International Journal of Mine Water, vol. 5 (4), (1986) 41 - 47
Printed in Madrid, Spain

WATER CONTROL BY INTEGRATED GROUTING METHOD IN MINING

E. Ja. Kipko, Prof., D Sc Min. Eng.
Director General of STG Association
Vice-President of IMWA

The specialized industrial association on grouting and geological services Spetstamponazhgeologia (STG) has developed a highly-effective method for grouting the fissured aquifers that has been being successfully applied in mining from the late 60s. This technique foresees the preparation and injection of grouts to be carried out on the ground surface, and is employed to provide water control in deep mine construction under complex hydrogeological conditions.

In my report I will try to briefly describe the basic principles and technological procedures of the Integrated Method keeping to the order that is characteristic for our approach to the problem of water control in mining. In addition, I will present more detailed information on some trends in grouting activities executed by STG.

The employed investigation methods of hydrodynamic properties of rock together with the geophysical logging and site geology studies make it possible to obtain reliable and complete data on aquifers that are of major importance during the design of the parameters of grouting curtains.

The usage of flowmetering techniques enables us to determine the number of aquifers intersected during drilling, the depth and thickness of each aquifer, and also the water pressure head, permeability and filtration factors, fracture void factor and the average opening of fissures in the rock. The developed hydrodynamic investigation technique with the use of packers is employed to estimate the degree of borehole blockage, water pressure and radius of influence, filtration factor, conductivity and elasticity capacity of water-bearing zones. The logging with the DAU-6 downhole instrument makes it possible to determine the direction of subsurface water flow and major fissuring systems in each aquifer that will be further used to evaluate the geometry of a general grouting curtain around the underground opening.

The technique employed of hydrodynamic studies in several adjacent boreholes enables us to quantitatively determine the anisotropy factor of water-bearing strata.

The grouting project is designed on the basis of data obtained during aforementioned studies. To carry out grouting operations, we employ specially developed clay-cement grouts which have good penetrating capacity and high hydro-sealing properties. These grouts consist of clay slurry, cement and structure-forming reagents. Clay-cement grouts having high consistency are in practice not washed out by subsurface water, do not segregate during the setting period and do not set while flowing through pipelines and in fissures but gain strength very rapidly when the injection is stopped. During blasting operations such grouts tend to consolidate. Rheological and strength properties of clay-cement grouts can be widely varied depending on the density of the initial clay slurry. The final plasticity strength of clay-cement grouts amounts to 0.5-0.8 MPa.

For the purpose of the grouting project design the strength and rheological properties of clay-cement grouts are evaluated experimentally. On the basis of strength analysis we design the size of a grouting curtain around the mine shaft, and taking into account the hydraulic capacities of the grouting machinery employed we evaluate the potential grout propagation contours during its injection into a grout hole. The required number of grout holes, their spacing and grout quantity are determined by calculation.

In carrying out a grouting programme from the ground surface the Integrated Grouting Method generally stipulates the drilling of inclined directional holes that are spaced out from the shaft outline.

The use of inclined directional holes makes it possible to eliminate water inflows into a shaft despite the development of a mine shaft site. However, too great a deviation of holes is not advantageous since they then fall outside the boundary of the general grouting curtain at shallow depths. It has been ascertained that the most rational method is to drill grout holes within the natural deviation dependent on the dip angle of the strata.

Shaft sinking is preceded by rather a long preparational period when drilling of vertical grout holes spaced in the proximity of the shaft can not be combined with the preparational activities. The inclined directional holes spaced at some distance from the shaft can be drilled during the preparational phase this, in the long run, contributes to cutting down the construction period both of the shaft and the mine as a whole.

The Integrated Grouting Method was first applied during the sinking of ventilating shafts No.1 and No.3 with depths of 690 m and 710 m respectively at the Nagolchanskaya Mine. Pregrouting from the ground surface was accomplished up to the total depth of future shafts parallel with equipping the shafts for sinking. The anticipated water inflow into shaft No.1 was 425 m^3/hr and into shaft No.3 was 437 m^3/hr. On the completion of grouting projects the residual water seepages amounted to 3.5 m^3/hr and 0.5 m^3/hr accordingly. In comparison with the shaft sinking in the central site of the mine it enabled the rates of sinking to increase by 4.7 times for vent shaft No.1 and by 5.5 times for vent shaft No.3.

The Integrated Grouting Method of the STG company has proved itself as a versatile tool in solving complex technical problems connected with hydrosealing and rock consolidation in mining and underground construction both in the U.S.S.R. and foreign countries. The research and technological capabilities of our company make it possible not only to guarantee the results and quality of the final construction but also provides considerable savings thanks to decreasing the construction time, allowing the possibility to employ ordinary types of lining in underground excavations and use of cheap grout materials, plus many others.

The scale and versatility of grouting projects carried out by the STG Association in the last 15 years is illustrated by the following table:

List of major trends in the use of the Integrated Grouting Method	Projects Completed	Projects In progress
Pregrouting of mine shafts	60	20
Pregrouting of shaft insets	10	-
Pregrouting of lengthy horizontal and sloped workings	16	-
Elimination of inundations into the mine workings	5	-
Elimination of residual water makes into the shafts	10	1
Elimination of abandoned workings	12	-
Rock consolidation	9	3
Repair of dams and tailings ponds	10	-

In the following sections a more detailed description and brief analysis of some new trends in grouting techniques used in mine construction will be given, in which STG has played a major role in recent years.

1. ELIMINATION OF ABANDONED MINE WORKINGS

The problem of neutralization of abandoned mine workings often arises in modern deep mine construction in the following cases: when sinking and driving through mined-out zones, when flooding the mined-out levels to prevent inundations of mine workings, in surface building construction over the abandoned mine workings, etc.

Based on the experience of grouting of large underground voids and performed analitical and experimental studies, it was ascertained that the process of sealing off the abandoned mine workings could be divided into two qualitatively different cases in the formation of a grouting curtain:
Firstly - the filling of a mine working proceeds in a 'no pressure' environment characterized by the accumulation of grout material in the floor of the working, and by its continuous filling up to the roof;
Secondly - the injection of grout in a 'pressure' environment to seal the artificial fissuring above the roof of the working in the so-called caving zone.

For each specific case there have been developed individual methods to design the parameters of the grouting curtain formation. Design methods are based on the detailed hydrodynamic studies in grout holes in which field the STG Association has some expertise. The above mentioned studies enable us to evaluate the size of water-bearing channels both of the mine working and caving zone, and to determine their filtration characteristics. Additionally, the size of the mine workings intersected during drilling can be more precisely determined by downhole TV cameras.

Our technique stipulates that firstly the abandoned working is sealed, and secondly a grouting curtain is formed in the zone of artificial fissuring.

To provide grout material, there has been developed cheap grout formulations. Such grouts consist of 90% water suspension of ordinary clay and 10% structure-forming reagents. A series of even cheaper grouts has also been developed which are based on the technological rejects of concentration plants and power stations. Grouting suspensions of such materials are treated by special additives for gaining the plasticity strength.

To reliably separate boreholes in the zone of artificial fissuring above the abandoned mine working during grout injection, there has been designed special packers for the holes with heavy-irregular walls and technical tools that enable packing practically in any downhole situation.

To give an example, the completed grouting project aimed to protect ventilating shafts No.2 and 3 of the Yuzhnaya Mine in the Rostov Region against underground water ingress through the mined-out coal seam K_2' of the abandoned mine that was planned to be flooded. The depth of the shafts is 668 m and 665 m respectively. The shafts No.2 and 3 encounter the mined-out zone of the coal seam K_2' at a depth of 211.2 and 208 m respectively. In the site area the average thickness of the seam amounted to 1.8 m. The roof consisted of 1.0-m-thick limestone overlaid by clay, sandy shales, and sandstone. The seam dips at low angles to the north-west at 8-10°.

The size of open underground voids estimated during drilling of the prooving holes amounted to 0.5-1.2 m. The water make on recovering the static level could achieve 320 cu. m per hour.

According to the design the formation of sealing curtains around the shafts within the mined-out coal seam K_2' and overlying fissured zone was performed through 13 holes in shaft No.2, and through 15 holes in shaft No.3. The volume of grout injection totalled 19190 cu. m for shaft No.2 and 19930 cu. m for shaft No.3.

The parameters of the completed grout curtains around the shafts in the mined-out strata were controlled by interhole acoustic logging.

After the grouting programme was completed and the workings of the seam K_2' were flooded, there was no water makes observed into the shafts. According to estimations the expenditures on the grouting project will be recovered within 8 years to elimination of the necessity to maintain water pumping systems in the old mine.

2. GROUTING OF KARSTIC ROCK

In recent years the STG Association has had great success in the field of karstic water control. We have already reported that an experimental grouting programme designed by STG resulted in the possibility to start mining the Dobrouge coal deposit in Bulgaria in an unprecedentedly complex hydrogeological situation. The coal measures strata encountered at a depth of 2000 m is overlaid by the Valange formation which is 700 m thick and intensively karstified. The estimated water inflow into any shaft sink in this formation according to the data from hydrogeological testing amounts to 33-35 thousand cu. m per hour with a flow rate of up to 400 m per day and a pressure head of up to 12 MPa. The execution of a basically new grouting technique for karstified rock during the construction of the Dobrouge Mine will enable the employment of the conventional concrete shaft lining instead of more expensive types of lining such as the double tubing lining or 'steel-sandwhich' lining.

Our company has accomplished a broad programme of both research and experimental studies that enabled the realization of a further large project: the curtaining of a lengthy sealing barrier at the North-Ural bauzite deposit.

This deposit is unique not only in the quantity and quality of minerals but also by the severeness of its hydrogeological conditions. The ore beds are encountered in intensively karstified and water-bearing limestones having hydraulic connection with a broadly developed river network in the deposit area.

The existing drainage system has enabled a reduction in the water inflow into the mine workings by up to 23000 cu. m per hour, but still it does not protect against sudden karstic water irruptions that in some cases exceeded 13000 cu. m per hour. All this calls for the necessity to maintain in the mine a high-capacity pumping system.

The formation of a lengthy filtration-proof barrier in accordance with the STG design will allow the interception of subsurface and surface flows into the mine workings and ensure normal conditions of mining.

The parameters of the barrier are unique:

- length - 3500 m,
- depth - 300 m,
- grout quantity - 380 thous. cu. m,
- time schedule of curtaining - 5.5-6 years.

3. GROUTING OF MAJOR WORKINGS

Driving of major workings in water-bearing strata presents no fewer complex problems as those encountered during sinking. At the STG Association there has been developed and broadly tested in practice new grouting schemes for driving lengthy major workings and shaft insets. These schemes are based on the principle of combining maximum grouting activities with drivage.

The preparation and injection of grout during driving is carried out in all cases with the use of high-capacity machinery located on the surface. The grout is injected in aquifers via a high-pressure pipeline run down a mine shaft or down a special well drilled from the surface, and further on along the openings up to a grout hole in the heading face, sidewall drill chambers, shaft insets or drill chambers of the overlying mining levels.

Two basic process patterns are being employed in practice:
1) - grouting through pilot holes drilled from the sidewall chambers which are set up in the direction of driving. This allows the drivage of lengthy workings to be carried out without stoppages since it is being formed considerably ahead of the driving face, and grouting operations are executed simultaneously with drivage.
2) - pregrouting within the entire designed zone of shaft inset workings. To provide it, a drill chamber is set up at the junction of the shaft with the inset, and a fan-shaped pattern of long horizontal holes is

As an example, the grouting project carried out during sinking the eastward vent and air-access shafts of the 1078-m level in the Zasiadko Mine in the Donets Coal Basin will be described. The vent shaft which is 1085 m deep and has an excavation diameter of 7 m encounters 21 acuifers with an estimated total inflow of 178 cu. m per hour. In accordance with the design pregrouting was performed through one directional grout hole that had been drilled using special tools within the designed contour near the future shaft. The designed pattern stipulated that the formation of grouting curtains with specified dimensions would be performed in each aquifer.

Grout was injected separately into each aquifer in succession from the bottom up, after jet perforation of the casings and a hydrodynamic testing programme.

Sinking of the shaft was completed within 20 months. The average sinking rates were more than 100 m per month excluding the time for shaft inset drivage. It was attained thanks to the fact that the residual water seepage during sinking was only 1.6 cu. m per hour.

At present the air-access shaft of the same mine has been equipped for sinking, and in this site pregrouting was performed using one directional hole up to the total depth of the shaft. We anticipate a successful high-rate sinking of this shaft.