WATER CONTROL IN METALS MINING

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ABSTRACT. The Ukrainian STG Agency has developed a clay-based grouting method for groundwater flow control in coal and metals mining. This method has been proven effective in dramatically reducing permeability in fractured and saturated karst rock, and in granular or porous media. It has been successful used in many applications dealing with ore and bauxite mines, copper and coal mines, diamond and rare earth metals pits. Over the last 30 years, STG has completed over 400 large to medium to small grouting projects using its method in the former Soviet Union, eastern Europe block countries, the USA and southeast Asian countries.

Keywords: saturated rocks, hydrodynamical investigations, water control, quality assurance

INTRODUCTION

Bringing metals and coal mines into operation requires sinking vertical shafts and driving horizontal openings. Ground water discharges into underground workings commonly reduces the efficiency of these operations. Early and complete suppression of ground water inflow to shaft and workings under complex hydrogeological conditions generally is the most cost-effective way of increasing efficiency in metals and coal mining. This is especially true in many Ukrainian and Russian hydrogeological environments where measures must usually be taken to prevent and eliminate the inflow of underground water into mines.

Traditional methods of preventing ground water inflow into mines consist of cement or chemical grouting from the faces of the shafts and workings or ground freezing during their construction. These methods have been used universally. However, in many cases, they have failed or have not been very efficient. The general deficiencies in the application of all hardening grout mixtures for creating grout curtains around shafts and underground workings in saturated rock are as follows:

a). The high cost of the grouting materials;

b). The brittleness and low plasticity of the solidified materials;

c). The possibility of the grouting compound setting in the pipes due to any disruption in the injection production mode or during an emergency;

d). The significant expenditure of time for drilling out cement barriers or plugging the holes;

e). The possibility of the deviation of the grout holes during subsequent drilling because of the resistance of the grouting materials after it hardens;

f). The necessity for carrying out grout injection operations in saturated rock in several production stages with interruption for the hardening of the grout;

g). The poor success during the isolation of large fractures.

As a rule, grout curtains are created in saturated rock with cement, using 10 to 20 holes that are arranged uniformly in a circle beyond the contour/outline of the shaft or extended underground workings. Analysis of the status of the technology for the cement grouting of permeable fractured rock permits the following conclusions to be drawn:

1. The final dimensions of grout curtains formed around shafts and underground workings in fractured rock may be small. Nevertheless when grouting saturated fractured rock, the volume of cement required is, as a rule, very high due to the erosion of cement grout by ground water before the grout hardens. The large radii of spreading also accounts for the large volume of cement grout. The primary cementing does not provide good long-term results in rock that contain large fractures with high ground water velocities.

2. Cement grout shrinks during hardening. Its brittleness and other negative factors cause it to have limited effectiveness for the isolation of saturated fractured rock under complex hydrogeological conditions.

3. The selection of the best method of grouting shafts and underground workings from the ground surface or from the working face depend heavily on the site-specific hydrogeological conditions of the hydrostratigraphic section and on the organizational plan of the mine site.

4. Great subjectivity is required in the selection of the technical parameters required for cement grouting. The low level of development of methods to obtain initial information about the hydrogeology of complex fractured rock sites leads to poor estimates of the volume of cement grout required. The absence of reliable methods for determining the optimal parameters of cement grouting is one of the reasons for the poor performance of these grouting operations.

5. The high cost of cement grouts, the high loss rate of cement, the inefficient production of the grouting technology and the low productivity of cement grouting operations all add substantial cost to the construction of shafts and underground workings when cement grout is employed to control ground water inflow into the workings.

METHODOLOGY

STG has developed an integrated method of grouting saturated fractured rock that takes into account all these disadvantages of cement grouting. Generally, we prefer to produce and inject the grout from the ground surface to minimize the inflow of ground water into underground workings that are located in complex hydrogeological environments. The integrated method of grouting saturated rock differs from the traditional cementing methods in the following ways:

a). The method uses scientifically based calculations throughout the entire grouting process. The calculations include: the chemistry of the grout; the geometry of the isolation curtain around the opening; taking into account anisotropy of permeability; specification of the number and design of injection and monitoring wells; the injection pressure modes and; evaluating the effectiveness of the completed grout curtains.

b). Quantitative information is obtained from the analysis and categorization of geological samples, and on the character of the fracturing and on the transmissive properties of the rock.

c). The grouting is implemented with high-volume inexpensive, but highly effective, clay- or bentonite-based grouts.

d). The production layouts for implementing grouting operations stipulate the use of an STG-designed flowmeter and mechanical packers.

e). Directionally-inclined boreholes are used for grouting saturated rock during the excavation of vertical or inclined shafts. The design of such holes permits the number of intersected dipping fractures to be maximized while substantial economic advantages are achieved due to the combining of grouting operations with exploratory drilling prior to shaft construction.

f). The results of the pre-shaft grouting are evaluated objectively prior to the beginning of underground excavation operations using quality control methods developed by STG.

The main provisions of the STG integrated method for grouting saturated fractured rock are itemized below.

1. It is important to properly locate, design, and orient exploration boreholes. The hydrostratigraphic units to be intersected by the proposed shaft or drift, their fluid potential distributions and the hydrogeologic properties of the fractured zones must be determined. In order to obtain such information, a number of borehole flowmeters have been developed by STG. These include the DAU-3M-57 and the DAU-3M-76, with hole sensor diameters of 57 and 76mm, respectively. The use of flowmetric methods facilitates the reliable determination of the number of hydrostratigraphic units intersected by a borehole along with their depth and thickness. The hydrogeologic properties of each water producing stratum, including its fluid potential distribution, the saturated hydraulic conductivity, the porosity and specific yield and the average fracture dimensions and geometry in the rock penetrated by the borehole can be determined also. A method of hydrodynamic measurements in saturated hydrostratigraphic units using packers facilitates the determination of the degree of induration of the rock ahead of the borehole, the hydraulic head distribution, the radius of influence of borehole, the saturated hydraulic conductivity, the piezoconductivity and the coefficient of elasticity (bulk modulus) of the unit.

These data are then used to design the general characteristics of the grout curtain around the shaft or underground workings. In aggregate, these hydrogeologic investigative methods applied to multiple boreholes permit the anisotropy of each hydrostratigraphioc unit to be determined quantitatively. The methods used to investigate the hydrologic characteristics of the saturated rock in combination with geophysical methods and with the study of the geological characteristics of the hydrostratigraphic section provide reliable quantitative information about the aquifers, aquitards and aquicludes. This information constitutes the basis for designing the grouting program.

2. As explained above, the grouting operations are planned based on the data obtained from the initial or preliminary investigations. Natural or modified clay based grouts developed by STG are used for grouting. These grouts possess the capacity for providing good water isolation properties even in highly permeable, fractured rock. These grouts consist of selected clay (sometimes modified), a small amount of cement and structure-forming additives.

The clay-based grouts that are designed properly are practically non-erodible by ground water in saturated rocks. In addition, they do not stratify during hardening and do not stabilize during injection trough fractures. They very quickly acquire strength as plasticity develops after the flow is stopped. After setting, the grout is compacted further only by explosions. The strength and rheological properties of clay-based grouts can be varied widely depending on the density and other properties of the initial clay slurry and additives. The final plasticity strength of the clay-based grout is 0.5 to 4.0 MPa. The strength and rheological properties of clay-based grout are determined experimentally and factored into the grouting process. For example, the dimensions of the isolation curtain around a shaft or drift are determined on the strength calculations. The grout’s probable spreading geometry during injection from a single borehole is determined, in part, based on the hydraulic capabilities of the grouting equipment used, on overburden pressure and on the bulk modulus of elasticity of the fractured rock. The necessary number of grout holes, their location on the ground surface or in underground working and the volume of grout are also calculated.

3. Directional drilling is necessary in order to implement a grouting program properly. In order to carry out directional drilling of grout holes under specific hydrogeological conditions, production layouts and equipment have been developed by STG. If at all possible, grout holes should be drilled to the entire design depth before the grouting commences. When implementing a surface-based program during the excavation of shafts or drifts, the drilling of grout holes is carried out by modern rotary drilling rigs; the holes are equipped with reliable pressure measuring devices.

4. A suite of flowmetric investigations is conducted in the drilled grout holes with complete processing and analysis of the results. On the basis of the data obtained, the design for each part of the isolation curtains, including the volume of grout required for the isolation of each hydrostratigraphic unit, is adjusted during operation.

5. The grout is injected using high-output grout pumping rigs with a feed rate of 3-5 L/sec. These feed rates permit a corresponding pressure of 5 – 20 MPa to be developed if necessary. The grout is injected along each hole into each hydrostratigraphic unit, each of which may constitute a separate fractured zone. A number of special packers have been developed for such production schemes; these facilitate the sealing of the boreholes at any single point.

These packer systems make it possible to inject grout into each of the hydrostratigraphic units separately. Grouting from the bottom up precludes the necessity of drilling out grout materials in the holes between grouting levels. Drilling through grout is a source of inefficiency that should be avoided if possible.

When carrying out operations underground from the bottom of a shaft or at the working face of a drift, the grout is injected along high-pressure pipe columns that extend up to the face, along the mineshaft or down a borehole drilled from the surface into the opening. The grout is injected into each hole according to the properties of the hydrostratigraphic unit intersected by the borehole. In the zone nearest the face, the grout is injected through a hole jig; in subsequent zones, it is injected through the mechanical packer, which is installed ahead of the water-producing zone.

6. The initial clay slurry is produced in a highly mechanized complex consisting of jet cutting mills and high speed feed pumps. The operation of the clay loader, pumps and jet cutting mills is controlled remotely from a separate location. All the equipment (except the loader) is located in a structure that is easy dismantled and mobile. A clay station can produce up to150 m^3 of clay slurry per day from untreated ball clay with a minimum number of 2 men per shift. The clay-based grout is produced from the clay by a continuous method using a mixer with a 20 ton capacity hopper for dry cement. The hopper is equipped with conveyors and a hydro mixing funnel. The equipment complex currently in use permits 50-150 m^3 of grout to be injected per shift. The control monitoring station is used for monitoring the grout production and injection process. This station continuously records the quality of the grout made during the injection process, the injection pressure, the injection flow rate, and the volume of grout injected on a strip chart. The station operator can actively intervene both in the grout production process and in regulating the injection modes. The recording of the entire grouting process and the timely adjustment of the production modes preclude any unintentional deviation from the design.

7. The results of the grouting are rigorously monitored after injection as a part of the overall grouting operation. For a shaft, the reduction of the saturated hydraulic conductivity of each hydrostratigraphic unit occupied by the grout curtain is evaluated. Whether or not the conductivity has been reduced to the calculated acceptable value will determine the maximum acceptable residual inflow of ground water into the shaft.

An assessment of the quality of grout isolation curtains constructed by injecting grout through holes drilled from the underground workings can be made using three methods:

a. monitoring the change in the permeability of the rock as the grout is injected into the drillholes;

b. checking the strength and stability of the grout curtain by conducting an injection test of the calculated design pressure;

c. checking for adherence to the final calculated modes of injecting the grout into the hole..

DISCUSSION OF RESULTS

The STG integrated method of grouting saturated rock has been used in many applications at underground coal and metal mines, and diamond and rare earth metals pits. It has been applied most widely in the sinking of vertical shafts in fractured, saturated rock and the excavation of underground horizontal workings through fractured and faulted water-bearing zones. As explained previously, grouting operations are preferably carried out from the surface and are integrated into the construction/excavation schedule. Such integration reduces significantly the length of time required for preparation of shaft construction and for sinking the shaft. The increased efficiency is achieved by the elimination of cementing operations from the working face upon the penetration of each aquifer. Concomitantly, labor and energy expenditures during shaft sinking are minimized because the more complicated and labor-intensive work is carried out at the surface. The same is true for grouting of underground openings. Table 1 shows examples of summary parameters for water control in different mines in which the STG integrated grouting method was applied.

CONCLUSION

On the whole, this water control method has the following advantages:

a). Methods and technical means are employed that allow the complete initial information on the fractured and faults seepage properties to be obtained. Scientifically based calculations are then used throughout the entire process of sealing fractured and faulted zones.

b). Efficient clay-cement or bentonite-cement grouts are used.

c). Water control is carried out on the basis of efficient technological patterns and by means of high-production equipment.

d). The results of the advanced water control are comprehensively estimated prior to the commencement of shaftsinking or tunneling .

The method makes it possible:

1. To reduce shaft sinking and tunneling time while driving through water bearing fractured zones and faults.

2. To reduce overall shaft sinking and tunneling costs.

3. To employ more lightweight lining in the region of seismic activity.

4. To gain considerable savings through the repayment of capital investments by reducing construction time and putting shafts and tunnels into operation ahead of schedule.

Table 1. Examples of Summary Parameters for Water Control in Different Metals and Coal Mines using the STG Integrated Grouting Method

N	Country	Mine, Open pit	Shaft, Working, Open pit	Depth, Length, m	Geology	Expected water inflow prior to grouting m^3/hr	Volume of grout injected, m^3	Quantity of grouting holes	Extent of drilling operations, m	Residual water inflow after grouting, m^3	Year of completion of work
1	Ukraine	Coal mine Nagolchanskaya	Ventilation shaft No. 1	690	Fractured rock	425	2625	6	4200	3.5	1970
2	Hungary	Copper mine Rechk	Crosscut of horizon 900 m	60	Fault zone	640	1210	4	320	0.5	1976
3	Ukraine	Potash mine Stebnyk	Chumber No.16	140	Karst Rock	2000	119400	40	5600	25	1979
4	Hungary	Coal-Bauxite. mine Nadyedy Haza	Western inclined shaft	550	Fractured rock	900	6320	24	2400	10	1981
5	Bulgaria	Coal mine Dobrudzha	Main shaft	960	Fractured rock	6000	9200	1	960	25	1982
6	Hungary	Coal-Bauxite mine Many	Inclined shaft	600	Fault zones	600	6510	28	2628	12	1983
7	Czech Republic	Coal mine Slany	Main shaft	1345	Porous rocks	380	9810	6	5970	14.5	1984
8	Yakutia	Diamond ope pit Mir	Dam	15	Unstable soil	54	102	11	165	0	1985
9	Ukraine	Coal mine Kyivska	Cross Cut No. 28	220	Fault zone	350	634	4	240	0	1986
10	Russia	Bauxite mine N21	Inclined shaft	150	Karst rock	1150	5940	8	560	4.5	1987
11	Russia	North Ural Bauxite mine	Cut-off wall	300	Karst rock	4000	14000	11	3300	16	1987
12	Romania	Ore mine Palazu Mare	Intake shaft	650	Karst rock	5980	2380	3	1950	0.9	1988
13	Czech Republic	Coal mine M.Mayerova	Abandoned workings of horizon 200 m	410	Fault zone	120	8200	9	1800	0.5	1991
14	USA	RareEarth Mike Horse Mine	Abandoned drift of horizon 100 m.	240	Fault zone	80	1195	11	1195	8	1994
15	Yakutia, Siberia	Diamond open pit Mir	Open pit	3200	Fault zones	2000	360000	320	168000	500	1998

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