Sealing of Fissured-Porous Rock during the Construction of Mine Shafts

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ABSTRACT

The paper deals with the problems of grouting methods for fissured-porous rock. The paper describes design procedure, injection process patterns and hydrodynamic testing technique to plan grouting programs for fissured-porous aquifers. A number of case histories is given to illustrate the implementation of developed methodology at various mining projects.

INTRODUCTION

Sealing of permeable rock during deep shaft sinking with the use of pregrouting technique is one of the most advanced and reliable method of ground water control. One can state that the problem of grouting of secure rock strata has been successfully resolved during the recent years owing to developments introduced by the STG Group from the U.S.S.R. and some other specialist companies from the U.K., France and Japan. Much more difficult situation is confronted in sealing porous and fissured-porous formations in which about 30% of mine workings is constructed. The grouting techniques used not always ensure residual seepages to be reduced within statutory inflow standards. This can be explained by the fact that fissured-porous strata represent a complex system from the view point of ground treatment. During grout injection intensive filtration of a liquid phase into rock pores occurs. From the other hand, even total sealing of all cracks will not mean the elimination of filtration field.

The basic idea about creating a sealing cover in fissured-porous media, as illustrated in Fig. 1, consists in the formation, development and grout impregnation of primary and artificial fissuring networks at injection pressures exceeding the pressure of hydraulic fracturing and hydraulic expansion of rock.

PARAMETERS OF GROUT COVERS FORMATION IN FISSURED-POROUS ROCK

From the theoretical viewpoint of hydraulic fracturing and hydraulic expansion of rock it is known that the development of artificial fissures and cracks depends on the rupture strength of rock, quantity of full and lateral strata pressure, elastic properties of rock and hydrostatic pressure. The interrelation of fissure aperture δ_p with the propagation and pressure of hydraulic fracturing P_p can be described by the equations:

$$\ell = \frac{\delta_p}{\frac{G}{2(1+\nu^2)E}\left(\frac{\Delta P_c}{G} - 1\right)} \qquad (1)$$

$$\Delta P_c = P_r - P_\kappa \qquad (2)$$

$$P_p = P_\kappa - (1-\nu)\cdot(2G - 6_p) \qquad (3)$$

where $P_r = \gamma_T H$ - full strata pressure, MPa,

γ_T - rock strata specific gravity, N/m^3,

H - depth of aquifer roof, m,

$G = \frac{P_r}{2{,}5}$ - lateral strata pressure, MPa,

ν - Poisson's ratio,

E - Young's modulus, MPa,
G_p - rupture strength of rock, MPa,
P_K - hydrostatic pressure, MPa.

The required quantity of fissure aperture δ_p is assumed on condition to provide impermeability of a grout layer in fissures and cracks:

$$\Phi = \frac{H_{CT} - J_0 \delta_P}{M} = 1 \qquad (4)$$

where Φ - filtration threshold,
H_{CT} - hydrostatic pressure head, m,
J_0 - initial gradient of grout filtration,
M - aquifer thickness, m.

The values of initial gradients J_0 and permeability K_Φ of clay-cement grout in relationship to grout cover formation pressure have been expermentally determined during lab testing and are enlisted in Table 1 and illustrated in Fig. 2

Table 1

Grout cover formation pressure, MPa	Initial filtration gradient $\cdot 10^{-4}$	Permeability $K_\Phi \cdot 10^{-10}$ m/s
0.0	0.0035	7.50
0.5	0.25	5.53
1.0	0.45	2.78
2.0	1.85	1.62
3.0	3.65	0.73
4.0	4.23	0.64
5.0	4.60	0.30
6.0	6.10	0.15
7.0	7.35	0.11
8.0	8.83	0.10
9.0	10.32	0.06
10.0	12.06	0.044
12.0	16.65	0.036

Formation and development of fractures of specified aperture is attained at some excess pressure P_0 of clay-cement grout in fractures on the completion of injection. This excess pressure P_0 which ultimately provides conditions for grout covers formation in fractures with permeable walls, is determined on the basis of equation (4) and diagram in Fig. 2. In practice the value of excess pressure P_0 is taken to calculate residual pressure P_{OH} at surface grout pump

$$P_{OH} = P_0 + \Delta P_{OT} - P_{r.c} + P_H \qquad (5)$$

$$P_{OT} = \frac{4L\tau_0}{d} \qquad (6)$$

where ΔP_{OT} - pressure differential originating from locked-up stresses in grout, MPa,

τ_0 - dynamic shear strength, MPa,

L - length of manifold line and pipe string in a borehole, m,

d - inner diameter of pipes, m,

$P_{r.c}$ - hydrostatic pressure of grout column at aquifer bedding depth, MPa.

GROUTING PATTERN

In accordance with process patterns used by the STG Company pregrouting through surface holes involves the following operational procedures:

- drilling of grouting holes to the total shaft depth,
- borehole casing,
- hydrodynamic testing of all aquifers in the course of drilling,
- coring for physical-mechanical and permeability lab test,
- shaped-charge perforation of casings in aquifer zones,
- hydraulic fracturing and hydraulic expansion of fissured-porous strata in the course of grout injection,
- quality control of grouting by hydrodynamic technique monitoring reduction in permeability of a treated strata.

INDUSTRIAL TRIAL AND RESULTS

Experimental activities related to sealing of fissured-porous sandstones were accomplished during sinking vent shaft No. 7 and downcast shaft No. 4 with total depth of 2000 m at the Stakhanov Mine, Donets Coal Basin, U.S.S.R. According to hydrogeological report the shafts No. 4 and 7 were to intersect fissured-porous sandstone strata at a depth of

380 to 510 m with estimated water inflows of 116 and 136 cu. m/hr respectively. The sandstones are charaterized by low strength properties: $\sigma_{сж}$ = 36.9-49.8 MPa, $\sigma_{раз}$ = 1.7-3.7 MPa and total porosity up to 14.7%.

Grouting operations on sealing 380-510 m fissured-porous zone were undertaken within the general pregrouting program designed to the total depth of future shafts. Results of shaft sinking after pregrouting program which included also the interval of fissured-porous rock, and in comparison with conventional cementation program accomplished from underground at adjacent shafts No. 8 and 5 of the same mine are given in Table 2.

Table 2

Shaft description	Depth, m	Total shaft inflow, m³/hr		Inflow from porous rock		Average sinking rates m/mn
		Estim.	Resid.	Estim.	Resid.	
Pregrouting program accord. to STG technique						
Vent shaft No.7	1000	377	13.5	116	11.4	56
Downcast s. No.4	1000	339	11.5	136	9.5	60
Cementation program from shaft sump						
Vent shaft No.5	1311	412	37.0	131	35.5	30
Downcast s. No.8	1277	324	13.2	31	6.8	34

SUMMARY

The application of grouting technique for fissured-porous rock developed by the STG Company allows to achieve the following:

- to cut down water makes into the shafts under construction by 80 - 90 per cent,
- to eliminate the need for steel tubbing lining,
- to increase average shaft sinking rates by 2 tymes.

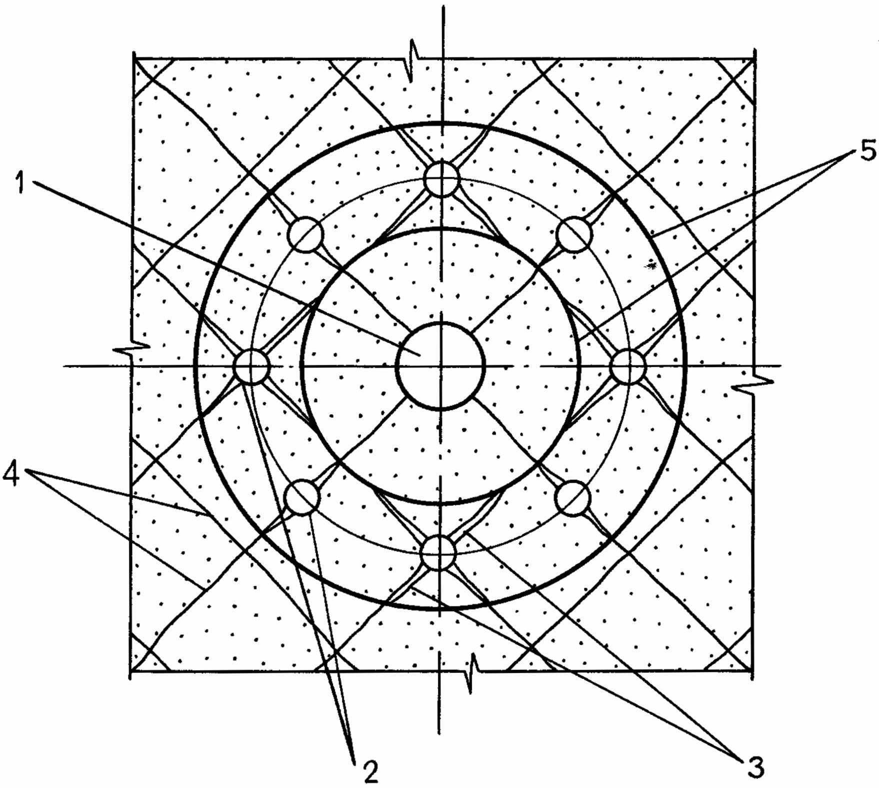

Fig. 1 Schematic diagram of sealing cover formation in fissured-porous strata

1-mine shaft, 2-grout injection holes, 3-artificial fractures, 4-primary fissuring, 5-sealing cover boundaries

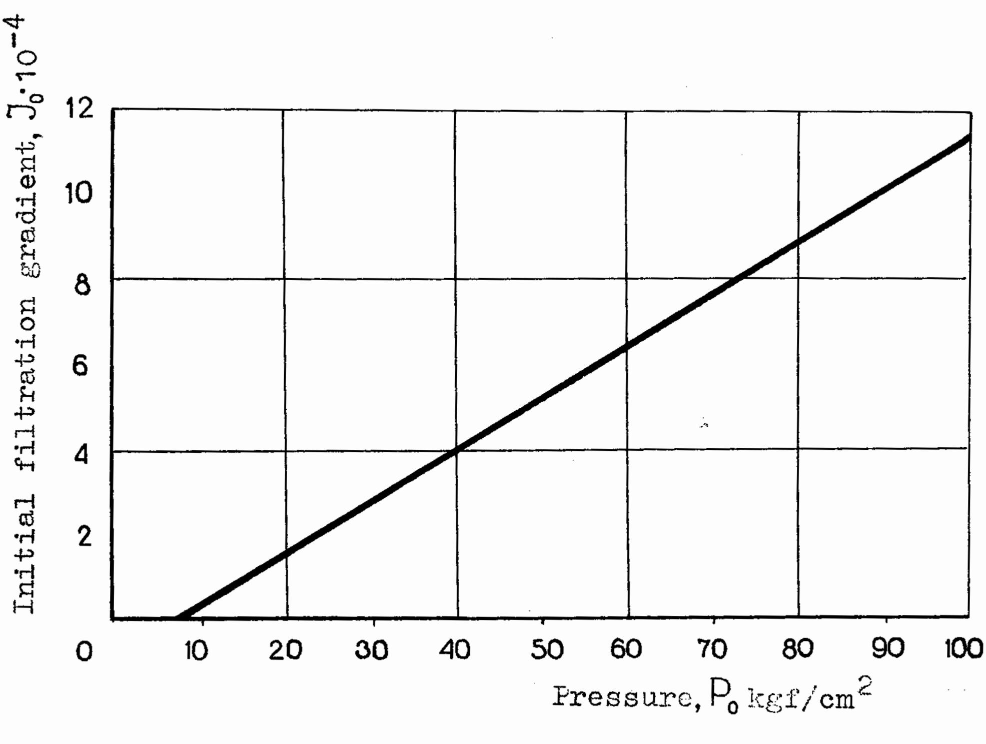

Fig. 2 Initial filtration gradient and grout cover formation pressure relationship