TÜRKİYE 8. KÖMÜR KONGRESİ BİLDİRİLER KİTABI / PROCEEDINGS OF THE 8th COAL CONGRESS OF TURKEY

Drift Support Estimated by " Critical Depths" Method

"Kritik Derinlikler" Yöntemi ile Galeri Tahkimatı

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ABSTRACT

In this paper, following an introduction on the coal mines and their rift supports in Albania, the possible ways of analysing drift stability have been treated and the "critical depths" method has been presented. Rock mass quality and rock mass- drift support interaction have been estimated by a mathematical approach. In situ stress fields and eight possible classes of drift supports used in Albanian coal mines have been given graphically.

It has been concluded that, for a more economical support, it is fundamental to change the existing support structure by using more effective drift support system.

ÖZET

Bu bildiride, Arnavutluk'taki kömür madenleri ile galerilerde uygulanan tahkimatların tanıtımını takiben galeri duraylılığını analiz yolları işlenmiş ve "kritik derinlikler" yöntemi sunulmuştur. Kaya kütlesi kalitesi ve kaya kütlesi- galeri tahkimatı etkileşimi matematiksel bir yaklaşımla tahmin edilmiştir. Birincil gerilme alanları ve Arnavutluk kömür ocaklarında kullanılan sekiz olası tahkimat sınıfı grafiksel olarak verilmiştir.

Sonuç olarak, daha ekonomik tahkimat için, mevcut tahkimat yapısının daha etkin galeri tahkimatları ile değiştirilmesinin önemi vurgulanmaktadır.

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1. DATA FOR COAL MINES IN ALBANIA

Actually, in Albania, coal mining is developed in three zones: The south eastern, the south and the central one, all in the Tertiary formations from Eocene to Pliocene age.

In the south eastern zone there are some coal deposits: The older deposits of the country (Eocene - Oligocène) near Korça, the middle-aged deposits near Pogradec and the later deposit near Erseka (Bezhan).

In the southern zone it is found the best quality coal deposit of the country (Memaliaj) near Tepelena.

In the central zone near Tirana there are some coal deposits in different horizons of the new Tertiary field. There are three coal mines in activity and the principal of them is the mine of Valias.

1.1. Short characteristics of the coal mines

In each of the mentioned coal deposists it is applied underground mining. The individual mines developed the workings on two, three or more seams, horizontal extent of which is from three to more then ten kilometres. The thickness of the industrial seam is of 0.4 to upper 3 metres, when their inclination vanes from flat bedded to edge seam.

The mines have a productive capacity of 0.2*0.6 Mt per year and their exploitation fields are a few square kilometres to more than 10 km .

Mine layouts are of various sorts (shafts, drifts, inclines) and development works in main and working levels are compounded by haulage and development drifts, parallel headings, cross-cuts, raises and other drifts.

The main used working system in the different coal mines is the wall system (long and short walls) by caving and rarely are applied room pillar caving and working in slices systems.

1.2. Drifts and their support

Drifts, as mine layout and developement works, are the most problematic in our underground mining. Their support and maintenance is the object of many studies and estimations for an economical drifting and exploitation (1).

In all the coal mines, annually are worked about 130km drifts and so much are in maintenance and liquidation. The used cross sections are 4*14m , but more frequently arş the 5*8m^z ones for single railed drifts and more then 10m" for the double railed ones in the 15-*-18X of the total prolongation.

The characteristics of the formations encountering drifts are variable in the different coal deposits and often in the same mine. That depends on the geological age and structure, lithological composition of the deposits and the drifts position in them.

Strength data for intact rocks in uniaxial compression (<7c) of specimens from the principal coal mines are graphically described in figure 1. It means that, after the engineering classifications, they are rocks of a very low, low and medium strength. Practically, in the coal deposits, rock material is compounded by indurated or poorly cemented materials (shales, mudstones, marls and sandstones), which often are very sensible against the water (plastic deformations and swelling phenomena associate the contact with them).

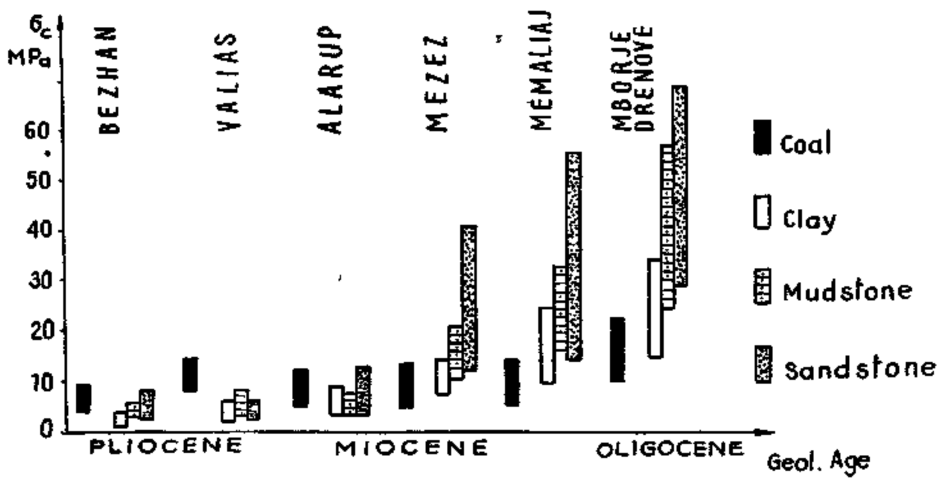


Figure 1. *ac* data for characteristic rocks of coal deposits.

Lay out drifts, at ruling, are supported by concrete or prefabricated concrete blocks lining (0.25*0.4m thickness). There also are used drift supports with prefabricated sets and, in very heavy conditions, full circle concrete lining or double concrete and prefabricated rings (total thickness 0.6m). Seldom are used bolting, grouting and their combination.

Developement drifts are supported by timbering and by steel arch sets (opened systems). In the unstable floors steel elliptical or circular ring supports (closed systems) are used.

Many problems of choice and specification in drift support» are investigated by the Mining Research and Design Institute (ISPM) in Ti-rana in cooperation with other specialized institutions and specialists of coal mines. In mines are observed the loading and the deformations of the applicated supports and the displacement of the rocks around.

2. CLASSIFICATION OF ROCK MASSES AND DRIFT STABILITY IN COAL MINES

Mining engineering practice in various coal fields gives us a great number of classifications of rock masses and drift stability. The simplest are based on a few paramètres as the rock strength (oc), depth (H) of the workings or the loading column of the overburden rocks (?H) *(y-* density of rocks) and the width (B) or the cross section (S) of the drifts. The most complicated are based on geomechanics procedures and technical or technological data for advancing drifts.

Our mining engineering practice has accepted both forms of classification, with our specific interpretations.

2.1. The simple rock masses **and** drift stability classifications

A logical local generalization of the drift (rock masses) stability and the applicated support systems is given in the classifications of OKR and Donbass coal fields (2). The first is represented in table 1. As principal classifying criteria is used the rock loading index RLI=ïH/c»o. In these classifications are distinguished four classes of rock masses (drift stability for 4m drifts width). The fourth class (RLI > 0.45) presents a very unstable rock mass with floor déplacements in the drift.

Table 1. Classifications of drift stability in OKR.

Drift's stability	Paramètres		Recommended drift supports	Work paramètres	
	H de	ÏfH <7c		pk kPa	uk mm
Stable	<0.8	<0.2	Light support systems Light arch steel sets	*150	50* 150
Almost stable	8 * 18	0.2 * 0.45	Middle support systems: prefabricated supports and arch steel sets	150* 250	200* 250
Unstable	>18	>0.45	Steel rings and prefabricated renforced concrete rings	>250	>250

Analysing all the drifts situated in the coal mines of our country and fixing their cross section in S=9m , the average index RLI is as in figure 2, but the factic index in many mining levels is often over YH/cc=o.8. So, the above mentioned classifications are inconvenient and we need a more representative one.

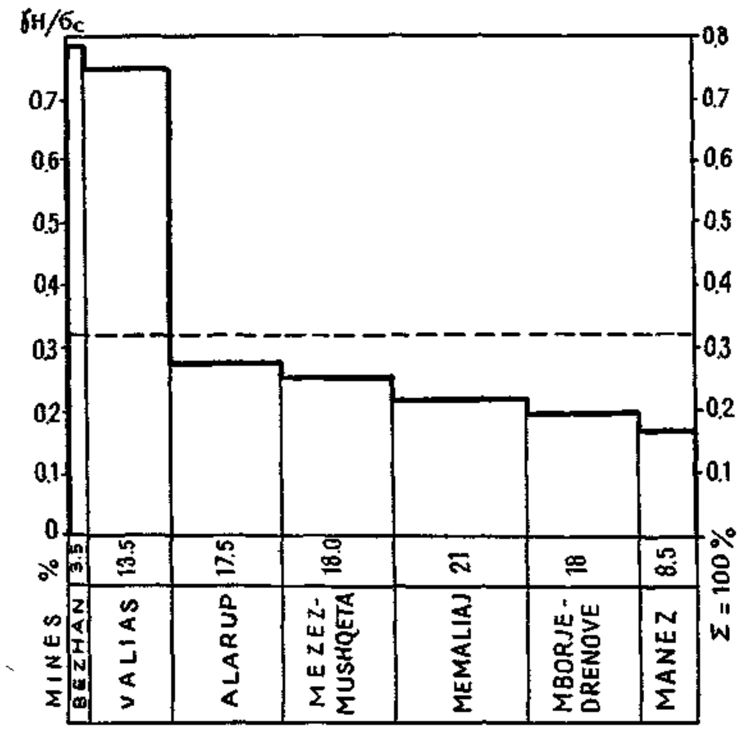


Figure 2. The RLI distribution in different coal mines.

2.2. The complex rock masses and drift stability classifications

There are many engineering and geotechnical rock classifications and most of them are centred on tunnel design and construction.

In mining support problems, it widely is used Beniawski's classification, which with some modifications is also used by albanian authors for engineering approaches in drift support of metal mines. Another rock masses classification, proposed by Beniawski for USA coal mines, is combined with Lauffer's diagram to estimate the rock support for rooms in- room and pillar working system (3).

In both cases, statistical' analysis are used describing the correlation of geomechanical paramètres with types of rock support without calculating for the probable pressures and deformations of rock masses.

Through these "improved classifications'* it is very difficult to operate for other coal fields, which are very different in rock characteristics and located mining objects.

Our mining practice required also prognostic data for mining support in different depths. A serious help in this way our designers have found in the "Complex method of critical depths" (4), which, in the last ten years, is completed and applied for many local and national research works.

3. THE "COMPLEX METHOD OF CRITICAL DEPTHS" ANALYSIS

More than 30 years of systematic observations in coal mining and drift support convinced us that, for a better knowledge of all the probable situations in rock masses stability, we must have a clear vision in:

a) rock masses structure of the coal deposits, their natural geotechnical characteristics as laying, bending, fracturing, alteration and water containing;

b) single rocks physico-mechanical characteristics (at minimum laboratory ones);

c) space location of mining workings (depth and volumetric distribution);

d) technical characteristics of drifts: cross section (shape, width and height), orientation in the structure, service life;

e) technological characteristics in construction (methods of construction and rhythmes).

The complex method, in each case of drifts stability, estimate:

-The stead-fast limits of rock masses against the stresses, expressed by the general Taw of Coulomb-Mohr;

-The critical stability conditions for drift roof, side walls and floor, each of them separately (the critical depths);

-The unstable (non elastic) zones around the drifts, the attended "normal pressures" and "normal contoural displacements" in the prescribed conditions;

-The interaction rock masses-rock support;

-The development in time of the prognosticated rock pressures and displacements.

The whole method is widely exposed in the monographic publication (5).

3.1. Rock masses critical equilibrium state (mathematical approach)

As a "quasi elastic media" which characterizes rock masses, critical equilibrum state can be mathematicaly expressed by:

$$\tau = \sigma \ tg\phi_m + C_m \qquad (1)$$

x, o - shear and normal stresses;
Cm - the internal cohesion of rock mases;
<fm - the angle of internal friction.

The correlations between Cm, 4* of rock masses and C, *$* for the compact specimen, from the structural blocks of the rock can be approached (4) by:

$$C_m = C \ / \ [1 + \beta_0 \cdot \ln((B,h) \cdot n_0)] \qquad (2)$$

$$\phi_m = k_0 \cdot \phi \qquad (3)$$

B, h - drift width or height (the greatest value), m;
n - number of interblock fractures per 1 m contoural 1ine;
ß0 - weakeness coefficient: *ß* =0.67*7, for normal coal deposits *ß0*=^.2*2.8.
k_Q - 0.85 * 0.98.

The coefficient *ßQ* can be fixed after a detailed estimation of the eight groups of natural, technical and technological factors (5).

3.2. The critical depths

Analysing the problems of the critical stability in roof, wall-side and floor drifts area after the theory of limit equilibrium in asymétrie charged areas (Prandt) and arches, three critical depths are distinguished: Hi, H2, H3, respectively for the drift roof, wall-side and floor, estimated as:

$$H_1 = \frac{C_m}{k_n \cdot \gamma \left(a \cdot n_0 - \lambda tg\phi_m \right)} ; \qquad (4)$$

$$H_2 = \frac{2 \ C_m tg \frac{90+\phi_m}{2}}{k_t \cdot k_n \cdot \gamma} ; \qquad (5)$$

$$H_3 = \frac{C_m}{2 \cdot k_t \cdot k_n \cdot \gamma \cdot tg\phi_m} \left(e^{\pi tg\phi_m} \cdot tg^2 \frac{90+\phi_m}{2} - 1 \right) \qquad (6)$$

a = B/2; $\lambda = \nu/(1-\nu)$; ν - Poissons ratio;
k - near workings influence coefficient;
k_t - side-wall stress concentration coefficient.

In homogenous rocks is Hi < H2 < H3, but if the fracturation of them change, it can be Hi a H2. If the drifts are in heterogenous rocks and the floor is on very weak ones, it can be H3 < H2. That is also verified by models with equivalent materials.

For a general view of drift stability with variability in cross section area and depth, it is used a graphical presentation in parametric coordinates $\sqrt{\frac{S}{S_o}}$, $\frac{\gamma \cdot H}{\sigma_c}$ (figure 3) where $S_o=4m^2$ is an etalon minimal cross section.

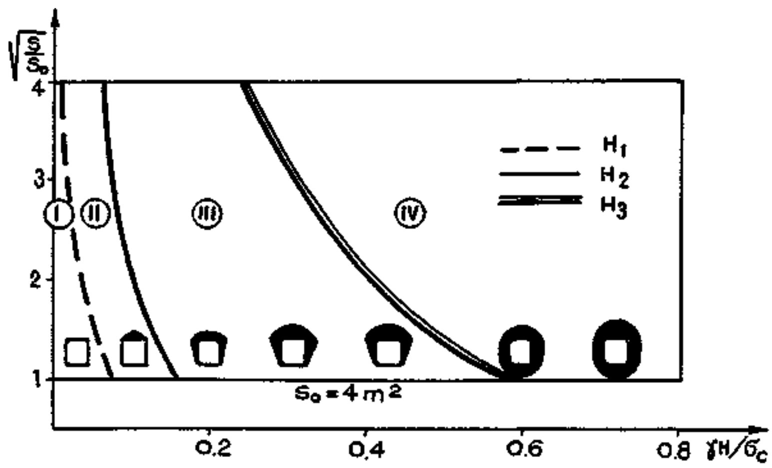


Figure 3. Drift stability fields
I-Full stability; II-Roof instability; Ill-Roof and wall sides instability; IV-Full instability.

By Hi, H2 and H3 curves (in fact they are zones), four drift stability fields are separated:

- Full stability for H < Hi;
- Roof instability for Hi * H < Ha;
- Roof and wall sides instability for H2 * H < H3;
- Full instability for H * H3.

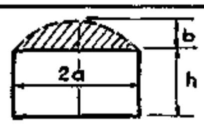
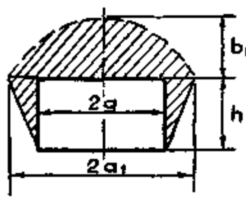
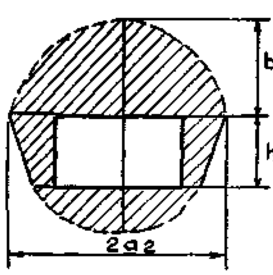
In each of instability areas, the non elastic zones are created, which increase with the depth.

3.3. "Normal" rock pressures

"Rock pressure' results as an interaction between deformed rock masses and drift support. We have distinguished the "normal rock pressures" as a conventional case of the deformed elastic zone around the drift. This action is controlled by the operating laws in elastic masses (4). The formulas of normal rock pressure calculation in rectangular drifts for the three instability fields are expressed in table 2.

Normal rock pressures are calculated in kPa as roof normal pressures (pr), side-wall normal pressure (ps) and floor normal pressure (pr). In square drift cross sections are pr > ps > pr (for homogenous rocks). Usually pr is the representative of the maximal drift normal pressure.

Table 2. The formulas of normal rock pressure in rectangular drifts.

$H_1 \leq H < H_2$		$p_r=\gamma b$; $b=\frac{a}{2\left(\lambda \, tg\phi_m + \frac{C_m}{K_n \gamma H}\right)}$
$H_2 \leq H < H_3$		$p_r=\gamma b_1$; $b_1=\frac{a_1}{2\left(\lambda \, tg\phi_m + \frac{C_m}{K_n \gamma H}\right)}$ $a_1 = a + h \, tg \frac{90-\phi_m}{2}$ $p_s = \frac{\gamma}{2}(2b_1 + h)\, tg^2 \frac{90-\phi_m}{2}$
$H \geq H_3$		$p_r=\gamma b_2$; $b_2=\frac{a_2}{2\left(\lambda \, tg\phi_m + \frac{C_m}{K_n \gamma H}\right)}$ $a_2=a_1+2a\, e^{-\frac{\pi}{2} tg\phi_m} \, tg\frac{90-\phi_m}{2}$ $p_s = \frac{\gamma}{2}(2b_2 + h)\, tg^2 \frac{90-\phi_m}{2}$ $p_f=2\gamma(b_2 + h)e^{-\pi tg\phi_m} \, tg^2 \frac{90-\phi_m}{2}$

Graphically, by isolines, we can separate the normal pressure fields, as are distinguished by other authors as we11. They are:

- low pressure field: pr = 0 ÷ 50 kPa;
- middle pressure field: pr = 50 - 150 kPa;
- high pressure field: pr = 150 * 300 kPa;
- very high présure field: pr > 300 kPa.

In figure 4 are represented the probable pressure fields for rock masses with $\lambda = 0.3$, $\beta_0 = 2.5$ and no = 2.

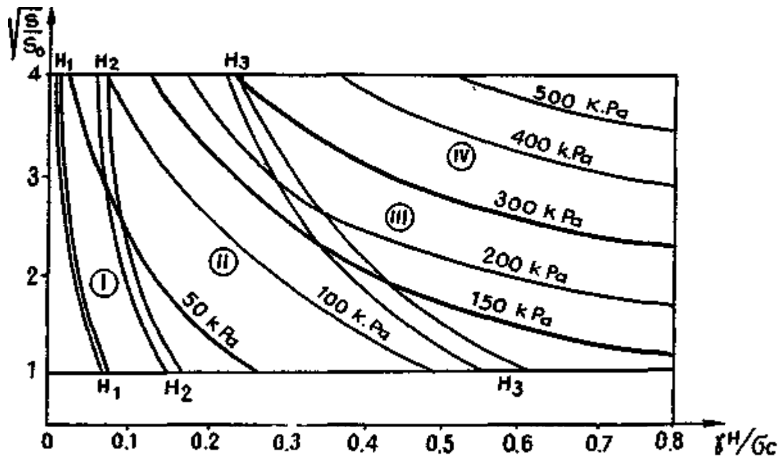


Figure 4. Rock pressure fields.
I-low; II-middle; HI-high; IV-very high.

3.4. The interaction rock masses - drift support

As a rule, normal rock pressure is present in the supports with a controlled yielding, where their reaction (pk) is nearly equal (pk ss p_r).

By using the theory of the compression and decompression in elastic media (5), contoural displacement of the non-elastic zone "i^ " supported by a reaction "£> " is equal to:

$$u_k = K \cdot \frac{p_r}{p_k} \cdot \ln \frac{k_n \cdot \gamma \cdot H}{p_k} \quad , \text{ cm} \tag{7}$$

$$K = \frac{50}{\gamma} \cdot k_{pi} \cdot n \cdot e^{\frac{n}{2}} \qquad (8j$$

k_{pl} = Sp/Se, index of rock plasticity determinated from stress-strain cu> ve, during the specimen tests in uniaxial compression;

SP, Se - specific work for plastic and elastic deformation;

n = $2 \cdot k_n \cdot \gamma \cdot H / \sigma_c$

The normal contoural deformation case ($u_k = u_r$) is for pk=pr. when stiff or less stiff supports are used by u < u is pk > pr, often several times'greater.

3.5. The development of the contoural displacement in time

It is observed that the contoural displacements in time (ut), with an acceptable approximation, can be expressed by the development equation:

$$u_t = u_{max} \cdot \left(1 - e^{-\delta t}\right) \qquad (9)$$

u_{max} - the attended maximal displacements for a reaction pk;

t - time of the activity of the support system in months;

5 - connective parameter evaluated $\delta \approx k_{pl} \cdot k_n \cdot \frac{\gamma H}{\sigma c}$

When in a drift are used two support systems (initial and permanent supports) the formula (9) can be used to estimate the favorable time of change.

When pk < pr, the support can resist for a time t, in which will be pr<t)= pk.

During the displacement measurement in place are estimated also the mean velocity of deformation and the full time of their development (t = To) for a uo = o.99umax.

4. SOME EVALUATIONS AND CONCLUSIONS

4.1. Observation and calculation agreements

.Analysing- the drift support problem for each mine separately and, in general izated way, for the country is observed and calculated that:

a. The most avaluable way for drift support classification is using the boundary values of normal rock pressures and the rock loading index. The most representative interval of rock- pressure is about 20 kPa.

b. In each mine, two or three classes of rock support are represented and for the whole country, in total, are eight of them. In each class, for rock support, can be used different systems and materials in layout and developement drifts.

c. The distribution of the normal rock pressure in drifts with variable medium cross sections from a mine to another can be reflected clearly in parametric graphics $\sqrt{\frac{S}{S_o}}$, $\frac{\gamma \cdot H}{\sigma c}$ as in figure 5. For a simple, -informative representation can be used also the *oc*, H graphic, in which the normal pressure isolines are calculated for a statistical medium cross section. In figure 6 is represented the normal rock pressure

Situation in all the mines for the *Sxtf* cross section.

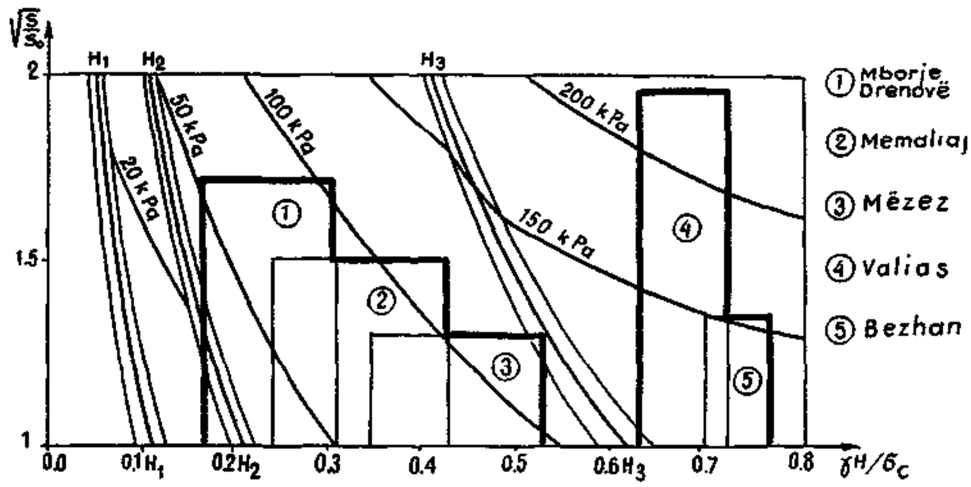


Figure 5. The distribution of normal rock pressure in drifts of different coal mines.

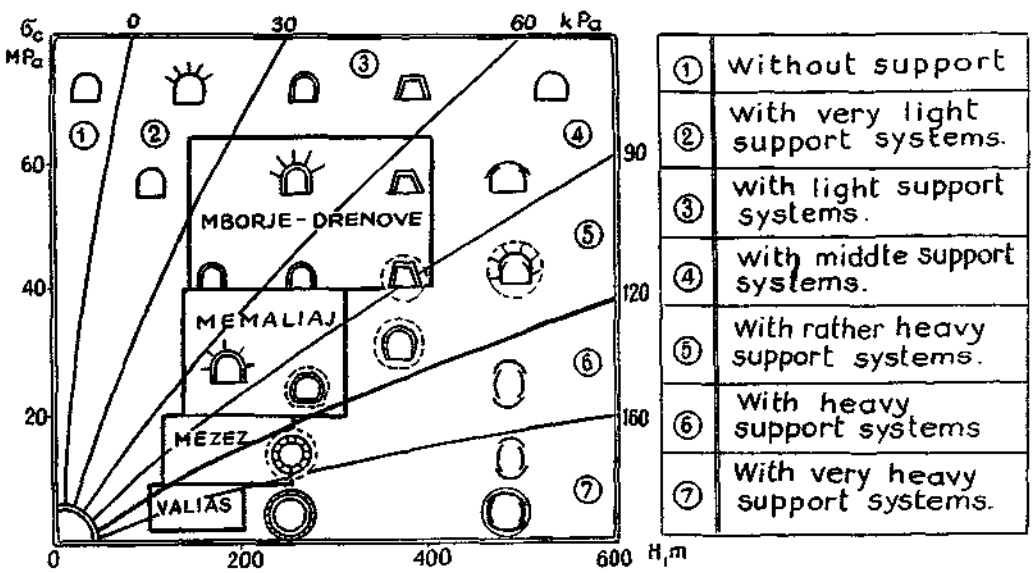


Figure 6. The normal rock pressure for 9m cross section drifts.

d. The RL index intervals for drift support classification are variabble and depend from rock masses quality and the representative cross section. In rock masses with no=2, and 9m drifts, RLI intervals for the eight classes are as in table 3.

Table 3. The RLI intervals for different support classes in drifts with 9m cross section.

Drift support class	I	II	III	IV	V	VI	VII	VIII
RLI interval (ïH/ac)	0.040 0.090	0.091 0.135	0.136 0.225	0.226 0.330	0.331 0.450	0.451 0.600	0.600 0.800	>0.8

If n * 2, the respective intervals we can obtain also graphically as in figure 7.

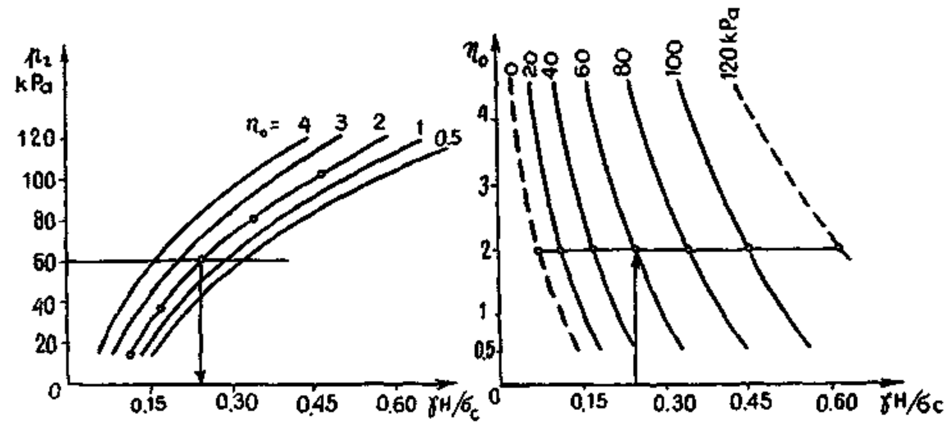


Figure 7. Rock pressure zones for different values *of* no.

e. In layout drift where are not used yielding supports, support system reaction (pk), for a stable equilibrium, enlarges as a multiple of normal rock pressure, with the grouth of RLI. In ?H/<?c=o. 7^-0.8 is observed a very important reaction pk=3-*-5-pr, particulary in swelling environment.

f. In development drifts, where are used yielding supports, the grouth of the RLI causes an intensive developement of rock displacements, so as observed in other coal fields, from few cm to more than 40 cm. It is associated the grouth of the rock movement velocity (from few mm/a month to many cm/a day) and a shortening of the time of the deformation development (To), from some months to a few days. Based on such paramètres, we can estimate too the influential degree of the near exploitation and workings (kn).

4.2. Conclusions

Analysis of drift support point out several practical and methodical conclusions:

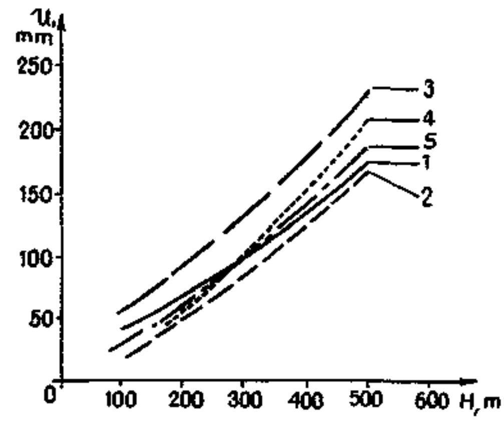
a. Actual state of drift support in coal mining of our country is not so appropriate. As it is reflected in a publication (6), the support structure must change i⁄i a more effective one (table 4).

Table 4. Actual and possible support structure in coal mines.

Sorts of supporting systems	% in conditions	
	actual	possible
Light support systems: Anchoring, shotcrete and their combinations	3	32
Steel arch support systems	12	34
Heavy support systems: Concrete and prefabricated concrete blocs lining. Prefabricated reinforced concrete sets	34	22
Timber sets	51	12

Table 5. The calculation of roof displacement by different authors.

No	Author, year	Calculating formula	Value mm for H m		
			200	400	600
1	Zaslavskij J.Z. 1976, 1986	$u_r=0.1B\left[e^{\frac{\gamma H-10(\sigma_o/\sigma_e)^2 p_k}{\sigma_c}}-1\right]$	48.6	106.3	173.6
2	Melnikov OI 1987	$u_r=\left(H-5\sigma_c\right)\left(0.12+\frac{17.3}{\sigma_c-2.7}\right)k_o$	22.6	95.1	171.1
3	O K R 1984	$u_t=u_r+u_r=0.1B\left[e^{\frac{1.5H-p_k}{45\sigma_o}}-1\right]$	61.0	137.7	230.6
4	Wilson A.H. 1980 ~ 1983	$u_t= B\frac{1+\nu}{E}\left[\frac{p(k-1)+\frac{\sigma_c}{k_d}}{(k+1)}\right]\cdot\left[\frac{2p-\frac{\sigma_c}{k_d}}{(p_k+\sigma_o)(k+1)}\right]^{\frac{(2+\varepsilon)}{k-1}}$	21.0	104.2	211.5
5	Sauku H. 1982 - 1989	$u_k= K\cdot\frac{p_r}{p_k}\cdot\ln\frac{k_n\cdot\gamma\cdot H}{p_k}$, $K=\frac{50}{\gamma}\cdot k_{pl}\cdot n\cdot e^{\frac{n-1}{2}}$, $n=\frac{2k_n\gamma H}{\sigma_c}$	40.5	111.1	181.2



<u>Data</u> (also for table 5):

$B \times h = 3 \times 3$ m

$\gamma = 25 kN/m^3$; $\sigma_c = 30 MPa$; $\nu = 0.3$

$\sigma_e = 30 MPa$; $\varepsilon = 0.2$; $k_{pl} = 2$

$k_d = 5$; $k_o = k_m \cdot k_2 = 1.2 \cdot 0.5 = 0.6$

$$k = \frac{1 + \sin\phi}{1 - \sin\phi} = 3$$

Figure 8. The roof displacements in function of depth by different authors.

b. The methodical way used is a manner of proceeding with a wide interval. Data from other coal fields analysis in drift support (2), (7), (8), (9), confirm that, in this way, we can treat succesfully and the support problems in the greater cross section drifts (table 5 and figure 8).

Drift support is a dynamic process conditioned by the passage in greater depths and by the qualitative improvements in time of the support systems and support materials. We think that the complex analysis by the exposed method is also suitable for many perspective prognostic solutions.

The above mentioned procedure of estimating rock masses quality, mine workings stability and supports is traited completely by calculating programs in ECM as PREGAL (10) and others. In this way, at the Mining Chair of Geology and Mines Faculty (Technical University in Tirana), the scientific research work is continuing for more detailed solutions.

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