INTEGRATED METHOD FOR GROUTING OF AQUIFEROUS FORMATIONS DEVELOPED AT THE P/O "SPETSTAMPONAZHGEOLOGIA"

Kipko E. Ja., Eng. Sc. D.

Specialized Association on Grouting and Geological Service "Spetstamponazhgeologia"
Antratsit, Voroshilovgrad Region, USSR

ABSTRACT

The integrated method for grouting water-bearing rocks is one of the most progressive technical solution to the problem of controlling water inflows while shafting, driving or building other structures. In sinking shafts and driving other permanent mining workings, the use of the integrated method permits development rates to sharply increase, consumption materials to be reduced, the total mine construction period to be decreased and, as a result, a quicker repayment of capital investment. The integrated method eliminates any pollution problems; makes it possible to guard underground water reserves; reduces labour and energy consumption of sinking and driving operations; and improves sanitary conditions of underground workers labour.

INTRODUCTION

In the last few years in the USSR a new method for sealing and consolidating fissured and fissured-porous strata has been developed by the production assotiation "Spetstamponashgeologia". The method is bradly used in various mining and civil engineering fields and is called the integrated method for grouting of water-bearing rocks. When constructing mines or any other type of underground structures under complex rock conditions. The use of the integrated method makes it possible:

- to reduce construction time in driving through minings on the average of 20.5 %;
- to cut down the estimated cost of shafting on the average of 16.4 %;
- to reduce labour consumption in driving and shafting on the average of 2.5 %;

- to gain considerable cost savings through a quicker repayment of capital investment because of reducing construction time and commissioning of mines ahead of schedule.

PROCESS BASIC FEATURES

The integrated method for grouting of water-bearing rocks radically differs from those formely used for the following reasons:

- for the first time in world mine construction activities, a scientifically substantiated method was developed, based upon a comprehensive engineering analysis of the ntire process of sealing water-bearing rocks. This permits, with a high degree of reliability /97-98 %/, to determine optimum volume, durability and cost of grouting;

- the method permits grouting through directional holes drilled from the surface, instead of strictly vertical ones. This permits drilling procedures to be combined with the preparatory phase for mine construction, and as a matter of consequence, to decrease mine construction period and gain a considerable saving in investment;

- to form water-isolating curtains, universal mud-cement grouts were innovated for incorporating versatile structure-forming additives and for replacing cement and chemical grouts. Clay or loam, available on site as a rule, serves as a basic material for grout making. This contributes to saving large amounts of costly brands of cement and chemicals as well as maintaining a high efficiency of grouting operations. The above grouts are absolutely harmless to the environment;

- exhaustive data on water-bearing strata hydrodynamic properties form the basis for engineering methods of calculating and projecting. The needed data are obtained by the help of special techniques in predrilled exploratory boreholes.

- high efficiency in the art of grouting is secured by applying new process schemes of hydrogeological investigation in boreholes and injecting grouts by the help of up-to-date devices and tools, such as the packering device "DAU-I", the flowmeter "DAU-2M" etc.;

- the results of pregrouting are objectively evaluated before starting excavation. This radically new method of grouting used for the first time in world mine construction practice guarantees residual influxes into the mining workings within the projected range and permits eliminating postgrouting.

METHODS, TECHNIQUE AND TECHNOLOGY

1. By specially developed methods and instruments, exploratory boreholes drilled on site are thoroughly surveyed to detect all water-bearing strata which will be intersected by a mine shaft, to determine the hydrodynamic characteristics and fissuring parameters of water-bearing rocks. To obtain such information, a number of instruments have been designed, for example, a standard series of downhole flowmeters with the outer diameter of their sensing units being 44, 57, 76 and $89 \cdot 10^{-3}$ m.

Flowmetering enables the operator to determine the number of water-bearing strata intersected by the hole, the depth of occurence and thickness of each stratum and also hydrodynamic characteristics of each aquifer: underground water head, filtration and permeability factors, fracture void factor and average fracture openness.

The developed and successfully applied method of hydrodynamic surveying using packering devices enables one to determine colmatage degree of around-the-hole-zone, underground water head and radius of influence, permeability factor and injection capacity of aquifers.

Other downhole instruments are designed to detect both the direction of underground water migration and the orientation of the main fracture system for each water-bearing stratum. These data are then considered in designing geometry of the total isolating curtain. The above methods for determining hydrodynamic characteristics of water-bearing rocks together with geophysical prospecting and geological surveying on site, supply reliable and comprehensive information on aquifers. This serves as the basis for designing the parameters of the isolating curtains.

2. The program and patterns of grouting are based on the investigation results. To execute grouting operations, specially developed mud-cement slurries with immense penetrating and isolating properties are used.

A range of effective and inexpensive grouts has been developed to carry out grouting in various ground conditions. The grout is injected into fissures and voids within the treated zone and starts to stabilize acquiring all the positive properties of natural clay thanks to the addition of structure-forming compounds. Application of such grouts enables the needed quantity of cement to be cut 9 times.

Apart from their high efficiency, the above grouts are ideal for environment, inert to aggressive underground water attack and to toxic problems arising from their use.

Being rather thick, these mud-cement slurries are practically not washed out by underground water, do not produce sediment and remain pumpable while flowing through the pipes and fissures, but gain strength rapidly when at rest. Blasting operations in driving or sinking only make them more compact. Strengh andrheological characteristics of the mud-cement grouts are broadly variable depending on the specific gravity of the base mud. The final plasticity strength of these grouts reaches 0.5-0.8 MPa.

Calculation enables one to determine the overall dimensions of isolating curtains, optimum number of grouting holes and their rational spacing around a mining working.

A drilling program is carried out from the surface using a directional drilling technique. The holes are directed cross-strike to the water-bearing fissures to ensure close to vertical intersection angles. This permits all the watered fissures in an excavation zone to be sealed. Besides, the use of directional holes saves much money, because pregrouting is carried out simultaniously with the preparatory phase for shaft sinking.

Standard equipment and instruments are employed to execute directional drilling which eliminates the need for extra expenditures.

3. A drilling program is accomplished. Drilling from the surface makes it possible to use up-to-date high-performance drilling equipment. Grouting holes are drilled, as a rule, to the total projected depth and only then grouting operations start, exept when it is technologically expedient to selectively grout a given aquifer. In these cases grouting is carried out to the depth of actual drilling, with subsequent drilling to the total hole depth.

4. In all the grouting holes drilled, flowmetering is carried out; the data obtained being fully processed and analysed. On the basis of the information obtained, operative corrections are put into estimations of isolating curtain dimensions and grout volumes for each water-bearing stratum.

5. The grout is injected by pump units, which can operate at pressures running up to 30.0 MPa and more. The pump rated delivery ranges from 0.002 to 0.022 m^3/s.

The mud-cement grouts are selectively injected through each grouting hole into a given water-bearing stratum according to specially developed patterns. To implement these patterns, a series of packering devices has been designed. Employing the packering devices, one can block off any part of the hole and inject the grout under pressure reaching 40.0 MPa or more. The method envisages also the application of double packers or a removable plug. Using the above devices, it is possible to inject the grout into each water-bearing stratum separately by the most efficient method, that is up-hole in several stages or selectively in a water-bearing zone which eliminates the need for redrilling.

A highly mechanized mud mixing plant has been designed and is employed to get initial mud available. The mud is prepared by special cutting-and-jetting mixers and high-delivery pumps. Loader, pumps and mixers are operated from the panel located in a separate cabin. All the equipment, except loader, is housed in an easy dismountable prefabricated building. Mud mixing plant capacity is equal to 300 m^3/day of the mud made raw of clotty clay and is operated by only a two-men shift.

The grout based on the mud is continuously mixed and injected by a set of oil equipment. This set of grouting equipment enables up to 300 cubic meters of the grout per day to be injected.

A control station is used to monitor mixing and injection of the grout. The station continuously registers the parameters which characterise the quality of the grout mixed in the process of injection, injection pressure, injection flow rate and volume of the grout injection into the hole. The station operator supervises the process of mixing and injecting the grout. The record of the grouting process data and due corrections to the technological patterns eliminate any departure from the project.

6. During the grouting operations a consistent control of grouting results is performed which follows a specially developed methodics. The quality control method based on measuring and reducing the residual permeability of water-bearing rock, within the isolating curtain formed, to the projected permissible value makes it possible to ensure USSR mining regulations for residual influx into a shaft; not more than $1.3 \cdot 10^{-3} m^3/s$ for coal mines and not more than 4 m^3/day for potash mines.

Grout injection in horizontal drivings is carried out with the help of the above mentioned grouting equipment located on the earth surface. The grout is injected through a high-pressure line lowered either down the shaft and then laid in horizontal/slope mining workings or down the borehole which is drilled to intersect the drivings.

The complex method for grouting of water-bearing rocks was first used in sinking the No. I and the No. 3 ventivating shafts, 690 m and 710 m deep, at Nagolchanskaya Colliery 1-2, the Donetsk Coal Basin. The grouting operations were carried out simultaniously with the preparatory phase for shaft sinking. After the completion of pregrouting from the surface, the shafts were sunk to the total depth without any additional grouting jobs. While water inflows were anticipated to equal $118 \cdot 10^{-3}$ m^3/s into the No. I shaft and

$112 \cdot 10^{-3}$ m/s into the No. 3 shaft, the actual total residual influxes, after the completion of pregrouting, amounted respectively to 0.0009 m/s and 0.0001 m/s. This permitted and increase in the rate of sinking the No. I shaft 4,7 times and the No. 3 shaft 5.5 times as compared with that of other shafts sunk on the same mine construction site and where cementation had been carried out from the shaft bottom.

On the whole, the integrated method for grouting makes it possible to cut down the preparatory period for mine construction by 15-20 % and the overall time of shafting by 25-40 %. The following factors contribute to such a sharp increase in construction efficiency:

- the length of preparatory phase for mine construction is reduced because the grouting program is carried out from the surface before or simultaneously with equipping shafts for sinking;

- shafting time is decreased by eliminating the cementation of each water-bearing stratum from the shaft bottom;

- costly postcementation, which is usually performed with great difficulties and produces poor results, is eliminated;

- dewatering with the help of suspension and water-handling pumps is eliminated;

- labour and energy consumption is reduced and, which is especially important, most complicated and labour consuming operations are partially performed from the surface, rather than from the shaft bottom;

- sanitary conditions of sinking jobs are improved; therefore the number of accidents and catarrhal deseases is reduced and, as a result, labour productivity is increased.

INDUSTRIAL APPLICATION OF THE INTEGRATED METHOD

The integrated method for grouting is applied on the most broad scale in numerous mining projects both in the USSR and abroad. It is successfully used to employ pregrouting in the construction of coal and potash mine shafts, shaft stations and horizontal mining workings. Besides, it is used to eliminate hazardous inrushes of underground water into shafts and drivings, to fill out large underground cavities and abandoned workings, to stabilize dam feet and structure foundations, to shut off, from the surface, residual influxes into the mining workings and to settle other technical problems.

The broad industrial application of the integrated method is illustrated in the list of activities of the production association "Spetstamponazhgeologia" /Table I/.

Within the next five years the integrated method is planned to be employed in more than 120 mining projects.

The following examples illustrate the application of the integrated method for grouting, presenting more details.

"VOROSHILOVGRADSKAYA No. I" COAL MINE

A convincing example of the method's efficiency is its application while sinking two shafts of the "Voroshilovgradskaya No. I" coal mine, the Donetsk Coal Basin. Heavy water-bearing formation of marl was the most troublesome for sinking. The thickness of the formation is 330 m, the value of fracture voidness amounts to 22.5 %. The presence of large cavities and fractures had been proved by numerous "drops" of drilling tools. Water inflow outlook from this formation was 0.075 m^3/s.

Successful execution of grouting enabled the shafts to be sunk without any water inflow. While sinking, there were intersected begrouted fractures with openness ranging from several millimetres to several tens of centimetres.

"ZHDANOVSKAYA-CAPITALNAYA" COAL MINE

It is of interest to mention the use of the integrated method while constructing four shafts of this mine, the projected depth of which was in the range of 370 to 680 metres. The occurence of a large number of artesian water-bearing strata /sandstone, limestone, sandy shale/ with water inflow of up to 0.047 m^3/s called forth the necessity of employing the special sinking methods.

Grouting of each shaft was projected to be carried out through six directional boreholes. Grouting of each water-bearing stratum was accomplished through four holes. Water shut off operations coincided in time with the preparatory phase for mine construction.

Successful completion of pregrouting kept down the residual influxes to a minimum of $0.14-0.42 \cdot 10^{-3}$ m^3/s during sinking which enabled the crew to achieve stable shaft sinking rates of more than 100 metres per month. All this contributed to cutting down the shaft construction time by 40 % and to a saving of over 1 million roubles.

"ZASYADKO" COAL MINE

An example of efficiency of the method is the completion of grouting while constructing the ventilating shaft of this coal mine /Donetck Coal Basin/. According to this project pregrouting was accomplished, for the first time in USSR mining, to the depth of 1090 m through one hole drilled from the surface. At present shaft sinking is completed with the development rates of up to 120 m/mth. The residual influx amounts to $0.33 \cdot 10^{-3}$ m³/s, whereas the anticipated water inflow was 0.049 m³/s.

"NAGOLCHANSKAYA 1-2" COLLIERY

960 m level shaft station

Water inflow into would-be drivings of the shaft station was anticipated to equal 0.40 m³/s. Treatment of the water-bearing sandstone stratum to its full depth was carried out in the course of sinking the skip shaft, 1066 m deep, through a series of fan-shaped holes ranging in length from 47 to 170 metres. Drilling operations were advanced from special chambers at the 960 m level.

Using the flowmeter "DAU-3M", a hydrodynamic investigation program was carried out. The results obtained were used to form the basis of the optimum project decisions.

The grout was injected through a high-pressure line lowered down the shaft. The injection was accomplished into every fissured zone intersected by the holes. The grouting operations were brought in line with the deepening of the skip shaft.

Completed grouting contributed to reducing the shaft station construction time almost by 2 years and attaining a cost saving equal to 13,5 million roubles.

690 m level and 960 m level crosscuts

Pregrouting was carried out through pilot holes advanced from the drilling chambers which enabled combining driving with grouting. The anticipated water inflow from fissured zones was estimated to be 2000 m³/h. In the course of driving, there were exposed a great number of begrouted fractures with openness ranging from portions of millimetres to one metre.

According to our information, successful grouting of such a fracture was accomplished for the first time in world mining practice. The common practice in such cases had been to employ freezing and line the driving with waterproof tube lining.

The 960 m level and 690 m level drivings are lined with standard arches and reinforced concrete slabs. Residual influxes are not in excess of $0.56 \cdot 10^{-3}$ m³/s on 100 metres of driving.

At present, the integrated method for grouting is used while constructing most coal mines in the USSR. Besides, it is applicable while constructing potash mines, in mining diamonds in northern regions, in tunneling while constructing the Baikalo-Amurskaya railway line, etc.

Licences for the integrated method were sold to Hungary, Bulgaria and Czechoslovakia.

As an example one can mention tha Dobrogea coal field in Bulgaria where it is projected to sink 2000 m shafts. The anticipated water inflow only from the Valage water-bearing formation, located in the interval of 700-1400 m, should amount to more than 30.000 m/h. At present the production association "Spetstamponazhgeologia" has executed a program of hydrodynamic investigations and is accomplishing experimental grouting of the most complex stratum of the Valange formation.

In conclusion, it is necessary to mention that considering prices which exist in the USSR mine construction, the integrated method allows a cost saving of about 170.000.- roubles for each million of capital investment.

Table I

Item	List of services employing the use of the integrated method	Projects	
		Completed	In progress
1.	Pregrouting of mine shafts	35	11
2.	Pregrouting while constructing shaft stations	5	1
3.	Pregrouting while driving lengthy and slope workings	10	9
4.	Elimination of hazardous inrushes of underground water	5	1
5.	Elimination /from the surface/ of residual influxes into the mine shafts	7	1
6.	Insecure rock stabilization	6	1
7.	Liquidation of abandoned mining workings	4	1
8.	Repair of dams, tailing ponds and storages	8	1