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Professional paper

CHOICE OF OPTIMAL SUPPORT FOR CONDITIONS IN BCM "JASENOVAC" KREPOLJIN

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Abstract: Inadequate choice of support regarding geological characteristics of intact rock and pressures in rock mass, very quickly leads to creation of problems in functionality of developed roadways, damages of installed equipment and endangering safety of workers. To avoid big investments in process of subsequent remake of already supported roadways, this issue should be solved. Solving this issue reduces costs of total production and increase work safety. This paper analyses support issues in the most unfavorable working conditions of the test brown coal mine "Jasenovac" Krepoljin.

Key words: rock pressure, support, bearing capacity, Jasenovac

1. INTRODUCTION

During drifting of underground roads natural – primary balance is violated, causing change of stress in surrounding rock massive. Secondary stresses formed around emerging cavity, i.e. road can be lower than mechanical strength of rock massive. No significant deformations of contour and support of roadway will happen in this case. If secondary stresses are higher than mechanical strength of rock material, then rock mass tends to fill excavated space and deformations occur. Supporting underground roadways we oppose to deforming of rock massive. On the contact of support with rock massive, forces called rock pressure appear. Rock pressures appear as a consequence of interaction between rock mass and support (Jovanović, 1994).

Forming and demonstration of this way defined rock pressure depends on series of factors, where the most significant are:

- Technology of roadway drifting;
- Moment the support is embedded;
- Support bearing capacity.

Regardless the current level of science and technology, there is no universal method of calculation of road dimensioning and suitable support. Semi-empirical methods are used for solving those issues. Those methods are based on theoretical calculations and measurements during development. Based on this way obtained results corrections of support dimensioning are done.

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Choice of the type of support based on capacity is a very complex issue for which different authors suggested several solutions. Each of those solutions can be applied only for specific conditions, while for different conditions doesn't provide satisfying results. The first necessary step to solve this task should be defining of influential parameters, and then, based on that, correct selection of theoretical principle for choice of optimal support (Jovanović et al. 1992).

This paper describes the results of tests, performed in test brown coal mine "Jasenovac" – Krepoljin (Tokalić, 2002).

With the objective to find better analytical way to solve this issue, original program "Support" was made, used to make all necessary calculations and their analysis. Based on input data, program gives calculation of: trapezoidal timber support, steel rigid and yielding support, concrete and reinforced concrete support. According to results obtained and technical-safety and economical principles, choice of rational support for given conditions is made.

2. WORK CONDITIONS

Jasenovac coal mine is characterized with very complex tectonic structure which leads to disturbance of hypsometrical relations of coal seam (Vidanović et al. 1998).

Miocene coal-bearing series is represented with: hornstones, sandstones, clayey sandstones in foot-wall, then coals and clayey-marly sandstones, clays and rare marls in hanging wall. Thickness of layers varies.

Lithological column of coal seam (by N.Petkovic) is shown in Figure 1.

3. DETERMINATION OF ROCK PRESSURE

Determination of rock pressure was done in analytical procedure based on data of average values of physical and mechanical features of rock material and in situ measurements.

3.1. Analytical determination of rock pressure

Analytical determination of rock pressure was done by Cimbarevic′s procedure, according to which support is loaded with the material inside natural balance roof and from side wall of the road. In cases of week-strength rocks, side walls of rooms cave in, so the abutments of natural balance move inside the massive. Sliding of material from side walls is done along the plane that is standing at an angle to the horizontal.

To determine a value of pressure for given work conditions, depending on the cross-section size, calculation was done for all rocks and support types represented with more than 15% from total supported roads in "Jasenovac" pit, and those are:

- Steel arc support, frame type R1, of special mining profile RI-110;
- Steel ring support, type of frame ZO, of special mining profile YU-21;
- Concrete moonlit roofed support.

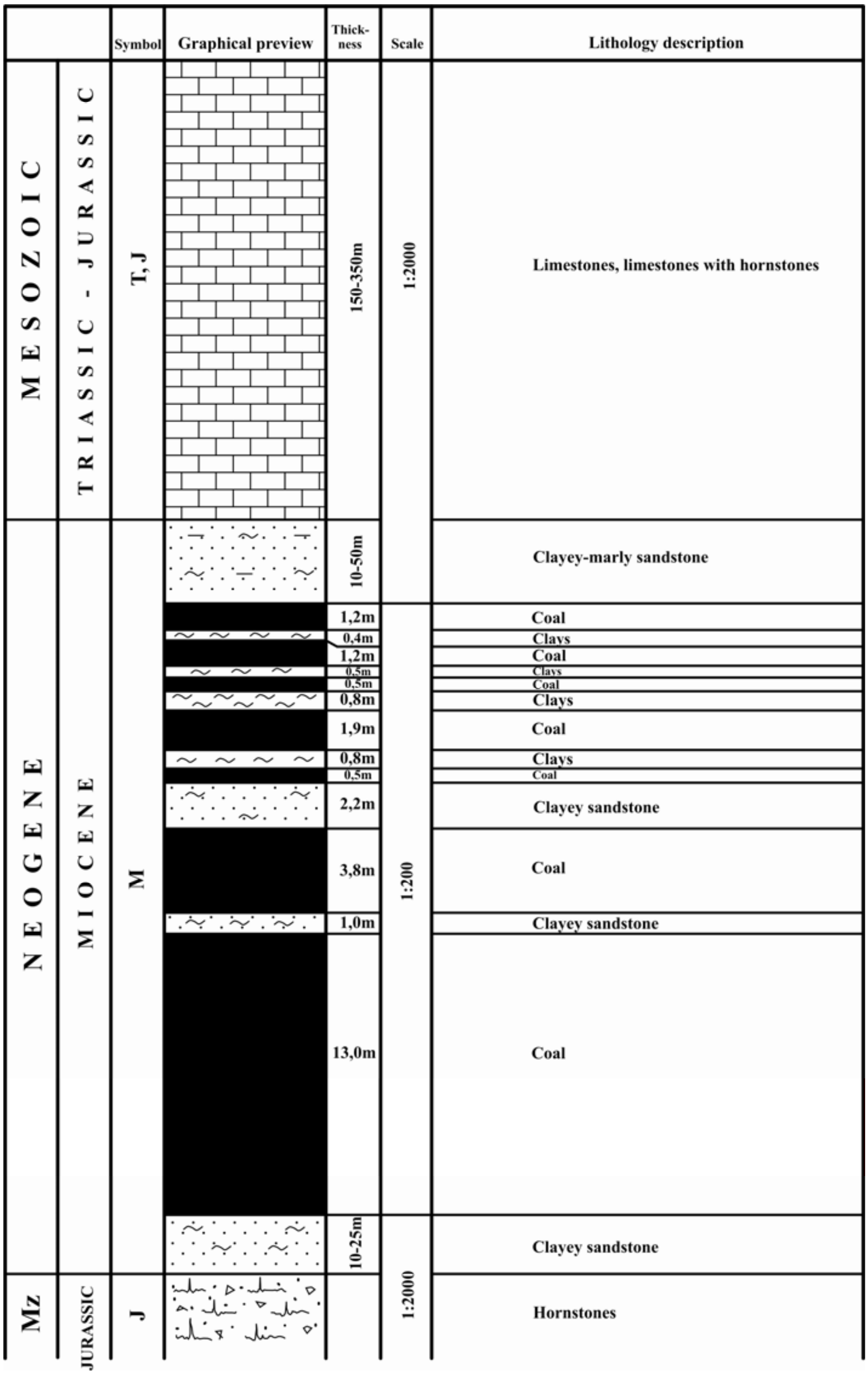


Figure 1 - Coal seam lithology column (by N.Petković)

3.2. Determination of rock pressure value in-site

Determination of rock pressure value in-site was done by the method of direct measuring of pressure to the support frame, using hydraulic dynamometers – measuring cells type Welbir-Ambitijelo. Preview and installation of measuring cell are shown at Figure 2.

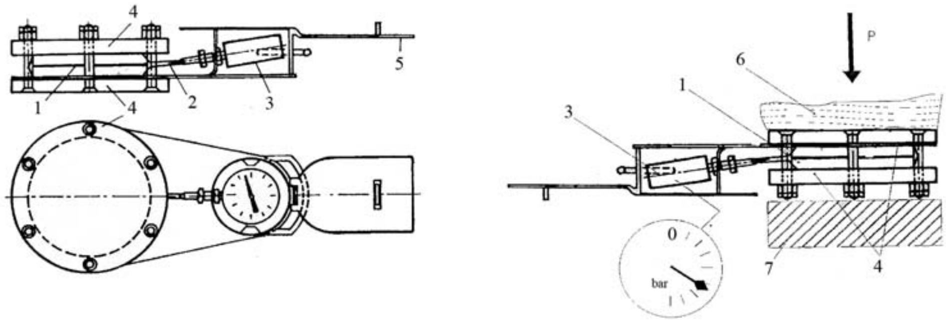


Figure 2 - Preview and installation of measuring cell:
1 - metal pad filled with oil; 2 - capillary tube; 3 - manometer; 4 - protective steel pannel; 5 - protective cover; 6 - rock mass; 7 - support

Chosen method and equipment are providing satisfactory results, because the construction of dynamometer is suitable to mining conditions, and simple installation and reading without interferences to production process provide a possibility of everyday reading.

Measuring stations are located at points where pressure is expressed and expected. Readings at measuring stations are done until the pressure value is stabilized. Readings were done in intervals from 25 to 50 days. In most cases pressure values were stabilized after 45 days. Total of 14 measuring stations were formed for this testing.

Records provided from measuring were processed and recalculated based on load diagram, distance between frames and dip angle of road, and they are reduced to a concentrated load per meter of road length. This way, comparison with analytical pressure values is enabled.

Figure 3 shows the scheme of disposition of measuring cells at measuring point MM-1 with load diagrams.

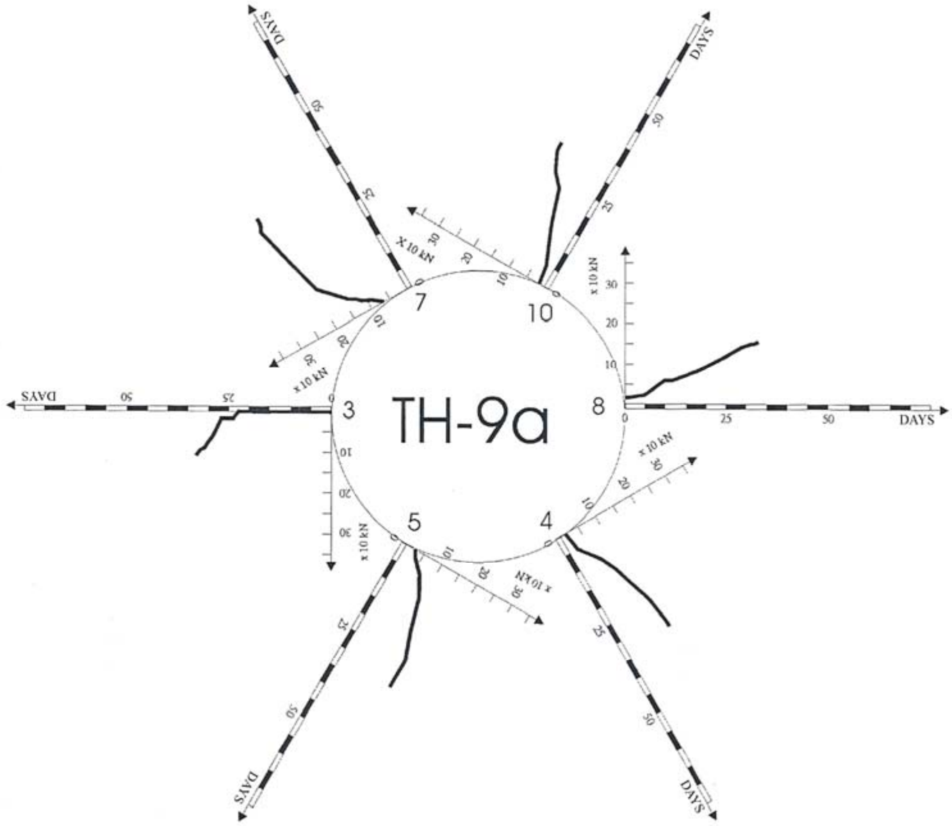


Figure 3 - Disposition of measuring cells in TH-9a and load diagrams for MM-1

Table 1 shows values of measured loads per m' of road, and preview of vertical and horizontal pressure component for measuring cells 10, 8, 4, 5, 3 and 7.

4. ANALYSIS OF ANALYTICALLY DETERMINED ROCK PRESSURES

According to analysis of rock pressures based on parameters working conditions of "Jasenovac" Mine, it can be concluded that the most unfavorable rocks for locating of mine roads is direct roof of coal seam, i.e. clayey-marly sandstones, because of expressively small bearing capacity of rock material.

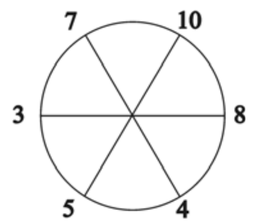
Big influence at the state of rock material and dimensioning of support has cracks and faults and their orientation, i.e. very complex tectonic structure of this deposit.

For that reason, when roads are designed, locating of roads in rocks with week strength coefficient and parts of rock mass with expressed tectonics should be avoided, if possible.

Table 1 - Records from MM-1 measuring point in TH-9a road

Days	Load per m' of roadway [kN]					
	Measuring cells					
	10	8	4	5	3	7
1	9	15	15	45	0	90
3	12	14	16	51	0	114
4	15	24	18	60	0	120
5	24	42	27	67	0	141
10	39	60	57	96	0	177
11	42	60	57	99	0	183
12	45	60	60	102	0	192
14	57	73	73	111	0	204
18	66	84	78	120	0	210
19	78	87	84	120	0	213
20	81	87	87	120	0	213
22	90	99	93	132	0	213
23	90	105	96	135	0	225
24	99	105	105	135	15	228
25	105	120	108	141	15	231
26	108	120	111	141	15	234
27	120	135	120	141	15	240
29	126	141	126	141	60	240
30	135	147	129	141	75	240
31	144	150	132	141	90	240
32	144	150	132	141	96	237
33	144	156	132	141	108	234
35	140	150	130	140	105	230
38	140	150	130	140	105	230

Cell	Load	Components	
		Horizontal	Vertical
10	140	70	121
8	150	150	-
4	130	65	112
5	140	70	121
3	105	105	-
7	230	115	199
Mean value		96	138



Regarding analytically determined pressures, the most favorable working conditions have rocks in direct foot wall of coal seam, i.e. hornstones and limestones, if they are not weakened. If a road is developed in coal, the best is that it is located in foot wall of coal seam.

Regarding the influence of cross-section size, if technical conditions for dimensioning allow it, support frames with smaller area of finished cross-section should be used.

According to the results of analytical calculation of steel rigid support, it can be concluded:

- Appling support frames with smaller cross-section larger distances between frames are obtained or fewer frames per m′ are needed;
- Steel support of RI profiles can be used in coals with strength coefficient over 1.5 and in limestones with strength coefficient over 3;
- For rocks with strength coefficient below 1, support of R1 steel rigid frames is not satisfying, or more support frames per m′ are needed then it is technically possible to imbed;
- For concrete and reinforced concrete support, using results of calculations of concrete lining it was concluded:
  - As finished cross-section size is increasing, also the thickness of concrete lining is increasing;
  - Concrete support can be used in all working conditions. Limiting condition is that $d < 30$ cm, and area for application is limited to coals, limestones and hornstones;
  - For direct roof and floor concrete monolith support is partially satisfying. According to calculation in those rocks for the smallest cross-section ($P = 4.85$ m^2) 23 cm thickness of concrete lining is obtained, and for the largest cross-section $P = 11.62$ m^2 thickness is $d > 50$ cm, therefore this kind of support is rejected as unsuitable for those working conditions, because it would lead to huge excavating work and imbedding a large mass of concrete and cause negative financial effects;
  - For rocks with strength coefficient below 1, reinforced concrete support is recommended;
  - Calculation of reinforced concrete support shows that this support can be used for supporting in the most threatened parts of the test mine. Quality of reinforced concrete construction can be increased using welded reinforcement meshes with 280 MPa allowed caring capacity, and handling is significantly easier.
- In calculation of steel yielding support of ZO support frames it was determined:
  - ZO yielding steel frames can be used for supporting in working environments with strength coefficients $f > 1$;
  - As the cross-section size is increasing the number of frames per m′ of roadway is increasing;
  - Application field of yielding ZO frames is larger then rigid RI frames, i.e. yielding frames can be partially used to support roads with strength coefficient below 1. A limiting factor for application of support of ZO frames are the dimensions of YU-21 profiles.

5. ANALYSIS OF ROCK PRESSURES OF PERFORMED IN-SITU MEASUREMENTS

Performed comprehensive terrain measurements of rock pressure values in test mine enabled the calculation of support parameters in special software developed for managing this issue. Results of calculation could be compared with analytically obtained support calculation values.

Based on results of analytical support calculation and calculation based on on-site measurements, following conclusions were reached:

- Steel ring support can be applied for supporting in clay rocks with strength coefficient below 0.5, because large number of frames per m', that is technically not possible to embed;
- For rocks with strength coefficient over 0.5 support of ZO-3 frames can be applied. Based on done analysis following distances are recommended:
  - for sandstone with clayey impurities $l = 0.40$ m;
  - for coal average distance of $l = 0.60$ m;
- If recommended distances would slow planned drifting dynamics, problem could be solved by using higher quality steel for support frames. Satisfactory steel in this case would be micro-alloyed steel with mark R-1 and tensile strength $\sigma_{max} = 88.3$ kN/cm^2.

6. RECOMMENDED SUPPORTING METHOD

Based on performed tests, a choice of support construction for rocks with strength coefficient over 1, can be done based on analytically determined pressure with necessary correction of compressive strength determined at smaller samples. For weaker rocks no corrections are necessary because the environment is too week and requires recommended specific supporting method.

Based on performed analysis, without including financial parameters, we can conclude that in the test mine, steel, concrete and reinforced concrete support can be successfully used in roadways driven through relatively stable rocks. When steel arch support is used, it is better to use arch yielding support, because its parameters are more favorable then rigid steel support. Installation of steel support doesn't require any additional work, so supporting is finished in one cycle. Installation of concrete support requires additional work related to securing the excavation, setting of shuttering, cementing and removing of shuttering. All this requires completely different organizational scheme and engaging more labour.

Based on that we can conclude that steel support presents better choice for stabile working conditions in Mine "Jasenovac".

For sections of roadways driven through rocks with strength coefficient below 0.5 and have significant percentage of clay component, suitable support must be found to suppress rock pressure and to isolate working environment from negative influences of mine water and moist.

For those sections, combined RI-6 frame support, steel mesh and cast concrete support if suggested. Technology of such support installation would have following sequence: right after excavating, steel frames at 0.50 m would be embedded, covered with steel mesh, with a role to prevent caving of loose pieces. Embedded frames would have a role of temporary support. When adequate distance from the face is provided, concreting would be done, while frames would be removed, but stay inside concrete. Steel frames are set in pressed zone of cross-section. Because of increasing of concrete tensile bearing capacity it is necessary to install reinforcement in lacing zone. Thickness of concrete lining is calculated by equation:

$$d = \frac{\left(q \cdot R \cdot L - 0.6 \cdot R_i \cdot F \cdot 10^{-4}\right) \cdot k_b}{4 \cdot \sigma_{zb} \cdot L}, \quad [\mathrm{m}] \tag{1}$$

Where:

q - equally-distributed load from roof in clay working environments, average $q = 0.50$ Mpa;
R - diameter of roof (R=B- road width) $R = 3.90$ m;
L - distance between frames $L = 0.50$ m;
R_i - yield point of steel the frame is made of $R_i = 220$ MPa;
F - area of frame profile cross-section $F = 31.1$ cm^2;
k_b - coefficient depending on size of aggregate for concrete preparation $k_b = 1.25$-1.50 adopted 1.30;
σ_{zb} - tensile strength of concrete, reinforced concrete type not less then MB 30 with allowed bending strength is 12 MPa, i.e. tensile strength is $\sigma_{zb} = 1.2$ MPa.

For reinforcement, welded reinforcement mesh of cold drown wire with capacity 280 MPa is suggested. According to the calculation mesh of ϕ12 wire with 10 x 20 cm holes is required. As support frames accept a part of load, this way calculated reinforcement with concrete provides high support safety under affect of the highest static and dynamic loads. For RI-6, support frame with reinforcement mesh type 30, in direct roof as the most unfavorable rock type, calculated thickness of concrete is $d = 30$ cm. This way dimensioned support will provide holding of the most difficult sections in the Mine.

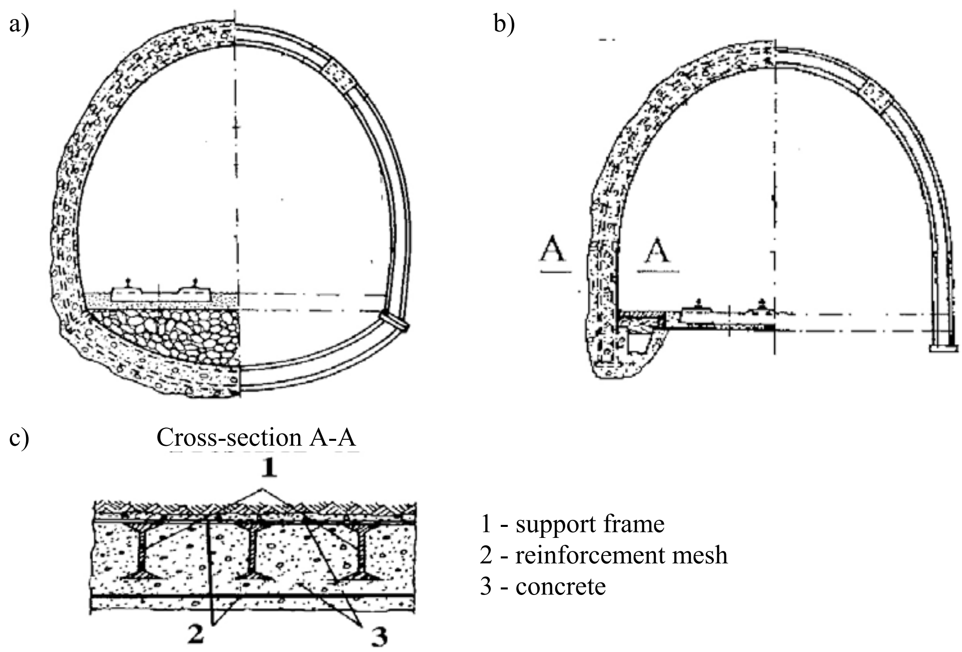


Figure 4 - Proposed support method: a) Frame with contra roof; b) Uncompleted frame; c) Support details

Figure 4 shows this way of supporting. Complete frame would be use in cases of floor heaving – lifting. The picture shows disposition or reinforcement meshes and support frames. Outside mesh is used to prevent caving in and isn't included into calculation because it is located is stressed zone, which is not the case with inside mesh located in stretching zone and plays significant role to accept stretching stress.

7. CONCLUSION

Tests described in this paper have practical application, because proposed methodology of the best roadway support method choice in the test mine is also acceptable for other coal mines, considering specificities of each individual mine.

This methodology determined application scope for rigid and yielding support and changing of distance between support frames in the function of compressive strength of rock mass. Beside that, application scope for concrete and reinforced concrete support with a suggestion of optimal supporting method for extremely week rocks. That way coal exploitation costs would be decreased, because costs of additional remake of already made roads for inadequate support would be down to minimum.

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