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Izlaganje sa znanstvenog skupa

ROCKBOLTS SUPPORT OF THE DRIFTS AND CROSSCUTS IN BAUXITE

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The article discusses the excavation method in bauxite underground exploitation of the »Trobukva« mine in the »Bauxite Mine Posušje«, and the experiences in drift and crosscut supporting so far. Frame support is the only activity which is not mechanized and it has an important part in the production costs. Therefore the possibility of supporting by bolts and wire mesh has been developed. The estimation of bolting elements was performed for the Swellex bolt and it proved, that bolt support compared with the frame support, beside the technical and safety advantages has also a considerable economic justification.

Ključne riječi: Boksit, Podzemna eksploatacija, Podupiruća podgrada, Sidro Swellex, Podgrađivanje sidrenjem

U članku prikazana je otkopna metoda kod jamske eksploatacije u jami »Trobukva« – Rudnika boksita Posušje, kao i dosadašnja iskustva na podgrađivanju otkopnih hodnika. Podgrađivanje podupirućom podgradom jedini je posao koji nije mehaniziran, a u toškovima proizvodnje ima značajnu ulogu. Stoga je razrađena mogućnost podgrađivanja sidrenjem i žičanom mrežom. Proračun elemenata sidrenja izveden je za Swellex sidro, a pokazalo se je da podgrada sidrima, pred podupirućom podgradom, osim tehničkih i sigurnosnih prednosti, ima i značajnu ekonomsku opravdanost.

Introduction

Sublevel caving is mostly applied in the bauxite underground exploitation, with the level height from 6 to 10 m. In such exploitation it is necessary to drive both drifts and crosscuts in bauxite, by which practically 25 to 40% bauxite is mined. Therefore supporting of these drifts and crosscuts is a safety and economical problem.

In Yugoslav bauxite mines the drift and crosscut support in bauxite is carried out exclusively by frame support. The support material is wood or steel or the combination of both. Support installation is mostly manually performed.

All works of driving the rooms in bauxite by mining are mechanized except supporting. Consequently, the most difficult part of the work remains unmechanized, which is also very unsafe. Supporting presents one of the biggest production costs due to a large number of man–shifts and much consumed material.

The article discusses basic geological and geotechnical characteristics of bauxite and accompanied sediments of the »Trobukva« mine. It also presents the mining methods of bauxite underground excavation as well as the experiences in supporting the crosscuts in bauxite up to now. The possibility of supporting the crosscuts in bauxite by bolting and with the wire mesh is treated on the basis of theoretical assumptions and informations from experience.

The problem of supporting the drifts is more complex, because crossings are driven on them, so that these drifts should be supported by bolting after such solutions will be first experienced in the crosscuts.

Geological and geotechnical characteristics of bauxite and accompanied sediments

The bauxite deposit »Trobukva« was formed in the paleorelief forms created in the period between the Senonian and the Eocene. The footwall is composed of the cenonian–turonian limestones, and the roof of the heterogenous series of eocene clastites with typical features of molasse. The footwall limestones are relatively well bedded. Layer thickness varies from 10 to 40 cm. Bedding is very often camouflaged by additional tectonic and chemical changes.

Limestones were structurally altered during the pre–ore and post–ore phases. Systems of tensile fractures, slidings due to foldings and fractures near large faults are clearly expressed. Physical–mechanically viewed, limestones express stable characteristics (Table 1) and present a favourable environment for the performance of mining activities. Drifts driven in these limestones are usually self supported.

Bauxite originated in the age of long–lasting dry–land phase. It represents a dry–land sediment accumulated in the deepest negative forms of the old relief. Bauxite has structurally changed together with the sediments of floor and roof. The sliding planes are mostly expressive in the deposit along which breaking and caving in mining spaces occur. These planes are characterized by the motion of millimetre and centimetre dimensions.

Groundwater circulates along them, which intensifies sliding or breaking and caving. Physical–mechanical characteristics of bauxite (Table 1) indicate, that there is a weak rock in question and the rooms driven in it should be supported.

The immediate roof of bauxite is composed of different varieties of marl with thin enclosures of coal. Marl thickness amounts 20 to 40 m. The contact of bauxite and marl is under the angle of 0 to 50°. Physical-mechanical parameters were examened on marl samples bulding the immediate roof of bauxite (Table 1) indicating, that there is a soft rock. The rooms driven in marl are more inclined to caving than the rooms in bauxite, because marl in contact with air looses its physical–mechanical properties.

Table 1. *(Tablica 1.)*

EXAMENED PARAMETERS (ISPITANI PARAMETRI)	*Unit of measure (jedinica mjere)*	*Limestone (Vapnenac)*	*Bauxite (Boksit)*	*Marl (Lapor)*
σ_t – uniaxial compressive strength *(jednoosna čvrstoća)*	kN/m^2	30400	21270	19490
σ_v – tensile strength *(vlačna čvrstoća)*	kN/m^2	14710	3860	4860
σ_s – bending strength *(čvrstoća na savijanje)*	kN/m^2	8830	1830	
φ – angle of internal friction *(kut unutrašnjeg trenja)*	°	44.00	44.91	44.44
C – cohesion *(kohezija)*	kN/m^2	18840	4040	4280
E_e – moduls of elasticity *(modul elastičnosti)*	kN/m^2		26140	22530
E_d – moduls of deformation *(modul deformacije)*	kN/m^2		15460	16570
v – Poisson's ratio *(Poissonov koeficijent)*			0.30	0.23
ϱ – bulk density *(volumna gustoća)*	t/m^3	2.60	2.50	2.33

Mining method

In the Yugoslav bauxite mines sublevel caving method is mostly applied. This method changes due to the variation of its basic parameters:

- position of drift,
- level height,
- possition of crosscuts in relation to crosscuts of previous level,
- dimensions of drifts and crosscuts,
- distance between crosscuts.

In the Bauxite mine Posušje this method is used in the variant illustrated in Figure 1. Drifts are driven along the strike of the ore body in the level centre. Crosscuts are driven perpendicular to drifts with the distance of 6.5 m among them. The width of the pillar to the mined and caved area amounts 3 m.

The drifts and crosscuts have square cross–section with the dimension of 3.5 x 3.1 m unsupported and of 3 x 2.8 m supported. They are adapted for the operation of loading–transport machines by Eimco–Secoma 912 B and of drills by Eimco–Secoma ATH 12. In order to enable this equipment to enter undisturbed from drifts into crosscuts, the crosscut is widened by length of 2 m on one side of the crossing. Therefore the pillar width is decreased at this point to 2 m (Figure1).

The vertical spacing amounts 7 to 7.5 m, and at the crosscut height of 3.1 m the intact ore averages between 3.9 and 4.4 m.

Drilling and blasting of fans is performed in the roof and pillar towards the caving waste with leaving the tracer layer in roof and side with the thickness of 1 m. Boreholes are inclined to the waste under the angle of 60°. Fan burden amounts 1.5 to 2 m. Fan blasting is performed from the supported crosscut whereby a great deal of the support is damaged.

Calculation of pressures on the support

There are several hypotheses on the occurrence of underground pressures and the ways of estimating loading on the support of underground rooms. All attempts up to now to estimate pressure on the support of underground rooms have been more or less disadvantageous, so the results obtained by calculation have to be considered carefully. Therefore the estimation of pressures on the support of mining roads with the shape and the dimension compatable with the current way of supporting is performed here (Figure 2), in order to compare the obtained results with the experienced ones. The calculation is accomplished for the conditions of the mine »Trobukva«.

According to Protodjakonov the pressure on the support in narrow opening occurs due to the caved roof under selfbearing arch of a parable shape. Protodjakonov suggests the determination of pressure arch height for coherent rocks according to the equation:

$$v = \frac{5 \cdot 1}{\sigma_t} = \frac{5 \cdot 3{,}5}{21{,}27} = 0{,}82 \text{ m} \qquad (1)$$

where:
1 = 3.5 m – width of the drifts (Figure 2), σ_t = 21.27 MPa – uniaxial compressive strength of bauxite which is in the equation (1) taken as dimensionless value.

Loading on the support from pressure arch for a metre of the drift amounts:

$$q_v = \frac{21 \text{ v g } \varrho}{3} = \frac{2x3{,}5x0{,}82x9{,}81x2{,}5}{3} = 47 \text{ kN} \quad (2)$$

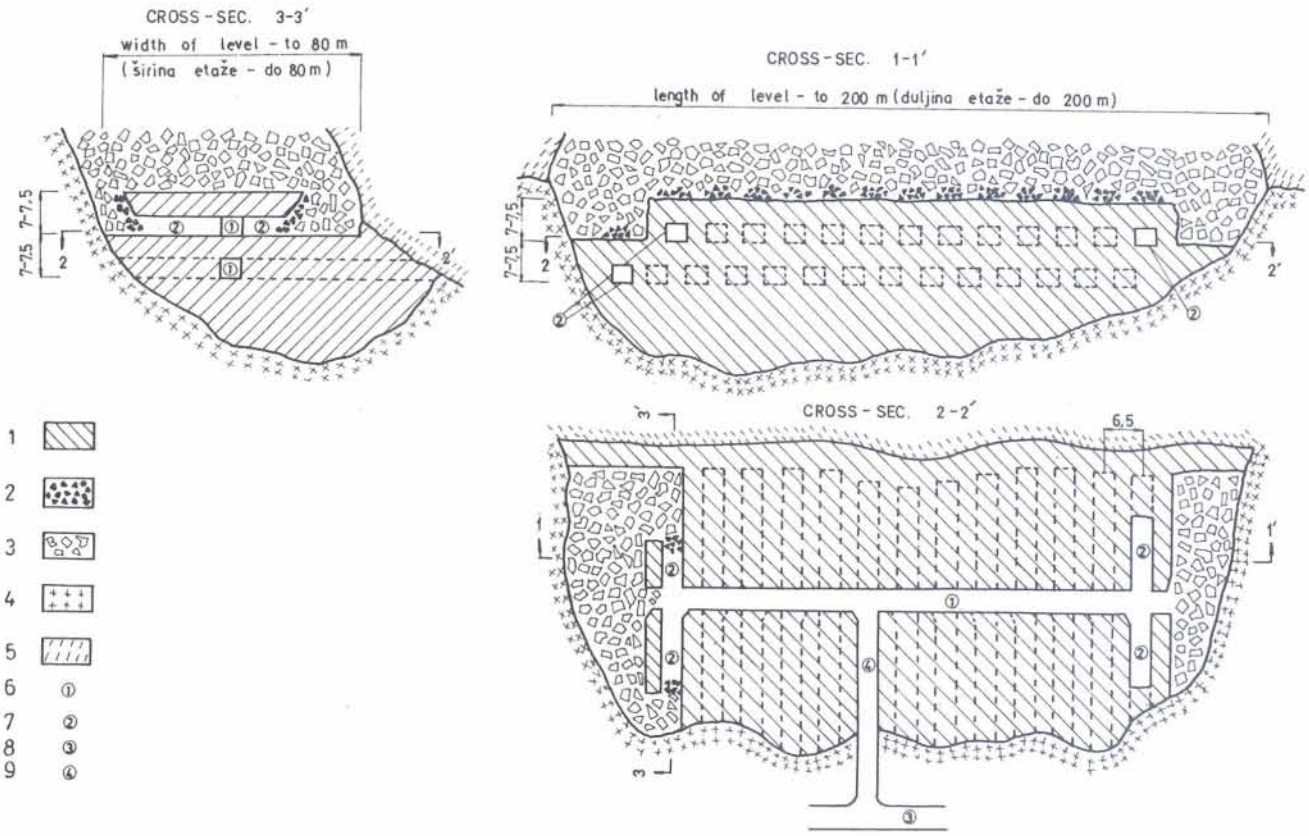

Fig. 1. Sublevel caving method in the Bauxite Mine Pusušje

Sl. 1. Podetažna otkopna metoda otkopavanja boksita sa zarušavanjem krovine u Rudniku boksita Posušje

LEGEND (LEGENDA):

1. Ore (Čvrsta ruda); 2. Blasted ore (Minirana ruda); 3. Caving waste (Obrušena krovina); 4. Footwall–Cretaceous limestone (Podina–kredni vapnenac); 5. Hanging wall–marl (Neposredna krovina–lapor); 6. Drift (Smjerni hodnik); 7. Crosscut (Otkopni hodnik); 8. Footwall haulage drift (Izvozna rampa); 9. Access drift (Pristupni hodnik)

where:

ϱ = 2,5 t/m^3 – bulk density
g = 9,81 m/s^2 – acceleration of gravity.

According to terzaghy (Szechy 1970) there is no pressure on the support of underground opening if the following condition is satisfied:

$$\varrho \cdot g \leqq \frac{2 \cdot c}{1 + 2h \cdot tg(45 - \frac{\varphi}{2})} \qquad (3)$$

where:

c = 4040 kN/m^2 – bauxite cohesion
l = 3,5 m – width of the opening
h = 3,1 m – height of the opening
φ = 44.91° – angle of internal friction

Resulting in $\varrho \cdot g$ = 2,5 · 9,81 = 24,5 kN/m^2 and

$$\frac{2 \cdot c}{1 + 2h \cdot tg(45 - \frac{\varphi}{2})} =$$

$$= \frac{2 \cdot 4040}{3,5 + 2 \cdot 3,1 \cdot tg(45 - \frac{44,91}{2})} = 1330 \text{ kN/m}^3$$

consequently, according to equation (3) there is no pressure on the opening support in bauxite.

According to Bierbaumer (Szechy 1970) vertical loading on the support along the opening axis amounts:

$$q_v = \frac{\varrho \cdot g \cdot l^2}{2 \cdot tg\varphi} = \frac{2,5 \cdot 9,81 \cdot 3,5^2}{2 \cdot tg\ 44,91} = 151 \text{ kN/m} \qquad (4)$$

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According to Sallustowiez (Szechy 1970) there is no pressure on the opening support in bauxite if the following condition is satisfied:

$$\frac{1}{2}\left[(\frac{1}{\nu} - 2) - (\frac{1}{\nu} - 1)\frac{\sigma_v}{\varrho \cdot g \cdot H}\right] \leqq 0 \qquad (5)$$

where:

ν = 0,3 – Poisson's ratio
σ_v = 3860 kN/m^2 – tensile strength of bauxite
H = 200 m – maximal depth of the opening position

Resulting in:

$$\frac{1}{2}\left[(\frac{1}{0,3} - 2) - (\frac{1}{0,3} - 1)\frac{3860}{2,5 \cdot 9,81 \cdot 200}\right] = -0,25$$

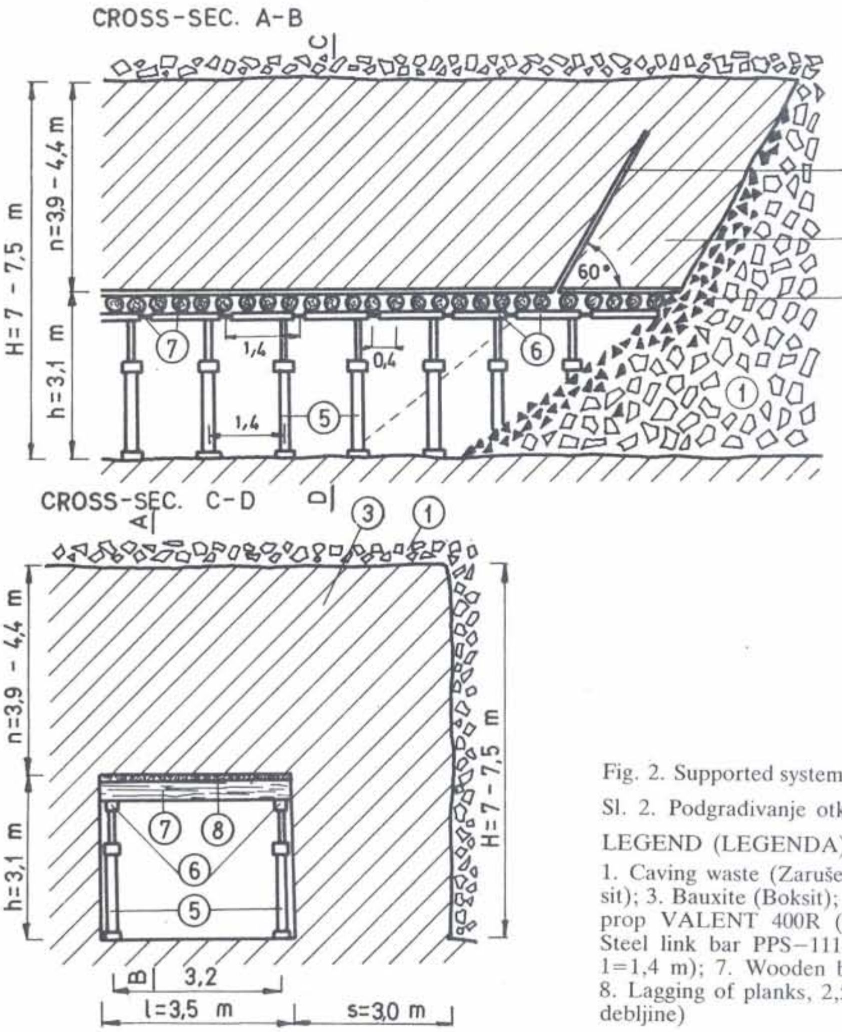

Fig. 2. Supported system of the crosscuts in the Bauxite Mine Posušje

Sl. 2. Podgrađivanje otkopnih hodnika u Rudniku boksita Posušje

LEGEND (LEGENDA):

1. Caving waste (Zarušena krovina); 2. Blasted bauxite (Minirani boksit); 3. Bauxite (Boksit); 4. Blasthole (Minska bušotina); 5. Steel friction prop VALENT 400R (Čelična frikciona stojak VALENT 400R); 6. Steel link bar PPS−111, l=1,4 m (Čelična člankasta gred PPS−111, l=1,4 m); 7. Wooden bar ∅=0,25 m (Drvena stropnica ∅=0,25 m); 8. Lagging of planks, 2,5 cm thick (Zalog od okoraka ili daske 2,5 cm debljine)

Since the equation (5) is satisfied, acccording to Sallustowiez there is no pressure on the opening support.

The calculation of stress and deformation round the opening in bauxite was performed by the finite element method on the mathematical model where it was assumed, that in the dept of 116 m two openings were driven with the pillar of 3 m thickness between them. The dimension of one opening being 6 x 3 m and of the other one 4 x 3 m. It was proved that maximal tensile stresses were in the roof of opening of 6 x 3 m and amounted to 170 kPa, and that maximal compressive stresses occured in the pillar varying to 8,100 MPa. Tensile and compressive stresses do not exceed the area of Mohr's envelope, and consequently breaking in the side and roof of the drift need not occur.

According to particular theories, the obtained results from the estimating of pressures on the drift support in bauxite, considerably differ among themselves, the differences ranging from the statement that loading of 47 kN/m (Protođakonov) and of 151 kN/m (Bierbaumer) act to the support from roof, to the conclussion that opening need not be supported (Terzaghy, Sallustowietz and the finite element method).

Present methods of support

The present methods of support the crosscuts in the Bauxite Mine Posušje are illustrated in Figure 2. The support consists of the friction props of the Valent type, 400−R, carrying the link bar PPS−111 with the length 1.4 m, fixed along the crosscut. The bars are mounted into chain and each is stand on one single prop. Perpendicular on the steel bars there are wooden bars 0.25 m distance among them being 0,4 m. The crosscut roof has lagging of the 2,5 cm thick planks. The crosscut sides are lined with the same material if necessary.

The support constructed in such a way can take over from the roof the pressure of 20,39 kN/m^2, on 0,83 m of the caved bauxite, which proved to be absolutely enough in practice, because it was stated up to now, that bauxite cavings in the roof of crosscuts (driven about 2300 m) range to maximum 0,6 m, which is compatible with pressure of 14,72 kN/m^2. The support of crosscut sides proved also to be satisfying at some places, by lagging with planks, because cavings from the sides are small and range maximally to 0.25 m.

All wooden support material and about 35% steel props and 17,5% steel bars are damaged in excava-

Table 2. *(Tablica 2.)*

SUPPORTING MATERIAL *(Podgradni materijal)*	Unit of mesaure *(Jedinica mjere)*	QUANTITY *(KOLIČINA)*		COST IN DINARS *(CIJENA U DINARIMA)*				TOTAL *(UKUPNO)*
		Built in *(ugrađena)*	USED *(utrošena)*	MATERIAL *(materijal)*		LABOR *(ugradnja)*		
				amount *(iznos)*	%	amount *(iznos)*	%	
Wooden bar *(obla jelova građa)* Ø 0,25; l = 3,5 m	piece *(kom)*	2.5	2.5	598	38	983	62	1 581
Valent prop 400R *(Valent stupac 400R)* l = 3,15 m	piece *(kom)*	1.43	0.5	1 582	85	281	15	1 863
Steel link bar PPS-111 *(Čelična člankasta greda PPS-111)* l = 1,4 m	piece *(kom)*	1.43	0.25	438	61	281	39	719
Logging planks *(zalog od daske)*	m^2	7.5	7.5	330	61	212	39	542
TOTAL *(UKUPNO)*:				2 948	63	1 757	37	4 705

tion. Costs of support for a metre of the crosscut amount 48 020 Din, of which the material costs make 63% and labor costs 37% (Table 2).

Bolting

Bauxite is classified essentially as a soft rock with rather expressive fracture systems. Consequently, the best way of room supporting in bauxite is bolting with bolts fixed into borehole along the whole length. These bolts are grouted with synthetic resinsor cement. We suppose the Swellex bolts to be the most favourable and advantageous. At least in bolting introduction due to the following reasons:

- very simple performance,
- rock bolt act immediately after installation,
- the blasting impact on the load–bearing capacity of bolt is irrelevant,
- they are relatively sheap.

The supporting by bolts and grid enables the drive of 3.2 m wide and 3.1 m high arched drift (Figure 3). Such a shape and dimension of the drift give objectively greater safety from caving than those by the drift driven by the present way of supporting (figure 2).

The Swellex bolts were developed by the firm »Atlas Copco« from Sweden in the beginning of 80–ies. They are made of steel metal in form of bending tube closed on both ends by special small pipes (Figure 3).

On the pipe sticking out of borehole, a small hole is drilled through which water is injected under pressure of 30 MP. The pump for water injection is driven by compressed air and it can be either independent or installed on the bolting machine or the drill. The pump weight is 35 kg and can be carried by single worker. By injection the tube extends to the borehole rock (Figure 3a). By pressure on the borehole wall, friction between borehole wall and the bolts is created. Material the bolt is made of, is elastic and it follows uneven spots in the borehole, which increases friction between the bolts and the rock.

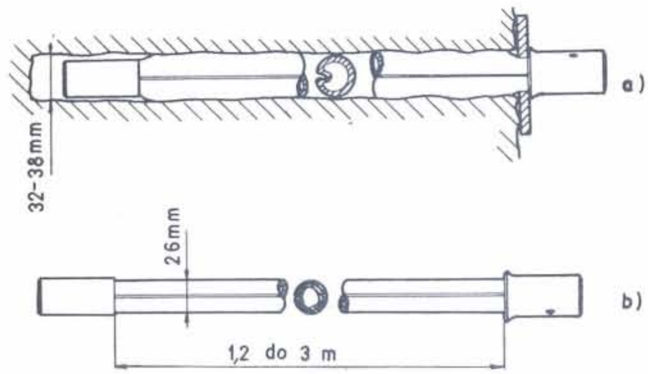

Fig. 3. The Swellex bolt: a) installed: b) not installed

Sl. 3. Swelec sidro: a) ugrađeno; b) neugrađeno

Bolt installation in the rock depends on the borehole diameter and water pressure. The best bolt effect is attained by the borehole diameter of 38 mm and water pressure of 30 MP, and it amounts 200 kN/m. The other technical characteristics of the Swellex bolt are:

- loading by breaking 100 kN
- diameter of unistalled bolt 26 mm
- thickness of bolt walls 2mm
- length of bolt 1,2 to 3 m.

The load–bearing–capacity of Swellex bolt being defined, we have just to estimate the length and the pattern of boreholes.

The bolt length presents the expanding part of the bolt and is defined by

$$l_s = l_r + l_u \qquad (6)$$

where l_r is the bolt length which is equal to the thickness of loosen zone and it will be defined by:

$$l_r = k \cdot l_{rs} = 1.5 \cdot 0.6 = 0.9 \text{ m} \qquad (7)$$

where $l_{rs} = 0,6$ m is maximal height of the loosened zone in roof of the crosscut observed in the mine »Trobukva« so far, and $k = 1.5$ – safety coefficient.

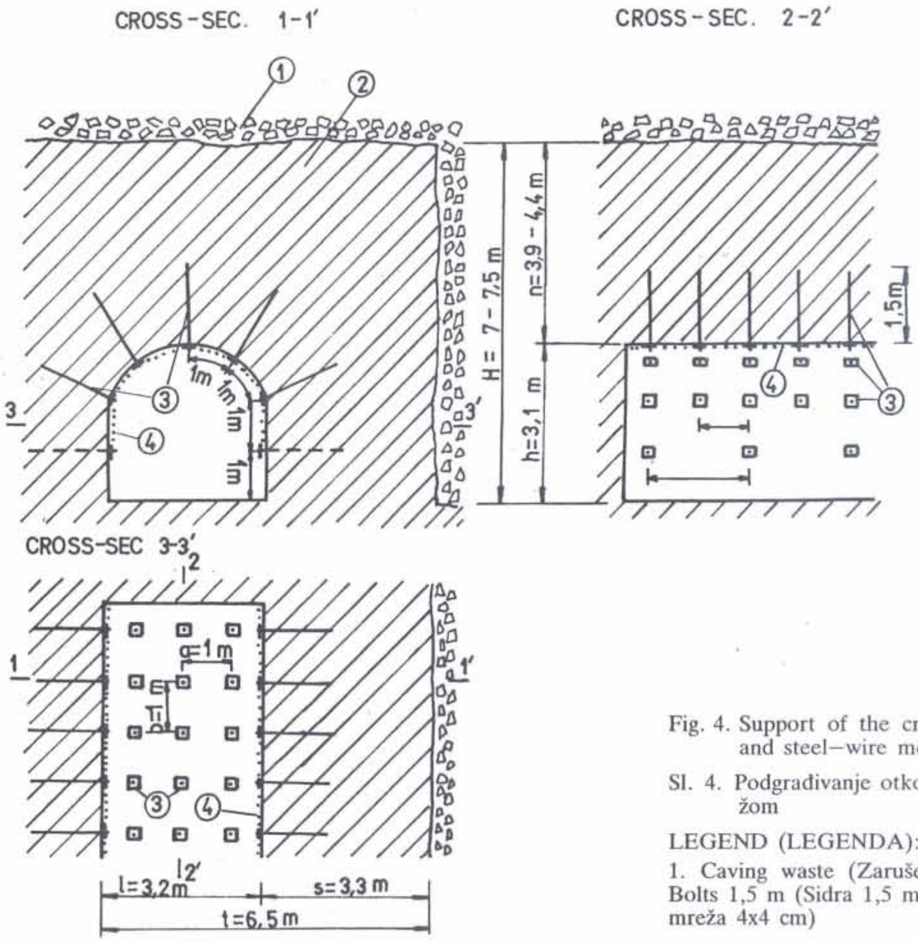

Fig. 4. Support of the crosscut in bauxite by the use of bolts and steel–wire mesh

Sl. 4. Podgrađivanje otkopnih hodnika u boksitu sidrima i mrežom

LEGEND (LEGENDA):

1. Caving waste (Zarušena krovina); 2. Bauxite (Boksit); 3. Bolts 1,5 m (Sidra 1,5 m); 4. Steel wire mesh 4x4 cm (Čelična mreža 4x4 cm)

The bolting length in undistrubed zone l_u is defined from:

$$l_u = \frac{P_s}{f} = \frac{100}{200} = 0.5 \text{ m} \quad (8)$$

where:

$P_s = 100$ kN – force of the Swellex bolt breaking

$f = 200$ kN/m – force of friction between the bolts and the borehole rock.

According to the equation (6) the required length of bolts are:

$$l = l_r + l_u = 0,9 + 0,5 = 1,4 \text{ m} \sim 1,5 \text{ m}.$$

Pattern of bolts is:

$$a \leqq \left(\frac{p_s}{k_s \cdot \varrho \cdot g \cdot l_r}\right)^{1/2} = \left(\frac{100}{4 \cdot 2,5 \cdot 9,81 \cdot 0,9}\right)^{1/2} = 1,13 \sim 1 \text{ m} \quad (9)$$

where:

$k_s = 4$ – safety coefficient.

Before the installation of bolts, a wire mesh with an opening of 4 x 4 cm is mounted in the crosscut roof and in the sides to 0.75 m from the bottom, which is then fixed to the walls by bolts and bearing plates. Figure 4 illustrates the way of supporting in crosscuts by the use of bolts and steel–wire mesh.

In excavation, the bolts plates and wire mesh will be damaged, which is assumed by the calculation of supporting costs (Table 3).

In accordance with the development of bolts in this article, the Bauxite Mine Posušje acquire the whole necessary material, i.e, the bolts, installation devices, examination and testing devices. The results will be anounced with further research.

Table 3. *(Tablica 3.)*

SUPPORTING MATERIAL *(Podgradni materijal)*	Unit of mesaure *(Jedinica mjere)*	Quantity *(Količina)*	COST IN DINARS *(Cijena u dinarima)*				TOTAL *(Ukupno)*
			Material *(materijal)*		Labor *(ugradnja)*		
			amount *(iznos)*	%	amount *(iznos)*	%	
Swellex bolts *(Svellex sidra)*	piece (kom)	6	990	52	931	48	1 921
Wire mesh *(Žičana mreža)*	m^2	6,5	286	61	184	39	470
TOTAL for 1 m length of crosscut *UKUPNO za 1 m dužine hodnika*			1 276	53	1 115	47	2 391

Conclusion

The supporting of sublevel drifts and crosscuts in bauxite remained the only activity in the technology of underground bauxite exploitation in Yugoslav mines that has not been mechanized so far. This means, that the most difficult and the most dangerous work has still to be performed by using frame support system, and it play a very relevant part in production costs.

This article discusses the possibility of crosscut support in the mines of the Bauxite Mine Posušje by bolting. Elements of the bolt support are analized on the basis of technical characteristics of the Swellex bolts which we have chosen for the beginning of introduction of the bolts mostly due to their very simple installation, which may have considerable importance in overcoming the starting problems.

Beside technical and safety advantages of the bolting support compared with the frame support, the other are:

- a very small possiblility of support damage with mechanization,
- masses of the support elements are far less (in average even to 20 times), which enables easy handling and quick installation,
- there is a possibility of total mechanization of bolts' installation, which for the staff considerably decreases the possibility of being hurt by supporting.

The drift and crosscut support in bauxite proved to have economic advantages as well. Costs of bolting by the Swellex bolts and wire mesh are smaller than the costs of the frame support (Table 4) in relation:

- material cost for 57%,
- labour costs for 37%,
- total costs for 49%.

All this leads to the conclusion that it is necessary to start with the application of bolts support in bauxite. Parameters of the bolt support and the type of bolts have to be estabilished by the investigation of working environment and by the confirmation in practice.

Table 4. (*Tablica 4.*)

COSTS (DINARS	*SUPPORT SYSTEM (Način podgrađivanja)*		*COST DIFFERENCE (Razlika troškova)*	
CIJENA (Dinara)	PRESENT (*Sadašnji*) A	SWELLEX BOLTS + WIRE MESH (*Swellex sidra + žičana mreža*) B	(A − B) DINARS (*Dinari*)	%
MATERIAL (*Materijal*)	2 948	1 276	1 672	57
LABOR (*Ugradnja*)	1 757	1 115	642	37
TOTAL (*Ukupno*)	4 705	2 391	2 314	49

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Podgrađivanje hodnika u boksitu sidrenjem

S. Majić i S. Vujec

Članak se bavi problematikom podgrađivanja otkpnih hodnika pri podzemnoj eksploataciji boksita. U jugoslavenskim rudnicima boksita primijenjuje se uglavnom podetažno poprečno otkopavanje sa zarušavanjem krovine, a hodnici se podgrađuju isključivo podupirućom podgradom, nemehanizirano.

Prikazane su osnovne geološko–geotehničke karakteristike ležišta boksita (tablica 1), kao i otkopna metoda (slika 1) u jami »Trobukva« Rudnika boksita Posušje.

Proračun pritisaka na podgradu obavljen je po Protođakonovu, Terzaghiu, Bierbaumeru i Sallustowiezu a proračun naprezanja i deformacija metodom konačnih elemenata.

Postojeći način podgrađivanja otkopnih hodnika u boksitu s čeličnim frikcionim stupcima i člankastim čeličnim gredama prikazan je na slici 2, a pregled troškova po dužnom metru otkopnog hodnika u tablici 2.

Također, obavljen je i proračun sidrene podgrade za Swellex sidro, što je prikazano na slikama 3 i 4, te su troškovi pri tom načinu prikazani u tablici 3.

Pokazalo se je da podgrada sidrima pred podupirućom podgradom, osim tehničkih i sigurnosnih prednosti daje i značajnu ekonomsku uštedu (tablica 4), radi čega se u praksi prelazi na primjenu sidrenja za podgrađivanje hodnika u boksitu.