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OPTIMIZING A SUPPORT OF A FACE-ROADWAY JUNCTION LOCATED UNDER GOAFS

1. Introduction

Face-roadway junctions are vital for the effective exploitation of seams of coal and longwall drivage. These are areas where a lot of potentially dangerous incidents and even accidents can take place. Working in these areas is difficult and hazardous because of the number of personnel present and the limited work space. Additionally the space may be even further limited due to deteriorating conditions in numerous coal mines, intensive movements of rock mass in form of: floor heave as well as vertical and horizontal convergences [10, 11]. The probability of the occurrence of dangerous incidents increases when a seam of significant thickness is exploited with caving (with subdivision into layers). In the case of face-roadway junctions located under the immediate stone roof, anchoring, especially high anchoring, can improve the situation [3, 6]. Yet when a thick seam is exploited from the top towards the bottom anchoring is impossible because of goafs on the roof of the working. That is why it is necessary to look for new options, especially through the better usage of the potential of currently used means to strengthen basic support of junctions (steel horseheads, props).

Taking into consideration the above mentioned criteria Główny Instytut Górnictwa (Central Mining Institute) initiated works on optimizing the design of a support of a face-roadway junction located under goafs. The works were realized within the framework of the PROSAFECOAL project (2007–2010) within the framework of "The Research Fund for Coal and Steel" (RFCS) [9].

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2. Load measurements in the working and at the face-roadway junction

Underground tests were a significant part of the PROSAFECOAL project. Their aim was to measure support load as well as vertical and horizontal convergence of the roadways located under reconsolidated caving debris [5]. The underground tests were carried out in five workings, marked A to E in the paper, in two chosen coal mines of Kompania Węglowa SA.

Due to operational reasons (e.g. shooting to prepare niches) the load tests with hydraulic dynamometers in workings B, C and E were completed 10 m from the face of the longwall. Nevertheless, as the measurements of the forces affecting the support (taken by GIG in the coal mines of Upper Silesian Coal Basin) show that values of the forces are not significantly different from the ones measured at the face-roadway junction (Fig. 1). It was then assumed that the forces reflect the support load at the face-roadway junction.

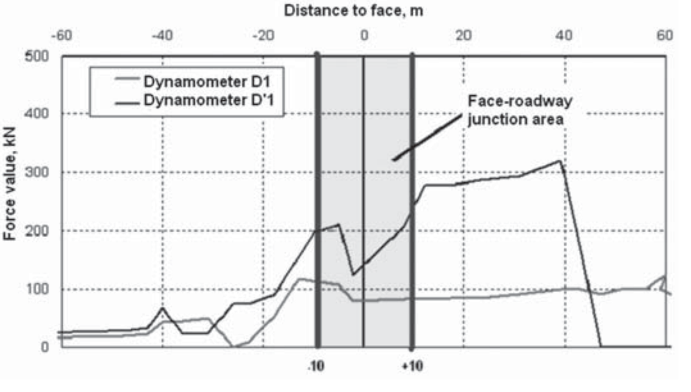

Fig. 1. Example results of measurements of the forces affecting the roadway support in GZW coal mines

In Figure 2 are presented results of measurements of load of a roadway support taken with hydraulic dynamometers placed under frames of an arch support.

Figure 2 shows that support load near a face junction is quite diversified, which is a result of the geological and mining conditions. On average it is 64 kN. In all the cases the load measured on the frames on the rib at the longwall was higher than the load on the other rib.

Of all the registered results working D is exceptional. There the maximum value of the load on one rib was 180.8 kN and on the other 143.2 kN. Much higher values of load were probably influenced by layers of sandstone of significant thickness in the rock mass over the caving debris. Working C where the load values were the lowest was located in an area where good geological and mining conditions prevail resulting from optimum reconsolidation of caving debris.

In general the underground tests of load as well as horizontal and vertical convergence, which did not exceed 120 mm, confirm existing opinions [4] of the workings located under

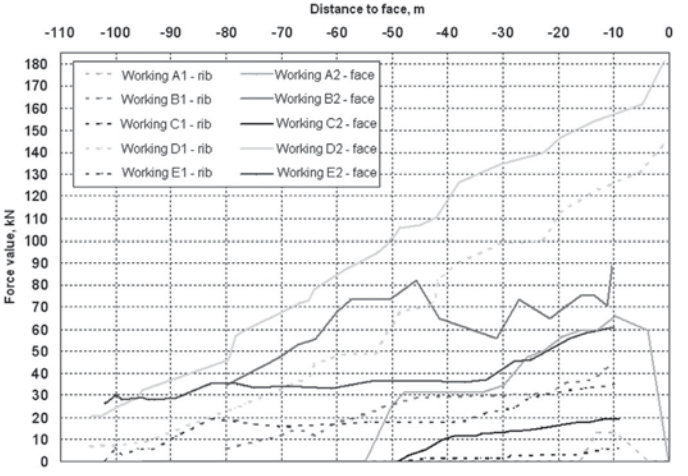

Fig. 2. Results of measurements of the load on a roadway support

caving debris. Extracting the upper layers eases tensions. That is why the values of horizontal and vertical convergence as well as the heave of the floor are lower than in case of workings located under the immediate rock roof.

3. Options to optimize the face-roadway junction support

At the initial stage of optimizing the design of a face-roadway junction the support was analyzed. On the basis of this analyses four projects were chosen and meticulously examined. They are as follows:

— The main drive is located in the main gate, no independent support is used at the face, up to 4 meters of sidewall arches of the support frames are disassembled (Fig. 3a),

— The main drive is located in the main gate, an independent support is used at the face up to 3 meters from the junction, up to 4 meters of sidewall arches of the support frames are disassembled (Fig. 3b),

— The auxiliary drive is located at the face, an independent support is used at the face up to 3 meters from the junction (Fig. 3c),

— The auxiliary drive is located in the tail gate, an independent support is used at the face up to 3 meters from the junction and up to 4 meters of sidewall arches of the support frames are disassembled (Fig. 3c).

On the basis of the four chosen basic designs of the support, the influence of props and steel horseheads placement on the face-roadway junction support load-bearing capacity was analyzed. Additionally, the influence of using high strength steel and making niches in the area of the roadway ahead of the face was determined.

For each of the different versions of support, numeric computations were made with the use of ABC Rama 3D [1] and COSMOS/M [2] based on the finite element method (FEM). Results of the computations are presented in subsections 3.1–3.3.

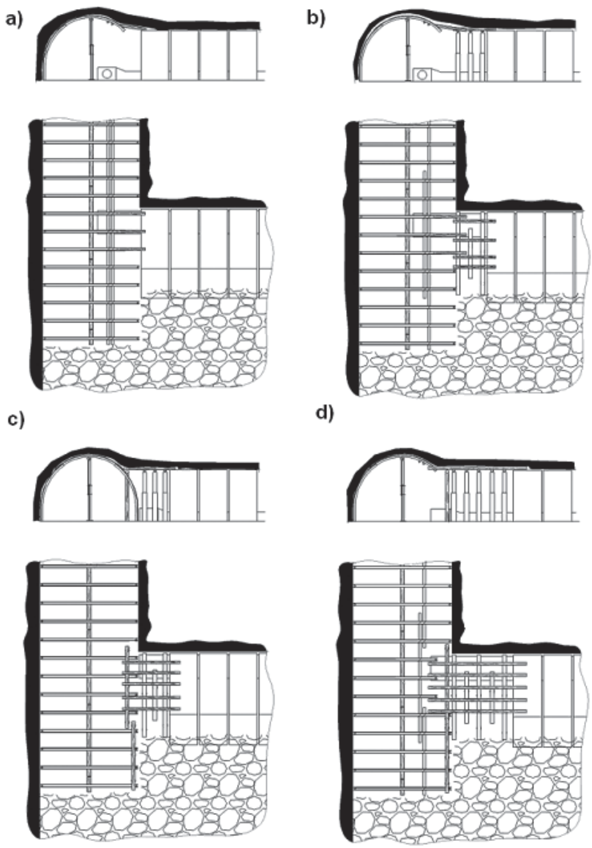

Fig. 3. The four chosen basic designs of a face-roadway junction support

3.1. Steel horseheads placement in a face-roadway junction

Steel horseheads were the first elements of a face-roadway junction support to be analyzed at the initial stage of optimization. Rails and V-sections mounted on roof arches with hook bolts are most often used in coal mining. They are commonly used in face-roadway junctions where the support is exposed to a greater load and additionally sidewall arches have to be disassembled. Because of the dimensions of the face conveyor and the route of the shiftable conveyor it is very difficult to use any other method of strengthening the support.

That is why the case in possibility changing the position of a steel horsehead from the end of a disassembled sidewall arch towards the heading axis was meticulously analyzed. Layout of the analyzed solution is presented in Figure 4.

In such a case the position of a horsehead below the roof arch of the frame may be adjusted within the distance between the end of the roof arch and the axis of symmetry of the frame (*a* in Figure 4). The strength analysis of the support showed that the Von Mises stress distribution σ_{red} in profiles of a horsehead change depending on the span of the frame (*d* in Figure 4) as well as the number of disassembled sidewall arches. An example of the stress distribution in a horsehead profile along its length is presented in Figure 5. The frames of the support used were made of V29 profiles, format 9, span 0.8 m (4 disassembled sidewall arches).

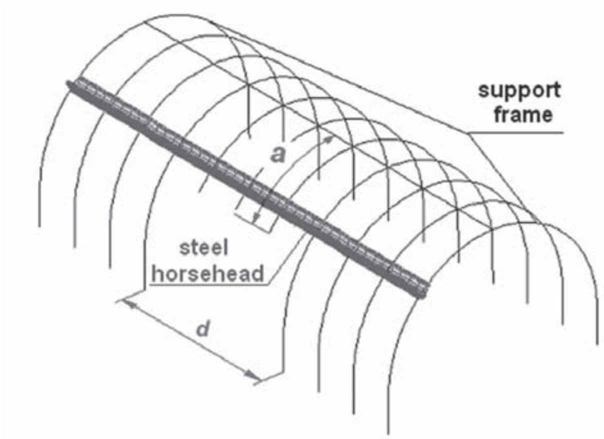

Fig. 4. Layout of the analyzed face-roadway junction with an adjustable position of horseheads

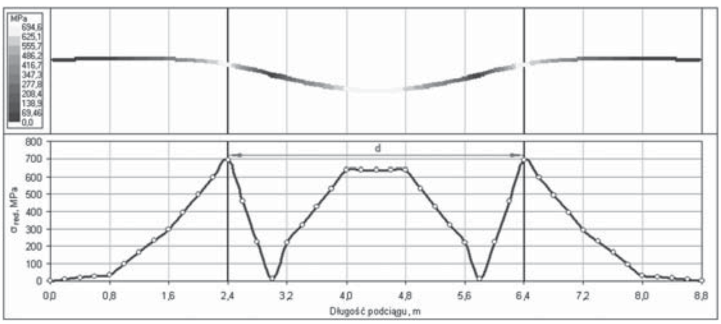

Fig. 5. Distribution of Von Mises stress in a joist profile of 8.8 meters

The values of the stress and displacements of a horsehead, at a steady load of the support, depends on its location under the roof arch (*a*) and the size of the horsehead profile.

In Figures 6–8 graphs are presented showing load-bearing capacity of a face-roadway junction support P_{sk} [MN/m] at the length of *d* [m] (compare Fig. 4) and vertical displacement of the horsehead *u* [m] depending on the distance between the axis of the horsehead profile and the end of a roof arch *a* [m]. The distance *a*, because of overlapping, is 0.5–1.8 m. These calculations were made for a joist made of V29 profile and steel of the parameters given in Polish Standard PN-H-93441-1:2004 (min. R_e = 340 MPa, min. R_m = 550 MPa) [8] as well as high strength steel (min. R_e = 480 MPa, min. R_m = 650 MPa) — according to Polish Standard PN-H-84042:2009 [7].

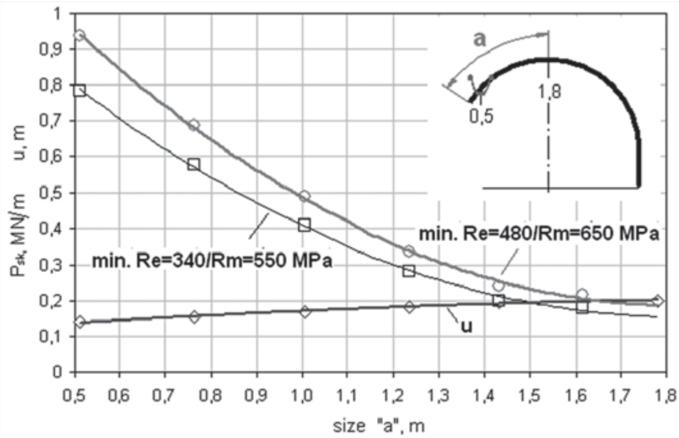

Fig. 6. Dependence of junction support load-bearing capacity and horsehead deflection on a horsehead placement under the roof arch of an ŁP8-sized frame and a grade of steel

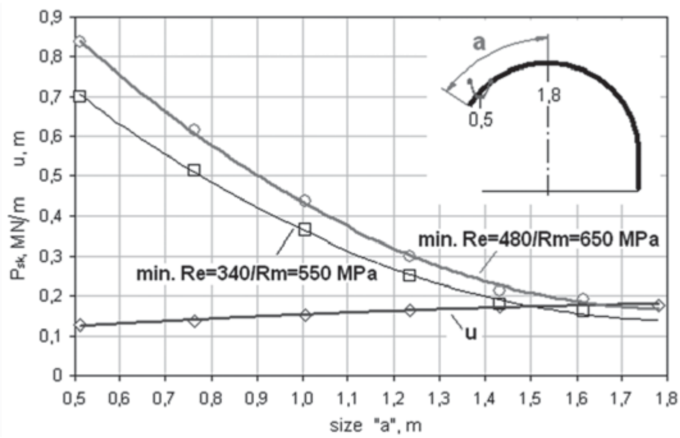

Fig. 7. Dependence of junction support load-bearing capacity and horsehead deflection on a horsehead placement under the roof arch of an ŁP9-sized frame and a grade of steel

On the basis of these calculations (their results presented in Figures 6–8), a conclusion can be drawn that the application of elements made of high strength steel increases the load-bearing capacity of a junction support by approx. 20% in comparison with a support made of steel according to Polish Standard PN-H-93441-1:2004. In figures 6–8, for each size of the frames a distinct dependence of load-bearing capacity of a junction support P_{sk} and the placement of a horsehead (*a*) is clearly visisble. The farther from the end of the roof arch a horsehead is placed, the lower the load-bearing capacity of the junction support and the bigger vertical displacement of a horsehead *u* are, although the value of the changes are insignificant in comparison to the changes of load-bearing capacity P_{sk}.

Moreover we can state that the load-bearing capacity of face-roadway junction support P_{sk} decreases with the increase in the number of frames with disassembled sidewall arches and the load-bearing capacity is dependent on the size of a horsehead profile.

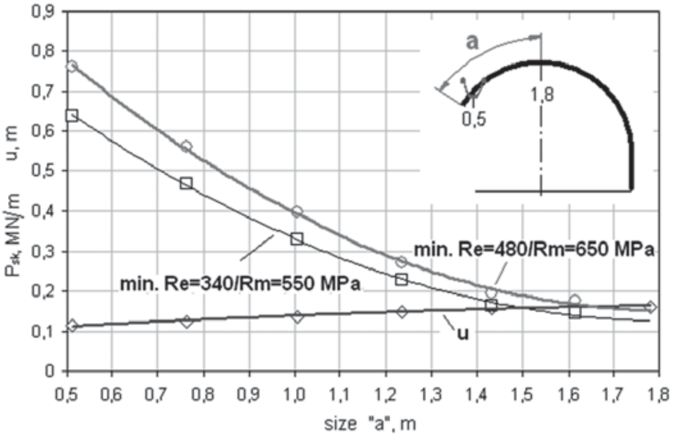

Fig. 8. Dependence of junction support load-bearing capacity and horsehead deflection on a horsehead placement under the roof arch of an ŁP10-sized frame and a grade of steel

On the basis of these numeric computations a generalized relation was formulated to calculate junction support load-bearing capacity *Psk*, placement of a horsehead, size of a profile and a grade of steel a joist is made of. The equation:

$$P_{sk} = k_{LP} \cdot k_{ST} \cdot (-0.0434 \cdot a^2 + 0.1996 \cdot a + 0.1854) \tag{1}$$

where:

- a — the distance of the horsehead from the end of roof arch (measured along the curve), m;
- k_{LP} — size of the arch coefficient, non-dimentional;
- k_{ST} — grade of steel of the joist coefficient, non-dimentional.

Values of the coefficient k_{ST} are presented in Table 1; values of the coefficient k_{LP} are presented in Table 2.

TABLE 1
Values of the coefficient k_{ST}

Grade of steel	k_{ST}
Steel according to Polish Standard PN-H-93441-1:2004	0.5001
High strength steel according to Polish Standard PN-H-84042:2009	0.5975

3.2. Props placement in a face-roadway junction

Because the frames of a standing support are also strengthened with props, the next subject requiring analysis is the influence of: a prop load-bearing capacity, the prop placement and a grade of steel an ŁP support frame is made from, on the load-bearing capacity

TABLE 2
Values of the coefficient k_{LP}

Size of the frame	k_{LP}
ŁP8	1.12
ŁP9	1.00
ŁP10	0.91

of a support in a face-roadway junction. In Figure 9 a strength diagram of a support made of V29 profile 9 format is presented. The diagram is used to analyze the influence prop placement on a frame load-bearing capacity.

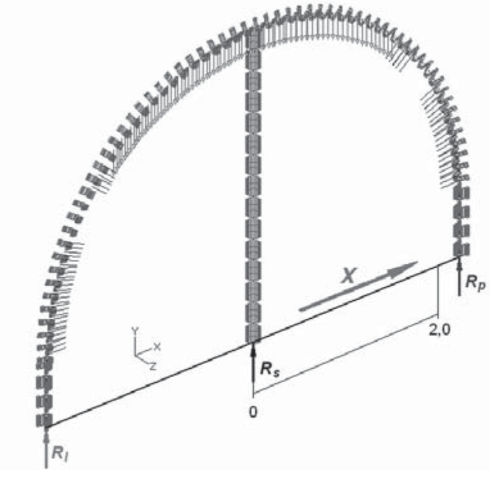

Fig. 9. Layout of a support to assess influence of a prop placement on the load-bearing capacity of a support frame. R_l — reaction under the left sidewall arch, R_p — reaction under the right sidewall arch, R_s — reaction under a prop, x — the distance between a prop and the axis of symmetry

On the basis of numeric computations a correlation was formulated which describes changes in Von Mises stresses σ_{red} in most often used frame profiles (ŁP support, 9 format) depending on a prop placement (Fig. 10).

On the basis of the computations presented in figure 10, it is possible to calculate xmax maximum span between a prop and the axis of symmetry of a frame according to the ultimate values of maximum stress within a frame profile. In Table 3 examples of results for an ŁP support 9 format are presented.

The dependence of the load-bearing capacity of a single frame P [MN] on the span between a prop and the axis of symmetry x [m] can be expressed as a general equation:

$$P = k_V \cdot k_{ST} \cdot S^{-2.2797} \cdot e^{0.029 \cdot x} \tag{2}$$

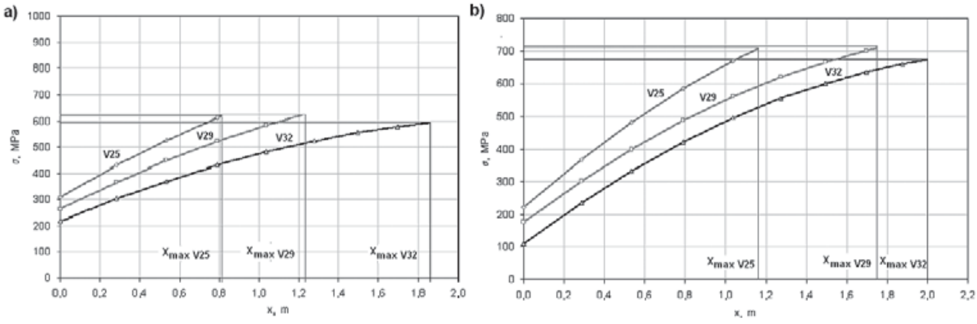

Fig. 10. Changes of Von Misses Stresses in Polish Standard PN-H-93441-1:2004
a) and Polish Standard PN-H-84042:2009,
b) grade steel frame profile depending on the prop placement

where:

- S — the width of a frame at the bottom, m;
- k_V — size of a profile coefficient, non-dimensional;
- x — the distance of a prop from the axis of symmetry, m;
- k_{ST} — grade of steel horsehead coefficient, non-dimensional.

Values of coefficient k_V are presented in Table 4; values of coefficient k_{ST} are the same as presented in Table 1.

TABLE 3
Maximum distances between a prop and the axis of symmetry of a frame x_{max} according to the ultimate values of maximum stress within a frame profile

Frame profile	Steel according to Polish Standard PN-H-93441-1:2004	High strength steel according to Polish Standard PN-H-84042:2009
	x_{max}, m	
V25	0.82	1.16
V29	1.25	1.75
V32	1.85	2.00

TABLE 4
Values of the coefficient k_V

Profile of a frame	k_V
V25	12 912
V29	16 040
V32	18 694

3.3. Preparing technological niches ahead of the face

Passive sidewall load is also an important factor which, together with active rock mass load, influences how the frame of a support behaves at the face-roadway junction. Lack of passive load in the area significantly decreases the total load-bearing capacity of a frame. In Figure 11 an example of a layout of a face-roadway junction used in one of GZW coal mines together with a marked area of a technological niche is presented.

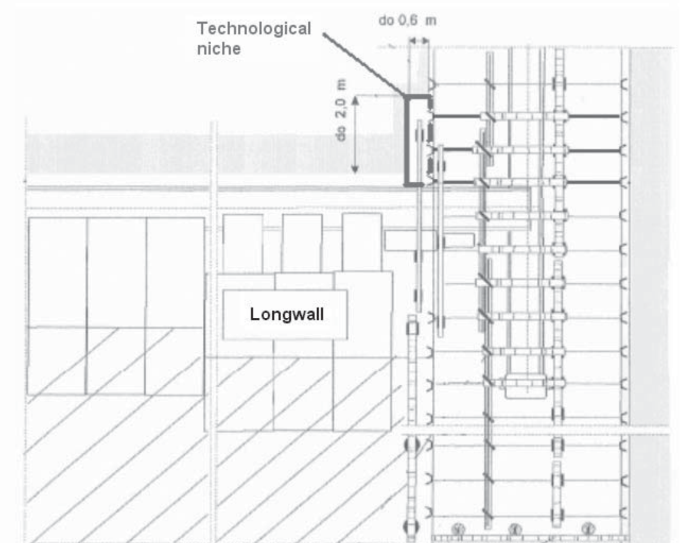

Fig. 11. An example of a face-roadway support layout applied in one of coal mines

The influence of the length of a niche ahead of the face on the load-bearing capacity of a face-roadway junction support Psk was analyzed. An example of a graph showing the relation between the load-bearing capacity Psk for an ŁP9/V29/A frame, with a span of 0.75 m, and the length of a section „w" without the passive load because of a niche is presented.

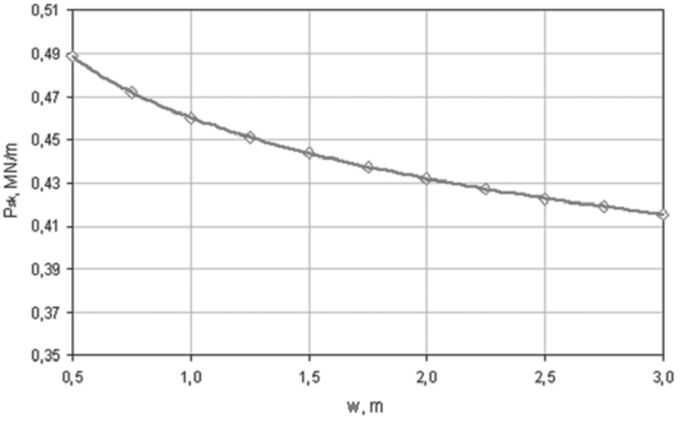

Fig. 12. Dependence of a junction support load-bearing capacity on the length of a niche (no passive load for a support frame)

As it is shown in the graph (Fig. 12) it is advisable to use technology which requires as short a niche as it is possible or to alter the technology to avoid making it at all.

4. Summary

Face-roadway junctions are extremely important in exploitation of coal seams. Their stability has a decisive influence on both the obtained production results and the safety of personnel. In the case of mining under goafs, it is impossible to apply anchoring to strengthen a support or the rock mass. Instead props and steel horseheads should be used to strengthen the support.

In this paper the influence of a horsehead and a prop placement on the load-bearing capacity of a face/roadway junction support have been presented. These dependencies should be helpful in designing supports in the area.

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