PROPERTIES OF HYDRAULIC STOWING MATERIAL WITH PARTICULAR REFERENCE TO DRAINAGE REQUIREMENTS

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ABSTRACT

In the hydraulic stowing practice, a great deal of effort has been put in trying to develop drainage systems by which rapid and safe water removal would be provided in the panel. However, damaging actions of stowing water for example "mud-runs" are frequently observed within the stope. One of the fundemental requirements of an effective drainage system is that the permeability of the stowing material must be equal or greater than stowing rate to be employed in the project. Otherwise the use of decant towers can become necessary for removal of excess water. The study presented is connected to the improvement of stowing drainage requirement by setting up an analytical design method which was based upon results of experimental investigation. A nomogram proposed in this work can be utilized for directly determining the required permeability of a stowing material depending upon design parameters such as face length, pour area, seam thickness and rate of stowing material.

INTRODUCTION

In order to prevent fires and loss of coal in the panel hydraulic stowing will be again experimented in the Armutçuk Coal Mine pertaining to the Zonguldak Coal Establishments. 500 tons of bituminous coal per day will be produced from the trial panel. According to outcomes of the project, the hydraulic stowing system will be then initiated to practice in the entire district.

The importance of drainage requirements originates from the following factors :

- From the practice it is well known that is an unproductive process and frequently gives rise to a long delays resulting from excessive water and the very fine-size (slimes) material utilized between stowing and production cyles. Especially, this factor becomes more important in nearly vertical coal seam worked by overhand stoping method.

- Control of "mud-runs of potential" (liquefaction potential) involves reducing the flow and the water pressure. Under liquefaction condition excessive pressure takes place on the decant towers or the stowing fences, causing tons of fluid mud flowing into the mine workings. In the past application of hydraulic stowing system frequent "mud-runs" were observed. These events impaired markedly the merits of system. Especially, the clean up operation performed through the water channels in the main galleries was a considerable cost item.

- Strength of stowing material in place is largely affected by water content. As the effective water drainage improves the in situ density of the stowing dense material with low void ratio yields a higher strength stowing material and diminishes strata movements at the face. In the past operation of hydraulic stowing, the weak material due to insufficient dewatering was reported to have an accelerating effect on the fire hazards of the seam. The reason responsible for this event would be excessive settlment of the seam, enlarging friability of coal.

Permeability is a major factor having a great influence on effectiveness of drainage. In other words, the drainage requirements depends on the drainage potential of the stowing material. Grading (size and shape) and physical properties of the material, degree of saturation, pulp density of the slurry and stowing (pour) area are all affected to some degree by the ease or difficulty with stowing water drains.

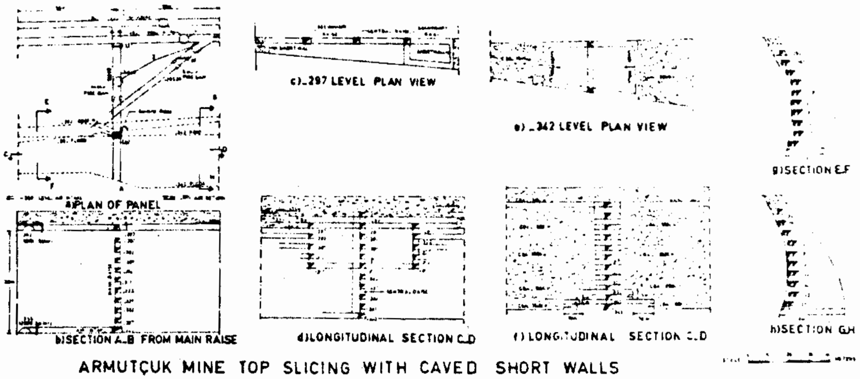
A study of the available reports Özkal (1961), Arıoğlu and Yüksel (1983 a), regarding the past practice in the Armutçuk Coal Mine has led the authors to come to conclusion that there exists a serious need for an analytical approach to the drainage requirements. The work presented is relevant to the improvement of stowing drainage requirement by establishing an analytical design method which was based upon results of experimental study carried out at the laboratory. An example was also made to illustrate the application of the design.

GENERAL ASPECTS OF THICK SEAM MINING IN THE ARMUTÇUK COALFIELD

This mine now works thick steeply inclined seams up to 20 m. employing horizontal slicing with caved shortwall (Üçüncü 1978, Birön, Arıoğlu 1979). In order to minimize to occurrence of spontaneous fires and to realize the total extraction in the panel a hydraulic stowing system was introduced with rising stowed shortwalls in 1961 (Özkal 1961). These two systems are demonstrated in Figure-1 (Birön, Arıoğlu 1979).

The mine management ceased the hydraulic stowing method mainly because of the reasons mentioned in chapter 1. However, it was reported (Özkal 1961) that the recovery of coal had enhanced from 60% to 90%, the overall output per day manshift of the panel from 2.5 tons to 4.0 tons while the explosive and timber comsumptions desceased respectively from 60 gr to none and 0.035 to 0.015 m^3 per ton.

In order to determine the influence of hydraulic system on the spontaneous heating of coal statistical decision theory was utilized. For the sake of brevity the entire data and results are not involved in the paper, being summed up in Table-1 (Birön, Arıoğlu, Yüksel 1985). It is obvious from table-1, that the hydraulic stowing system used has a concrete effect on reducing of spontaneous fires at a 95% confident (i.e 5% level of significance).



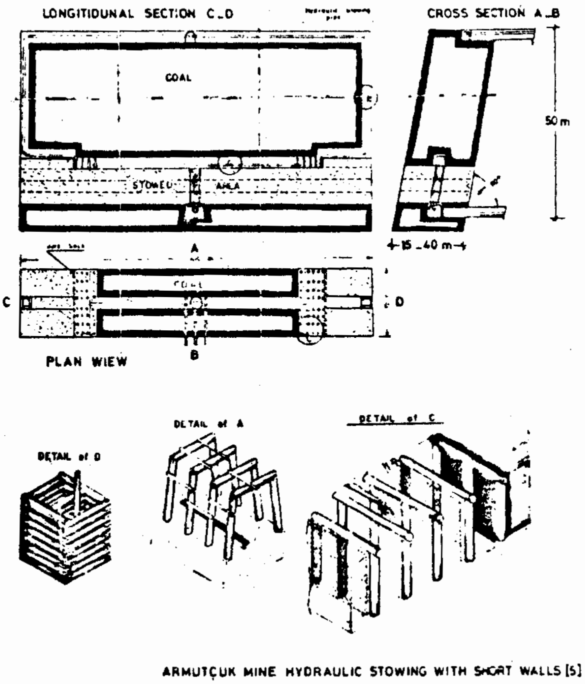


Figure-1: Sub-level caving and hydraulic stowing methods in the Armutçuk Mine.

Table-1 : Application of Statistical Test (the t-test) to Method of Working (Birön, Arıoğlu, Yüksel, 1985)

Method of Working	Sub-Level Caving (1)	Hydraulic Stowing (2)
Average (*) Life of panel (month) $\bar{X}_2$	8.2	16.33
Standart deviations S_i (month)	7.48	11.58
Number of case, N_i	15	9
The t-test (t_t student value)	$t_h = \frac{\lvert X_1 - X_2 \rvert}{\sigma_o} < t_t$	$\sigma_o = \sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}$
Confidence level and degrees of freedom	95% $d.f = N_1 + N_2 - 2 = 15\ 9 - 2$	$t_{0.975} = 2.074$ "double-sided" test
Result	$t_h = 1.884 < t_{0.975} = 2.074$, Hence there is a significant difference between two methods with reference to prevention of spontaneous heating of coal.	

(*) It is the life of the panel in which spontaneous fire is observed.

TEST RESULTS AND ANALYSIS

The washer reject is an important source of stowing material for the project under consideration. It was experimentally shown that this can be successfully utilized as a good stowing material. (Arıoğlu, Yüksel 1983 b, Birön, Arıoğlu, Yüksel 1985).

In order to examine the influence of the grading properties on the permeability of the stowing material the grading property was deliberately varied in this study. The four samples having different grading properties were prepared (Figure-2). The grading properties of these samples, defined in terms of the coefficient of uniformity "C_u" and the coefficient of curvature "C_c" are summarized in Table-2.

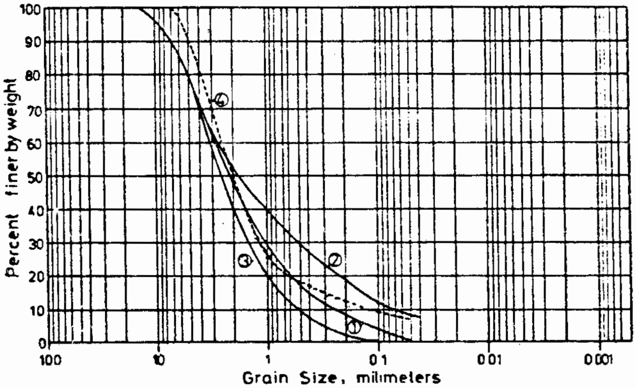


Figure-2 : Particle size distributions of tested stowing samples.

Table 2 - Grading Properties of The Tested Stowing Samples

Sample No.	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	$C_u = \frac{D_{60}}{D_{10}}$	$C_c = \frac{(D_{30})^2}{D_{60} \cdot D_{10}}$
1	0,20	1,0	3	14,28	1,58
2	0,074	0,5	1,5	20,27	2,25
3	0,500	1,5	3,2	6,4	1,40
4	0,100	1,2	1,5	15	9,6

In which D_{60} is diameter of 60 percent on the grain-size distribution. The sizes D_{30} and D_{10} are expressed in a similar way. A uniformity coefficient of (4-6) possesses optimum grading property for a suitable stowing material containing minimum void (Arıoğlu 1982, Nicholson, Wayment 1967).

It is evident that only sample no.3 has a well grading property with a low percentage of silty sands. Other samples are essentially poorly graded and reduce permeability.

The permeability of the stowing material was measured in the laboratory by means of a simple test based on the specifications of Mining Research Centre, Canada (1968). The permeability studies were performed in test apparatus with overflow tube (consant head permeameter). The range of void ratio varied from about 0.55 to 0.85. Table 3 presents the effect of grading properties on the permeability of the sample. As can be noticed the permeability is a function of the grading properties of the stowing material such as effective size "D_{10}" void ratio.

Table-3 : Influence of grading properties on permeability

Sample No.	Effective size "D_{10}" (mm)	Average Void ratio (in-test)	Average porosity (in-test)	Measured permeability (cm/s)	Permeability(*) (cm/s) (in place)	Degree of saturation (%)
1	0,210	0,697	0,410	$7,6 \times 10^{-3}$	$1,083 \times 10^{-2}$	-
2	0,074	0,570	0,363	$6,38 \times 10^{-4}$	$1,584 \times 10^{-3}$	0,814
3	0,500	0,844	0,457	$5,46 \times 10^{-2}$	$4,76 \times 10^{-2}$	0,520
4	0,100	0,770	0,435	$9,495 \times 10^{-3}$	$1,042 \times 10^{-2}$	0,39

(*) Corresponding to 0.800 void ratio

From these experimental results, an empirical formula can be established as the following :

$$\ell n\ k = -1.292 + 1.94\ \ell n\ (e.D_{10}) + 0.245\ (e.C_c)$$

in which

k : coefficient of permeability, cm/sec.

$k_{0.80}$: coefficient of permeability, cm/sec. for stowing void ratio = 0.800

e : initial void ratio

D_{10}: effective size, cm.

C_c : coefficient of curvature

r : coefficient of correlation, r = 0.9998

Another equation (Arıoğlu 1982, Lambe, Withman 1969, Mithchell, Smith 1979) that relates permeability corresponding to a void ratio of 0.800 and effective size can be derived as ;

$$k_{0.80} = 0.1337\ D_{10}^{1.471}\ , \quad r = 0.899$$

It is obvious that the coefficient of permeability is determined to decrease exponentially as the effective size decreases. It must, therefore, be concluded that the effective size has very sensitive influence on the permeability with reference to the drainage requirements.

DESIGN OF DRAINAGE REQUIREMENT

Hydraulic stowing placed in the stope consists of a saturated, settled material with an excess layer of free mixture water. As mentioned earlier, the removal of this excessive water from the stowed stopes is of considerable importance (Thomas, Nantel, Notley 1979). To realize the drainage of the excess water through the stowing under the gravitational head as effectively as possible, hence avoiding decant towers in the stope the permeability (percelation rate) must be equal to or greater than the stowing rate to be utilized in the project (Mitchell, Smith 1979). By taking into consideration this condition the required percolation rate can be obtained analytically.

$$P = 0.0277 \, \frac{(1-n) \cdot \gamma_s + n - \gamma_p}{\gamma_p - \gamma_w} \cdot \frac{M_s}{(1-n) \cdot \gamma_s \cdot A}$$

in which ;

P : percolation rate, cm/sn

n : porosity of settled stowing

γ_p : density of stowing slurry (solid+water), tonnes/m^3

γ_s : density of stowing material, tonnes/m^3

γ_w : density of water, γ_w = 1 tonnes/m^3

M_s : weight of stowing material, tonnes/hour

A : pouring area, m^2

To assist in designing of drainage requirements the authors perpared a nomograph displaying relationships among the important parameters related to the project. An example was made to demonstrate the use of design chart (Figure-3) below. The following conditions and allowables are taken in this example.

Thickness of the seam m = 2,0 m.

Length of the face L = 200 m.

Pouring area A = 400 m^2 (A = m.L)

Concentration of Slurry (*) by Weight K = 0,50

Concentration of Slurry by Volume K_v = 0,30

Rate of the Stowing material, M_s = 150 tonnes/hour

Effective size of the stowing material material D_{10} = 0,2 mm.

(*) The ratio stowing material to (stowing material + water)

From Figure-3, the percolation rate of the stowing material corresponding to the given effective size was graphically found to be $1,6 \times 10^{-2}$ cm/sec. On other hand, according to the working conditions such as face length, seam thickness, pour area and rate of stowing material, concentration of slurry percolation rate must be required to be $6,5 \times 10^{-3}$ cm/sec. (The use of the nomograph is indicated by broken lines).

As can be noticed, the percolation rate of the stowing is greater than the value defined by the working conditions. In other words, without placing decant towers in the stope the excess water can be effectively removed.

In brief washery reject to be employed for the project can be said to satisfy the drainage requirement under the data given.

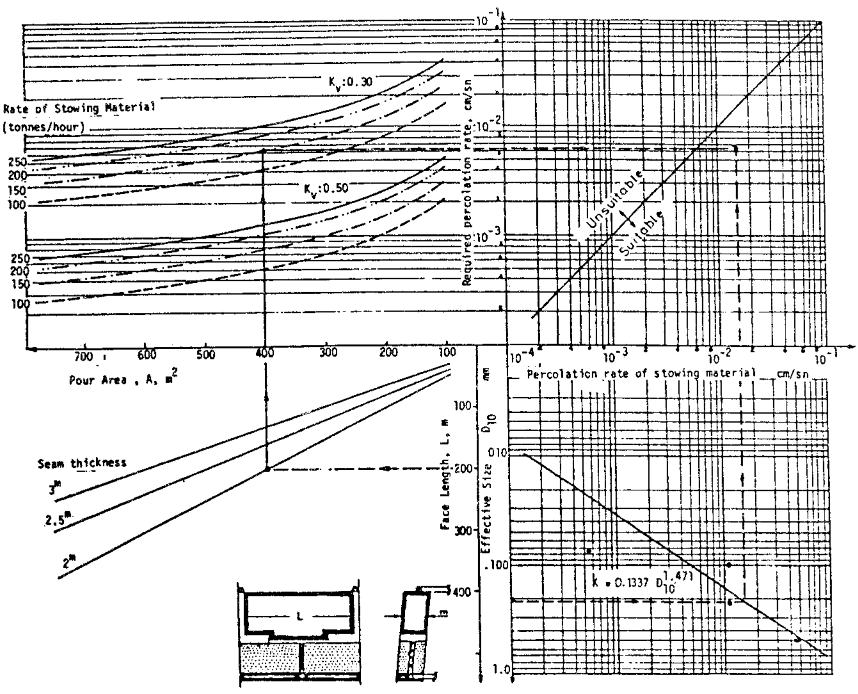


Figure-3 : Design Nomograph of the Hydraulic Stowing.

CONCLUDING REMARKS

The major conclusions of this study can be summarized as follows :

- The statistical data (table-1) demonstrated that the hydraulic stowing system has significant effect on minimizing the spontaneous heating of coal.

- The coefficient of permeability was established to lessen exponentially as the effective size decreases. Hence the effective size has a marked influence on the permeability with regard to drainage requirements.

- In order to work out the drainage requirements, a design nomogram based upon the experimental work was presented (Figure-3). For given working conditions the required permeability can be directly obtained from the nomogram under consideration. As can be noticed suitable permeability and rate of stowing material and concentration of slurry are vital parameters of effective drainage systems.

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