Arch. Min. Sci. **65** (2020), 3, 453-468

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.24425/ams.2020.134129

WOJCIECH MASNY[1*]

POWERED SUPPORT IN DYNAMIC LOAD CONDITIONS – NUMERICAL ANALYSIS

Tremors occur randomly in terms of time, energy as well as the location of their focus. The present state of knowledge and technology does not allow for the precise prediction of these values. Therefore, it is extremely important to correctly select a powered roof support for specific geological and mining conditions, especially in the case of areas where dynamic phenomena are often registered. This article presents information on rock burst hazard associated with the occurrence of rock mass tremors and their influence on a powered roof support. Furthermore, protection methods of a powered roof support against the negative effects of dynamic phenomena are discussed. As a result of an analysis the methodology, to determine the impact of dynamic phenomena on the powered roof support in given geological and mining conditions is presented.

Keywords: hard coal, rock burst, dynamic, powered support, numerical modelling

1. Introduction

The production of hard coal in Poland is conducted in increasingly challenging geological and mining conditions that result from greater depths of mining operations or previous mining activity which has resulted in edges and/or residues (Majcherczyk & Niedbalski, 2017). There are numerous factors that generally increase the level of natural hazards in Polish mines. One of them is rock burst hazard associated with the occurrence of rock mass tremors. According to (Patyńska & Stec, 2017) only some of the seismic tremors (short-term dynamic phenomenon), are the direct cause of rock bursts, which consequently caused damage and/or destruction of underground workings, thus the continuity of coal production (Lubosik et al., 2020), and dangerous and often fatal accidents among miners. On the other hand, according to Polish regulations (Regulation of the Minister of Energy, 2016) a rock burst is defined as a dynamic phenomenon

---

[1] CENTRAL MINING INSTITUTE, 1 GWARKÓW SQ., 40-166 KATOWICE, POLAND

[*] Corresponding author: w.masny@gig.eu

caused by a rock mass tremor which results in destroying or damaging a mine working, or its fragment, leading to the complete or partial loss of its functionality or making it dangerous to use. While decompression is defined as a dynamic phenomenon caused by a rock mass tremor which causes damage to a mine working (or its fragment), yet does not result in loss of functionality nor renders it unsafe for personnel.

The rock burst hazard is confirmed by the data presented in the Annual Report (2019) prepared by the Central Mining Institute. It shows that despite steadily decreasing output, by just over 20 million tonnes in the last decade, the number of high-energy seismic events remains high – Figure 1. It can therefore be assumed that the process of underground coal mining in Poland is associated with the widespread occurrence of dynamic phenomena. Before the dynamic impact of the rock mass, the roadways and longwalls are protected by a support (respectively steel-arch support or powered support) that must be resistant to this impact (Brodny, 2011; Szurgacz & Brodny, 2019a; Szurgacz & Brodny, 2020).

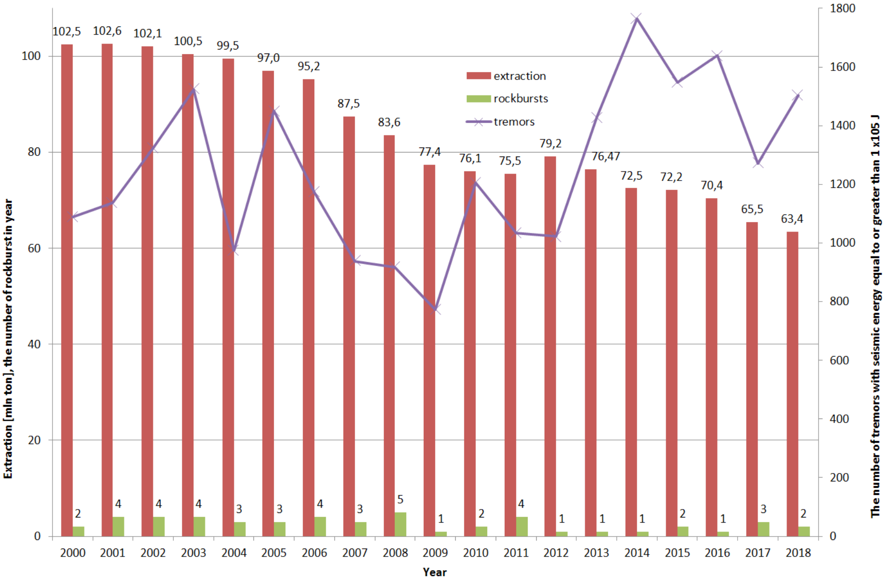

Fig. 1. Output, number of rock bursts and tremors in hard coal mines in the USCB (Annual Report, 2019)

At the same time, the Polish coal mining industry is currently based on the use of a longwall caving system only. In this case, the powered roof support is the main element followed by the main gate supported by yielding arch support which is often reinforced by rock bolts (Niedbalski & Majcherczyk, 2018). In general, a construction of powered roof support with two legs and a lemniscate system is used. These supports are commonly equipped with two-stage legs and rarely one-stage types, with a mechanical or hydraulic extension. The internal diameters of these legs are normally between 210 and 250 mm. Recently, a trend has been observed to increase the inner diameter of the support legs (300 mm and more), which most often requires the unit pitch to be increased to 1.75 m.

2. Evaluation of the influence of dynamic phenomena on a powered roof support

The exploitation of hard coal based on a longwall system is associated with the risk of dynamic phenomena. Prusek and Masny (2015) used the analysis of a 10 year period and pointed out that in the case of the mines of Kompania Węglowa S.A. (Now PGG S.A.), 76% of cases of rock burst and decompression occurred during mining in longwall areas, and 24% of cases occurred during the excavation of galleries. Therefore, in order to ensure safe and economically justified mining operations, it is important to assess the impact of dynamic phenomena on the powered roof supports and use the results to take appropriate technical and organisational measures to minimise this impact.

The basic form of assessment of the impact of dynamic phenomena on the powered roof support is the analysis of registered events. Profaska (2001) identified the most frequent damage to powered roof supports in longwalls caused by tremors in the years from 1979 to 1997. The research show that it is the hydraulic leg of the powered roof support that is damaged most often (in 39% of cases), usually by breaking or tearing the rod. A similar analysis is presented in the paper (Prusek & Masny, 2015) for the years 2003-2012.

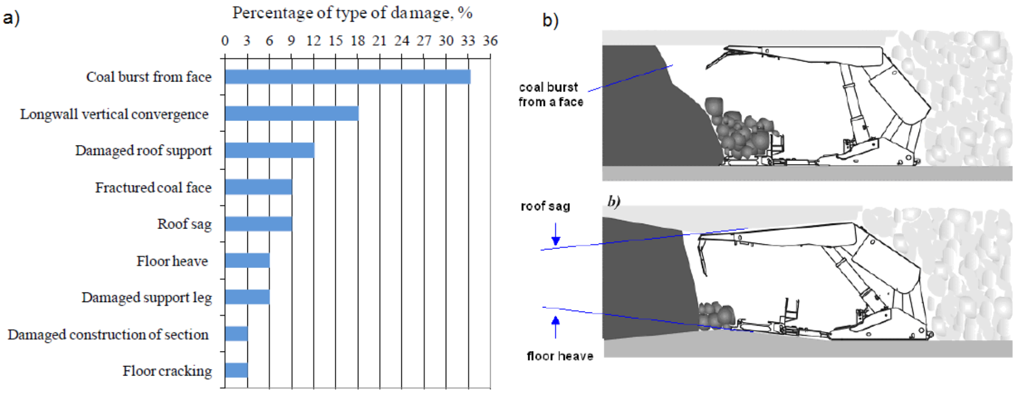

Fig. 2. Types of damage to longwalls and shield supports caused by dynamic phenomena (a) and characteristic forms of damage to a longwall (b) (Prusek & Masny, 2015)

The data presented in Figure 2 indicates that in most cases (33%), coal was most often thrown out of the sidewall to longwall excavations due to the dynamic impact of the rock mass. In over 18% of the longwall excavations, the height decreased (Fig. 2a and b), and in 12% of cases individual supports located in the area of the longwall entries also experienced damaged.

It is extremely difficult to measure the actual increased levels of load impacting on the powered roof support during in situ tremors due to the specific nature of the structure, the method of installation in the excavation and the characteristics of operation. Currently used automatic measurement systems, mainly focused on pressure measurements in under piston space of legs, due to the frequency of measurements, cannot directly record effects of dynamic events (Płonka & Rajwa, 2011; Prusek et al., 2016). Szweda (2003, 2004) presented the results of dynamic load measurements using strain gauges placed on the mechanical extension of the hydraulic leg. He then used the analysis of the results to characterize the dynamic load courses of the powered roof support over time. An example of such measurement is shown in Figure 3.

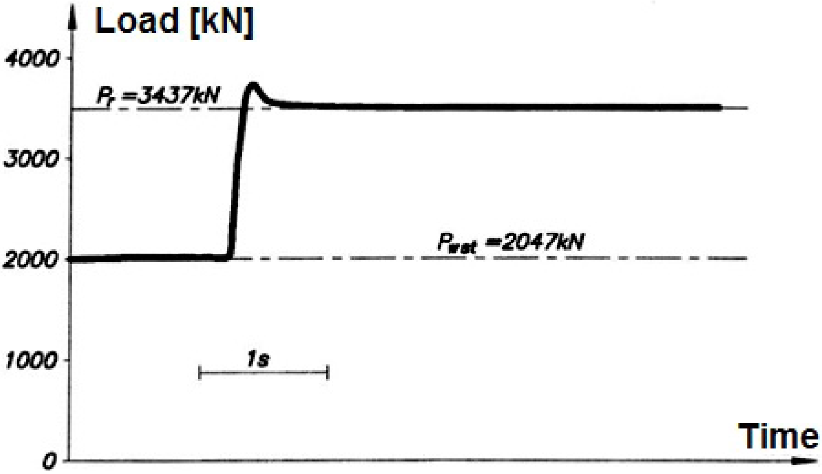

Fig. 3. Changes in load impacting on a powered roof support over time, during a rock burst of 5·104 J (Szweda, 2004)

The seismic events were also simulated using explosives (Szuścik & Bomersbach, 2000a, 2000b) in order to investigate the behaviour of the powered roof support under dynamic impacts. The results of these tests are presented in the form of values of dynamic coefficients k_d, understood as the maximum dynamic pressure in leg in relation to the static pressure before dynamic loading. The values of dynamic coefficients k_d are in the range 1.2-1.7.

3. Protection of a powered roof support against the negative effects of dynamic phenomena

In order to limit damage to powered roof supports or limit the loss of stability of the longwall workings, a range of rock burst and seismic prevention measures are applied. Such practices require various steps including the periodical discharge of stresses in concentration zones or the provocation of tremors. The technical methods include: irrigation of the seam, destressing drilling, blasting, directed hydrofracturing of rocks, directional fracturing of rocks with the use of a blasting method, and the destressing of a seam by mining an adjacent seam (Dubiński & Konopko, 2000; Braeuner, 1994; Junker et al., 2006).

The impact of dynamic loads on the behaviour of the powered roof support can be taken into account during the process of its design and after, when individual features of the support are adjusted to given geological and mining conditions by means of appropriate calculations based on empirical and analytical relations (Biliński, 2005). However it must be clearly emphasized that support designing with consideration of tremors occurrence, must not and should not replace activities for coal burst prevention. Planning and measures to reduce the effects of dynamic events must always have priority.

When using the powered roof support in conditions characterised by frequent tremors, in compliance with Polish legislation (Regulation of the Minister of Energy, 2016), it is expected that support should be prepared to take over dynamic loads as a derivative of these seismic events, without exceeding the permissible overloads of the hydraulic leg, the so-called yielding of the roof support. In practice, the powered roof support is usually yielded by yielding the hydraulic support system (hydraulic legs) by means of quick release (yielding) valves. They have the ability to open and close quickly to reduce the under piston pressure to a safe value by draining the liquid from the leg's working space to the outside when the dynamic load occurs (Peng, 1984; Świątek, & Stoiński, 2019). The diagram of the operation of a quick release valve is shown in Figure 4.

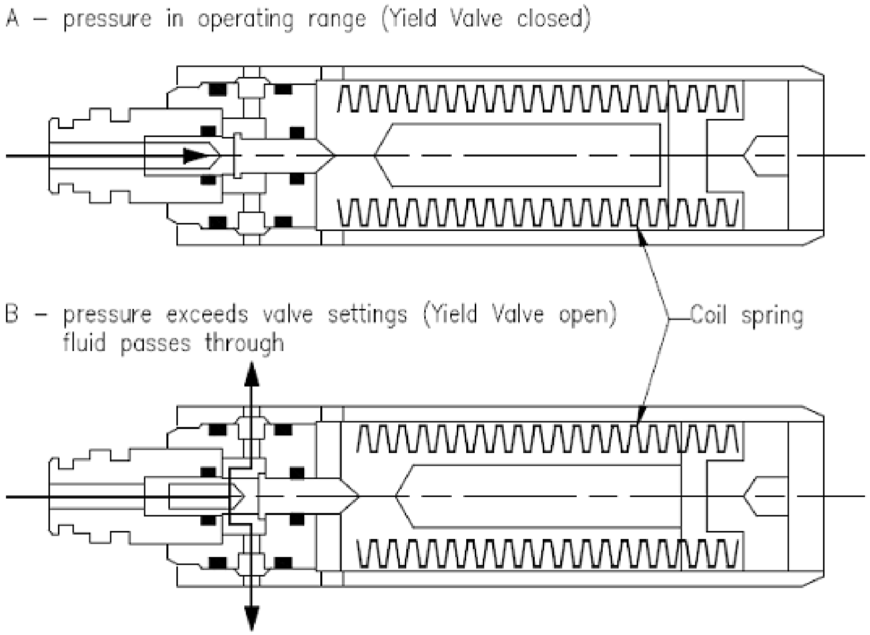

Fig. 4. Diagram of the operation of a release valve (Peng, 1984)

An analytical method is used to assess the yielding level of the powered roof support. The basis for determining the yielding level of the powered roof support in compliance with the methodology is a comparison of the predicted loads of the unit, resulting from tremors, with its nominal support. The main assumption of this method is based on the fact that the unit support is determined by the hydraulic leg as the main support, including the kinematics (Prusek et al., 2005; Stoiński, 2006, 2008).

Recently, work has also been undertaken to determine the required overload capacity of the powered roof support's leg. This method assumes that ensuring the safe operation of the powered roof support during a rock burst can be achieved if the overload capacity of the hydraulic leg is greater than the predicted support load (Szurgacz 2013; Szurgacz & Brodny 2019b).

4. Numerical modelling of the powered roof support

The numerical analyses of the powered roof support focus mainly on the strength calculations of its individual elements under static loads resulting from standardised schemes of extortion. Such calculations are usually performed by construction engineers and designers. Moreover, the advanced calculation software (such as ANSYS, NASTRAN or ABAQUS) makes the whole process easy and smooth (Badura et al., 2006; Matusik & Gwiazda, 2011; Polak-Markowicz & Łagoda, 2012; Qin et al., 2013). However, reproduction of the actual operation of the powered roof support in a rock mass environment differs. In the case of computer programs that seamlessly reproduce the parameters and behaviour of geological structures (FLAC, PHASE, UDEC), the implementation of the powered roof support into such a model is difficult and sometimes even impossible.

Available pieces of work present different ways of mapping the powered roof support using two-dimensional numerical modelling programs, such as applying forces to the contour of the longwall (Prusek et al., 2005; Gonzalez-Nicieza et al., 2008), using equivalent resilient material (Unver & Yasitli, 2006), placing beam elements between the roof and the model grid (Singh, Singh, 2009) or using coated roof support (Yasitli, Unver, 2005). However, these programmes do not allow for the direct reproduction of the geometry and the resulting support of the powered roof support

5. Calculation methodology and assumptions

Taking all presented information into account, a new methodology was developed to determine the impact of dynamic phenomena on the powered roof support operating in specific geological and mining conditions. This methodology uses numerical modeling in FLAC program, based on the finite difference method and ANSYS, based on the finite element method. Due to the article framework, not all details are explained, but a general outline of the methodology is presented – Figure 5.

The assumed strength and deformation parameters of the rock mass for the conditions of the analysed hard coal mine are presented in Table 1.

TABLE 1

Strength and deformation parameters assumed in numerical modelling

Materials		**Volumetric density**	**Internal friction angle**	**Cohesion**	**Young's modulus**	**Poisson's ratio**	**Compressive strength**	**Tensile strength**
		ρ	φ	c	E	n	R_c	R_r
		kg/m^3	degrees	MPa	GPa	—	MPa	MPa
Roof	Sandy shale	2650	26	6.8	11	0.25	21.7	2.0
	Sandstone	2500	27	8.5	14.0	0.25	27.7	2.7
	Shale	2600	26	6.0	10.0	0.25	19.2	1.9
	Coal seam 510	1300	24	3.2	3.5	0.30	10.0	1.0
Floor	Shale	2600	25	4.3	8.0	0.25	12.8	1.3
	Sandy shale	2650	26	7.0	11.1	0.25	22.7	2.2

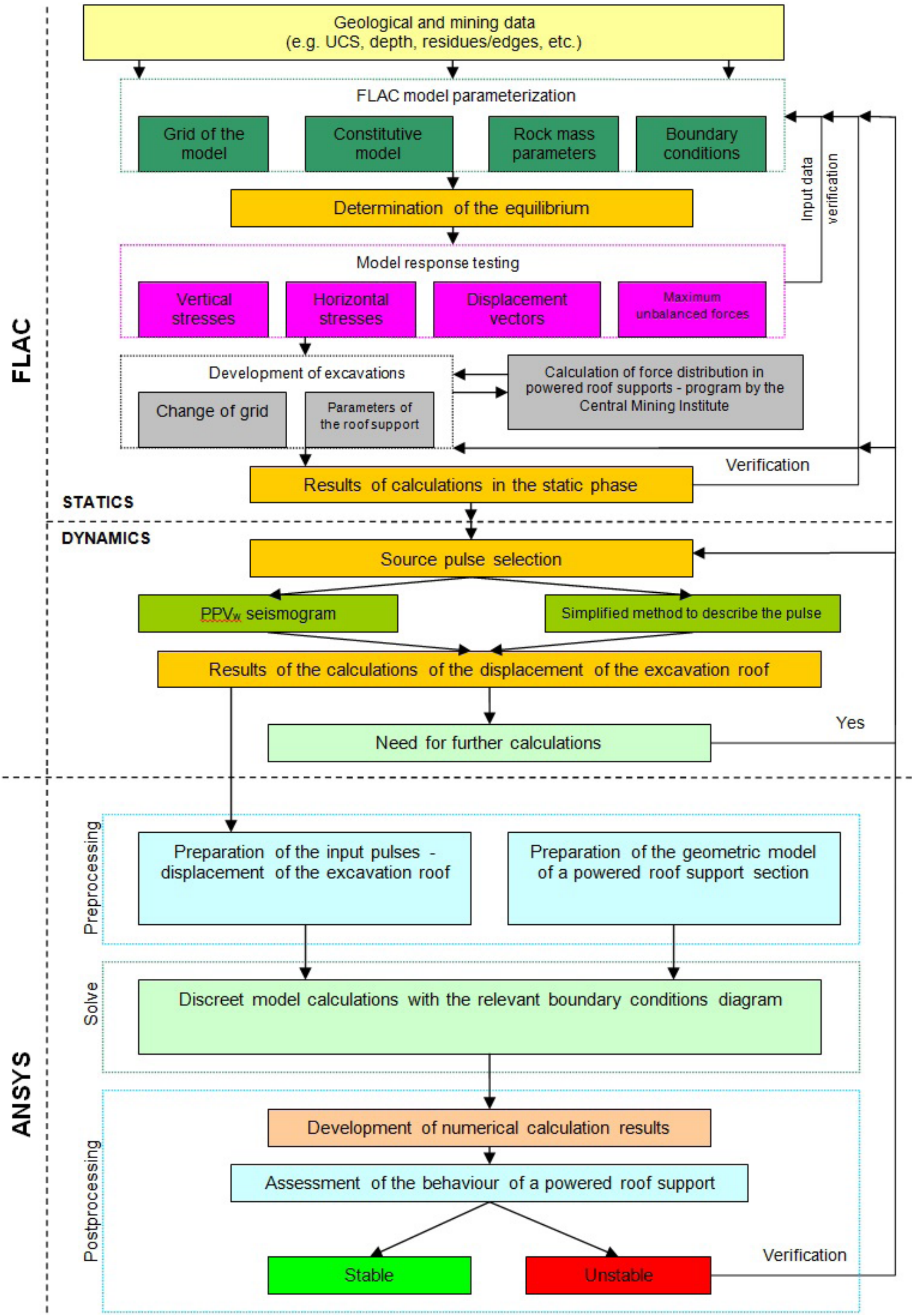

Fig. 5. Methodology of calculating the behaviour of a powered roof support impacted by dynamic phenomena

Figure 6 shows the numerical model together with the analysed longwall excavation.

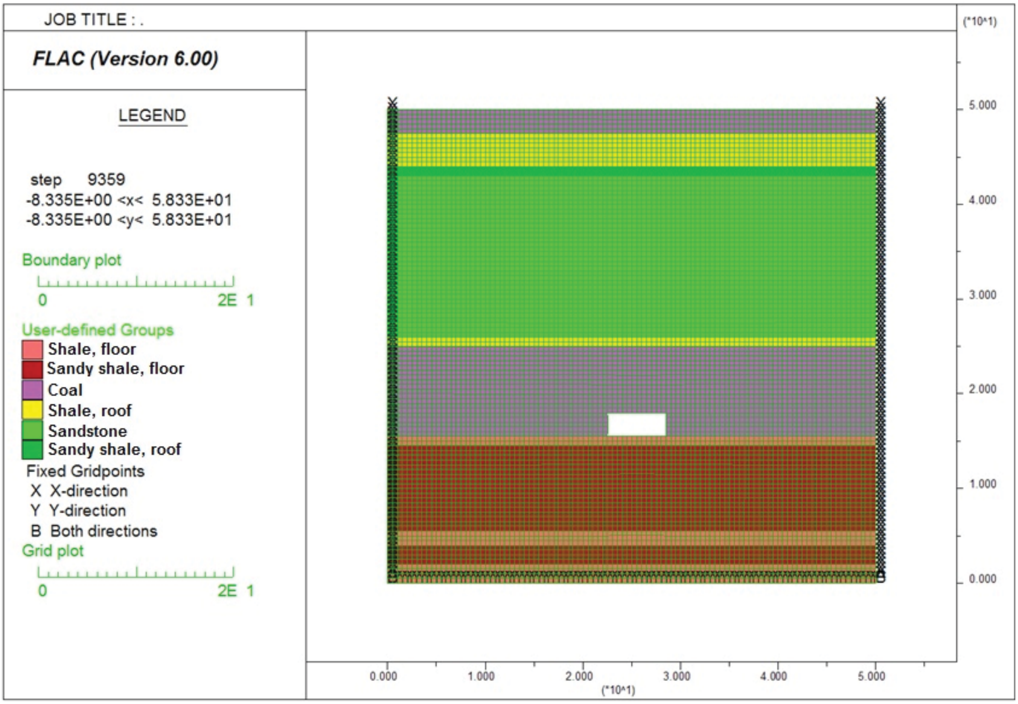

Fig. 6. Models of rock mass including the location of longwall excavations

In addition, the numerical calculations included the following assumptions:

- the rock mass model was built as a plate in plane strain state, consisting of 10,000 elements and divided by a grid of $0.5 \cdot 0.5$ m mesh,
- displacement conditions at the side edges for static calculations; zero horizontal displacements at both side edges and zero vertical displacements at the bottom edge,
- a vertical stress of 17.9 MPa and horizontal 7.7 MPa was obtained in the place of the planned location of the excavation, which corresponds to a depth of approximately 715 m,
- the constitutive model of the elastic-ideal plastic body with Mohr-Coulomb failure condition was assumed for the rock mass.

The calculation of the static phase was followed by the calculation taking into account the additional load resulting from tremors. Appropriate changes were made to the numerical model by applying a source impulse on the upper edge of the model and elements simulating an infinite area (free-field boundaries) were introduced on both side walls. This assumption meant that the waves, when propagating down the model, were not distorted by the model boundaries as conditions similar to those of the infinite model were provided (FLAC v.6.0, 2008).

To map the dynamic pulse, PPV_w values were used, which were obtained from actual measurements obtained in a hard coal mine. The analysis included the influence of five dynamic impulses with maximum PPV_w values: pulse 1 = 0.110 m/s, pulse 2 = 0.046 m/s, pulse 3 = 0.038 m/s, pulse 4 = 0.049 m/s, and pulse 5 = 0.122 m/s (pulse caused by explosives) (Figure 7).

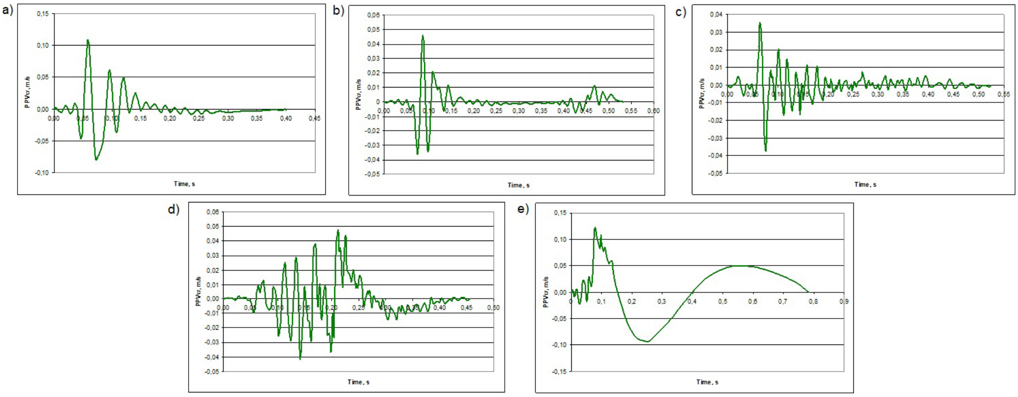

Fig. 7. Seismograms: a) pulse 1, b) pulse 2, c) pulse 3, d) pulse 4, e) pulse 5

Numerical calculations carried out in the FLAC program show the roof displacement values changing over time. The results of FLAC calculations were used for further calculations in ANSYS.

In the calculations made in the FLAC program, the calculated pressures on the floor and the roof of the powered roof support were mapped using beam elements simulating these two elements. Concentrated forces were applied in the end nodes that corresponded to the values, as in Figure 8a, RA, RB for floor base and P1 and P2 for canopy, based on the methodology (Płonka & Rajwa, 2009; Rajwa et al. 2020). In addition, Qy = 295 kN component was applied to the roof, also through a beam element of the appropriate length, associated with the impact of the caving shield (Figure 8b)

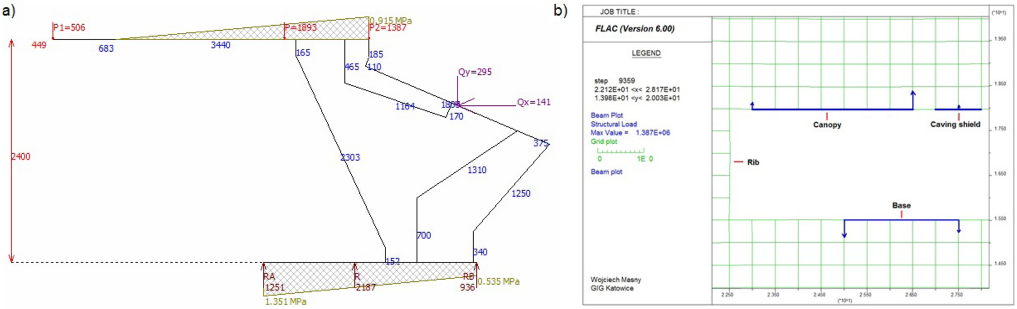

Fig. 8. a) Numerical model of powered support (image from a program developed by Central Mining Institute) and b) the method for modelling a powered roof support in FLAC program

Discrete SOLID elements were used to build a model of the powered roof support in ANSYS software. As material models, the bilinear characteristics corresponding to three different grades of steel were adopted, from which, according to the construction documentation, individual elements of the analysed support were made, i.e. S355J2+N, S420N and S690Q.

The use of appropriate dependencies and software scripts enabled the simulation of the operation of the support, taking into account the actual operation of the support as a kinematic system with substitute hydraulic elements. The support scheme (Figure 9) was selected to show the actual interaction between the sections and rocks surrounding the longwall excavation (Witek, 2014). The extortion diagram in the model was appropriately modified to ensure compliance with current design assumptions, i.e. to allow for the transmission of a variable amplitude extortion pulse and to reproduce the operation of the roof support under dynamic conditions.

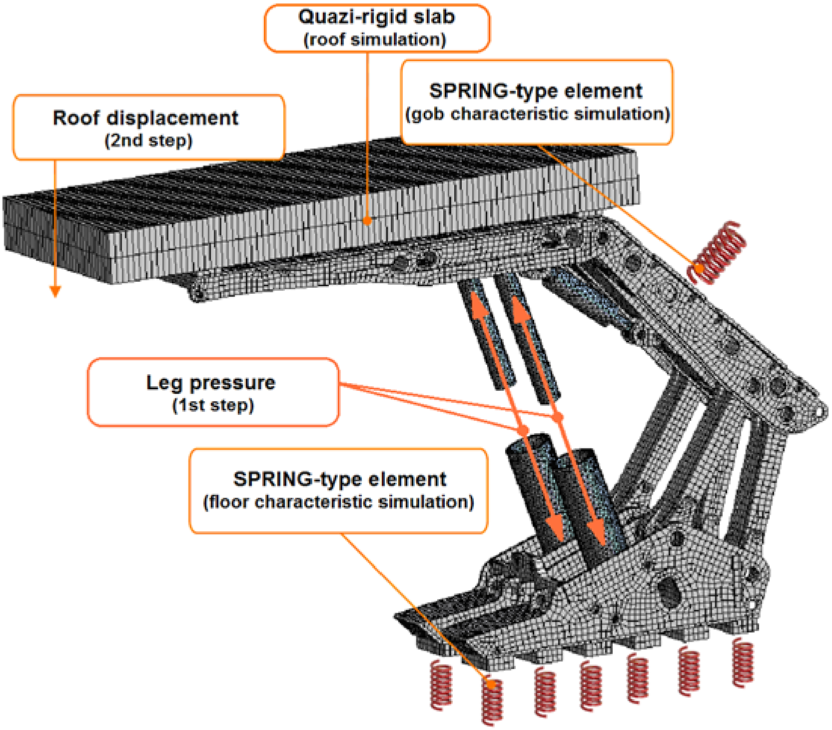

Fig. 9. Calculation model of a powered roof support with support and extortion scheme

Calculations were made for variants of roof displacements, corresponding to dynamic phenomena with different values of PPV_w, measured in situ (PPV_w = 0.038; 0.046; 0.049; 0.110; 0.122 m/s). The course of individual pulses and maximum displacement values for individual PPV_w cases are shown in Figure 10.

The load in the model was set in two stages. Initially, the unit of the powered roof support was set in the rock mass by a force resulting from the working pressure in hydraulic legs (25 MPa), which introduced the initial stress state into the system. Next, the roof displacements (of variable amplitude) resulting from the PPV_w value obtained by numerical calculations in the FLAC environment were applied.

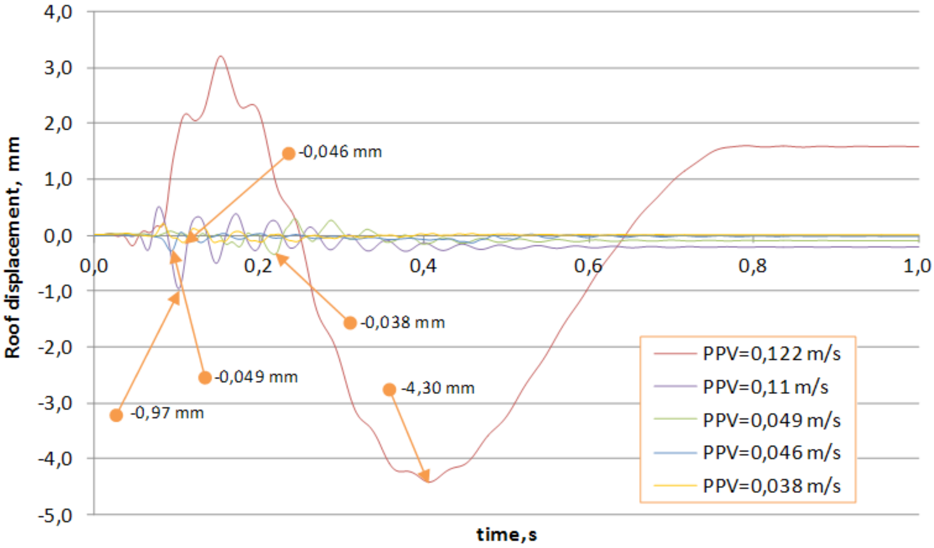

Fig. 10. Course of roof displacement changes for particular PPV_w values measured in situ; maximum roof displacement values in the direction of the excavation section are marked

6. Results of the calculations

The calculations resulted in model deformations, stress components and their distribution under the given load were obtained. Figure 11 shows an example of reduced stress distribution from the Huber-Mises-Hencky hypothesis. Maximum values of HMH stresses caused by the assumed load, as well as the pressure change in the roof support's legs are shown as a diagram in Figure 12.

As presented in Figure 12, each of the analysed pulses caused a specific increase in HMH stress in the structure of the powered roof support and at the same time an increase in pressure in the under piston space of the leg. The highest HMH stress increases were located always in main load-bearing elements of canopy and base and in case of PPV_w = 0,122 m/s that was 88% of the limit value.

By analysing the actual dynamic phenomena and the associated measured PPV_w values, it can be concluded that when the PPV_w values are less than 0.049 m/s, the HMH stress changes in the steel of the structure of the powered roof support and the pressures in the space under the piston are so small that no adverse effects in the longwall are expected to occur.

Moreover, the results of the calculations indicate that the behaviour of the powered roof support, in addition to the maximum PPV_w value, is also significantly influenced by the frequency of the dynamic pulse. This relationship is clearly visible if the changes of reduced stress in the powered roof support are compared, as in Figure 12, with $PPV_w = 0.122$ m/s and $PPV_w = 0.110$ m/s. The first phenomenon caused an increase in reduced stress by 16%, while the second one by 3% in relation to the static phase, even though the difference between the pulses was as low as 0.012 m/s. Figure 13 shows the frequency spectra of both input pulses obtained by means of a fast Fourier transform.

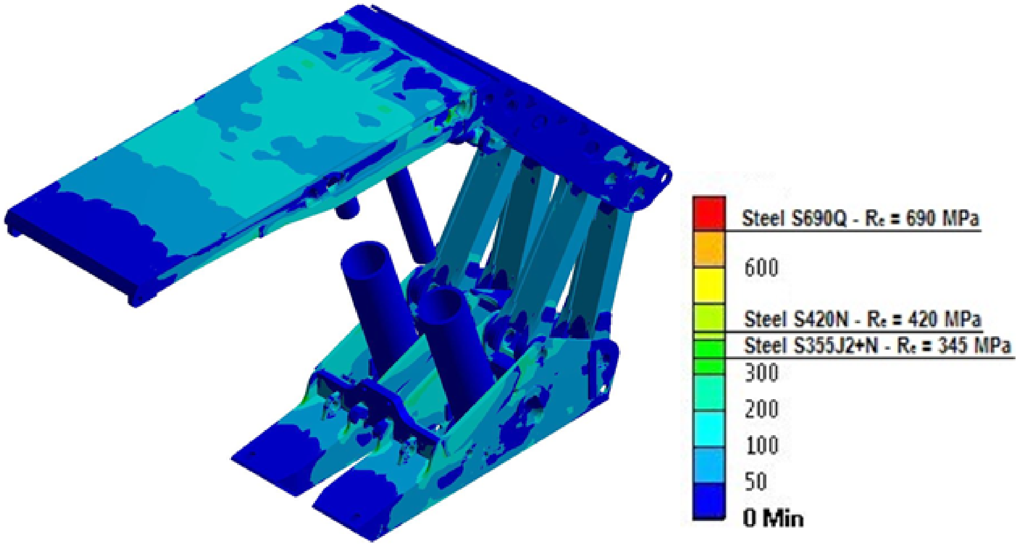

Fig. 11. Distribution of HMH stress in a unit of a powered roof support impacted by variable amplitude roof movements associated with dynamic in situ pulses: PPVw = 0.11 m/s

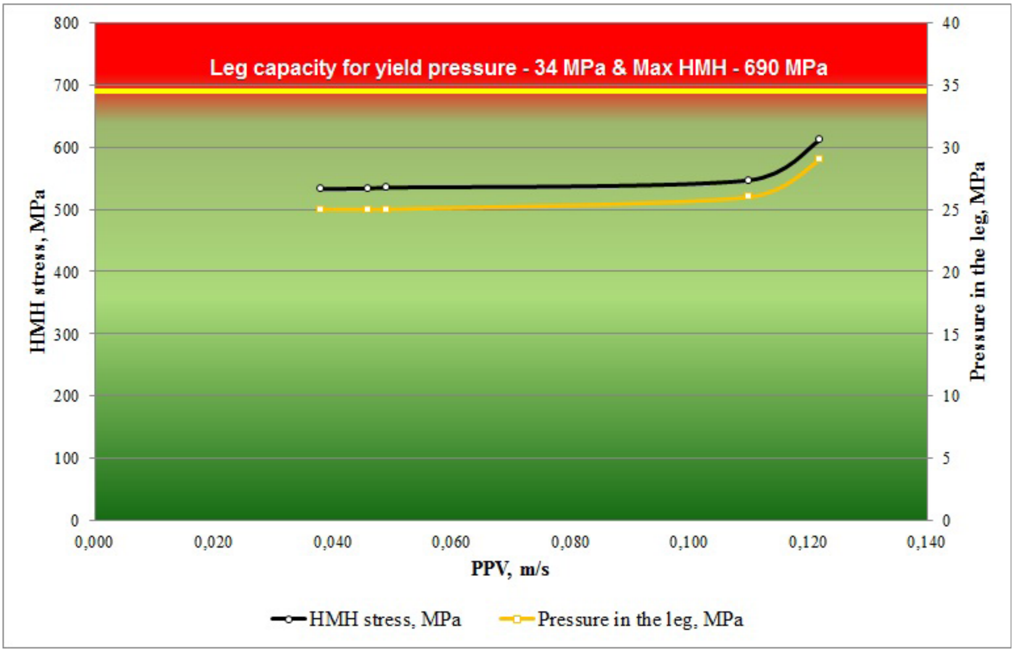

Fig. 12. Maximum readings of the HMH stress values in the unit of the powered roof support together with the values corresponding to the pressure in the leg for the individual PPV_w values measured under in situ conditions

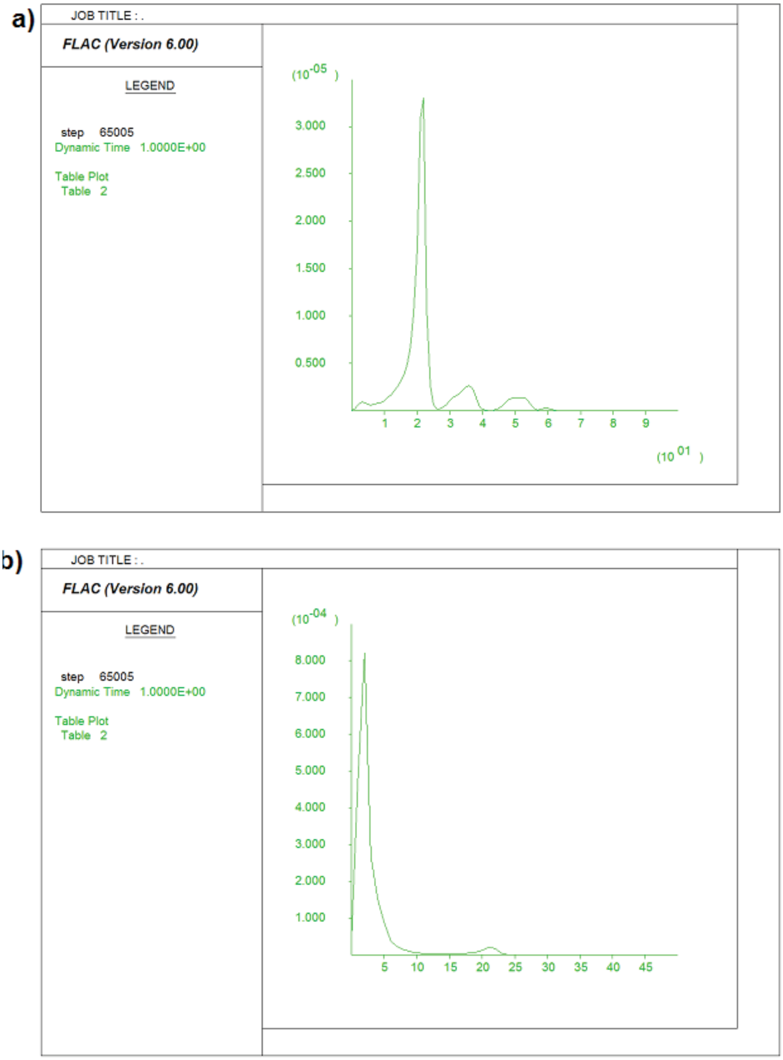

Fig. 13. Input pulse frequency spectrum, obtained with fast Fourier transform (FFT):
a – dynamic pulse $PPV_w = 0.110$ m/s, b – dynamic pulse $PPV_w = 0.122$ m/s

As presented in Figure 13, the input pulse $PPV_w = 0.110$ m/s had a dominant frequency of about 20 Hz (Figure 13a) which is ten times higher than in the case of the pulse $PPV_w = 0.122$ m/s (2 Hz) (Figure 13b). From the point of view of design behaviour, the lower the pulse frequency value, the more unfavourable it is. This is directly reflected in changes in HMH stress values.

The load impacting on the powered roof support is also important in the case of a static operating phase. When the powered roof support is heavily loaded and the pressure in the under piston space amounts to almost 34.0 MPa (valve opening), even a small dynamic impulse may lead to negative effects in the longwall related to e.g. deterioration of roof conditions or even rock fall.

7. Conclusion

Tremors occur randomly, in terms of time, energy as well as location of their focus. The present state of knowledge and technology does not enable the precise prediction of these values. Therefore, it is extremely important to select a powered roof support with parameters adjusted to specific geological and mining conditions. The main goal when the powered support is used in condition of rock mass tremors is always to limit the pressure in the under piston space of the legs to values that do not cause damage. For this purpose, following parameters should be considered:

- load exerted on longwall support,
- seismic energy,
- the angle of inclination of the leg,
- the operation height of the support,
- minimal height of liquid column in the under piston space of a hydraulic leg,
- the flow rate of the hydraulic system (together with a yielding valve).

This selection, due to the complexity of the issue, should be comprehensive and take into account the latest available tools.

The method of evaluation of the behaviour of a powered roof support impacted by dynamic phenomena presented in the article allows for a thorough analysis of the construction of the roof support during the occurrence of such phenomena. It enables the analysis of the construction of roof support, the materials from which it is made and enables the determination of behaviour in specific geological and mining conditions. Furthermore, one of the main advantages of the methodology is the ability to perform multi-variant analyzes in a relatively short time. The methodology can be used whenever the powered support is designed for the given geological and mining conditions, especially if the mine orders a new construction from the manufacturer.The improved support dimensioning increases the safety in the longwall mining area if, for example, a rock burst unexpectedly despite measures taken to prevent it.

The assessment will be further developed as it has numerous advantages and benefits, as mentioned above.

Acknowledgements

The author would like to express his gratitude to Łukasz Szot, M.Sc., for his valuable comments and observations during the course of this work.

References

Annual report (2019) on the natural and technical hazards in hard coal mining, 2019. Ed. J. Kabiesz. GIG Katowice.

Badura S., Bańdo D., Migacz K., 2006. *The strength's analysis of MES of sill piece of mechanized casing „Glinik 15/32 Poz.* Górnictwo i Geoinżynieria Rok 30, **1**, 9-14.

Biliński A., 2005. *Method of selection of longwall face and roadway supports for the panelling conditions*. CMG Komag. Gliwice.

Braeuner G., 1994. *Rockbursts in coal mines and their prevention*. Balkema, Rotterdam, 144.

Brodny J., 2011. *Tests of friction joints in mining yielding supports under dynamic load*. Arch. Min. Sci. **56**, 2, 303-318.

Dubiński J., Konopko W., 2000. *Rockbursts – assessment – forecast – fighting*. GIG Katowice.

FLAC v.6.0, 2008. *User's Guide*. Itasca Consulting Group, Minneapolis, USA.

Gonzalez-Nicieza C., Menendez-Diaz A., Alvarez-Vigil A.E., Alvarez-Fernandez M.I., 2008. *Analysis of support by hydraulic props in longwall working*. International Journal of Coal Geology **74**, 67-92.

Junker M. et al., 2006. *Gebirgsbeherrschung von Flözstrecken*. Verlag Glückauf, Essen.

Lubosik Z., Rajwa S., Walentek A., Masny W., Wrana A., 2020. *The role of powered support in ensuring the proper longwall working cross-section area in rockburst-prone seams*. 9th International Symposium on Occupational Health and Safety – *SESAM 2019,* Petrosani, Romania. MATEC Web Conf. **305** DOI: 10.1051/matecconf/202030500081

Majcherczyk T., Niedbalski Z., 2017. *The impact of multiple seam mining exploitations on seismic activity and state of stress*. Studia Geotechnica et Mechanica vol. **39** no. 1, 53-62.

Matusik T., Gwiazda A., 2011. *Analysis of loads and stability of mining supports*. Wybrane Problemy Inżynierskie **2**, 255-260.

Niedbalski Z., Majcherczyk T., 2018. *Indicative assessment of design efficiency of mining roadways*. Journal of Sustainable Mining **17**, 3, 131-138.

Patyńska R., Stec K., 2017. *Regional rockburst inidicator for structural units of upper silesia coal basin.* Studia Geotechnica et Mechanica **39**, 3, 2017 DOI: 10.1515/sgem-2017-0027

Peng S., 1984. *Longwall Mining*. Wiley. New York.

Płonka M., Rajwa S., 2009. *Bearing capacity and distribution of forces in the nodes of hydraulic powered roof supports' sections*. Wiadomości Górnicze **10**, 611-617.

Płonka M., Rajwa S., 2011. *Assessment of Powered Support Loadings in Plow and Shearer Longwalls in Regard to the Pressure Measurements in Props*. International Mining Forum, Dyczko et al. (eds), A Balkema Book. CRC Press, © Taylor & Francis Group, London, UK, 221-232.

Polak-Markowicz M.P., Łagoda T., 2012. *Estimation of fatigue life for powered roof supports FAZOS*. Modelowanie inżynierskie **44**, 237-244.

Profaska M., 2001. *Causes of damage to the elements of powered roof supports in longwalls affected by rockbursts*. PhD Thesis. Gliwice.

Prusek S., Kostyk T., Rajwa S., Walentek A., 2005. *Roof stability in the frontal area of longwall depending on the rock mechanical properties and powered support characteristic*. Prace Naukowe GIG, Seria Konf. **50**, 37-44.

Prusek S., Masny W., 2015. *Analysis of damage to underground workings and their support caused by dynamic phenomena*. Journal of Mining Science **51**, 1, 63-72.

Prusek S., Płonka M., Walentek A., 2016. *Applying the ground reaction curve concept to the assessment of shield support performance in longwall faces*. Arab J Geosci **9**: 167.

Prusek S., Rajwa S., Stoiński K., 2005. *Kriterien zur Abschatzung des Risikos von Strebschaden*. Glückauf-Forschungshefte **3**, 92-95.

Qin D., Li H., Liu Z., Chen J., 2013. *Research on structural optimization design for shield beam of hydraulic support based on response surface method*. APCOM & ISCM, 11-14th December. Singapore, 1-7.

Rajwa S., Janoszek T., Prusek S., 2020. *Model tests of the effect of active roof support on the working stability of a longwall.* Computers and Geotechnics **118**, DOI: 10.1016/j.compgeo.2019.103302.

Szurgacz D., Brodny J., 2019a. *Analysis of the influence of dynamic load on the work parameters of a powered roof support's hydraulic leg*. Sustainability **11**, 9, art. no. 2570; DOI:10.3390/su11092570.

Szurgacz D. Brodny J., 2019b. *Tests of Geometry of the Powered Roof Support Section*. Energies **12**, 20, art. no. 3495; DOI:10.3390/en12203945.

Szurgacz D., Brodny J., 2020. *Adapting the Powered Roof Support to Diverse Mining and Geological Conditions.* Energies **13**, 213, art. no. 405, pp.1-24. DOI:10.3390/en13020405.

Regulation of the Minister of Energy, 2016, (23.11.2016 r.) *on detailed requirements for the operation of underground mining plants*. Journal of Laws No. 2017, item. 1118, Warszawa, 9 June 2017.

Singh G.S., Singh U.K., 2009. *A numerical modeling approach for assessment of progressive caving of strata and performance of hydraulic powered support in longwall workings*. Computers and Geotechnics **36**, 1142-1156.

Stoiński K., 2006. *The method of powered roof support yielding*. GIG, Katowice.

Stoiński K., 2008. *Practical aspects of flexibility of the mechanized lining.* Napędy i Sterowanie **7/8**, 101-106.

Szurgacz D., 2013. *A modified method for powered roof support selection to work in hazardous conditions of mining tremors*. PhD Thesis, Katowice.

Szuścik W., Bomersbach G., 2000a. *Theoretical foundations of dynamic tests of powered roof supports using a pile driver method*. KOMTECH **I**, Szczyrk, 1-3.

Szuścik W., Bomersbach G., 2000b. *Comparison of methods of dynamic load simulation on hydraulic legs of powered roof supports caused by pile driver and explosive methods*. TĄPANIA 2000 "Profilaktyka tąpaniowa w warunkach zagrożeń skojarzonych", Pr. nauk. GIG nr **36** Seria: Konferencje, 169-171.

Szweda S., 2003. *Dynamic action of rock mass on the powered support legs*. Journal of Mining Science **39**, 2, 154-161.

Szweda S., 2004. *Identification of parameters characterizing the dynamic load of the powered roof support unit caused by the dynamic action of the rock body*. Politechnika Śląska, Zeszyty Naukowe **1648**, Gliwice.

Świątek J., Stoiński K., 2019. *Case Analysis of Damages to Control Hydraulics of the Leg in the Powered Roof Support Section*. E3S Web Conf. Volume **105**, IVth International Innovative Mining Symposium, Article Number 03013. DOI: https://doi.org/10.1051/e3sconf/201910503013.

Unver B., Yasitli N.E., 2006. *Modelling of strata movement with a special reference to caving mechanism in thick seam coal mining*. International Journal of Coal Geology **66**, 227-252.

Witek M., 2014. *Influence of strength parameters of floor rocks on the work charateristic of the powered roof support in the longwall.* PhD Thesis, Katowice

Yasitli N.E., Unver B., 2005. *3D numerical modeling of longwall mining with top-coal caving*. International Journal of Rock Mechanics & Mining Sciences **42**, 219-235.