to the reduction of the convergence of heading [10].

Medhurst applied the rock mass reaction curves in the analysis aimed at selecting the powered roof support units [12, 13]. Simultaneously, he exhibited that the shape of curves shifts as a result of changes in geological and mining conditions. At higher wall heights the rock mass reaction curve shifts to the right, which indicates the need to use a support unit with higher load bearing capacity to limit convergence of the heading associated with reduction in the stiffness of support from the coal seam. Similarly, the selection of the support unit is influenced by the increase in depth of exploitation, as the rock mass reaction curves are also shifted to the right (figure 9).

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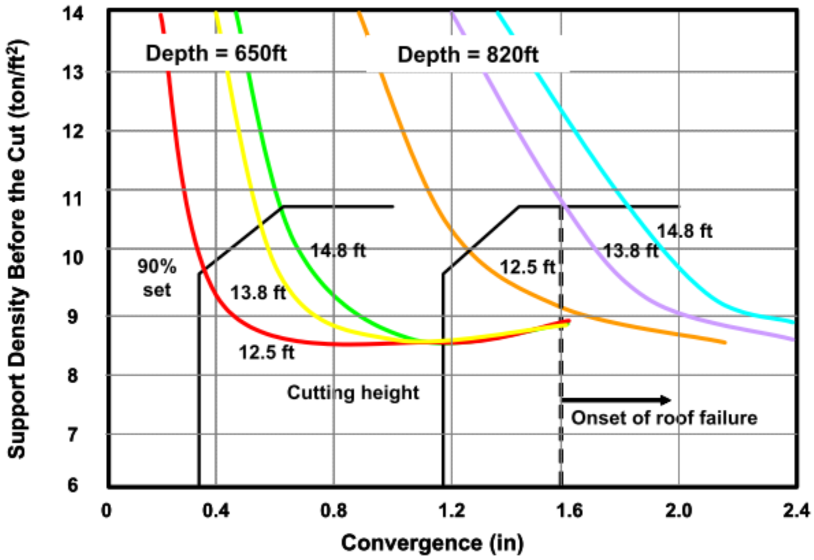

Figure 9. The impact of the depth of exploitation and wall height on the course of the rock mass reaction curves [10].

The above exhibits that the concept of the rock mass reaction curves includes a range of curves, each of which represents specific geological and mining conditions. While the development of curves of the rock mass reaction in the American and Australian mining conditions is not a problem due to the relatively small variation in the properties of rocks occurring in the roof of longwall headings, the large geological diversity of the rock mass in Polish mines poses a serious limitation in the development of these curves.

The main problem associated with this method therefore involves obtaining the shapes of rock mass reaction curves for various geological and mining conditions [10]. This can be done based on the results of in situ research, including measurement of the load exerted on the powered roof support unit and the convergence of the heading. In practice, this is very difficult because obtaining the rock mass reaction curves requires obtaining various yield capacities of the support unit, which is achieved by controlled lowering of the initial pressure. However, thanks to the development of numerical methods new possibilities for obtaining the rock mass reaction curves were created. The currently used software allows for the modelling of rock behaviour, taking into account the displacements and deformations associated with the destruction of the rock structure, rock anisotropy, and the change of strength associated with the weakening of rocks due to cracking. It allows to set the load and displacement conditions of the rock mass, but limits the possibility to properly model properties of the powered roof support unit. In addition, obtaining data characterising particular layers of rocks lying in the roof of a longwall heading may also prove to be a problem.

The computer simulations and analyses of the obtained results allowed to determine the impact of the initial load bearing capacity and the yielding capacity of the unit resulting from the stiffness of the props, the degree of aeration of the working medium, and the height of the wall, as well as the load exerted on the caving shield, on the load bearing capacity of the powered support unit. In addition, based on the analysis of the research data, the effect of the actual initial load bearing capacity on the the load bearing capacity of the props of the powered roof support units and the impact of the variability of the load bearing capacity of adjacent units on the load of the props in the powered roof support unit was determined [2].

3.1. The impact of geometrical features of props on the load bearing capacity characteristic of the powered roof support unit

The structural features of the props have a significant influence on their yielding capacity, which is determined by the stiffness indicator. The analysis was carried out for a double-telescopic prop, one-telescopic prop, and one-telescopic prop with a mechanical extension for the same height of use. From the point of view of yielding capacity, the use of props with a mechanical extension is the least advantageous solution.

Therefore, the choice of the initial load bearing capacity for the conditions of a given wall should be made while taking into account the load bearing capacity characteristics of the powered roof support unit, depending on the construction of the props and their stiffness. Figure 10 presents the load bearing characteristics of units with two-telescopic props and with the use of other analysed props. The authors have also applied simple imaging of the required unit's load bearing capacity for given geological and mining conditions F_{kybad}. It may be observed that for the various construction types of props and initial load bearing capacity, the yielding capacity of the powered roof support unit changes, therefore the increase of inclination of the roof part of rock mass changes, for which the state of balance of the roof part of rock mass is determined.

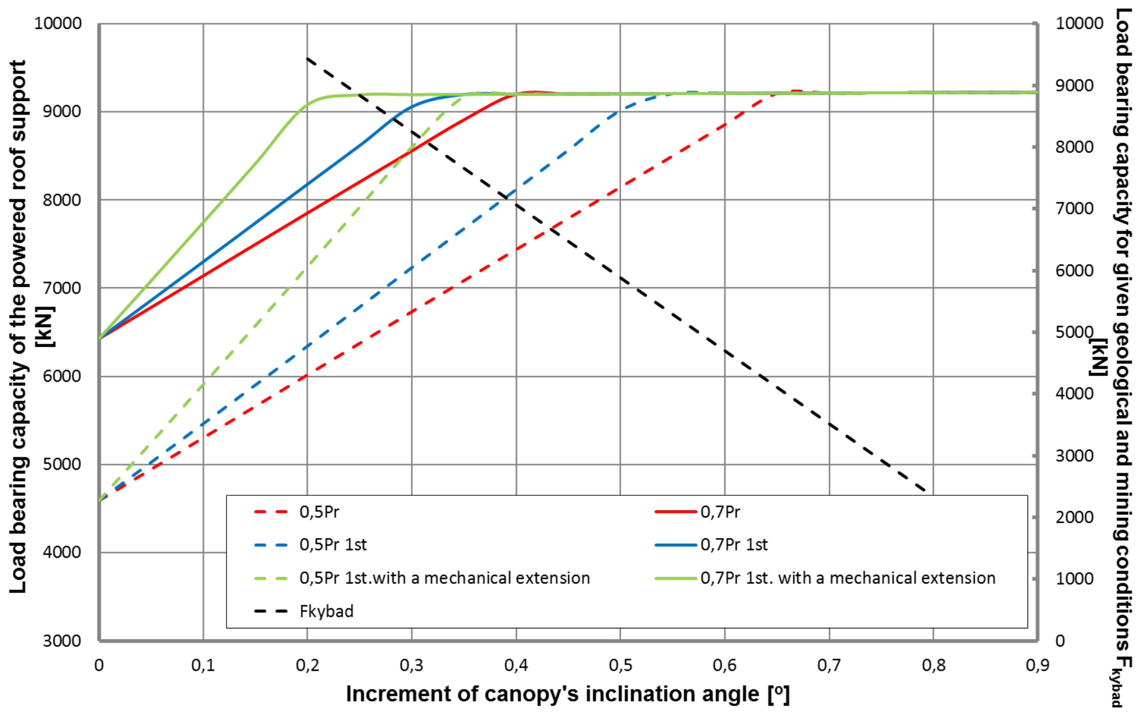

Figure 10. The load bearing capacity characteristics of a unit for different heights, taking the variability of the initial load bearing capacity and the construction type of the props into account [2].

3.2. The impact of load exerted on the caving shield on the load bearing capacity of the powered roof support unit

Based on the analysis, it was found that the load exerted on the caving shield by the caving rubble affects the position of the load bearing capacity characteristics of the unit (figure 11).

The load exerted on the caving shield decreases the load bearing capacity of the powered roof support unit for the same initial pressure, which increases the convergence of the heading and may cause deterioration of roof maintenance conditions.

The load exerted on the caving shield by caving rubble significantly impacts the load bearing capacity of the powered roof support unit. With the increase in the load of caving rubble, due to the contact of the shield with the caving rocks on increasing length, the working load bearing capacity of the unit decreases in relation to the support unit not loaded with caving rubble. The lower load bearing capacity of the powered roof support unit is caused by the load bearing system taking over load exerted on the caving shell.

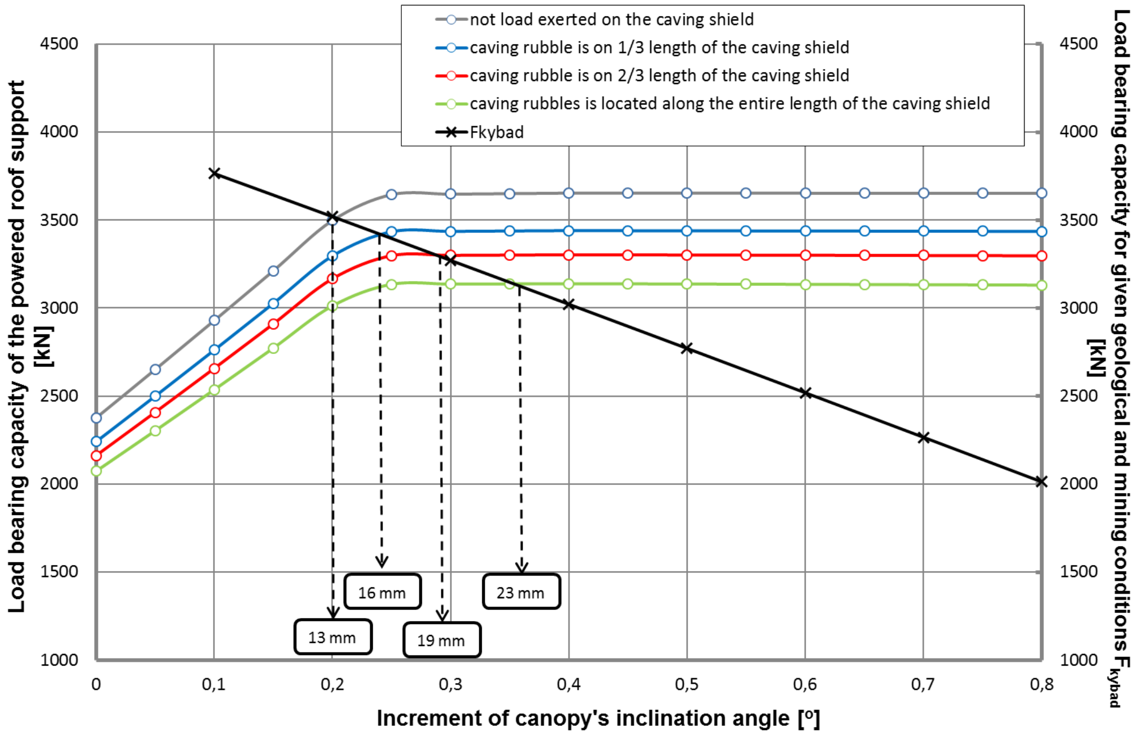

Figure 11. The relation of the convergence of the heading with the load bearing capacity of the powered roof support loaded with a caving rubble at different lengths of the shield [2].

3.3. The impact of the initial load bearing capacity on the load bearing capacity of props of the powered roof support unit

In order to analyse the impact of operational factors on the load bearing capacity of the support unit, we used the measurement data obtained from the research carried out in the longwall X. The analysis was based on the obtained values of pressure change in the under-piston part of the props of the powered roof support unit, measured in time. From the obtained curves, data regarding the initial pressure and the final pressure was collected in each of the load cycles of the analysed powered roof support units.

To determine the impact of the initial load bearing capacity on the load bearing capacity, the unit load cycles corresponding to the normal course of the technological process in the wall were used. The values of the initial pressure p_w and the final pressure p_k of the props in individual cycles were compared to the pressure of the power supply p_{zas} and the working pressure p_r. This facilitated the further analysis by dividing the area of relative final pressure p_k/p_{rob} and initial pressure p_w/p_{zas} into four sections marked I÷IV respectively, taking into account the threshold values of both the parameters (figure 12).

It was determined that the smaller the value of the initial load bearing capacity, the greater is the range of variability of the working load bearing capacity corresponding to a given value of the initial load bearing capacity. The dispersion of points decreases with the increase of the initial pressure, and after exceeding the value of this pressure corresponding to the relation p_w/p_{zas} equal to 0.6, the relation between the relative final pressure and the relative initial pressure was approximated by a linear relation.

The above exhibited that getting the initial load bearing capacity in the range close to the power supply pressure makes the pressure build up in the hydraulic props predictable and leads to good support of the heading roof.

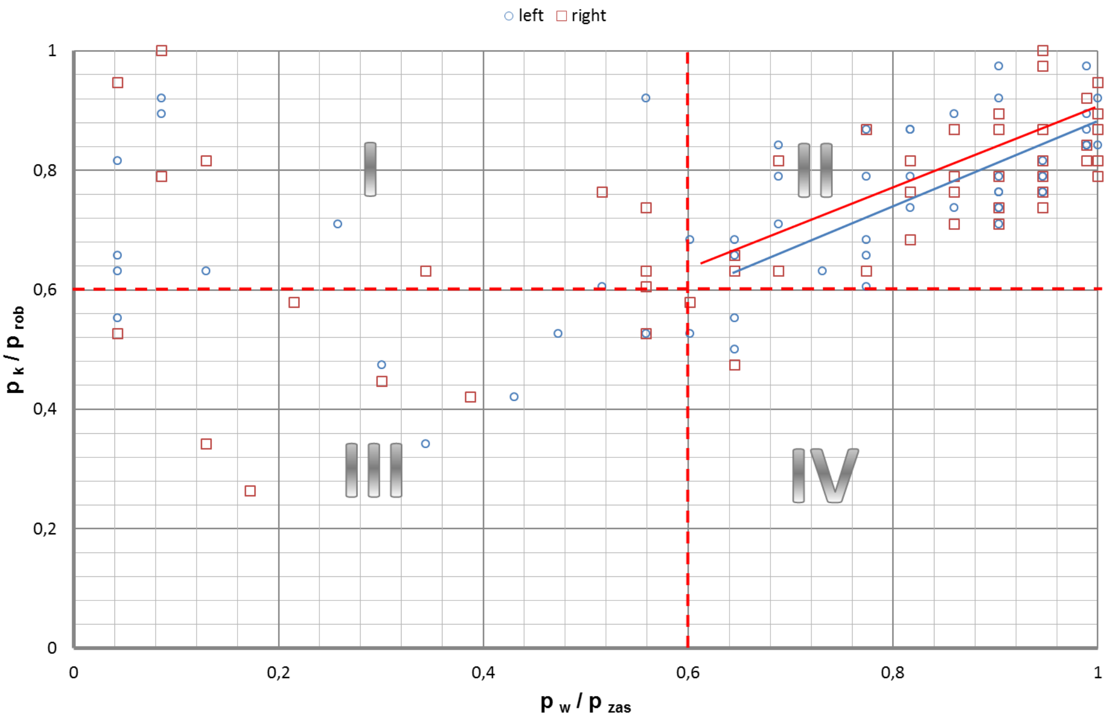

Figure 12. The relation of the load bearing capacity to the initial load bearing capacity $p_k/p_{rob} = f(p_w/p_{zas})$ of the props of the powered roof support unit [2,14]

3.4. The impact of the load bearing capacity variability of adjacent units on the load exerted on props of the powered roof support unit

In order to determine the impact of the adjacent units' load bearing capacity on the load exerted on props of the powered roof support unit, a diagram was prepared, illustrating the load on the three consecutive powered roof support units in the initial and final expansion phases during the subsequent load cycles of the powered roof support unit (figure 13).

The inclination of individual coloured units illustrates the load exerted on adjacent units, the initial pressure, and the pressure increase in props of the central unit.

For all the load cycles of powered roof support units analyzed within a period of one month, performed for three adjacent support units, a smaller load on the adjacent unit caused a larger pressure increase in the prop of the analysed unit, adjacent to a given unit in 70% of cases. This prop then takes over the additional load from the roof part of the rock mass, compensating for the smaller load on the adjacent unit. Uneven expansion of the adjacent units has a detrimental effect on the load exerted on individual props of the central unit, causing twisting of the roof-bar and the shield as well as bending of the lemniscate linkages. Uneven unit expansion also causes bending of the heading roof along the length of the wall. Proper roof support therefore requires achieving the same levels of initial load bearing capacity in all units in the wall.

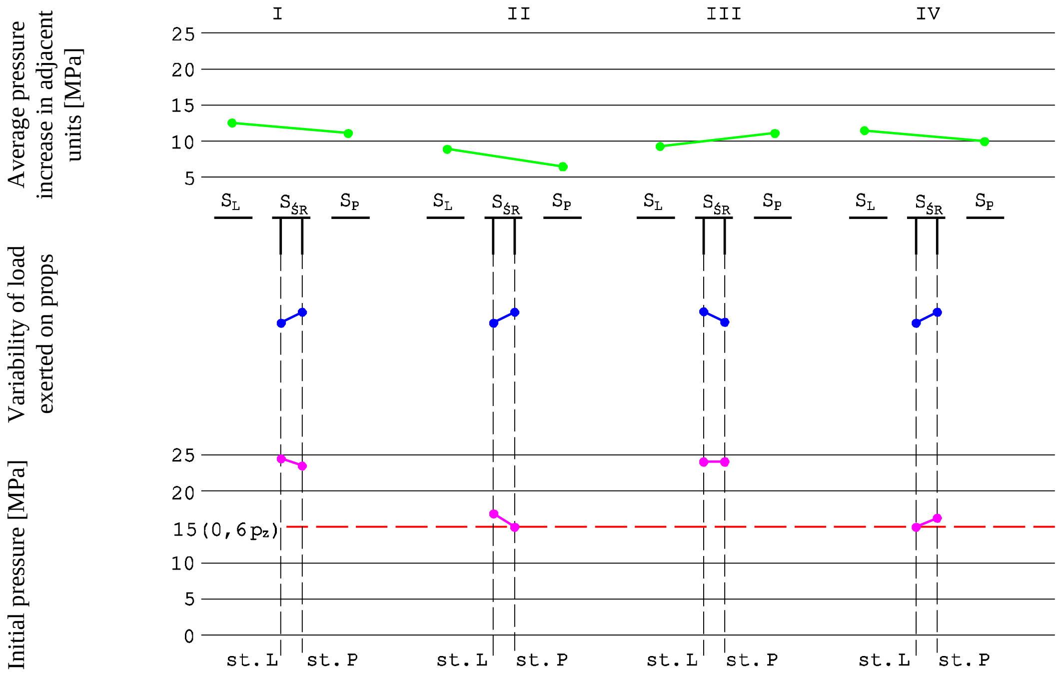

Figure 13. Drawings of the load exerted on three adjacent support units, the load exerted on the middle unit props, and the pressure value at which they were expanded [2].

4. Discussion

The research procedure proposed in [2] using the developed model allows to obtain a characteristic relating the load bearing capacity of the powered roof support unit with the convergence of the heading. The method of determining this characteristic includes operational parameters as well as structural features of the currently used caving shield units, making it possible to carry out analyses aimed at the determination of the impact of selected factors on the load bearing capacity of the powered roof support units.

In relation to the model used in the method of selecting a powered roof support unit, based on the theory of permissible roof deflection [5], this model provides for several new solutions:

- the dependence of the support unit's load bearing capacity on the inclination angle of the roof part of rock mass and the properties of the working medium, taking into account the aeration of the hydraulic system,
- the introduction of load exerted on the caving shield by caving rubble, in the determination of which all forces in the powered roof support unit – rock mass system are taken into account,
- the introduction, in an explicit manner, of the support of the roof part of rock mass by the coal seam R_A, dependent on the deformation and carbon strength parameters [12],
- taking into account the additional roof support of the roof part of rock mass by rocks forming the regular caving in the form of a horizontal component of the goaf reaction R_{01H}, resulting from the impact of the main roof on the rocks forming the regular caving, dependent on the roof displacement of the roof part of the rock mass.

5. Conclusions

The analysis of the impact of selected factors on the load bearing capacity of the powered roof support unit should be carried out based on a model of interaction of the powered roof support unit, taking into account all forces in the support unit – rock mass system. This model must allow for the determination of the characteristics relating the load bearing capacity of the support unit with the convergence of the heading, the measure of which is the inclination angle of the rock mass. It is therefore possible to analyse the impact of the structural and operational factors on the load bearing capacity of the powered roof support units. In addition, by determining the characteristics of the required unit's load bearing capacity for given geological and mining conditions of the wall, which corresponds to the fragment of the GRC corresponding to the conditions of the roof part of rock mass reinforcement due to the presence of a horizontal component of the goaf reaction, it is possible to analyse how the inclination of the rock mass changes, which is used for the determination of the level of roof part of rock mass equilibrium for different types of props, different initial load bearing capacities, or the changing loads exerted on the caving shield.

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