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A contribution to the design of powered roof support for operations in a rockburst-hazardous environment

The paper presents an example of a numerical analysis using ANSYS to optimise the design of powered roof support designed to operate in rock mass tremor hazard conditions. The areas of excessive stress in the structure of powered roof support were identified, taking into account the increase in rock mass loading resulting from tremors. An increase in the load impacting on the support as a result of rock mass tremors is the cause of excessive stresses in the section structure. The paper aims to identify them and to find ways to apply the design using numerical analysis. The analysis was conducted for roof support type ZRP-15/35-POz produced in Repair and Production Plant (ZRP-Bieruń) of Polish Mining Group S.A. (PGG S.A.) The introduction of reinforcements in places of increased stress in the support section structure should increase its operational safety in the excavation.

Key words: *powered roof support, numerical modelling, rock mass tremors, dynamic loads*

1. INTRODUCTION

Powered roof support is part of the basic equipment of a longwall system and is responsible, among other things, for securing the workings against roof rockfall into the working space. The high variability of geological-mining conditions, including those resulting from natural hazards, in particular rock mass tremors, places high support requirements on lining sections. These requirements include both static and dynamic loads [1, 2]. Longwall powered roof supports are marketed following the regulations laid down in the Directives and Polish standards harmonised with them. The basic directive is the Machinery Directive [3] and Polish standards harmonised with it from the PN-EN 1804 series [4–6]. The scope of safety requirements laid down in harmonised standards does not cover the case of rock mass tremor hazards. The safety requirements for rock mass tremor hazard conditions are supplemented following the Regulation of the Minister of Energy of 23 November 2016, Journal of Laws No. 2017 item 1118 §523 paragraph 1, pt. 1, and concerns yielding [7]. The provision does not specify in detail the requirements and procedures to be followed, leaving the problem to the discretion of the scientific research unit preparing the evaluation of the yielding of the support. Figure 1 shows an example of the rules for the introduction of powered roof support intended for work in rock mass tremor hazard conditions into the market and service, based on the directives and harmonised Polish standards.

Currently, the yielding assessment is prepared by the Central Mining Institute (GIG) according to its methodology. The GIG methodology assumes that due to a rock mass tremor, the hydraulic leg of the support must not be overloaded beyond the permissible capacity, taking into account its overload factor [8–12]. Safety was related to the leg assuming that it is the most important element supporting the roof. Such assumptions allow for the overloading of individual support elements beyond their capacity.

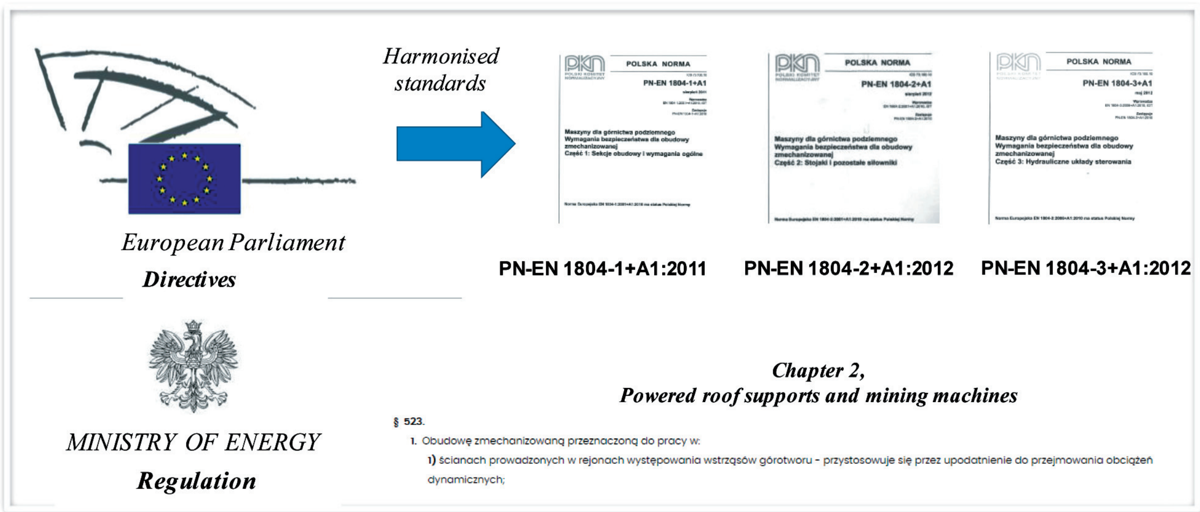


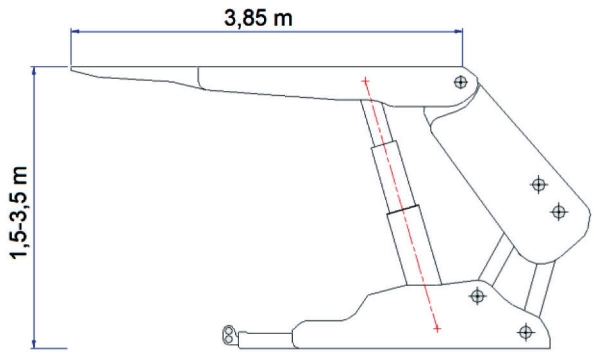
Fig. 1. Principles of introducing powered roof support intended for operation in rock mass tremor hazard conditions into the Polish market and exploitation

The paper aims to determine the locations in the support structure where stresses exceed the permissible values for increased strength loads on the support using numerical modelling, which has been successfully used in other fields of science such as aviation, construction, or the automotive industry [13–15].

For the cases analysed, an increased support load of 100% over the working values was assumed, while the method of support loading was referred to in the PN-EN1804-1+A1:2011 standard. Areas, where the stress in the material of the support exceeds the permissible limits, should be redesigned or reinforced for safety. Numerical methods using ANSYS [16] were used to analyse the stresses in the support elements for different support modes and overload values. The subject of the analysis is a powered roof support type ZRP-15/35-POz. The results, in the form of stress maps, will be used by designers when upgrading the support, as well as in the development of the support yielding evaluation.

2. THE SUBJECT OF THE ANALYSIS – A POWERED ROOF SUPPORT TYPE ZRP-15/35-POz

The ZRP-15/35-POz powered roof support was developed in the design office of Repair and Production Plant – ZRP Bieruń (ZRP) and is manufactured by ZRP, as well as by other companies commissioned by Polish Mining Group S.A. (PGG S.A.) The documentation is supplemented by 2D support drawings made using CAD software, which can be used for further numerical analysis. An overview drawing of the support and the basic technical parameters are shown below in Figure 2.



Geometric and support data	
Geometric/ lateral range of support height	1.5–3.5 m / 1.7–3.4 m
Sectional steps	0.8 m
Length of the canopy	3.85 m
Type	shield support equipped with two legs
Number of legs	2
I / II diameters of the legs	∅ 0.30/0.23 m
Initial leg support	1.767–2.121 MN
Working leg support	3.039 MN
Supply pressure	25–30 MPa
Working pressure	43 MPa
Leg securing system	type ZRP II

Fig. 2. Outline drawing and basic technical data of powered roof support type ZRP-15/35-POz

The designed section ZRP-15/35-POz is included in the current program of the ZRP plant connected with the unification and standardization of powered supports for the needs of PGG S.A.

3. PREPARATION OF THE MODEL AND ITS BORDER CONDITIONS

Using drawings imported from CAD, a 3D model was built to represent the structural form of the powered roof support in terms of the geometry of the entire system. Figure 3 shows the created 3D model of the ZRP-15/35-POz powered roof support used for further analysis.

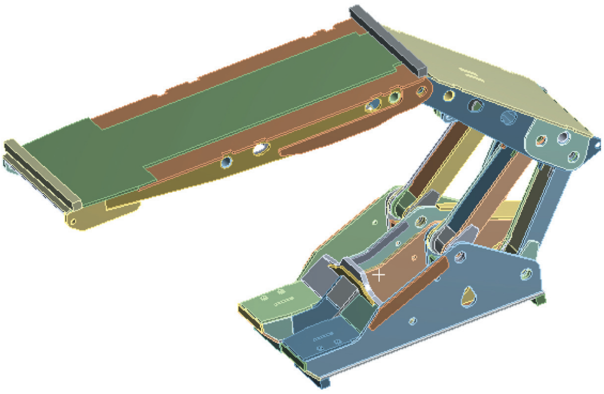


Fig. 3. A spatial model of powered roof support ZRP-15/35-POz used in numerical calculations

The kinetostatic calculations of the model were performed with the PrsLab 1.4.5 program [17] while the strength calculations were performed with the ANSYS program [16]. Isotropic material with linear deformation characteristics was assumed for the analyses. The material parameters were taken as for structural steel, i.e. Young's modulus E = 200 GPa and Poisson's ratio ν = 0.3. The minimum yield point of steel grade S690QL was used as the strength criterion, i.e. Re = 690 MPa. The mesh and number of elements were generated by ANSYS software. Numerical calculations were performed for loads of the support elements following PN-EN 1804-1+A1:2011 [4] and assumed overload coefficients of 1.05 for asymmetrical loads, and 1.2 for symmetrical loads. Additionally, for symmetrical and asymmetrical loads, an overload factor of 2.0 was adopted according to the GIG method for the yielding of powered roof support [11, 12]. The subject of analysis was supported as shown in Figure 4.

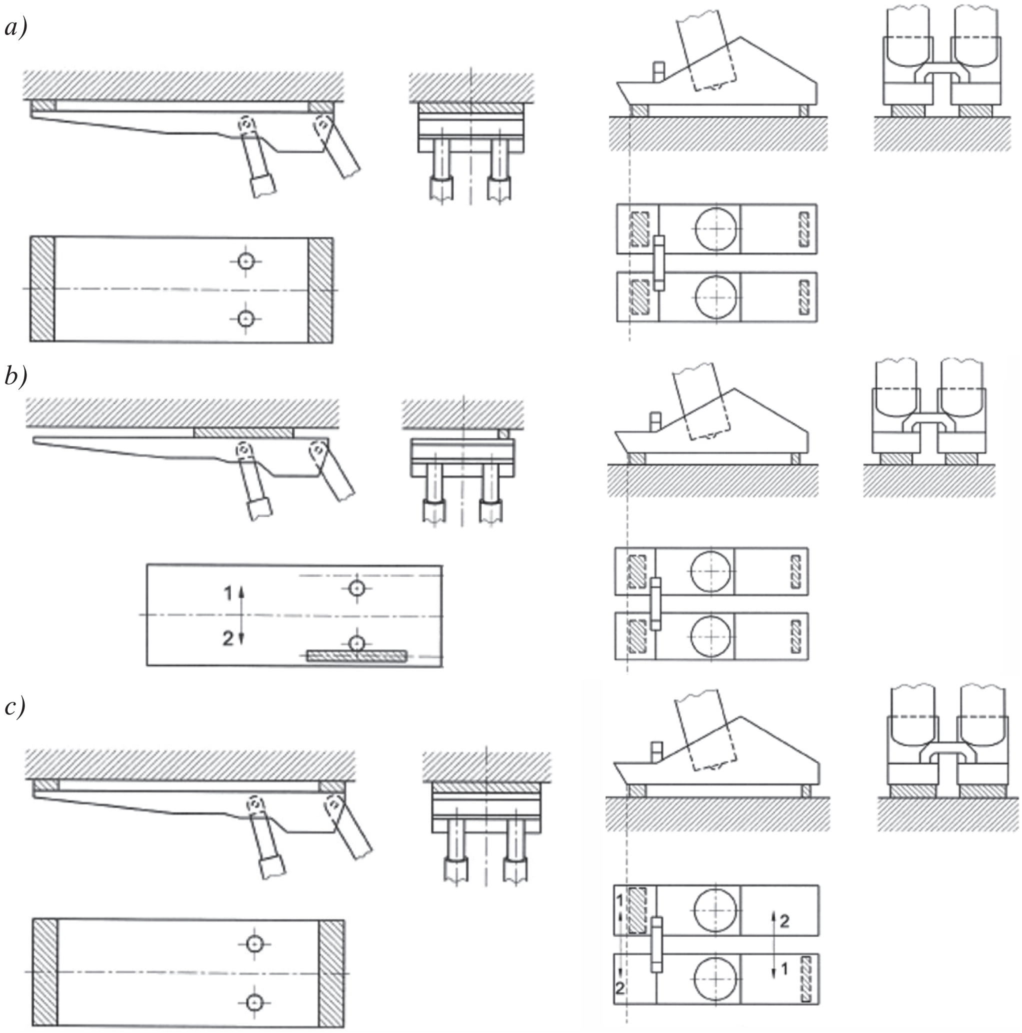
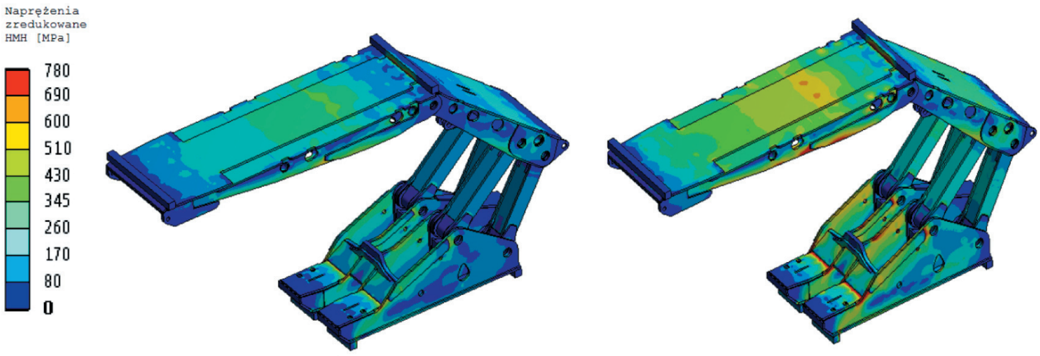


Fig. 4. Analysed ways of supporting sections: a) symmetry; b) asymmetry of the side of the canopy; c) asymmetry on the diagonal of the floor base

The numerical analysis was carried out for the three selected ways of support and for the working height of the ZRP powered roof support for which the highest stresses in the material of the elements occur.

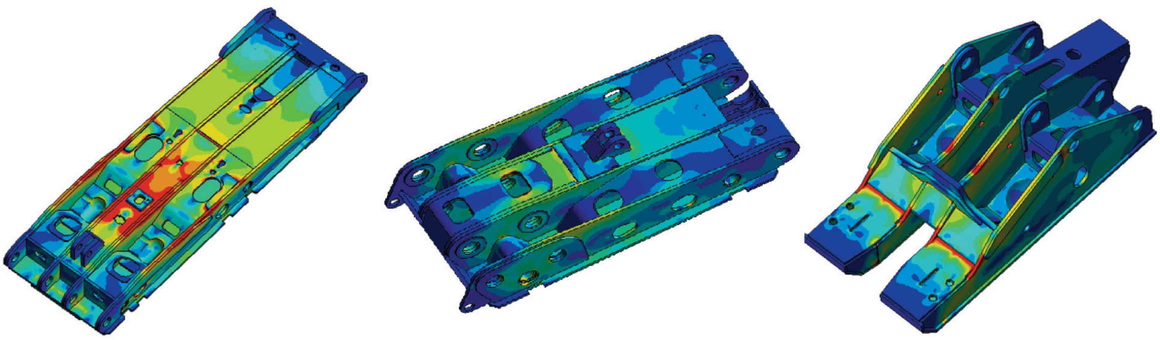
4. NUMERICAL CALCULATION OF POWERED ROOF SUPPORTS

The results of the numerical simulations carried out are presented in the form of colour maps of the stresses reduced in the individual elements of the powered roof support. The simulations were carried out separately for the basic elements of the support (canopy, caving shield, base) and jointly for the roof support. The publication only presents maps of reduced stresses that sufficiently represent the results of the numerical analyses carried out. The analyses were carried out for overload values resulting from the Polish standard for different ways of supporting the roof support (1.05 and 1.2) and for the case of overload resulting from the yielding condition (2.0), as a derivative of the rock mass tremor. Maps of the reduced stresses in the roof support and their components for different support modes and overload factors are shown in Figures 5–10.



Overload factor 1,2 Overload factor 2,0

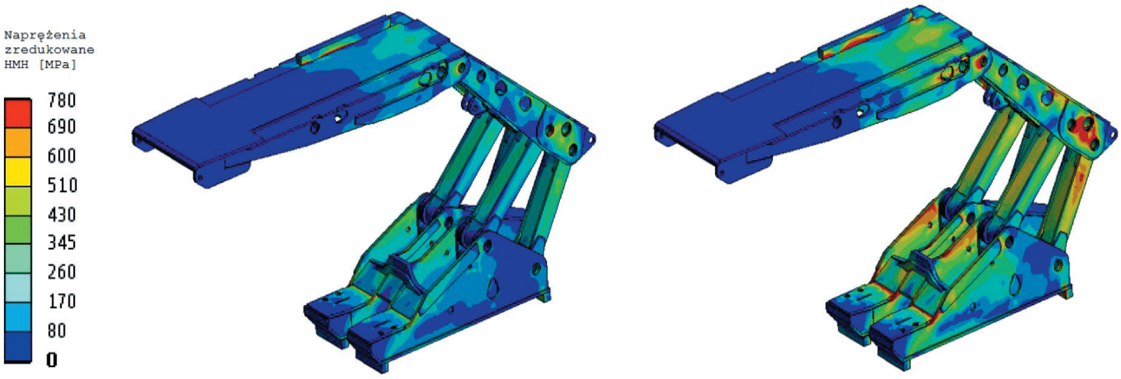
Fig. 5. Maps of reduced stresses in the section with symmetric support according to Figure 4a



canopy caving shield base

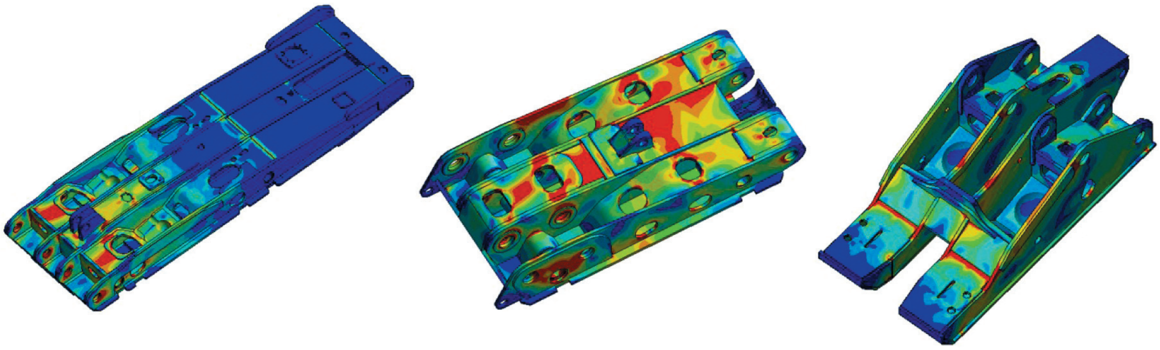
Overload factor 2,0

Fig. 6. Maps of reduced stresses in elements of sections with symmetric support according to Figure 4a



Overload factor 1,05 Overload factor 2,0

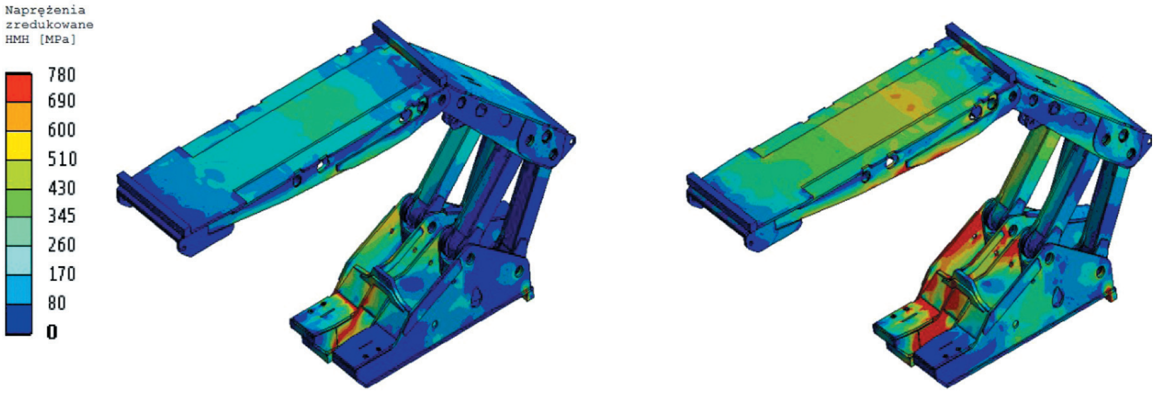
Fig. 7. Maps of reduced stresses in the section with asymmetric canopy support according to Figure 4b



canopy caving shield base

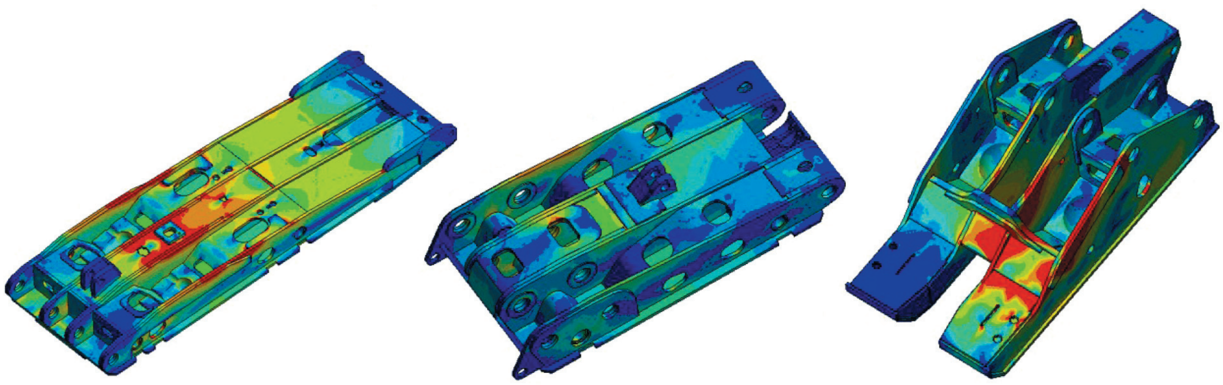
Overload factor 2,0

Fig. 8. Maps of reduced stresses in section elements with asymmetric canopy support according to Figure 4b



Overload factor 1,05 Overload factor 2,0

Fig. 9. Reduced stress maps in the section with diagonal asymmetry of the floor base according to Figure 4c



canopy caving shield base

Overload factor 2,0

Fig. 10. Maps of reduced stresses in elements of sections with diagonal asymmetry of the floor base according to Figure 4c

5. SUMMARY AND CONCLUSION

The problem presented in this article concerns an extremely important issue for the safety of longwall exploitation since currently more than 60% of extraction takes place in seams exposed to rock mass tremors. The occurrence of rock mass tremors results in overloading the powered roof support structure significantly above the coefficients (1.05 and 1.2) required by Polish standards [2, 5, 6, 11]. There is also the possibility of a large asymmetry in the load distribution on the roof support which further deteriorates the operating conditions of the section. This is why the authors of the publication decided to load the roof support with twice the overload to get an indication of the extent and location in the structure of the occurrence of increased overloads (marked in red in Figures 5–10). As shown in Figure 6, under symmetrical loading the largest overloads occur at the canopy of the section. In the case of asymmetric roof support, the highest overloads occur in the shield support – Figure 8. In the case of diagonal asymmetry of the floor base, the most overloaded elements are the elements of the base and the canopy, as shown in Figure 10.

The data obtained regarding the overloading of individual elements of the roof support allows the designer to strengthen these areas by changing the strength of the material, reinforcing them, or making structural changes. Each such action improves occupational safety and extends the failure-free operation of the powered roof support. The numerical analyses carried out also indicate that it is advisable to carry out numerical calculations of the section's structure given the large discrepancies between the overload coefficients required by Polish standards and the overloads occurring. The presented procedure will be implemented in the process of designing and manufacturing sections at ZRP-Bieruń.

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