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THE CONDITIONS FOR PROPER OPERATION OF THE ARCH-RECTANGULAR SUPPORT

WARUNKI POPRAWNEJ PRACY ODRZWIOWEJ OBUDOWY ŁUKOWO-PROSTOKĄTNEJ

Steel arch-rectangular support has a wide range of applications in Polish coal mines due to its asymmetrical shape. The frame has an arched outline on one side of the side wall, while on the opposite side it is rectangular. As a result, the support is ideal for securing set up room and recovery room. It can also be successfully used to secure three-way intersections of underground workings. To a large extent, however, the importance of these advantages is diminished by relatively low load-bearing parameters, resulting from a partially straight canopy, as well as the asymmetrical distribution of the load acting on the support in underground conditions. In order to ensure the proper and optimal operation of such frames, in addition to the standard requirements for roof supports, additional conditions must be met. The basic requirement is to support the end of the canopy on the corner of the excavation.

This article presents examples of arch-rectangular supports, their applications as well as laboratory tests and strength analysis of the frames and its elements. These tests allowed the requirements regarding the construction of the frame, the selection of the support and the conditions of building in the excavation to be specified.

Keywords: Frame support, arch-rectangular support, strenght analysis

Stalowa odrzwiowa obudowa łukowo-prostokątna znajduje w polskich kopalniach węgla kamiennego i ma szereg zastosowań, wynikających przede wszystkim z jej niesymetrycznego kształtu. Odrzwia po stronie jednego ociosu mają zarys łukowy, natomiast po stronie przeciwległego ociosu – prostokątny. Z tego względu idealnie nadają się do zabezpieczania rozcinek rozruchowych i kanałów likwidacyjnych ścian. Odrzwia powodzeniem mogą być także stosowane do zabezpieczania trójstronnych skrzyżowań wyrobisk korytarzowych. Jednak z znacznym stopniu wagę tych zalet pomniejszają niezbyt wysokie parametry podpornościowe, wynikające z częściowo prostoliniowej stropnicy, oraz niesymetryczny rozkład obciążenia działającego na odrzwia w warunkach dołowych. Dla zapewnienia właściwej i optymalnej pracy takich odrzwi oprócz standardowych wymagań dotyczących wykonywania obudowy konieczne jest spełnienie dodatkowych warunków. Podstawowym jest zapewnienie oparcia końca stropnicy o naroże wyrobiska.

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W artykule przedstawiono przykłady obudów łukowo-prostokątnych, ich zastosowania, a także badania stanowiskowe i analizę wytrzymałościową odrzwi i ich elementów. Badania te pozwoliły sprecyzować wymagania dotyczące konstrukcji odrzwi, doboru obudowy oraz zabudowy w wyrobisku.

Słowa kluczowe: Obudowa odrzwiowa, Obudowa łukowo-prostokątna, analiza wytrzymałościowa

Introduction

Steel frame yielding support is the most popular roadway support in Polish coal mines. The similar situation occurs in many countries, for example in mines in Ukraine, Russia Turkey, China (Litwinskij et al., 1999; Gayko & Rotkegel, 2003; Grodzicki & Rotkegel, 2018). One of the types of this support is arch-rectangular support. Steel arch-rectangular support in coal mines has a wide range of applications. This is the result of its asymmetrical shape. The frame has an arched outline on one side of the side wall, while on the opposite side it is rectangular or close to rectangular. As a result, the support is ideal for securing set up room and recovery room. It may also be successfully used to secure three-way intersections of underground workings. To a large extent, however, the wide range of applications is limited by the not very high load-bearing parameters, resulting from a partially straight canopy, as well as the asymmetrical distribution of the load acting on the support in underground conditions. The load-bearing capacity of such a support is also largely dependent on frictional joints parametrs. This applies to both the props and the arch part (Brodny, 2010, 2011, 2012; Brodny & Tutak, 2016; Horyl et al., 2014). Proper operation of such support and stability of the excavation secured by it requires proper installation of the frames, allowing for proper foundation (Rotkegel & Bock, 2015), support and optimal load with full contact with the rock mass. It is not possible to expand the frame in the axcavation like shield support equipped with control system (Szurgacz & Brodny, 2017, 2018).

The frames of arch-rectangular support consist of two (less often three) curved (arched) elements connected with a straight canopy and supported on the other end by a friction prop. All elements are made of V-shaped profiles and are joined with an overlap using twofold and U-bolt stirrups. Various models of typical arches are applied as arch elements. Depending on the shape, they can be divided into two groups:

– based on yielding arch support or similar,
– based on arched-straight (flattened) support.

Figure 1 presents examples of the structural solutions of the arch-rectangular support.

In addition to the asymmetrical arc-rectangular shape, the characteristic feature of these frames is their considerable width and relatively low height which enables its main application – securing set up rooms. Dimensions can be changed to a certain extent by extending or shortening elements on straight sections so that the support can be individually adjusted to the height of the longwall and the length of the power support applied to the set up room. An important advantage of such support is also its component parts – they include most often side wall arches of typical frames and straight roof bar from the V-section. This allows the purchase procedures to be simplified in the simplest way, and in some cases use of the elements already produced and stored.

Thanks to their construction, the arch-rectangular supports are primarily used for securing longwall set up rooms, recovery rooms as well as in some constructions of the support for cross-

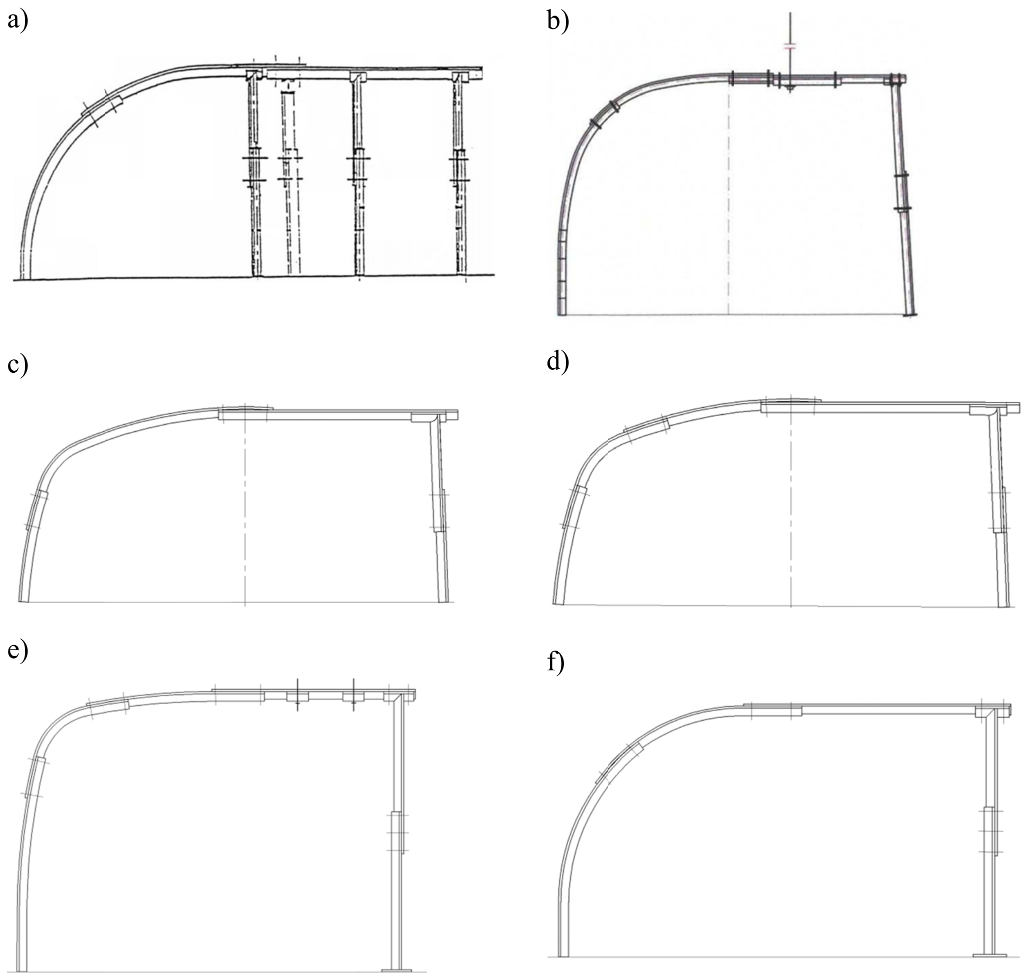


Fig. 1. Examples of structural solutions of the arch-rectangular support
a – OŁPP (Komisja ds. Obudów Zmechanizowanych i Kierowania Stropem, 1997); b – ŁPSpN (Europejskie Technologie Górnicze, 2016); c – ŁPrOJ option 1; d – ŁPrOJ option 2; e – ŁPrO/A (Huta Łabędy, 2017); f – ŁPrO/B (Huta Łabędy, 2017)

ing gallery. In the case of set up rooms, the arch-rectangular frame support ease the instalation of longwall equipment and simplifies work on longwall startup. However, in the case of longwall recovery room it simplifies enter longwall support and equipment into recovery room, as shown in Figure 2.

The arch-rectangular support may also constitute a part of the support of three-way intersection of workings. These frames are built in the area where the workings connect, and the ends of the canopies are supported on special rectangular frames (gates). A general diagram of such support using the arch-rectangular frame is shown in Figure 3. Figure 4 presents an example of the support of an intersection (Rotkegel et al., 2012).

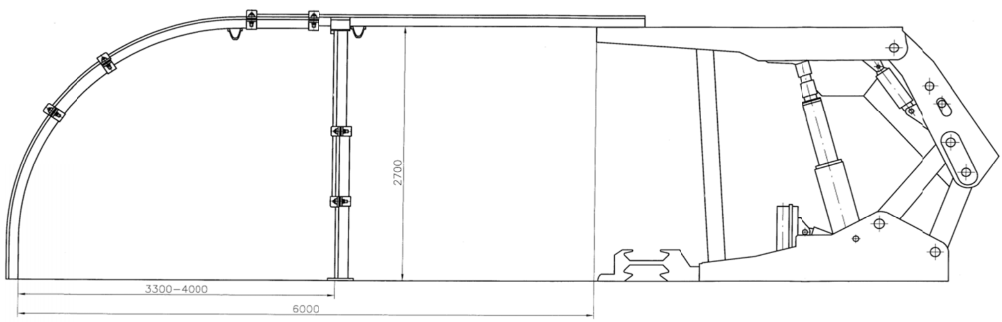


Fig. 2. Longwall recovery room support

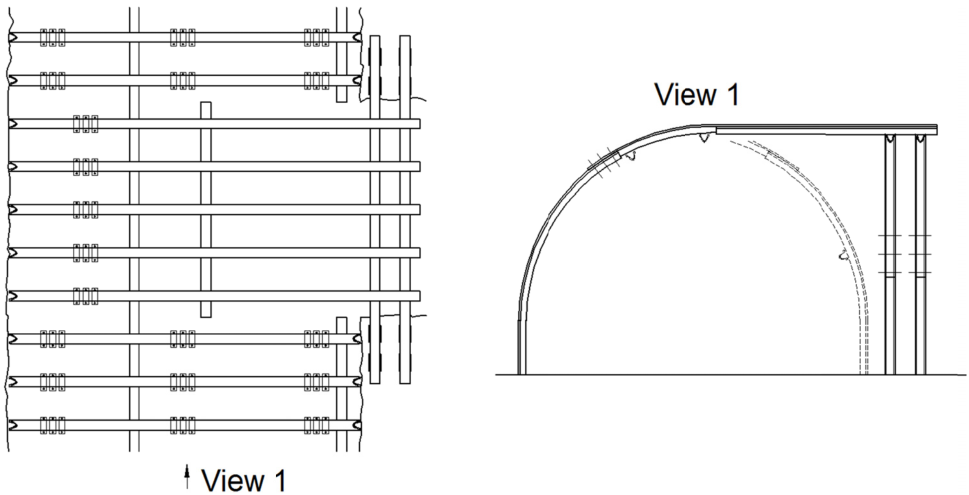


Fig. 3. General diagram of the support of the support of three-way intersection of workings

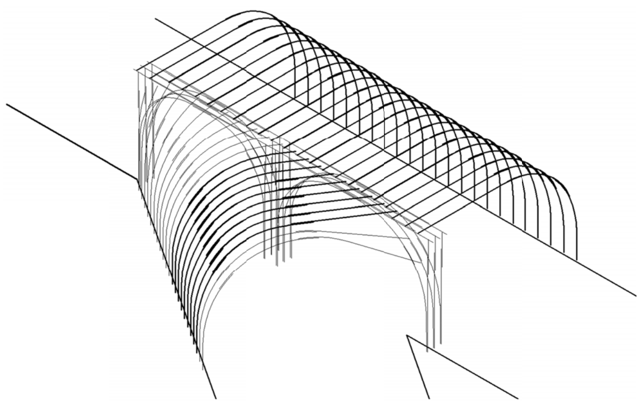


Fig. 4. Example of the support of underground workings secured by arch-rectangular support (thick lines)

1. Strength analysis of the arch-rectangular support

To illustrate the state of effort of the arch-rectangular support numerical analysis was performed based on the finite element method (Cook et al., 2002) using the COSMOS/M program (Rusiński, 1994). The main goal of the calculation was to recognize the behavior of the model in various boundary conditions – work of frame in various way of support. The simulations were carried out on flat models of arch-rectangular frame type ŁPrO/B/V32 with dimensions of 6100×3600 mm, consisting of 146 beam-type elements (BEAM). The elements were given cross-sectional parameters corresponding to the V32 profile – cross-sectional area, moments of inertia, depth and width. The elements were given stiffness parameters corresponding to steel – elasticity modulus, shear modulus, poisson ratio – and mass density. Additional spring elements (SPRING) were also defined, modelling different variants of the arch support and the rock mass relation – the resistance of the sidewall and the support of the end of the straight canopy. Additional bar anchors were adopted in two models. The model was supported on the floor and loaded uniformly with a load of 35 kN/m. The summed up total vertical load reached 200 kN. It is corresponding to maximum load registered in the laboratory test – maximum values transferred by the arches during the laboratory tests (Pacześniowski, 2010). The model of the frame support and the basic scheme of the boundary conditions and load is presented in Figure 5.

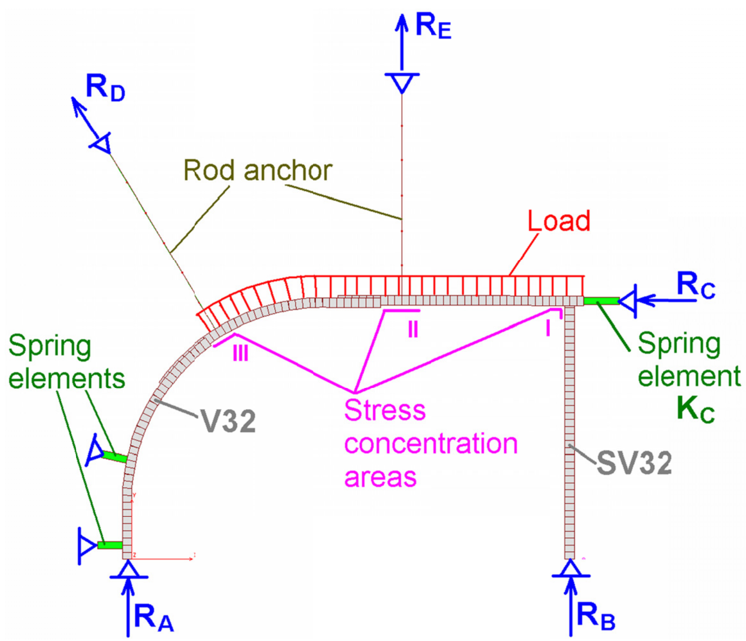


Fig. 5. The basic scheme of boundary conditions and load of the analysed frame support

During the analyses, in all models the way of the straight end of the canopy was changed by changing the K_C stiffness of the C support. The calculations allowed several colour maps depicting von Misses stress, support reaction values and a deformed model to be developed.

Figures 6-8 show the same scale of coloured stress maps in deformed models (deformation scale 5×) for the C support stiffness K_C = 100 kN/m, and the most important results of analyses are summarized in Table 1.

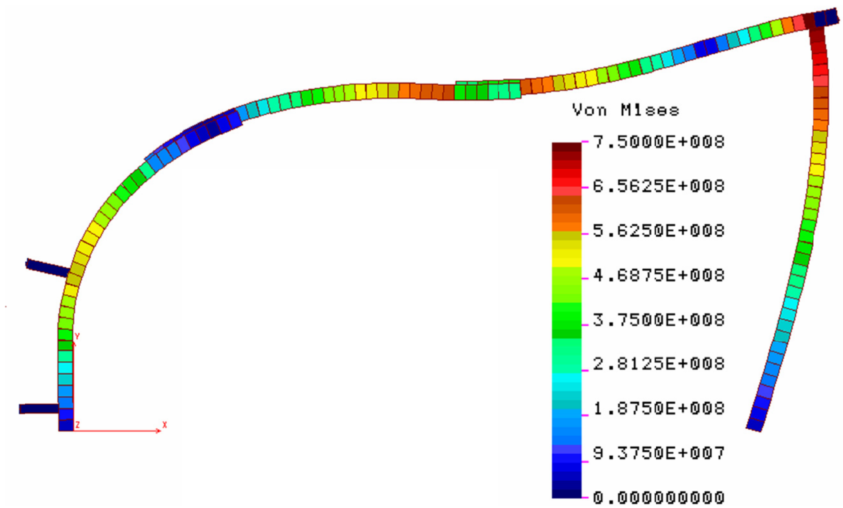


Fig. 6. Distribution of the von Misses stresses in the 1.3 model of the ŁPrO frame support (model designation consistent with table 1 – frame without bolts, C support stiffness modulus K_C = 100 kN/m)

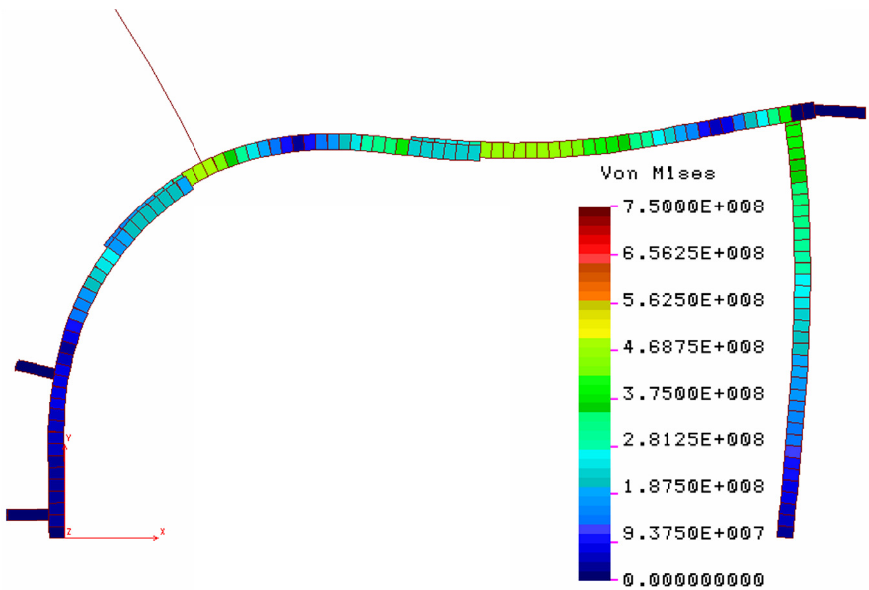


Fig. 7. Distribution of the von Misses stresses in the 2.3 model of the ŁPrO frame support with diagonally located anchors (model designation consistent with table 1 – frame with one bolt, C support stiffness modulus K_C = 100 kN/m)

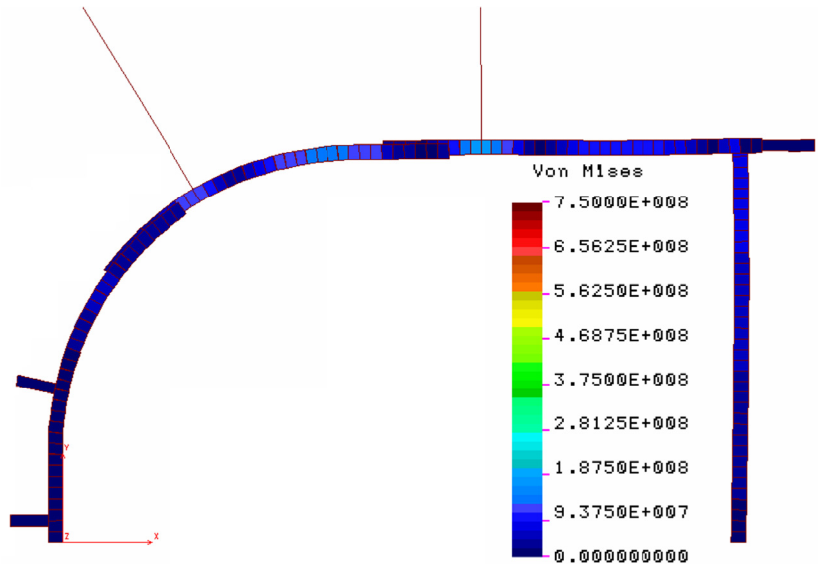
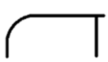
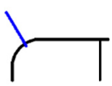
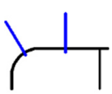


Fig. 8. Distribution of the von Misses stresses in the 3.3 model of the ŁPrO frame support with diagonally located anchors and anchored canopy (model designation consistent with table 1 – frame with two bolts, C support stiffness modulus K_C = 100 kN/m)

TABLE 1

Results of the numerical analysis of models for identical load (symbols as in Figure 5)

Model symbol	**Model diagram**	**C support stiffness modulus**	**Support reactions, kN**					**Canopy end displa-cement**	**Maximum reduced stress von Misses**	**Place of maximum stress – stress concentration areas**
		K_C, kN/m	**R_A**	**R_B**	**R_C**	**R_D**	**R_E**	**δ, mm**	**σ, MPa**	
1.1		1	69.5	117.2	1.2	—	—	125	792.0	I
1.2		10	70.1	116.9	1.2	—	—	124	787.6	I
1.3		100	75.8	114.2	11.3	—	—	113	747.5	I
1.4		1,000	103.3	100.9	59.7	—	—	59	554.3	I
1.5		10,000	128.9	88.6	104.6	—	—	10	442.2	II
2.1		1	22.9	92.0	0.0	110.0	—	11	478.1	II III
2.2		10	23.7	92.0	0.1	109.9	—	11	477.9	II III
2.3		100	24.0	91.9	1.1	109.0	—	11	476.2	II III
2.4		1,000	32.7	91.5	10.0	100.4	—	10	477.9	II III
2.5		10,000	77.9	89.1	56.3	55.7	—	5.6	448.5	II
3.1		1	6.0	43.9	0.0	64.1	96.1	3.1	167.7	II
3.2		10	6.0	43.9	0.0	64.1	96.1	3.1	167.7	II
3.3		100	6.3	43.9	0.3	63.8	96.1	3.0	167.7	II
3.4		1,000	8.8	43.9	2.8	61.5	95.8	2.8	167.7	II
3.5		10,000	22.6	44.1	16.6	49.0	94.1	1.7	168.1	II

As can be seen from the analyses carried out, the method of bearing the asymmetrical frame significantly affects the state of the stress and deformation, and thus the load-bearing capacity and stability of the whole support. The arch support that does not support the straight end of the canopy or support are ineffective (models 1.1-1.3, Fig. 6) is subject to significant deformations and its elements have significant stress values. Stress concentrations appear at the connection between the canopy and the leg. Slightly better parameters were obtained in the case of providing a support for the canopy, even with low stiffness, as in the 1.4 model. In this model, with the assumed load, the horizontal displacement of the canopy by nearly 60 mm results in the generation of a R_C support reaction with a value of nearly 60 kN. It is also essential to note that such action on the sidewall by profile with a cross-section of approximately 40 cm^2 is associated with pressures of 14.6 MPa, which may exceed the compressive strength of rocks, especially coal. Therefore, it would be beneficial to increase the surface area of the end of canopy that impacts on the sidewall, e.g. by applying special screw-on feet, similar to the support bearing plates. On the other hand, a significant problem is the appropriate shape of the cross-section of the excavation so that the contact of the sidewall and canopy can be obtained in any form. The ideal example is contact allowing horizontal dislocation of only 10 mm (model 1.5). The maximum values of the reduced stresses are then much lower and the places of their concentration are located in the middle of the length of the canopy.

Similar action are observed during the laboratory tests of arch-rectangular frames. During the tests the end of the canopy is supported in the testing station and, as a result of loading, the maximum deformations and stresses occur in a straight canopy and result in damage to the frames. It is also possible to observe the effects of significant loads in the connection of the canopy to the prop and the resulting significant bending of this node. These effects are shown in Figure 9. The bench tests also confirm the low load-bearing capacity of an arch support not equipped with any additional support or anchorage. An exemplary characteristic of the ŁPrOJ arch support with dimensions in the support of 6,200×4,000, from the V36 section is shown in Figure 10.

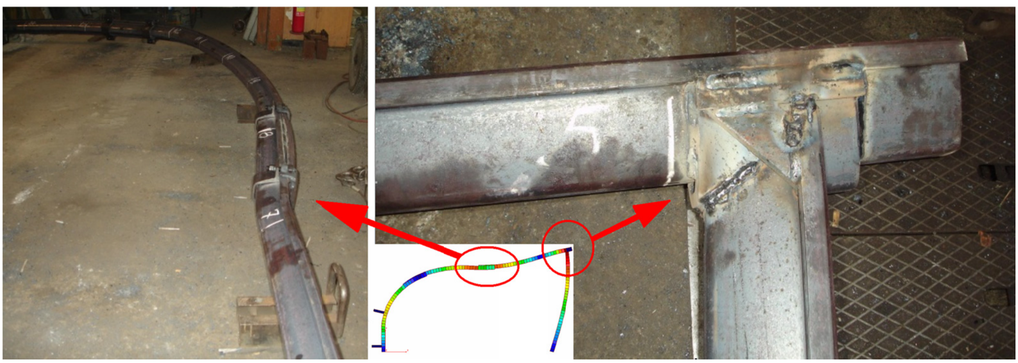


Fig. 9. Arch-rectangular support after tests and comparision with results of numerical modling. Deformation of the canopy (on the left) and deformation of the canopy and prop connection (right)

Here, the optimal solution may be the oblique anchoring of the frame, as in models 2.1-2.5. As shown in Table 1 and Figure 7, in these models, regardless of the stiffness of the C support, the values of the maximum von Misses stresses are at a much lower, practically constant level

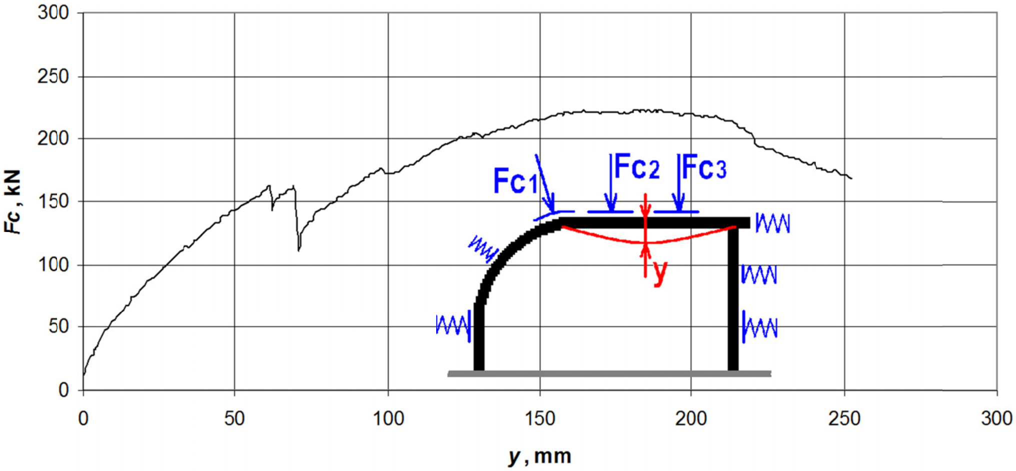


Fig. 10. Characteristics of the ŁPrOJ6.2/4.0/V36 support frame tested in a stiffened state
Fc – load of the arch support (*Fc* = *Fc*1 + *Fc*2 + *Fc*3), *y* – deflection of the arch (in midpoint of canopy)

and are located in the middle of the canopy and in the areas where anchors are placed. In addition, there are much lower horizontal displacements of the canopy and R_C support reactions.

A further improvement of the state of the stress of the arch support can be obtained by the additional anchoring of the straight canopy, as in models 3.1-3.5. This allows a clear reduction in the value of stresses in the frames (Fig. 8) to be obtained, and thus an increase in the load capacity of the support.

It should also be noted that in underground conditions, lack of support of the end of canopy or its inadequate stabilization leads to tilting the support and consequently may cause damage to the welds of the head of the prop, even when using reinforcing ribs, as shown in Figure 9. This is also confirmed by underground observations.

2. Conclusion

The presented frame support is an interesting solution due to the possible application of securing special workings, such as longwall set-up rooms, recovery rooms or three-way intersections. Due to its specific construction, however, it cannot practically be used as an independent support. The asymmetrical shape of the support and the resulting asymmetric load lead to generation of a horizontal load and, consequently, the tilting of the frame. To avoid this, the end of the straight canopy must be effectively supported on the side wall or the frames must be anchored diagonally in the arch section.

Therefore, arch-rectangular support must be selected an individually. It is necessary to calculate the stresses caused by the rock mass load with the assumed anchoring pattern. It is also necessary to consider the location and bearing capacity of the bolt, as well as the load capacity of the applied prop. A very important thing is also work of the friction joints (Brodny, 2012). Numerical methods, especially the finite element method, can be helpful to properly calculate the parameters (Filcek et al., 1994).

References

Brodny J., 2010. *Determining the working characteristic of a friction joint in a yielding support.* Archives of Mining Sciences **55**, 4, 733-746.

Brodny J., 2011. *Tests of friction joints in mining yielding supports under dynamic load*. Archives of Mining Sciences **56**, 2, 303-318.

Brodny J., 2012. *Analysis of operation of new construction of the frictional joint with the resistance wedge*. Archives of Mining Sciences **57**, 1, 209-227.

Brodny J., Tutak M., 2016. *Performance characteristics of the friction joint used in the mining support*. 16th International Multidisciplinary Scientific GeoConference. SGEM 2016, Conference proceedings. Book 1, Science and Technologies in Geology. **2**. Sofia: STEF92 Technology, pp. 657-664.

Cook R.D., Malkus D.S., Plesha M.E., Witt R.J., 2002. *Concepst and applications of finite element analysis*. John Willey & Sons, Inc. New York.

Europejskie Technologie Górnicze, 2016. *Katalog obudów specjalnych*. Sławków.

Filcek H., Walaszczyk J., Tajduś A., 1994. *Metody komputerowe w geomechanice górniczej*. Śląskie Wydawnictwo Techniczne. Katowice.

Gayko G.I., Rotkegel M., 2003. *Issliedowanija niesuszcziej sposobnosti arocznoj kriepi pri razlicznych wariantach nagrużienia*. Ugoł Ukrainy **2**, 45-47.

Grodzicki M., Rotkegel M., 2018. *The concept of modification and analysis of the strength of steel roadway supports for coal mines in the Soma Basin in Turkey.* Studia Geotechnica et Mechanica **1**, 38-45.

Horyl P., Šňupárek R., Maršálek P., 2014. *Behaviour of frictional joints in steel arch yielding supports*. Archives of Mining Sciences **59**, 3, 781-792.

Horyl P., Šňupárek R., Maršálek P. Pacześniowski K., 2017. *Simulation of laboratory tests of steel arch supports*. Archives of Mining Sciences **62**, 1, 163-176.

Huta Łabędy, 2017. *Katalog wyrobów dla górnictwa*. Gliwice.

Komisja ds. Obudów Zmechanizowanych i Kierowania Stropem w Podziemnych Zakładach Górniczych, 1997. *Katalog obudów rozcinek ścianowych* Gliwice.

Litwinskij G.G., Gajko G.I., Kyldyrkajew N.I., 1999. Stalnyje ramnyje kriepi gornych wyrabotok. Kijew „Technika" 1999.

Pacześniowski K. i współautorzy, 2010. *Stanowiskowe badania odrzwi obudowy łukowo-prostej typu ŁPrPJ6.6/4.0 oraz ŁPrOJ6.2/4.0. Sprawozdanie z badań nr BL-2/12-32*. Katowice GIG 2010 (niepublikowana).

Rotkegel M., Bock S., Witek M., Adamiec P., 2012. *Sposób zabezpieczenia połączenia wyrobisk korytarzowych w warunkach strefy uskokowej. Nowe spojrzenie na wybrane zagrożenia naturalne w kopalniach.* Praca zbiorowa pod redakcją S. Pruska i J. Cygankiewicza. GIG Katowice, 5-14.

Rotkegel M., Bock S. 2015. *Impact of bearing plates dimensions on interaction of mine workings support and rock mass*. Journal of Sustainable Mining **14**, 1, 12-20.

Rusiński E., 1994. *Metoda elementów skończonych. System COSMOS/M*. Wydawnictwa Komunikacji i Łączności. Warszawa.

Szurgacz D., Brodny J., 2017. *Role and Relevance of an Electro Control System for the Operation of a Powered Roof Support*. 17th International Multidisciplinary Scientific Geoconference SGEM 2017 **17**, 13, 781-788.

Szurgacz D., Brodny J., 2018. *Analysis of rock mass dynamic impact influence on the operation of a powered roof support control system*. Copyright / Published by: EDP Sciences. E3S Web Conferences **29**.