SIZE ESTIMATION OF WATER-SEALING CURTAINS AROUND MINE WORKINGS BY HYDRODYNAMIC TESTING

E.Ja.Kipco, Prof., D Sc Min. Eng.
O.Ju.Lushnikova, C Sc Min. Eng., I.V.Popov, C Sc M. E.

STG Association, 7a Petrovski St., Antratsit
Voroshilovgrad Region, U.S.S.R.

ABSTRACT

The paper describes a theoretical investigation into the method of estimating the size of water-sealing curtains formed by grout injection in the boreholes. The technique is based on hydrodynamic testing in the grout holes drilled beyond the boundaries of a treated zone.

To ensure guaranteed quality of water control in the shafts of mines under construction, it is necessary first of all to know the radius of grout propagation around the excavations. The developed technique of estimating the size of the formed curtains is based on hydrdynamic testing in boreholes drilled for grouting operations.

Let us consider first a problem to determine the radius of the formed curtain from a single hole in isotropic medium. It is known that in homogeneous rock the shape of a sealing curtain is similar to a cylindrical body. While testing a proving hole spaced beyond the boundaries of the curtain, a certain field of fluid flow arises that is dependent on the size of the curtain. To describe the field of fluid flow one can employ the method of transforms and introduce in our case a complex potential

$$\zeta = \varphi + i\,\psi \qquad (1)$$

where: φ - piezometric pressure head;
ψ - underground water flow rate.

In homogeneous media in the case of round boundaries in a two-dimensional flow the method of transforms was spread by Miln-Thomson. If the complex potential in unfinite space stipulated by the action of a source Q in a point Z_i is expressed by the function $\zeta = f(z)$ all singularities of which are beyond the curtain with a radius a and a centre at the origin of coordinates O, and if besides the region of flow is limited by an impermeable cylinder passing through the curtain's contour, then outside of this cylinder the complex potential is as follows

$$\zeta = f(z) + \bar{f}(a^2/z) \qquad (2)$$

In accordance with this method the real flow with its boundaries is substituted by a fictitious one with simplified boundary conditions but ordinary covering larger area. To form the required hydraulic effect within these boundaries imaginary holes are introduced (sources or discharges). Thus, the finite aquifer is transformed into an unfinite one in which the effect of real and imaginory holes can be determined from the known eqations. The complex potential in our case can be written as

$$\zeta = -\frac{Q_i \mu}{2\pi K} \ln (z - z_0) - \frac{Q_i \mu}{2\pi K} \ln \left(\frac{a^2}{z} - \bar{z}_0\right) =$$
$$= -\frac{Q_i \mu}{2\pi K} \ln (z - z_0) - \frac{Q_i \mu}{2\pi K} \ln \left(z - \frac{a^2}{\bar{z}_0}\right) + \frac{Q_i \mu}{2\pi K} \ln z + const \qquad (3)$$

where: K - permeability factor;
μ - dynamic viscosity of water;
Q - flow rate of water.

The flow around a sealing curtain is analogous to the flow in unfinite space stipulated by the action of the source Q_i at the point $A(z_0)$ and of the outher source of the same capacity Q_i located at the point $z = a^2/\bar{z}$ opposite to the point z_0 related to the curtain's contour, and also by the discharge with capacity Q_i acting at the origin of coordinates O that corresponds to the centre of a curtain. On having eliminated the singularities at points $z=z_0$, $z=\frac{a^2}{\tilde{z}_0}$ one can obtain the following expression of the complex potential

$$\zeta = -\frac{Q_i\mu}{2\pi K}\ln\frac{z-z_0}{r_0} - \frac{Q_i\mu}{2\pi K}\ln\frac{z-a^2/\tilde{z}_0}{r_0} + \frac{Q_i\mu}{2\pi K}\ln\frac{z}{r_0} + const \tag{4}$$

The values φ and ψ from the equation (1) are correspondingly equal

$$\varphi = -\frac{Q_i\mu}{2\pi K}\ln\frac{r_1}{r_0} - \frac{Q_i\mu}{2\pi K}\ln\frac{r_2}{r_0} + \frac{Q_i\mu}{2\pi K}\ln\frac{R}{r_0} + const \tag{5}$$

$$\psi = -\frac{Q_i\mu}{2\pi K}\theta_1 - \frac{Q_i\mu}{2\pi K}\theta_2 + \frac{Q_i\mu}{2\pi K}\theta_3 \tag{6}$$

Piezometric pressure head φ is the difference between dynamic levels in boreholes A and P, spaced beyond the contour of a curtain, i.e. $\varphi=\Delta H=H(A)-H(P)$. Constant term of the equation (5) one can find from: given that $r_1=r_2=R=r_0$, $\varphi=0$, then $const=0$. In accordance with the process pattern of testing we can write

$$z_0 = \tilde{z}_0 = x + Q_i \tag{7}$$

$$\frac{a^2}{\tilde{z}_0} = \frac{a^2}{L} \tag{8}$$

where L - distance from the centre of a curtain to borehole A,
r_1 - distance between boreholes A and P,
r_2 - distance between borehole P and arbitrary point B within a curtain,
r_0 - radius of a borehole around which the curtain is formed,
K - radius of influence during hydrotesting.

Piezometric pressure head φ one can write as

$$\Delta H = \frac{Q_i\mu}{2\pi K}\ln\frac{R r_0}{r_1 r_2} \tag{9}$$

Fluid discharge will amount

$$Q_i = \frac{2\pi K\Delta H}{\mu\ln R r_0/r_1 r_2} \tag{10}$$

Let us determine the radius of a sealing curtain a. Applying the cosine law one can find

$$r_2 = \sqrt{r_1^2 + \left(L-\frac{a^2}{L}\right)^2 - 2r_1\left(L-\frac{a^2}{L}\right)\cos\gamma} \tag{11}$$

where γ - angle formed between boreholes O, A, P with a vertex at a point A.

In its turn from the equation (9)

$$r_2 = \frac{R r_0}{r_1} e^{-\frac{2\pi K \Delta H}{Q \mu}} \qquad (12)$$

Equating the values r_2 from (11) and (12), raising to the second power the both parts of the equation and denoting $L-\frac{a^2}{L}=\rho$ one obtains

$$\rho^2 - 2 r_1 \cos\gamma \rho + \left(r_1^2 - \frac{R^2 r_0^2}{r_1^2} e^{-\frac{2\pi K \Delta H}{Q \mu}}\right) = 0 \qquad (13)$$

or having simplified

$$\rho^2 - 2 r_1 \cos\gamma \rho + r_1^2 - r_2^2 = 0 \qquad (14)$$

Solving the equation (14) for ρ

$$\rho = r_1 \left(\cos\gamma \pm \sqrt{\frac{r_2^2}{r_1^2} - \sin^2\gamma}\right) \qquad (15)$$

Having analysed the equation (15), we determine that $\frac{r_2^2}{r_1^2} - \sin^2\gamma > 0$, $r_2^2 > r_1^2 \cos\gamma$, since $\sin\gamma \geqslant 0$, when $0 \leqslant \gamma \leqslant \pi$, then we have $r_2 \geqslant r_1 \sin\gamma$. In calculations with the equation (15) the sign (+) is in case $\beta < \frac{\pi}{2}$ and the sign (-) is in case $\beta > \frac{\pi}{2}$, where β - angle formed between points P, A and B with a vertex at B.

Substituting for ρ into the (15) its value $\rho = L - \frac{a^2}{L}$, one obtains

$$L - \frac{a^2}{L} = r_1 \left(\cos\gamma \pm \sqrt{\frac{r_2^2}{r_1^2} - \sin^2\gamma}\right) \qquad (16)$$

Finally the radius of grout propagation is equal

$$a = L \sqrt{1 - \frac{r_1}{L}\left(\cos\gamma \pm \sqrt{\frac{r_2^2}{r_1^2} - \sin^2\gamma}\right)} \qquad (17)$$

In going from two-dimensional problem to three-dimensional one the expression (10) for a total fluid discharge through an aquifer can be written as

$$\sum_{i=1}^{M} Q_i = Q = \frac{2\pi K M \Delta H}{\mu \ln R r_0 / r_1 r_2} \qquad (18)$$

where M - aquifer thickness.

From the equation (9) one can obtain

$$r_2 = \frac{R r_0}{r_1} e^{-\frac{2\pi K M \Delta H}{Q \mu}} \qquad (19)$$

For the case of sveral begrouted boreholes the complex potential on the basis of the superposition principle will be defined as

$$\zeta = \sum_{i=1}^{n} f_i(z) + \sum_{i=1}^{n} \bar{f}_i\left(a^2/\bar{z}_0\right) \tag{20}$$

The contour of grout propagation in anisotropic media, on a first approximation, can be determined with a satisfactory degree of accuracy on the basis of data on the direction of a major fissuring system and parameters of anisotropy.

Having the data on fissuring anisotropy factor, it is easy to determine the radii of main semi-axis of an elliptical cylinder that corresponds to the propagation of a grout slurry in anisotropic medium. They will be equal

$$R_2 = \frac{a}{\sqrt{\varepsilon}}; \quad R_1 = \varepsilon R_2 \tag{21}$$

Thus, the presented method makes it possible to determine the overall size of a grout curtain formed from a single hole as a result of grout propagation both in isotropic and anisotropic rock.