https://doi.org/10.7494/miag.2020.2.542.23

PIOTR CABAN
KAZIMIERZ STOIŃSKI
MAREK ROTKEGEL
SYLWESTER RAJWA
ADAM GNATOWSKI
KRZYSZTOF PACZEŚNIOWSKI

The evolution of steel frame sets for longwall development drifts

The article presents the development of steel frame sets produced for mining purposes by Huta Łabędy S.A., intended for securing gallery workings, and longwall development drifts in particular. In recent decades, longwall development drift support has evolved in terms of characteristics such as its shape. The initially utilised rectangular frames and typical widened ŁP frames were replaced with flat frames based on ŁP arches (ŁPKO), and subsequently with special frame sets adapted to the shape of powered support units. The intermediate frame shape obtained in this way was a compromise between the rectangular (beneficial from the perspective of longwall equipment and development) and the arching design (beneficial due to the high load-bearing parameters).

Key words: *frame set, road support, longwall development drift*

1. INTRODUCTION

In the beginning of underground coal mining plant operations, the technology employed was only mechanised to a very minor degree. The deposits were extracted at shallow depths of 200 m to 350 m. As technology progressed, increasingly deeper deposits were mined, and their effective extraction required the application of advanced methods and technologies, such as the use of longwall shearers. Mining by means of the longwall method requires the excavation of a specific system of preparatory gates, such as longwall development drifts. It is a particular group of large and short-lived gallery workings, characterised by a significant height and width adapted to the deposit awaiting extraction. Longwall development drifts are driven in order to install the powered longwall support and the necessary auxiliary equipment enabling the development of the longwall and the extraction of the coal deposit. Today, there are about 60–70 longwall development drifts driven yearly in Polish hard coal mines. Considering the average longwall length, this corresponds to about 13 km of workings, which, assuming a spacing of 0.75 m, requires the application of frame sets with a total weight of nearly 8 thousand tonnes. In a global scale, this therefore constitutes a significant number of support elements.

The purpose of the article is to present the full spectrum of frame sets produced at Huta Łabędy over the last 30 years, intended for securing longwall development drifts. The presented frame set structural solutions make it possible to secure longwall development drifts while factoring in the dimensions of all the powered support systems utilised in hard coal mines. The presented constructions were designed at the Central Mining Institute in cooperation with Huta Łabędy and various hard coal mining plants, such as KWK Ziemowit, KWK Wesoła, LW Bogdanka, KWK Bobrek, KWK Wujek, KWK Pniówek, KWK Zofiówka and the already decommissioned Katowice and Kleofas mines. The mines made a significant contribution in terms of the verification of the support frames and their operational qualities, which served as the basis for certain corrections and structural detail enhancements introduced at the Central Mining Institute. Such a cooperation of these three entities in terms of the new frame set solution implementation makes it possible to combine GIG's design and testing experience with the robust manufacturing capabilities of Huta Łabędy, while including the needs and observations of the users, i.e. the mines. Huta Łabędy manufactures the presented frame sets using modern steel such as 25G2Ti, S480W [1] and S550W [2], which guarantees their high mechanical strength parameters and increased resistance to corrosion.

2. ORIGINS OF LONGWALL DEVELOPMENT DRIFT SUPPORT FRAMES

In the beginning of hard coal extraction via longwall mining with the use of longwall shearers, longwall development drift support was constructed by means of ŁP-type yielding arch frames [3–5].

A drawback of this solution was the necessity to fill a significant space in the roof between the powered support canopy and the top section of the arch support with timber to ensure the appropriate spragging of the powered support at the stage of longwall equipment and mining commencement. Eventually, ŁP frames with shortened side sections were applied in order to reduce the roof lining space, which decreased the amount of timber used for cribbing, thereby also reducing the time and costs required for equipping the longwall.

Rectangular frames were used as an alternative solution, where the straight top section made it easier to sprag the powered support units. However, the low load capacity of such a support limited the scope of its application [6, 7]. It was necessary to reinforce the straight top section. One such solution was the trapezoid support, designated with the letters OPP, whose structural variants are presented in Figures 1 to 3 [8]. Depending on the roof conditions, the top section is either to be supported by a catch prop or bolted.

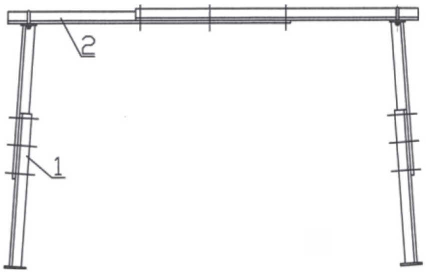


Fig. 1. OPP frame, variant 1:
1 – prop (supporting element), 2 – straight top section

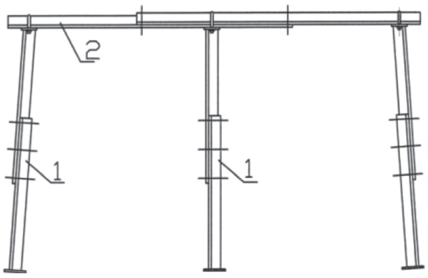


Fig. 2. OPP frame, variant 2:
1 – prop (supporting element), 2 – straight top section

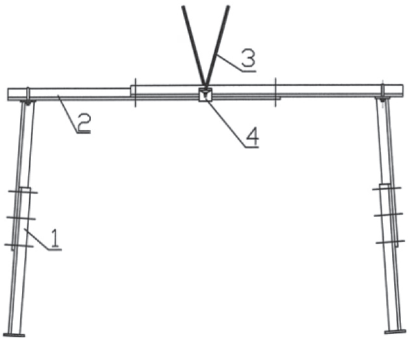


Fig. 3. OPP frame, variant 3:
1 – prop (supporting element), 2 – straight top section,
3 – bolt, 4 – washer

Progress towards the geometric optimisation of frames intended for securing longwall development drifts led to the drafting of a support catalogue [9] containing proposed series of frame set types designed for securing longwall development drifts. The series of frame sets included in the catalogue factored in the parameters of the powered support units commonly employed at the time. It was adopted as a principle that the unit transport length (*diameter of a unit in transport position* increased by 5%) would constitute the basic criterion determining the possibility of introducing a given type of powered support into a specific longwall development drift support. Adopting this principle in longwall development drift support frame selection ensured the possibility of manoeuvring with an introduced powered support unit in transport position. The main designs in the aforementioned catalogue that gained the approval of mining plants and saw common application in practice included the series of three-element (coupled) ŁPK frames presented in Figures 4 and 5 [9] and four-element (combined) ŁPKO frames. The ŁPK frames were configured using the top and side sections of various sizes adapted from three-element ŁP frames sized 5 to 10 [9]. Figures 6 and 7 [10] present a development drift support secured with an ŁPK support, and the longwall equipment. On the other hand, the ŁPKO series was configured using two pairs of side sections of various sizes, adapted from three-element ŁP frames sized 4 to 8.

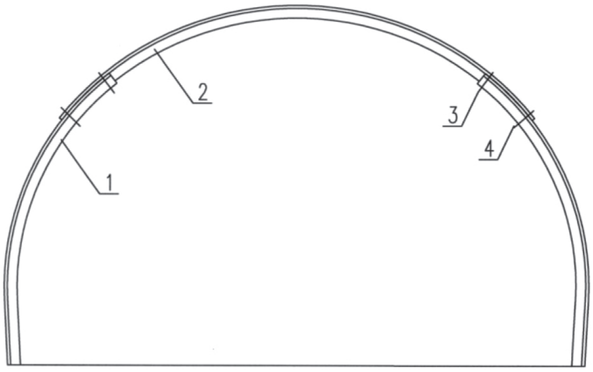


Fig. 4. ŁPK frame (coupled):
1 – side section, 2 – top section, 3, 4 – shackles

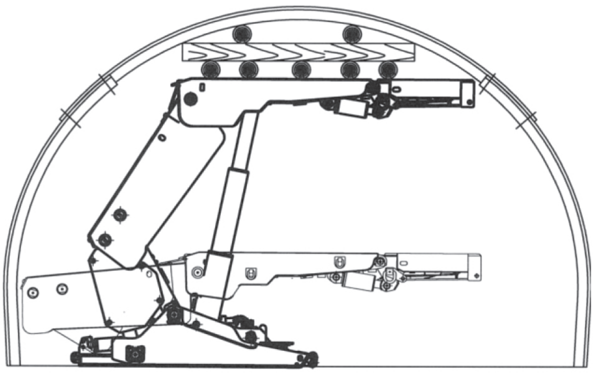


Fig. 5. Coupled ŁPK frame with an installed powered support unit (unit before and after spragging)

Fig. 6. Development drift driven in coupled ŁPK frames with shortened side sections

Fig. 7. Longwall equipment, development drift driven in coupled ŁPK frames

The experience gained during the longwall development drift performance, and the subsequent equipping and development commencement of the longwall, resulted in a rapid evolution of the designs towards specialised frame sets intended primarily for securing such workings.

3. WORK AND RESEARCH ON FRAME SET DESIGN DEVELOPMENT

Work on new structural solutions for frame sets intended for securing longwall development drifts was based primarily on the observations of the operation and functionality of already installed frames. These observations encompassed the entire working life cycle – from the driving, through the equipping to the development of the longwall. The numerous discovered deficiencies of the standard ŁP supports, the coupled ŁPK frames and the rectangular frames motivated the mining plants as well as the support designers and manufacturers to seek solutions that would improve the support functionality. As a result of these efforts, numerous frame set solutions were designed, which constituted a compromise between the arching ŁP support (with high load-bearing parameters but unfavourable shape for the powered support unit spragging and longwall mining commencement) and the rectangular support (with low load-bearing parameters but better functionality from the perspective of longwall equipment and mining commencement). The research and development work was conducted at the Department of Extraction Technologies, Rockburst and Mining Support and the Department of Mechanical Devices Testing and Rocks of the Central Mining Institute in Katowice.

The work encompassed frame set design based on the end-user requirements as well as laboratory and model testing, and appropriate certification.

Model testing is the key stage of design work. Combined with bench testing and its results, it enables the calibration of numerical models to determine the load-bearing parameters of an entire series of frames [11, 12]. The numerical analysis results are particularly important in the design and optimisation of frames with geometries diverging from typical ŁP frames, as is the case with flat frames of arching-straight shapes. These analyses are performed using the finite element method [13, 14], e.g. by means of the COSMOS/M software [15, 16]. A geometric model of the frame is constructed during the first stage, factoring in its dimensions and cross-sectional parameters. The appropriate material parameters are defined in the next steps. The key issue, particularly when modelling arching-straight frames, is to define the frame bearing and load case. The great significance of these factors can be observed by analysing the results of the simulated operation of an arching-straight ŁPrP frame. To demonstrate this issue, a strength analysis was performed for a size 28 six-element ŁPrP frame with a nominal width of 6200 mm and height of 2600 mm, constructed from V29 sections [17] rolled using 25G2 or 34GJ steel (per standard PN-H-93441-1 [18]). In order to carry out these analyses, a model of the frame was constructed using 126 beam elements corresponding to the arching sections, 10 beam elements corresponding to the shackles and 6 spring elements corresponding to the pressure exerted by ribs with a given stiffness. The full model is presented in Figure 8. Deformed frame shapes, bearing reaction values, internal force distributions and coloured reduced stress maps were obtained as a result of the performed simulations. An example of reduced stress distribution is presented in Figure 9.

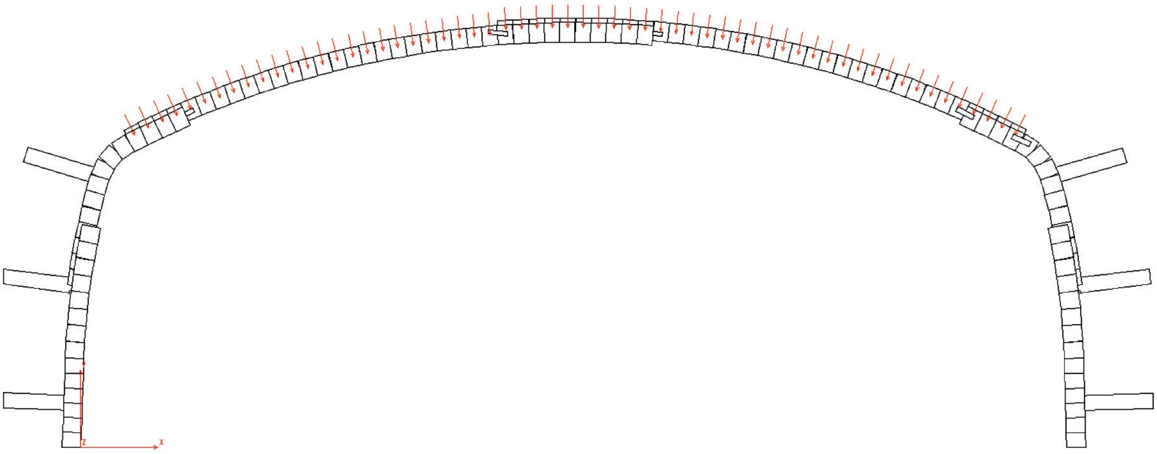


Fig. 8. ŁPrP/6/B/28 frame model (6200 mm × 2600 mm)

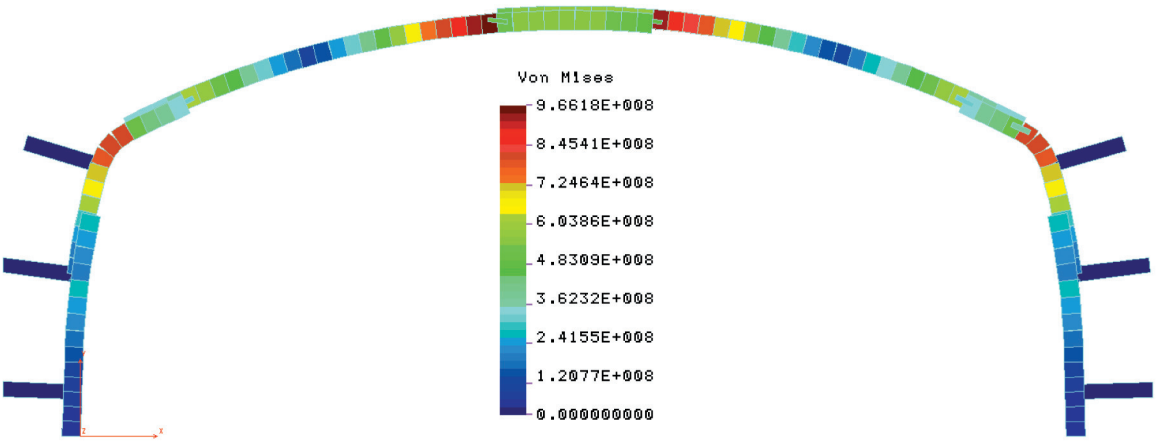


Fig. 9. Reduced stress distribution in the ŁPrP frame (stress in Pa, scale of deformation 1x, rib pressure element stiffness k = 1 MN/m, loaded top section length 2.18 m)

The influence of the frame loading method (loaded top section length) and of the rib pressure element stiffness on the frame load capacity was analysed during the tests. This factored in the strength of the V29 section formed from steel according to standard PN-H-93441-1 [18]. The analyses demonstrate that the frame load capacity increases significantly together with the increase in the loaded top section length. This can be clearly observed in the chart depicted in Figure 10. In the case of the analysed model and the stiffness of each of the elements modelling the rib pressure (the springs) at a level of $k = 15$ MN/m, a frame subjected to an almost single-point load (loaded top section length $L = 200$ mm) exhibits a load capacity of $N = 183$ kN, whereas when the load is applied over a length of 5.94 m, the load capacity achieves the value of $N = 417$ kN.

Very interesting conclusions can also be drawn by analysing the influence of the rib pressure element stiffness on the frame load capacity. Assuming that the load is applied over the entire length of the top section, depending on the rib pressure element stiffness the frame load capacity can vary from 72 kN at no rib pressure to 417 kN at a tight, stiff encasement. These variations are presented as a chart in Figure 11. This indicates the need to ensure a tight pressure exerted by the ribs, particularly at the points where the roof borders the ribs.

Additional attention was dedicated to the internal forces and reduced stresses in the arching sections, generated by the maximum load applied to the frame. Table 1 presents the values of these parameters in key locations.

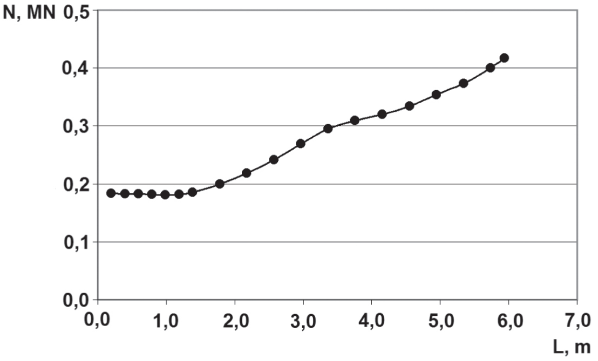


Fig. 10. Frame load capacity N depending on the loaded top section length L for a stiffness k = 15 MN/m of the elements modelling the rib pressure

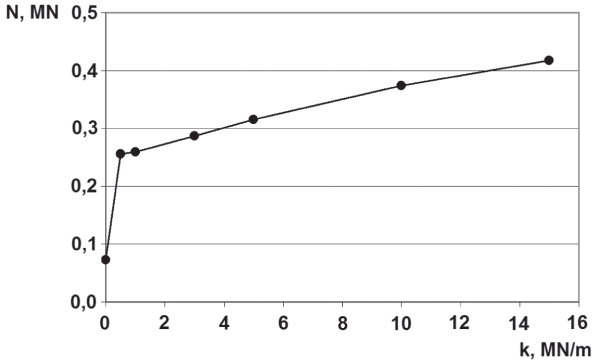
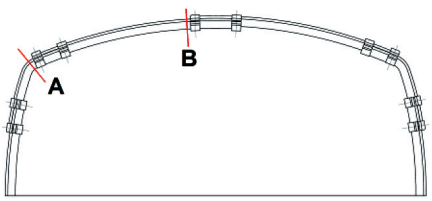


Fig. 11. Frame load capacity N depending on the stiffness k of the elements modelling the rib pressure at a load applied over the entire length of the top section

Table 1

Internal forces and reduced stresses in key frame locations once the load capacity is achieved for a load case applied over the entire length of the top section and for selected rib pressure element stiffnesses (locations with loss of V29 section load capacity in bold)

Place of measurement	Stiffness of elements modelling the rib pressure	Location	Axial force	Shearing force	Bending moment	Reduced stress
	k [MN/m]		N [kN]	T [kN]	Mg [kNm]	σ_{red} [MPa]
	0	A	19.3	29.2	10.0	143.8
		B	8.8	6.5	57.7	625.0
	0.5	A	139.7	56.1	50.9	581.7
		B	115.9	15.9	54.3	625.0
	15.0	**A**	331.9	23.9	47.6	625.0
		B	312.9	16.3	31.4	434.6

As can be seen in the presented compilation, in the event of no rib pressure, the top section experiences failure close to the sliding joint (location B). Great bending moments are generated in this location, whereas the frame operates as if rigid, since there can be no yielding in the overlaps at minor axial force values [19–21]. This situation occurs already at very low loads. On the other hand, at high rib pressure the loss of frame load capacity occurs due to the exceeded strength of the corner element at the location characterised by great curvature. At the same time, the stresses in the top section exhibit significantly lower values, whereas the great axial forces and the low bending moment at the sliding joint enable a yield in the overlaps and the yielding operation of the frame. Additionally, the presented analysis reveals the significance of the corner element in relation to the load capacity of the entire frame. This element must be constructed with precision and using the appropriate materials, particularly given that the bending of a V section at such a small radius entails a number of requirements concerning the material parameters.

Full scale frame prototypes are tested at the test facility of the Department of Mechanical Devices Testing and Rocks of the Central Mining Institute, depicted in Figure 12. During testing, frames in both rigid and yielding states are subjected to static loads. The purpose of the tests is to determine the actual load-bearing and deformational parameters of a new frame set and to confirm its correct operation. The frame tests were carried out according to standard PN-G-15000-05 [22] in the past, whereas today they are conducted per standard PN-G-15022 [23]. These standards define the applied bearing and loading methods as well as the remaining parameters of the tests. Figure 13 presents a load case for a frame tested at the test facility. Apart from the full frame sets, tests are also conducted for sliding joints, which are responsible for the correct operation of the frames [19–21].

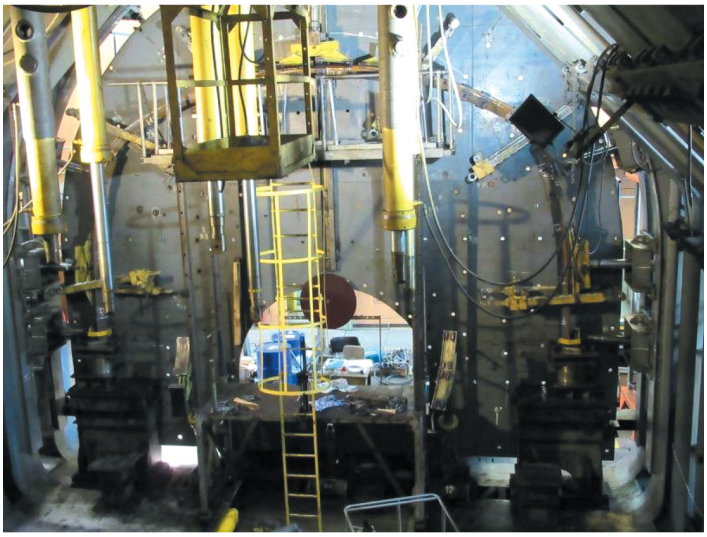


Fig. 12. Test facility with an installed frame during testing

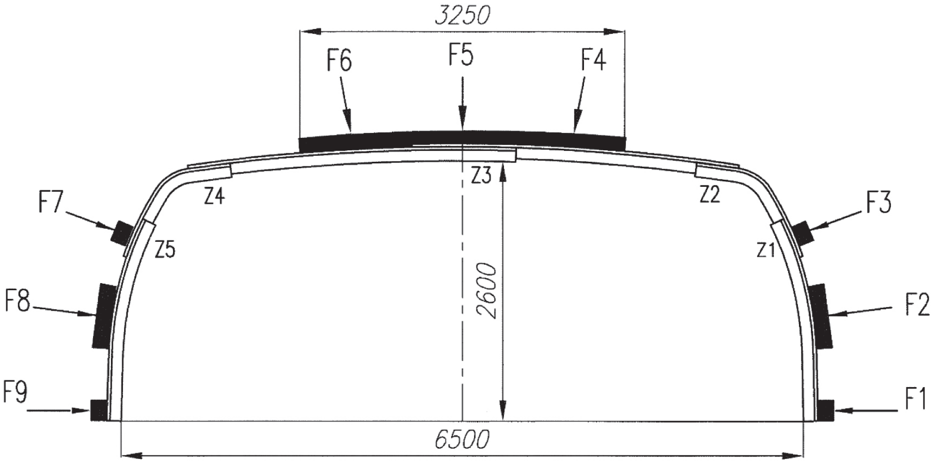


Fig. 13. Load case for an arching-straight frame tested at the test facility F_4, F_5, F_6 – active forces, F_1, F_2, F_3, F_7, F_8, F_9 – passive forces

The results obtained from the frame set bench tests enable comparisons with the results of numerical calculations, and the results of tests involving different constructions intended for development drifts as well as standard ŁP support frames. The result analysis also makes it possible to improve the digital frame models (model calibration) and serves as the basis for introducing potential changes in the frame structures. A report from the frame bench tests as well as the operation and maintenance documentation are the basis to grant a manufacturer a certificate for marking the frames with the safety symbol “**B**” Ⓑ.

4. FRAMES FOR LONGWALL DEVELOPMENT DRIFTS PRODUCED BY HUTA ŁABĘDY

One of the first structural solutions dedicated to securing longwall development drifts was the ŁPKO frame series. It was designed based on suggestions included in the 1995 draft catalogue [9] and the mining experience gained during the performance of preparatory work. The series was systematised and expanded with new variants constructed from all the V-type sections that are commonly employed in mines. The ŁPKO and ŁPKOw support frames are primarily intended for securing the longwall development drifts prepared for the installation of powered support units. The ŁPKO frame design utilises the standard and mass-produced side sections of the three-element ŁP and ŁPP frames (sized 7–10). To ensure a precise fit of the frame geometry to the planned working, it is permitted to modify the frame by shortening the side section from the direction of the straight part and by changing the size of the overlaps. In recent times, the ŁPKO frame series was expanded with the ŁPKOw variant based on the side sections of the three-element ŁPw and ŁPPw frames, which are characterised by a single bend radius of the side and top sections [24–27]. The expanded series encompasses frames with widths of 5400–8485 mm and heights of 3145–5320 mm. Figures 14 and 15 present the ŁPKOw and ŁPKO frame structures, whereas Figure 16 [28] depicts a development drift secured by means of the ŁPKO support.

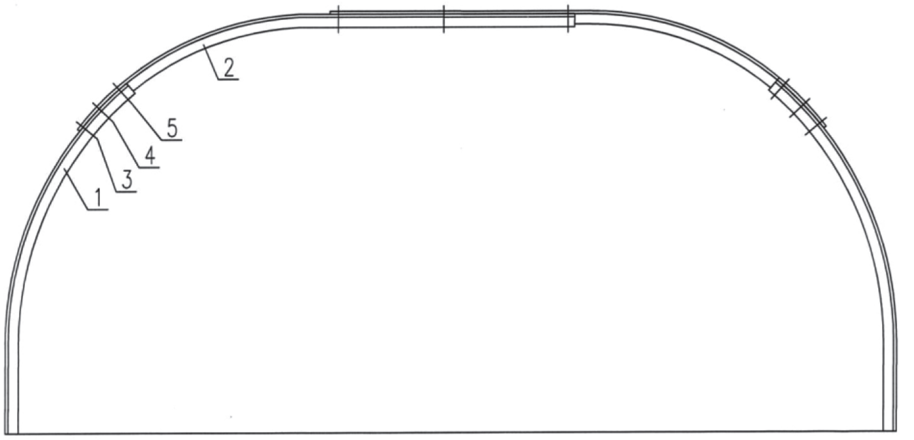


Fig. 14. ŁPKOw frame: 1 – ŁP frame side section, 2 – ŁPP frame side section installed as the top section, 3–5 – shackles

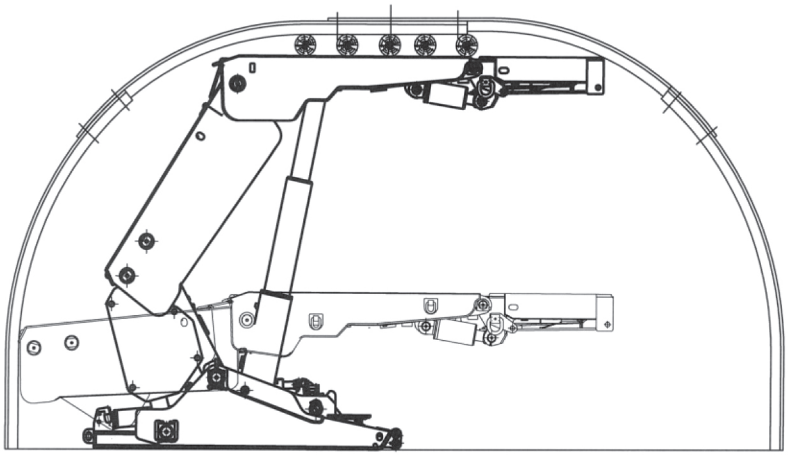


Fig. 15. ŁPKO frame with an installed powered support unit (unit before and after spragging)

Fig. 16. Development drift secured by means of the ŁPKO support

The ŁPro/B frame is a certain modification of the ŁPKO series. One of the ribs is supported by "half" of an ŁPKO frame, whereas the other – by a straight V section supported by a prop. The frame obtained in this way has an arching-rectangular shape [29]. Two types of these frames were designed in 2003 – ŁPro/A and ŁPro/B. The ŁPro/B arching-rectangular frame is intended primarily for securing longwall development drifts and longwall closure drifts, where it finds excellent application during the equipping and development commencement of a longwall, as well as when finishing the extraction of the panel. These frames can be used in configuration with KaPa frames [30] to effectively secure gallery working junctions [31]. The ŁPro/B frame type is produced in four variants depicted in Figure 17. Variants I and III are versions with two-element top sections, whereas variants II and IV are characterised by single-element top sections. The series encompasses frames with widths of 3120–7900 mm and heights of 3200–5420 mm. The shape of the frames leads to an excellent fitting of the powered support units, as depicted in Figure 18. Meanwhile Figures 19 and 20 present example applications of this support in a working.

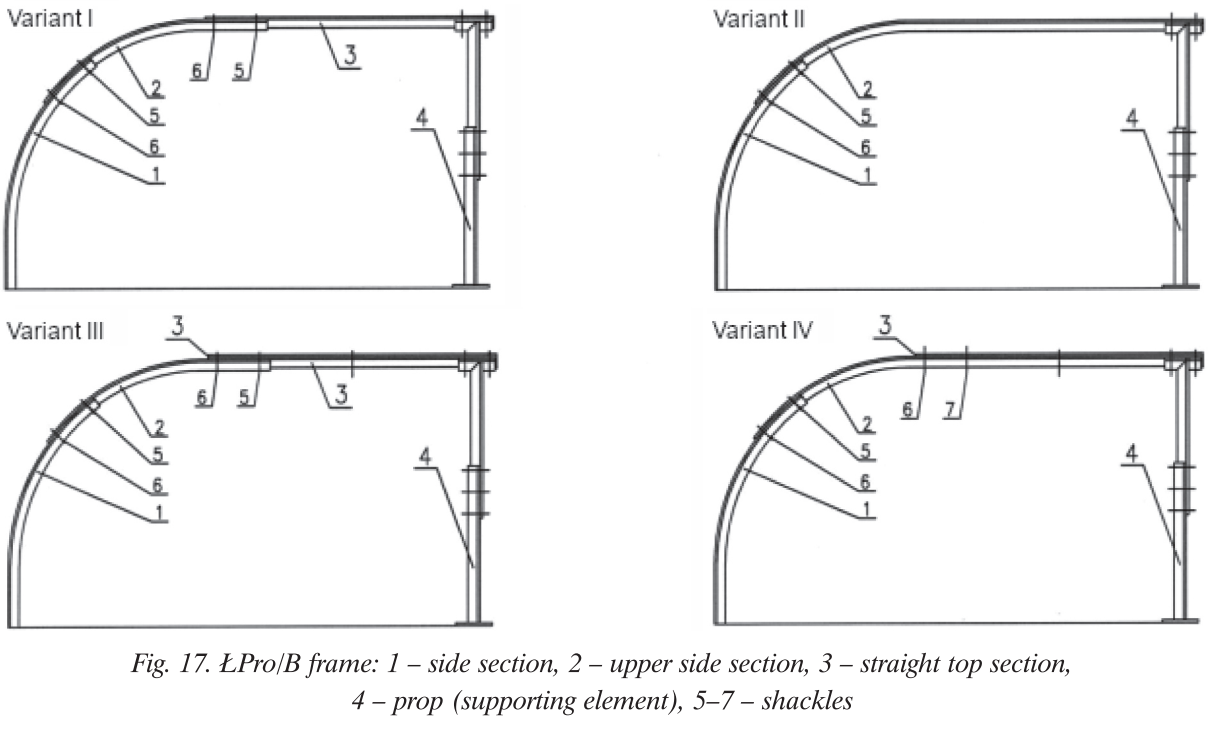


Fig. 17. ŁPro/B frame: 1 – side section, 2 – upper side section, 3 – straight top section, 4 – prop (supporting element), 5–7 – shackles

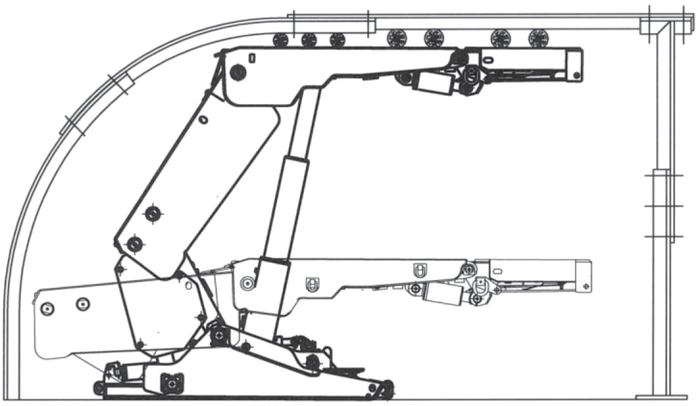


Fig. 18. ŁPro/B frame variant I with an installed powered support unit (unit before and after spragging)

Fig. 19. Development drift secured by means of the ŁPro/B support

Fig. 20. Longwall closure drift secured by means of the ŁPro/B support

The arching-rectangular ŁPro/A frame type depicted in Figures 21 and 22 is a certain variation on the ŁPro/B frame idea. Similarly to the ŁPro/B type, this frame is intended primarily for securing longwall development drifts, longwall closure drifts and gallery working junctions. This frame type was designed in 2003 for the needs of the LW "Bogdanka" mine. The design is based on the arching elements of the ŁPrP K frame, described in later parts of the article, while its dimensions are 5900–6900 mm in width and 3300–4400 mm in height. Example applications of the ŁPro/A frame are presented in Figures 23 and 24.

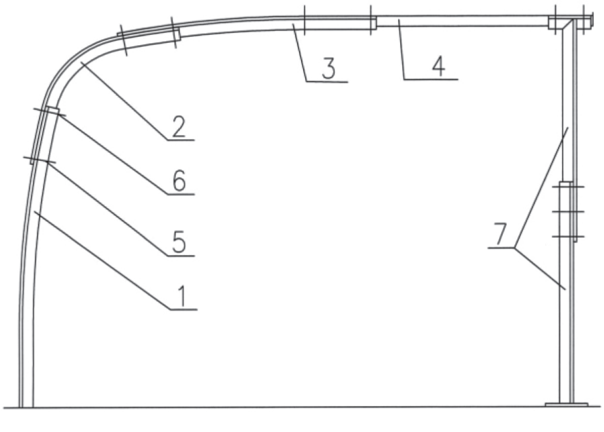


Fig. 21. ŁPro/A frame: 1 – side section, 2 – upper side section, 3 – top section, 4 – straight top section, 5, 6 – shackles, 7 – prop (supporting element)

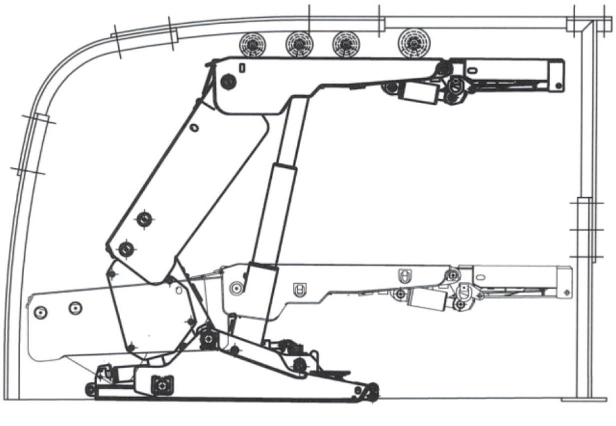


Fig. 22. ŁPro/A frame with an installed powered support unit (unit before and after spragging)

Fig. 23. *Development drift secured by means of the ŁPro/A support*

Fig. 24. *Development drift secured by means of the ŁPro/A support*

Observing the operation of support frames with straight top sections and identifying the deficiencies related to them resulted in the design of a new series of flat, arching top sections with low curvature. One of the first such designs was the ŁPS frame – its first version was produced in 1995. It is an arching-straight frame intended for development drift support. The frame design includes two variants: the first, with a single-element top section, is presented in Figure 25, whereas the second, with a two-element top section, is depicted in Figure 26. Given the coupling of the top section with the side section (short overlap), this frame is a rigid one. No yielding capability significantly limited the application of this frame, therefore the support was eventually replaced by the ŁPrP frame, which remains in use to this day.

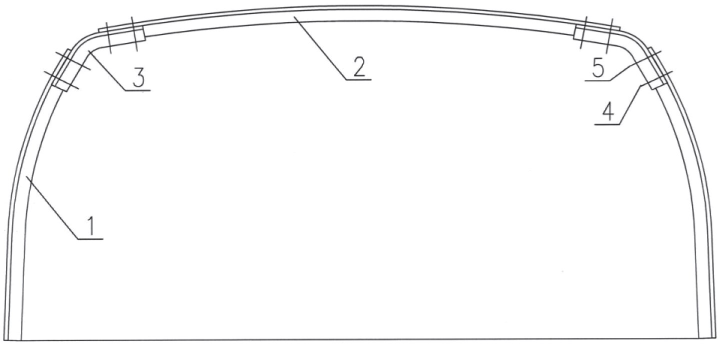


Fig. 25. ŁPS frame with a single-element top section: 1 – side section, 2 – top section, 3 – coupling, 4, 5 – shackles

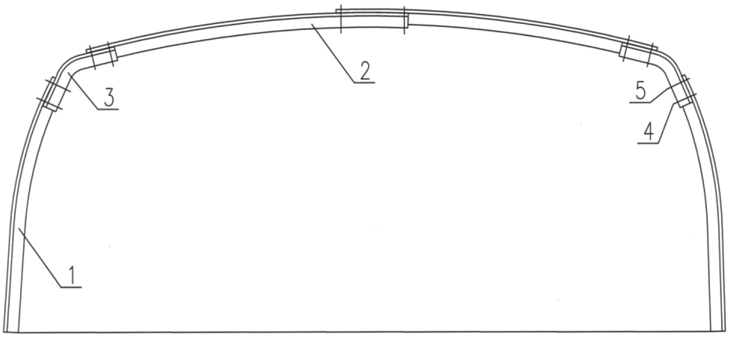


Fig. 26. ŁPS frame with a two-element top section: 1 – side section, 2 – top section, 3 – coupling, 4, 5 – shackles

The previously mentioned arching-straight ŁPrP frame is another series of frames made in accordance with the trend of designs dedicated to development drift support. It was designed in 1997 at the Central Mining Institute. The yielding arching-straight ŁPrP frames constructed from V sections are primarily intended for securing longwall development drifts as well as other utility gallery workings with increased lateral dimensions. The flat frame geometry, compared to the standard ŁP frame, limits overburden removal in low deposits, whereas the increased width makes it easier to equip the longwalls. The series includes three frame variants:

- four-element with a width of 4700–7650 mm, height of 2100–3000 mm (Figs. 27 and 28), and a triple-curved top section shaped for coupling with the side sections,
- five-element with a width of 3700–4200 mm and height of 2100–3000 mm (Figs. 29 and 30), a solid top section and corner elements for coupling the top with the side sections,
- six-element with a width of 4700–7650 mm and height of 2100–3000 mm (Figs. 31 and 32), a parted top section and corner elements for coupling the top with the side sections,

The frames earned the appreciation of mining plant preparatory work departments, as evidenced by the example applications presented in Figures 33 and 34 [10].

In the year 2000, the ŁPrP frame series was expanded with ŁPrP variants constructed from heavy V32 and V36 sections for use in the LW "Bogdanka" mine. The frames were designed in two variants, differing slightly in shape, and their designations referenced the names of their manufacturers at the time – Huta Łabędy Ł and Huta Katowice K. Additional sill pieces were designed as well, installed optionally should it be required. The frames were intended to secure workings with widths of 4800–6400 mm and heights of 3300–4400 mm. Figures 35 and 36 present the ŁPrP Ł frames, whereas Figures 37 and 38 – the ŁPrP K frames. Example applications of the support are depicted in Figures 39 to 44.

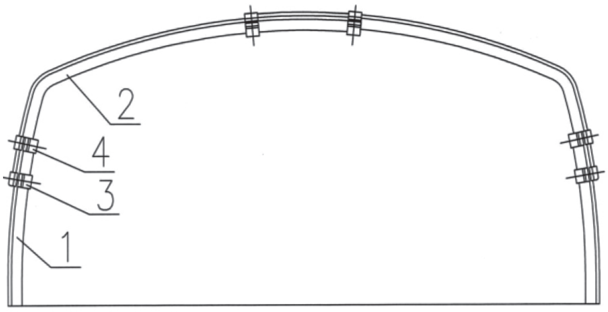


Fig. 27. Four-element ŁPrP frame:
1 – side section, 2 – top section, 3, 4 – shackles

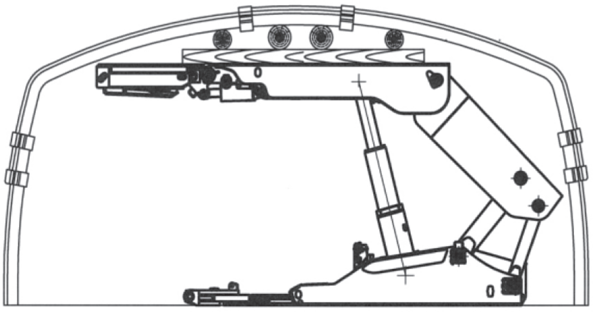


Fig. 28. Four-element ŁPrP frame with an installed powered support unit

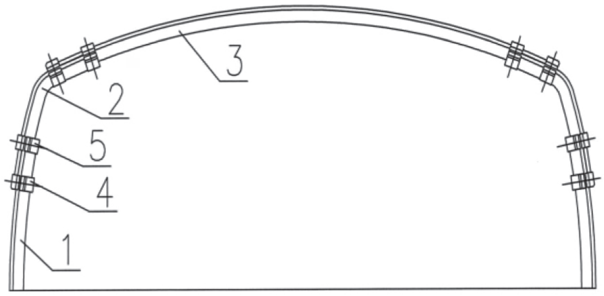


Fig. 29. Five-element ŁPrP frame: 1 – side section I, 2 – side section II, 3 – top section, 4, 5 – shackles

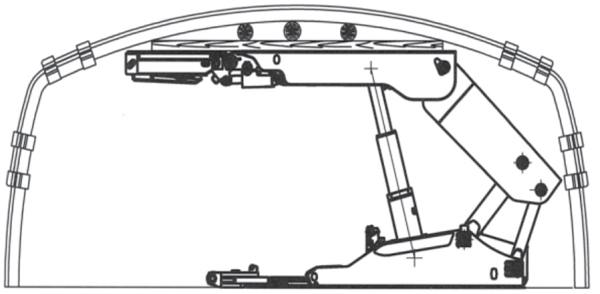


Fig. 30. Five-element ŁPrP frame with an installed powered support unit

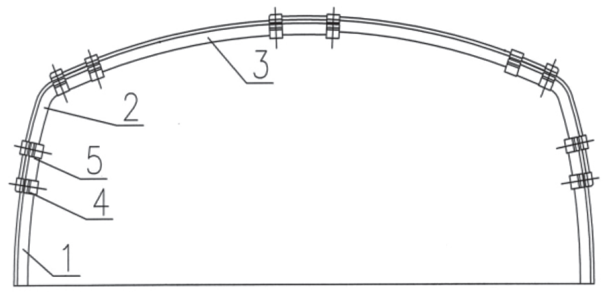


Fig. 31. Six-element ŁPrP frame: 1 – side section I, 2 – side section II, 3 – top section, 4, 5 – shackles

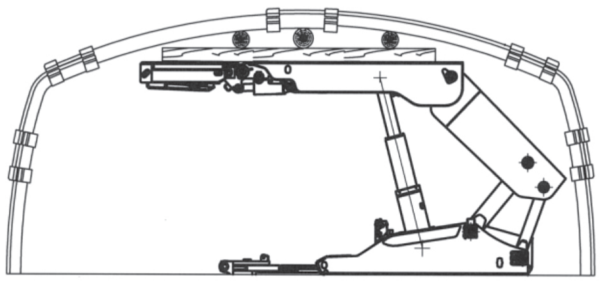


Fig. 32. Six-element ŁPrP frame with an installed powered support unit

Fig. 33. Development drift secured with four-element ŁPrP frames

Fig. 34. Longwall equipment, development drift secured with four-element ŁPrP frames

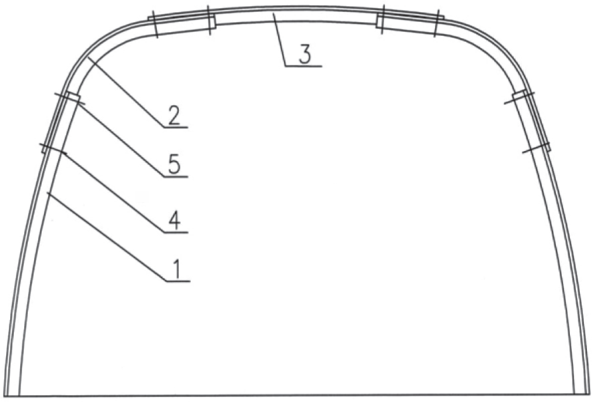


Fig. 35. ŁPrP frame variant Ł: 1 – side section I, 2 – side section II, 3 – top section, 4, 5 – shackles

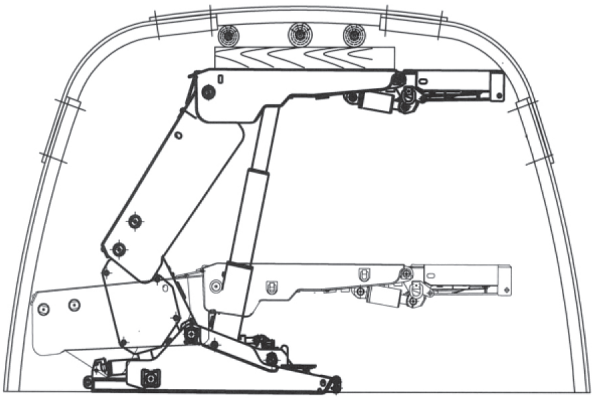


Fig. 36. ŁPrP frame variant Ł with an installed powered support unit (unit before and after spragging)

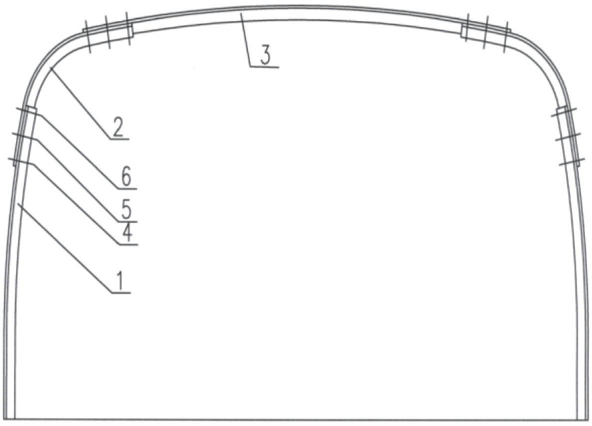


Fig. 37. ŁPrP frame variant K: 1 – side section I, 2 – side section II, 3 – top section, 4–6 – shackles

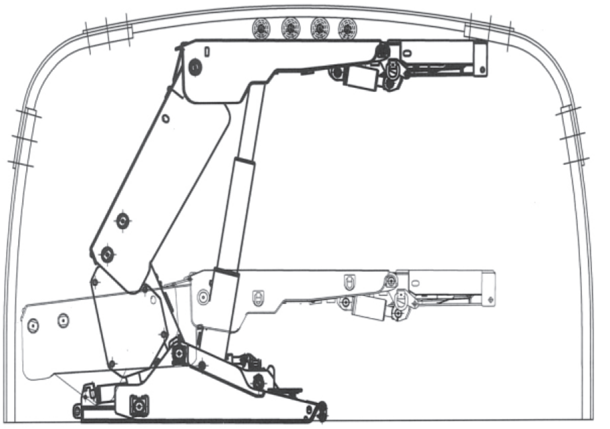


Fig. 38. ŁPrP frame variant K with an installed powered support unit

Fig. 39. Development drift secured by means of the ŁPrP variant Ł support

Fig. 40. Development drift secured by means of the ŁPrP variant K support

Fig. 41. Longwall equipment in a development drift secured by means of the ŁPrP variant K support

Fig. 42. Longwall equipment in a development drift secured by means of the ŁPrP variant K support

Fig. 43. Longwall equipment in a development drift secured by means of the ŁPrP variant K support

Fig. 44. Railway station constructed inside an ŁPrP variant Ł support

The reinforced arching-straight ŁPrw frame depicted in Figures 45 and 46, constructed from V29, V32, V34 and V36 sections, is a certain modification and expansion of the series presented above. The support was designed for securing the development drifts of longwalls developed with hydraulic filling, which makes it possible to equip the longwall with support units of great sizes. This was the reason why the frame exhibited such a significant size for that time. Initially, the series included frames intended for workings with a maximum width of 7200 mm and height of 5000 mm and was the subject of broad consultations with the first user – the Wujek mine [32]. The current series underwent significant expansion with bigger frame sizes a few years ago. The high load-bearing parameters of these frames, at a great width and low top section curvature, were achieved by utilising a reinforcing top section constructed from a section intended for the construction of shackle clevises. Figures 47 and 48 [33] present example practical applications of the ŁPrw frame.

At the same time, an attempt was made to combine a rectangular support with a (slightly flat) arching design. The result of this was the creation of the double arching-rectangular KaPa frame [30–35]. These frames were primarily intended for longwall development drifts characterised by great widths, driven under difficult geological and mining conditions, where top section bolting was impossible due to the low strength of the roof rock. Their structure is a “de facto” combination of the ŁPKO frame with a rectangular frame. The frame structure is presented in Figures 49 and 50. In combination with the ŁPro frames, this frame type also finds excellent application in securing the entries to workings at junctions [31].

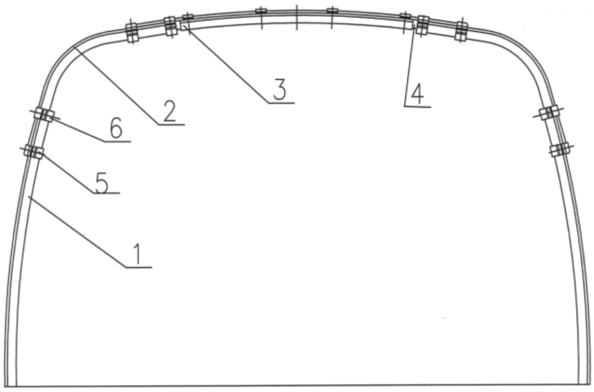


Fig. 45. ŁPrw frame: 1 – side section, 2 – upper side section, 3 – top section, 4 – reinforcing top section, 5, 6 – shackles

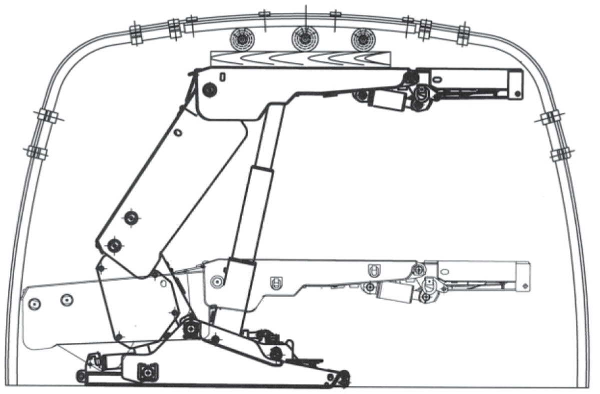


Fig. 46. ŁPrw frame with an installed powered support unit

Fig. 47. Development drift secured by means of the ŁPrw support

Fig. 48. Longwall equipment, development drift secured by means of the ŁPrw support

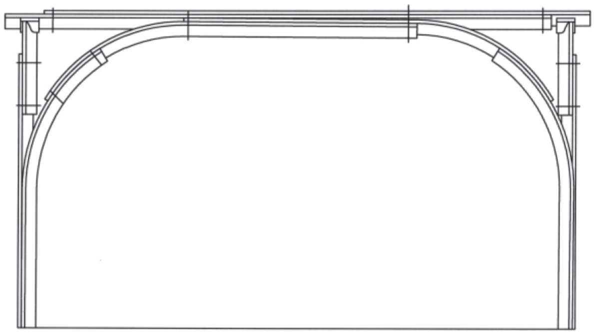


Fig. 49. KaPa frame

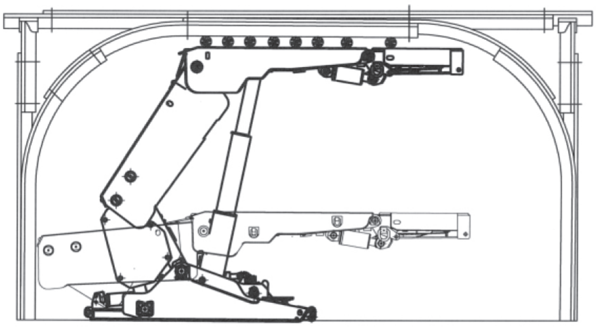


Fig. 50. KaPa frame with an installed powered support unit (unit before and after spragging)

In 2014, a new universal series of yielding arch frames designated ŁPS was designed at the Central Mining Institute [36]. Although their identification refers to the earlier constructions, these frames are completely different from those presented previously. The frames are intended for securing all types of gallery workings in underground mining plants. Their versatility stems from the potential for free configuration using arching sections of 17 sizes. Because of their particular geometry, arching sections of different sizes can be combined, resulting in frames that are varied in both dimensions and shape. Therefore, the scope of application of these frames encompasses more than just development drifts. This made it possible to obtain a universal series of frames with maximum element unification.

The second generation of the ŁPS support frame was designed as a four-element arching frame constructed from V29, V32 and V36 sections. In the basic variant, the frame comprises four identical arching sections of the same size. Each of the sections exhibits two different curvatures, one of which is shared by the entire series. The principle for assembling the arches is the same for the entire series – the sections are coupled with one another at the ends that exhibit identical geometric parameters. The frame structure is presented in Figures 51 and 52 [8], whereas Figures 53 and 54 [37] present the equipping of a longwall. Currently, the basic series (four identical arching sections) encompasses 18 frames, whereas the combined series (two pairs of different-sized sections) makes it possible to obtain 306 additional frame sizes. The nominal size range for the entire series encompasses widths of 5400–8800 mm and heights of 2790–5200 mm. The nominal arching sections make it possible to assemble 324 frames of different sizes, though the number of combinations increases once the possibilities of changing the side section lengths and the overlap arrangements are taken into consideration.

With such a great number of frame variants that can be constructed as part of a single series, it was necessary to develop specialist and accessible software for the computer-assisted design of these frames [38]. The main window of this software is presented in Figure 55.

In 2020, the second generation of the ŁPS frame series was expanded with asymmetrical variants, presented in Figures 56 and 57 [8].

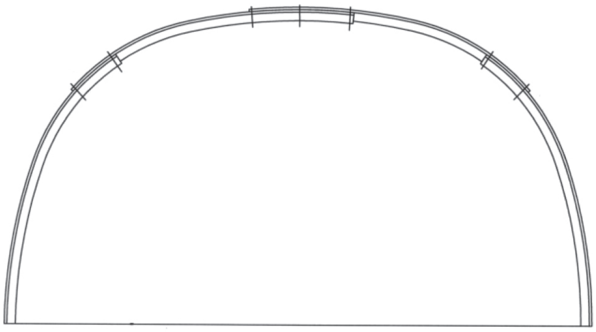


Fig. 51. Universal ŁPS II frame

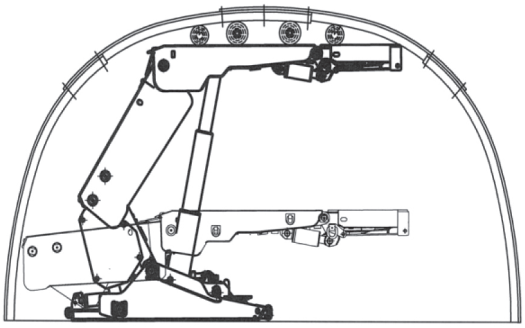
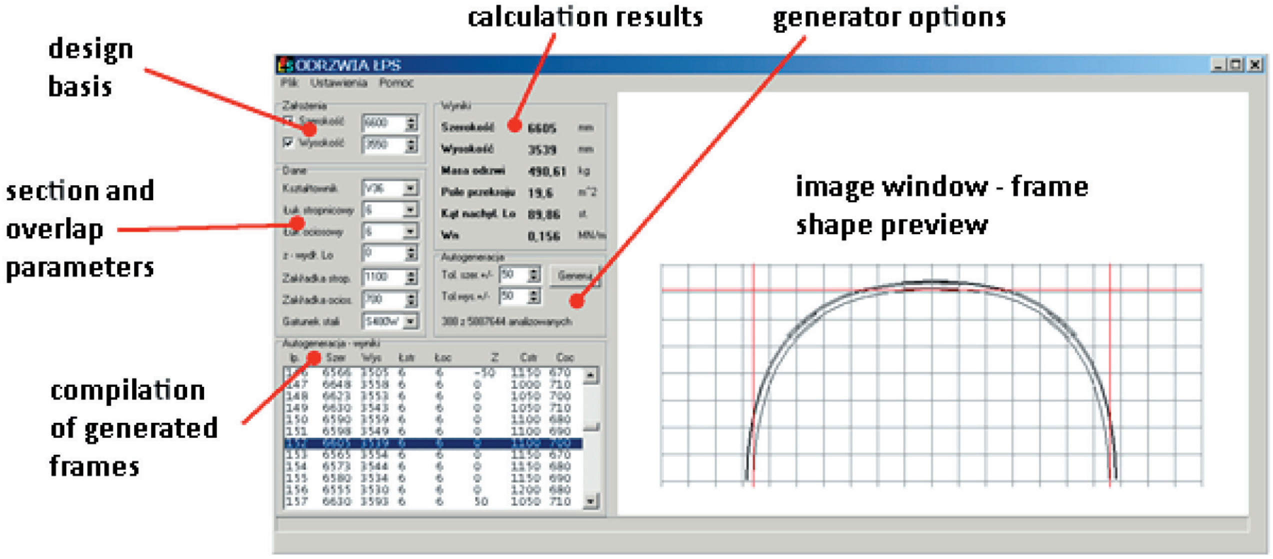


Fig. 52. Universal ŁPS II frame with an installed powered support unit

Fig. 53. Equipping a development drift driven in universal ŁPS II frames

Fig. 54. Equipping a development drift driven in universal ŁPS II frames



Założenia
☑ Szerokość 6600
☑ Wysokość 3550

Dane
Kształtownik V36
Łuk stropnicowy 6
Łuk ociosowy 6
z - wydł. Lo 0
Zakładka strop. 1100
Zakładka ocios. 700
Gatunek stali S480W

Wyniki
Szerokość 6605 mm
Wysokość 3539 mm
Masa odrzwi 490,61 kg
Pole przekroju 19,6 m^2
Kąt nachyl. Lo 89,86 st.
Wn 0,156 MN/m

Autogeneracja
Tol. szer. +/- 50
Tol. wys. +/- 50
300 z 5007644 analizowanych

Autogeneracja - wyniki

lp.	Szer	Wys	Łst	Łoc	Z	Cst	Coc
146	6566	3505	6	6	-50	1150	670
147	6648	3558	6	6	0	1000	710
148	6623	3553	6	6	0	1050	700
149	6630	3543	6	6	0	1050	710
150	6590	3559	6	6	0	1100	680
151	6598	3549	6	6	0	1100	690
152	6605	3539	6	6	0	1100	700
153	6565	3554	6	6	0	1150	670
154	6573	3544	6	6	0	1150	680
155	6580	3534	6	6	0	1150	690
156	6555	3530	6	6	0	1200	680
157	6630	3593	6	6	50	1050	710

Fig. 55. Main window of the computer-assisted ŁPS II frame design software [23]

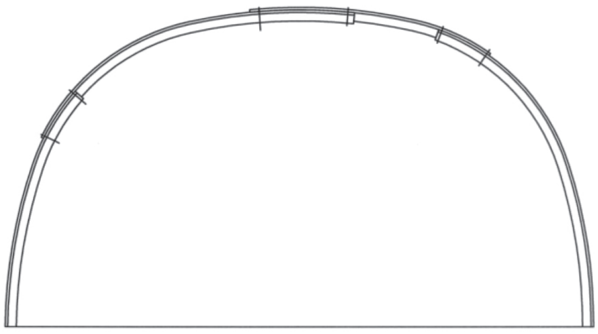


Fig. 56. Universal ŁPS II frame in the asymmetrical version

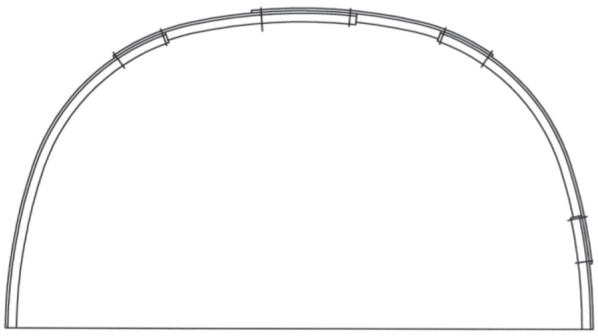


Fig. 57. Universal ŁPS II frame in the asymmetrical version with a parted side section

5. SUMMARY

Numerous series of frames dedicated to securing longwall development drifts have been designed over the last forty years as a result of the trilateral cooperation of the Central Mining Institute, Huta Łabędy and hard coal mining plants. Many of them also include several structural versions, which offers the users, i.e. the mines, even up to several dozen frame set variants to choose from. The solutions factor in the diversity of the geological and mining conditions found in specific mines as well as the individual circumstances resulting from the employed mining technology and powered support systems.

Such a number of structural solutions makes it possible to select the optimal support for specific conditions – the required dimensions, the expected loads exerted by the rock mass, the longwall height – which translates into the safety and efficiency of the conducted work both when installing and spragging the powered support units and during the subsequent development of the longwall.

The designed solutions are an effect of many years of research and development work as well as data gathering regarding the operation of arch support systems and their interaction with the powered support.

At the same time, the continued development of this support type should be expected, particularly in the context of increasing mining depth, deteriorating geological and mining conditions, and the consequent increase in loads. Furthermore, the increase in the lateral dimensions of both the longwall development drifts and the support systems is very likely, as a result of the growing concentration of output and the increasing dimensions of powered support units and the entire longwall networks. This will most likely involve the increased contribution of rock bolts in development drift support (mixed arch and bolt support, frame rock bolting), especially due to the necessity of reducing the support assembly costs while retaining a high level of safety [39, 40]. Another direction for the development of these supports, which can be conducted simultaneously, may be their further adaptation to the mining conditions – the longwall height or the type and size of the powered support units – accomplished through the appropriate selection of the arching section lengths and the optimal sliding joint placement. This will increase the efficiency of the powered support unit removal from the drift and the development of the longwall itself.

References

[1] PN-H-84042:2009: *Stale mikrostopowe na kształtowniki i akcesoria górnicze*.

[2] ZN/TT/2012/1: *Stal mikrostopowa S550W na kształtowniki i akcesoria górnicze*.

[3] PN-93-G-15000-02: *Obudowa chodników odrzwiami podatnymi z kształtowników korytkowych. Odrzwia łukowe podatne ŁP, z kształtowników typu V, typoszereg A. Wymiary*.

[4] PN-93-G-15000-03: *Obudowa chodników odrzwiami podatnymi z kształtowników korytkowych. Odrzwia łukowe podatne ŁP, z kształtowników typu V, typoszereg A. Łuki*.

[5] PN-G-15021:2019-05: *Obudowa wyrobisk górniczych. Odrzwia podatne z kształtowników korytkowych. Odrzwia łukowe podatne ŁP z kształtowników typu V*.

[6] Rotkegel M.: *Contribution to the problem of frame clear interval determination of rectangular steel support*, "Archives of Mining Sciences" 2001, 46, 3: 267–289.

[7] Rotkegel M.: *Siły wewnętrzne i reakcje podporowe w elementach obudowy prostokątnej*, "Kwartalnik Prace Naukowe Głównego Instytutu Górnictwa" 2009, 1: 51–66.

[8] Katalog Wyrobów dla Górnictwa, Huta Łabędy 2019.

[9] Katalog obudów rozcinek ścianowych "Projekt" – Komisja ds. Obudów Zmechanizowanych i Kierowania Stropem w Podziemnych Zakładach Górniczych przy Centrum Mechanizacji Górnictwa KOMAG, Gliwice 1997.

[10] Bobek R., Śledź T., Ratajczak A., Mąka B., Głuch P.: *Doświadczenia ze stosowania obudów podporowych i podporowo-kotwiowych w przecinkach ścianowych w kopalni "Knurów-Szczygłowice" Ruch Knurów*, Warsztaty Górnicze 2012 z cyklu "Zagrożenia naturalne w górnictwie".

[11] Prusek S., Rotkegel M., Bock S.: *Design and control of working support in Polish coal mines based on three-dimensional numerical modeling*, 28th International Conference on Ground Control in Mining, Morgantown, USA, 2009.

[12] Prusek S., Rotkegel M., Tor A.: *Przebieg kompleksowego procesu projektowania nowej konstrukcji obudowy wyrobisk korytarzowych*, Szkoła Eksploatacji Podziemnej, Kraków 2008: 333–351.

[13] Chmielewski T., Nowak H.: *Mechanika budowli. Metoda przemieszczeń. Metoda Crossa. Metoda elementów skończonych*, Wydawnictwa Naukowo-Techniczne, Warszawa 1996.

[14] Rakowski G., Kacprzyk Z.: *Metoda elementów skończonych w mechanice konstrukcji*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 1993.

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

[16] COSMOS/M – User's Guide, Structural Research & Analysis Corp. Los Angeles, USA 1999.

[17] PN-H-93441-3:2004: *Kształtowniki stalowe walcowane na gorąco dla górnictwa. Kształtowniki typu V. Wymiary*.

[18] PN-H-93441-1:2013-12: *Kształtowniki stalowe walcowane na gorąco dla górnictwa. Ogólne wymagania i badania*.

[19] Brodny J.: *Determining the working characteristic of a froction joint in a yieldning support*, "Archives of Mining Sciences" 2010, 55, 4: 733–746.

[20] Brodny J.: *Tests of Friction Joints in Mining Yieldning Supports Under Dynamic Load*, "Archives of Mining Sciences" 2011, 56, 2: 303–318.

[21] Pytlik A.: *Experimental studies of static and dynamic steel arch support load capacity and sliding joint temperature parameters during yielding*, "Archives of Mining Sciences" 2020, 65, 3: 469–491.

[22] PN-G-15000-05:1992: *Obudowa chodników odrzwiami podatnymi z kształtowników korytkowych. Odrzwia łukowe otwarte. Badania stanowiskowe*.

[23] PN-G-15022:2018: *Obudowa wyrobisk górniczych. Odrzwia podatne z kształtowników korytkowych. Wymagania wytrzymałościowe i badania*.

[24] Rotkegel M., Prusek S., Grodzicki M.: *Odrzwia obudowy chodnikowej ze stali nowej generacji. Nowa konstrukcja odrzwi i wyniki przeprowadzonych badań*, Szkoła Eksploatacji Podziemnej, Kraków 2012.

[25] Kuziak R., Żak A., Woźniak D., Rotkegel M., Grodzicki M., Nawrot J.: *Odrzwia obudowy chodnikowej ze stali II generacji*, "Prace Instytutu Metalurgii Żelaza" 2012, 4: 4–17.

[26] Rotkegel M., Prusek S., Kuziak R., Grodzicki M.: *Obudowa ŁPw ze stali o podwyższonych parametrach mechanicznych II generacji*, Szkoła Eksploatacji Podziemnej, Kraków 2013.

[27] Rotkegel M.: *Odrzwia obudowy ŁPw – projektowanie i wyniki badań*, "Journal of Sustainable Mining" 2013, 1, 12: 34–40.

[28] Bobek R., Śledź T., Ratajczak A. i Głuch P.: *Porównanie obudowy ŁPKO i ŁPSp w rozcince ściany wydobywczej w trudnych warunkach geologiczno-górniczych w kopalni Knurów-Szczygłowice*, "Budownictwo Górnicze i Tunelowe" 2013, 4: 1–9.

[29] Rotkegel M.: *The conditions for proper operation of the arch-rectangular support*, "Archives of Mining Science" 2019, 64, 1: 213–222.

[30] Skrzyński K., Rotkegel M.: *Obudowa podwójna dla rozcinek ścianowych wykonywanych w trudnych warunkach górniczo-geologicznych*, Prace Naukowe GIG, Seria "Konferencje", Nr 31, Katowice 1999.

[31] Rotkegel M., Bock S., Witek M., Adamiec P.: *Sposób zabezpieczenia połączenia wyrobisk korytarzowych w warunkach strefy uskokowej*, in: *Nowe spojrzenie na wybrane zagrożenia naturalne w kopalniach*, red. S. Prusek, J. Cygankiewicz, GIG, Katowice 2012: 5–14.

[32] Kowalski E., Rotkegel M., Kościerzyński Z., Wójcik D.: *Obudowa łukowo-prosta przeznaczona głównie do zabezpieczenia rozcinek ścian z podsadzką hydrauliczną*, "Przegląd Górniczy" 2003, 2: 13–18.

[33] Moszko M.: *Stosowanie obudów specjalnych do wykonywania rozcinek ścianowych w kopalni "Ziemowit"*, Konferencja Techniczno-Naukowa Huty Łabędy, 2009 [unpublished].

[34] Skrzyński K., Rotkegel M.: *Obudowa kombinowana prosto-łukowa jako skuteczne zabezpieczenie rozcinek ścianowych*, Szkoła Eksploatacji Podziemnej, Kraków – Szczyrk 2000.

[35] Kowalski E., Rotkegel M., Rułka K., Skrzyński K.: *Obudowy odrzwiowe proste i łukowo-proste*, in: *Stalowe obudowy odrzwiowe. Nowe rozwiązania konstrukcyjne i metody projektowania*, red. K. Rułka, Główny Instytut Górnictwa, Katowice 2006.

[36] Rotkegel M.: *Nowy typoszereg odrzwi łukowo-prostych*, "Wiadomości Górnicze" 2016, 11: 604–611.

[37] Łaskawiec Ł., Siudyła W., Caban P.: *Efekty techniczno-ekonomiczne z zastosowania uniwersalnych odrzwi ŁPS w warunkach KWK "Bobrek-Piekary"*, "Budownictwo Górnicze i Tunelowe" 2018, 1: 28–34.

[38] Rotkegel M.: *Program komputerowy wspomagający dobór obudowy typu ŁPS*, "Wiadomości Górnicze" 2017, 1: 8–12.

[39] Pytlik A.: *Comparative bench testing of steel arch support systems with and without rock bolt reinforcements*, "Archives of Mining Sciences" 2019, 64, 4: 747–764.

[40] Pytlik A.: *Tests of steel arch and rock bolt support resistance to static and dynamic loading induced by suspended monorail transportation*, "Studia Geotechnica et Mechanica" 2019, 41, 2: 81–92.

PIOTR CABAN, Eng.
Huta Łabędy S.A.
ul. Anny Jagiellonki 45, 44-109 Gliwice, Poland
pcaban@hutalab.com.pl

KAZIMIERZ STOIŃSKI, prof.
MAREK ROTKEGEL, prof.
SYLWESTER RAJWA, Ph.D., Eng.
ADAM GNATOWSKI
KRZYSZTOF PACZEŚNIOWSKI, Ph.D., Eng.
Główny Instytut Górnictwa (The Central Mining Institute)
pl. Gwarków 1, 40-166 Katowice, Poland
{k.stoinski; mrotkegel; srajwa; agnatowski; kpaczesniowski}@gig.eu