DESIGN AND IMPLEMENTATION OF GROUTING PROGRAMS FOR MINE SHAFTS SUNK IN COMPLEX GEOLOGICAL CONDITIONS

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ABSTRACT

The integrated method of grouting of water-bearing rocks work out at p/a Spetstamponazhgeologia is grounded on scientifically accurate methodology of engineering the parameters of sealing curtains in fissured, fractured, fracture-porous rocks in the area around vertical shafts at the pregrouting through the boreholes drilled from the ground surface. The methodology entails the assessment of geometric dimensions of grout injection and estimation of quality of sealing of the grouted rock massif.

Basing on the methods of engineering of sealing curtains the programs of automated design of the whole of the complex of operations on pregrouting meeting the concrete conditions were suggested and worked out.

INTRODUCTION

The process of shaft-sinking whilst mining mineral deposits is connected with development and reduction of ground water inflows. The shafts of modern times inevitably intersect dozens aquifers featuring, as a rule, various and independent values of hydrostatic pressure and hydrodynamic characteristics.

In the practice of underground mine development to provide the protection from ground waters the following specialist methods such as cementation, chemicalization, freezing and many others are known and applied. Thus, the rates and technico-economical parameters of shaft sinking are dependent on the scientifically based option of special way of sinking with regard to concrete geological conditions.

In the early 70's the integrated method of grouting of water-bearing rocks developed at p/a STG broad application both at vertical shaft sinking and long horizontal mine drivage under severe geological and hydrochemical conditions. Owing to its application in fractured, fracture-porous and fissured rocks with prognosed values of water inflows amounting to 2000 cu.m./h there were sunk more than 200 mine shafts to a depth of 800-1400m both in the former USSR and abroad. The method provides the elimination of water inflows, high rates of sinking and drivages, (not less than 80-120 m/month) and keeping to normative terms of development.

ESSENTIALS AND FEATURES OF THE INTEGRATED METHOD OF GROUTING

The integrated method of grouting is based on the complete engineering of the parameters of the process of sealing of water-bearing rocks: dimensions of sealing curtains around the shaft in each of the aquifers; counter holes; the optimum regimes of injection and quantitative assessment of quality of grouting process.

The basis of all engineering computations form accurate data on permeability and filtration characteristics of rocks obtained through the methods of hydrodynamic and flowmeter tests in boreholes. (Fig 1).

The highly effective and cost-efficient grouts with clay base amounting to 90-95% of the total volume were developed and largely applied as grouting material. The various sorts of cement, fly ash, water solutions of sodium silicate and many others are used as structure forming reagents. To prepare the grouts the highly productive mechanized complex of equipment is used.

The water-bearing rocks around the vertical shafts is carried out through the system of inclined boreholes, drilled from the ground surface to a depth equal to that of the shaft (Fig 2).

The configuration and dimensions of sealing curtain in each of the aquifers are dependent on that of water-conducting channels, ground water pressure head and strength of the grouting material. The application of inclined holes at angle of fractures allows to cross the potential to combine the operations on the pregrouting, shaft equipping for shaft sinking.

The creation of sealing curtains in each of the aquifers is carried out applying the effective technological schemes of grout injection into holes (Fig 3) and special technical value of injection pressure up to 30-50 MPa.

The integrated method of grouting includes continuous control over the quality of sealing of aquifers.

Through the methods of hydrodynamic and flowmeter tests the decrease of permeability of rock massif is observed and the value of residual water inflow is determined. The analysis of the current technological parameters of grout injection which are recorded on diagram allows to estimate the rates of grout impregnation in rock massif around the future shaft. Through the method of compaction of the grouted interval in the hole at the target pressure the concrete dimensions of sealing curtain in large fractures or fissures are determined. All of this mentioned allows to predict the residual water inflow into shaft after the completion of grouting programs.

GENERAL PRINCIPLES OF DESIGNING GROUTING PROGRAMS

The design of grouting operations for vertical shafts entails the following phases:

1 Gathering, generalisation and analysis of information on the parameters and characteristics of rock massif and water content of rocks;

2 Assessment and analysis of the data received from downhole flowmeter and hydrodynamic tests and also the data on the laboratory testing of hydraulic and physico-mechanical properties of samples;

3 Development of formulations of clay-cement grout for a specific grouting site and determination of structure-mechanical and rheologic characteristics;

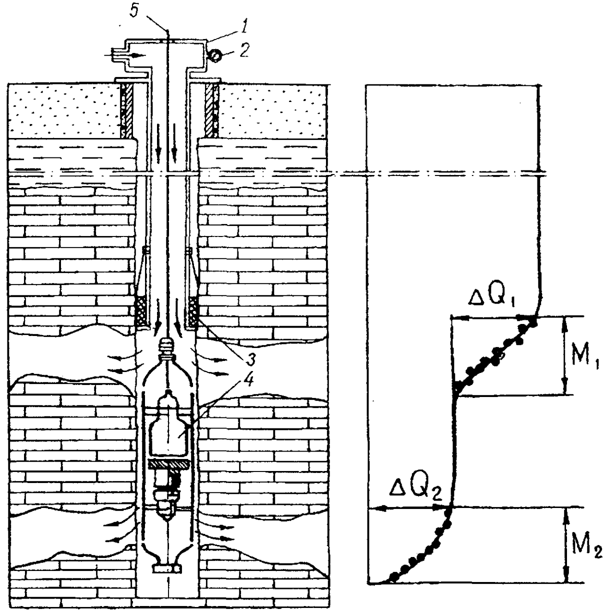

Fig.1 Downhole hydrodynamic testing scheme.
1 - sealer
2 - pressure gauge
3 - packer
4 - flowmeter
5 - logging cable

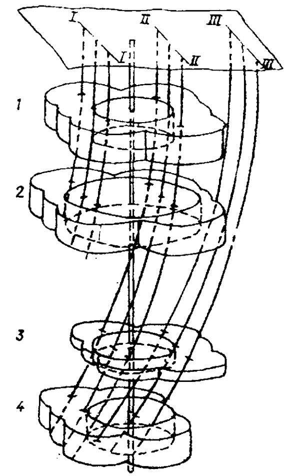

Fig.2 Arrangement of grouting holes around a mine shaft.
I-II-III - series of boreholes
1-2-3-4 - sealing curtains

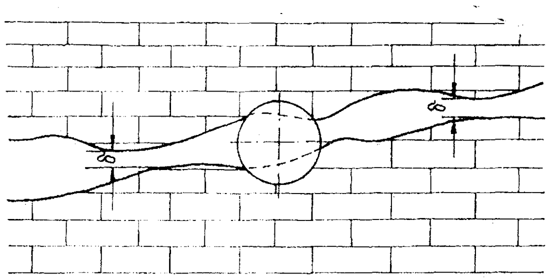

Fig.5 Sealing curtain design scheme for karst environment.

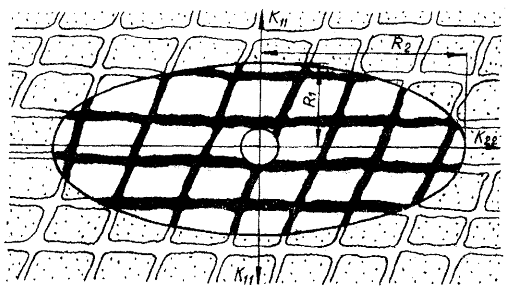

Fig.6 Sealing curtain design scheme for fractured rock.

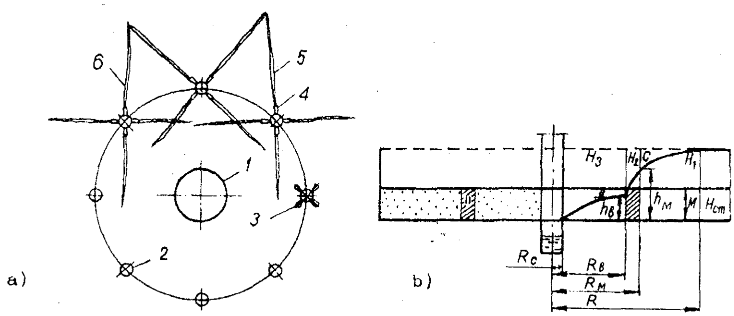

Fig.7 Sealing curtain design scheme for porous rock.

1 - shaft.2- grout injection hole.3-4- crack.
5-6 - artificial fracture

I-III - porous rock   II - sealing curtain

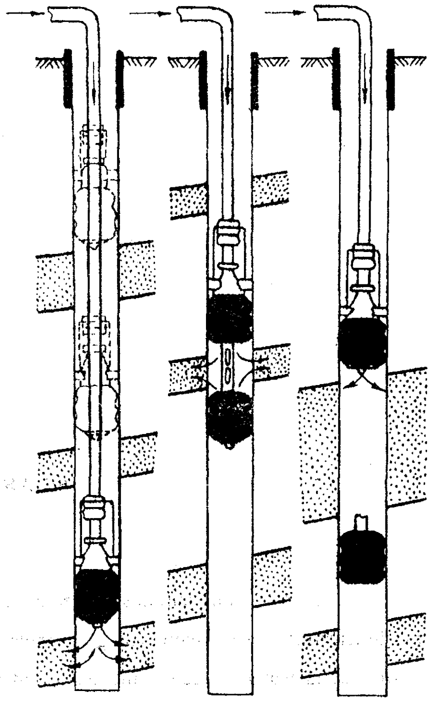

Fig.3 Technological scheme of grout injection.

4 Engineering and dimensions of sealing curtains for each aquifer, counters of grout spread out in separate holes, determination of number and places of counter interval of holes on the surface, volume of grout to form sealing curtains;

5 Assessment of coefficients of permeability decrease and admissible values of residual water inflows for each aquifer with the purpose of control over the quality of grouting process.

The principle scheme of fesigning the parameters of sealing of aquifers through the integrated method is given in Fig 4.

METHODS OF ESTIMATION OF SEALING CURTAINS AROUND MINE SHAFTS

The dimensions and configuration of the sealing curtains created around the shaft are dependent upon geometric dimensions of water-conducting channels in rock massif, hydrostatic pressure head of ground waters affecting the change of pressure in the system "shaft - aquifer", structure-mechanical, strength and filtration properties of grouting material and technological regimes of grout injection.

In fissured rocks the required dimensions of sealing curtain around the counter of a future mine shaft are obtained from the following equation regarding the condition of grout stability in a water-conducting channel (Fig 5).

$$R = \frac{\alpha \cdot \delta_{экв} \cdot P_к}{2[P_m]} \quad (1)$$

where α - coefficient of strength;

δ - dimensions of water-conducting channels, m;

P_K - hydrostatic pressure head of ground-waters in aquifer, MPa;

[Pm] - admissible value of plastic strength of the stabilized grout, MPa.

In the course of computations the equivalent quantity δ_{3KB} is the quantity of fissure channels in the areas of pinches upon which the dimensions of sealing curtain depend and is determined according to the flowmeter and geophysical testings in the holes.

In the process of grout injection the quantity δ_{3KB} is defined more exact according to the special methodology of treatment of the parameters of injection regimes.

In fractured rocks the dimensions of sealing curtains are determined regarding the condition of stability of grout in fractures and accounting the fracture anisotropy of rocks. At two systems of fractures, as it is seen from Fig 6, the configuration of sealing curtain is alike an elliptic cylinder and the dimensions of the sealing curtain are:

$$R_2 = \frac{\alpha \cdot \delta_{max} \cdot P_K}{2[P_m]} \quad (2)$$

$$R_1 = \Sigma R_2 \quad (3)$$

where δ_2 - opening of fractures of basic system, m;
Σ - coefficient of fracture anisotropy.

At the assessment of sealing curtain the maximum opening of fractures is taken which is observed in operating workings or alternatively according to the data on flowmeter and geophysical testings in the hole.

In porous rocks in the basis of sealing technology there is the idea of creation of sealing curtains as a closed system of artificial fractures (Fig 7). Geometric parameters of sealing curtain at the given number of grouting holes:

The length of cracks of hydraulic fracturing:

$$L = \frac{2\beta_2 R_c \sin \pi/n}{0.707\beta_1 \sqrt{1-\beta_2^2 \sin^2 \pi/n}} \; ; \quad n \geqslant 5$$

The space between grouting holes:

$$\rho = 0.707\,\beta_1 L$$

The radius of counter interval of holes:

$$R = \beta_2 \sqrt{R_c^2 + 0.125\,\beta_1^2 \cdot L^2}$$

where R_c - radius of shaft, m;
n - number of grouting holes;
β_1 - safety factor on borehole spacing;
β_2 - safety factor on length of open fractures.

The filtrational stability of sealing curtain provides the quantity of opening of artificial fractures caused by hydraulic fault and water resistant properties of clay-cement grouts in fractures of fault:

$$\delta = \frac{2 \cdot L \; \Delta P}{E(1 - \nu^2)}$$

where ΔP - pressure differential at grout spreading in fractures of fault, MPa;
E - modulus of deformation of rocks, MPa;
ν - Puaisson ratio;

RESULTS ON INTRODUCTION OF THE INTEGRATED METHOD OF GROUTING

In the fissured rocks the process of designing and performing of grouting works were successfully carried out at the sites of the testing shaft of "Dobrudzha" in Bulgaria, at the vertical shaft PA-1 of iron-ore deposit "Palazu-Mare" in Romania. The maximum dimensions of fissured channels at these sites, recorded in testing and grouting holes, amounted to 2.7-3.5m.

The expected value of water inflow into PA-1 shaft with the designed depth of 650m at the "Palazu-Mare" iron ore deposit with depth of layer of 500m with coefficient of filtration 37.8 m/day was reduced from 97.87 cu.m/min to 0.015 cu.m/min and the process of shaft-sinking was carried out without any complications.

At "Severnaya" mine site which is in the Northern Urals, Russia the sinking of a new ventilation shaft with depth of 780m was carried out in fissured rocks with co-efficient of filtration exceeding 21 m/day and expected value of water inflow of 2700 cu.m/h. To perform the program on pregrouting from the ground surface 12 boreholes were projected and the volume of grout amounted to 62700 cu.m. Currently these works are being completed.

In fractured rocks there were carried out the grouting operations at sinking of more than 100 mine shafts with depth of 600-1400m in Donets Coal Basin. At the expected values of water inflows from 115-580 and more cu.m/h those of residual inflows into shafts were not exceeding on average 1.5-3.5 cu.m/h, thus the percentage of sealing amounted to 99%. This can also be demonstrated with some more examples of carrying our of grouting works at sinking of ventilation shaft at N1 Zhdanovskaya-Kapitalnaya mine site with designed depth of 615m. The grouting of aquifers with water inflow of 115 cu.m/h was performed through 6 inclined boreholes. The dimensions of sealing curtains around the shaft amounted to 19.7 and 31m, the volume of grout - 5275 cu.m. The residual water inflow into the shaft was 1.4 cu.m/h. The average rates of sinking - 100m/month.

In porous rocks the worked out methodology of designing of sealing curtains and technology of grouting applying methods of hydraulic fracturing of rocks was introduced at sinking of 15 deep mine shafts in Donets Cal Basin, and also in Chechia at "Slany" coal deposit. In Donets Coal Basin at "Octyabrskaya" mine site at sinking of an air conducting shaft with depth of 1011m the values of reduced residual water inflows were from 622 to 13.2 cu.m/h - 87.9%. At shafts N4 and N7 at Stachanov mine site with depth of 1000m, the values of water inflows amounted to 9.0 and 13.3 cu.m/h respectively, and the percentage of reduction 97.4% and 95.7%. At "Slany" mine site as the result of surface pregrouting of fine-pore sandstone water inflow into the skip shaft with depth of 987m was reduced from 93.4 to 12.0 cu.m/h, and into the cage shaft - from 93.4 to 6.0 cu.m/h.

CONCLUSION

The methods of designing and performing of pregrouting programs at vertical shaft sinking under conditions of fissured, fractured and porous rocks with water content worked out at p/a STG were thoroughly tested under the most severe mine-geological conditions and can be recommended for application in various parts of the world solving technical and ecological problems connected with ground waters during mining processes.