GROUTING DURING THE DRIVING OF DRIFTS AND TUNNELS

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ABSTRACT

This paper presents case histories of grouting water-bearing fractured rock during driving of drifts in coal mines in Ukraine and the elimination of sudden inrush of water from large faulted zones in long Pin Lin Tunnel in Taiwan.

In order to provide safe excavation of drifts and tunnels through water-bearing faulted zones and fractured rock the Ukrainian Donbas Special Grouting company (former STG Co.) implemented the new High Ben-tonite-Based Grouting Technology.

1. INTRODUCTION

Bringing underground mines and pits into operation requires driving of horizontal and inclined drifts. Drift length for only a small mine may reach tens of kilometers. Efficiency in bringing mines and pits into operation depends on the rates at which drifts can be driven.

Ground water discharge into underground workings is the most common factor that reduced rates of drifts driving and impedes resource extraction. Early and complete suppression of ground water inflow to mined out openings generally is the most cost effective way of increasing efficiency in mines and pits construction and operation.

Therefore consequently, under complex hydrological conditions the installation process for mining usually requires measures for preventing and eliminating the inflow of underground water into mines and pits.

Conventional methods of preventing ground water inflow into mines, pits and tunnels consist of cement or chemical grouting from the face of drift and tunnel, or ground freezing from the face of tunnel. These methods have been used universally. However, in some cases they have not been very efficient, relatively expensive and great deal of time is required to execute such operations. As a result the mine, pit or tunnel installation schedules frequently must be extended excessively.

The general deficiencies in the application of hardening grout mixtures for creating grout curtains around underground drifts and tunnels in water - bearing rock are as follows:

□ The brittleness and low plasticity of the solidified grout;

□ The significant expenditure of time for re drilling out cement stone in holes after cement grouting;

□ The necessity for carrying out cement grout injection operations in water- bearing rock in several production stages with interruption for the hardening of the cement grout;

□ The poor success during the isolation of large water- bearing fractures.

As a rule, the creation of grout curtain around a drift or tunnel by cement grouting of water-bearing rock is accomplished through several horizontal holes that are arranged uniformly in a circle beyond the contour/outline of the mine 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 drifts and tunnels in fractured rock may be small. Nevertheless, when grouting water-bearing fractured rock, the volume of cement required is high due to the erosion of cement grout by ground water before the cement grout hardens. The large radii of spreading also accounts for the big volume of cement usually required. Due to the erosion, the 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. It's brittleness and other negative factors cause it to have limited effectiveness for the isolation of fractured rock under complex hydrological conditions.

3. The selection of the best production layouts of grouting drifts and tunnels depend heavily on the site-specific hydrological conditions and on the organizational plan of the construction site.

4. Great subjectivity is required in the selection of the technical parameters and estimation of the volume of cement required for grouting.

5. The high cost of cement grouts and their large loss rate lead to substantial cost in the driving of drifts and tunnels

when cement grout is employed to control ground water inflow into the workings.

2. NEW HIGH BENTONITE -BASED GROUTING TECHNOLOGY

The new High Bentonite-Based Grouting Technology of water-bearing fractured rock and faulted zo-nes has been developed by Donbas Special Grouting Co., Ltd. (DSG). Main goal of this Technology it's minimizing the inflows of ground water into underground workings. The DSG Grouting Technology differs from the conventional cementing methods in the following ways:

a. The Technology is based on analytical calculations throughout the entire grouting process, including definition:

- □ the shape and dimensions of the isolation curtain around the opening taking into account anisotropy of permeability;
- □ specification of the number and design of grouting boreholes;
- □ the injection pressure modes;
- □ the evaluation of the volume and the effectiveness of the completed grout curtain.

b. Quantitative information is obtained on the character of the fracturing and the permeability properties of the rock from direct hydrodynamic investigations in the underground grouting boreholes.

c. The grouting is implemented with highly effective bentonite-cement grouts.

d. The production layouts for implementing grouting operations stipulate the use:

- □ colloidal mixer for preparation of bentonite slurry with calculated viscosity and density;
- □ double-mixer for preparation bentonite-cement grout;
- □ agitator for adding the structure-forming reagent to bentonite-cement grout;
- □ high pressure double-piston grouting pump;
- □ manifold high pressure pipe line;
- □ control station registering the parameters of bentonite-cement grout quality, injection pressure, flow rate and quantity of grout during his injection into the rock mass through grouting boreholes.

e. The length of horizontal or inclined grouting boreholes depends from thickness of water bearing fractured or faulted zones along axis of drift or tunnel.

f. The results of the grouting evaluated objectively prior to the beginning of underground excavation operations using quality control methods.

3. INTEGRATION OF NEW BENTONITE-BASED GROUTING TECHNOLOGY IN MINING AND TUNNELING

New High Bentonite-Based Grouting Technology can be applied to many-purpose operations that include the driving and usage of horizontal and inclined drifts and tunnels. This section considers several industrial applications of this Technology in the form of case histories.

Above mentioned Technology has been applied most widely in the driving of openings in fractured and faulted water-bearing rock by application of different technological schemes for grouting of underground aquifers.

Examples of the use the bentonite-cement grouting technology to drive horizontal and inclined workings during construction and operation of the mines, pits and tunnels presents below.

4. KIEVSKAYA COAL MINE, HAULAGE DRIFT NO 28

At the Kievskaya Mine in Donbas coal basin in Ukraine during driving the haulage drift No 28 advanced horizontal hole with length 85 meters intersected large water-bearing fault zone, Fig.1. The ground water inflow rate from this borehole with diameters 112mm was 180m^3/hr. Miners decided to use this borehole for unwavering, and three years expected the positive results. However, three years of pumping 5 million cubic meters of ground water from mine to the ground surface resulted in the reduction of inflow from 180m^3/hr to 100m^3/hr.

For elimination this water inflow and guarantee continuation of safe driving the haulage drift No 28 through fault zone, DSG performed range of underground research and bentonite-cement grouting.

At first, in this borehole carried out flow meter investigations and recovery method for the purpose to obtain reliable information about hydraulic properties and parameters of jointing of fault zone. This information provided the basis for calculating the hydraulic coefficients of fractured and crushed permeable rock, the dimensions of grout curtain around the drift, the number and location of underground grouting holes, the injection pressure modes and the required volume of bentonite-cement grout.

For elimination water flow in haulage drift No 28 through first borehole injected designed volume of bentonite-cement grout as presented in Table 1. Then consecutively drilled second grouting hole with length 100 meters and injected through this hole calculated quantity of bentonite-cement grout for creation isolation grouting curtain around drift. After that drilled checking-grouting horizontal hole with length 85 meters and discharged the grout into fault zone for adherence the final calculated modes of injecting.

The parameters for creating isolation grouting curtain around haulage drift No 28 presented in Table 1.

Table 1. Drilling and grouting parameters for haulage drift No 28 of the Kievskaya Mine

Number of grouting holes	Length of grouting holes, m	Initial water inflow from borehole, m^3/hr	Volume of injected bentonite-cement grout, m^3	Final pressure in the mouth of the grouting hole, MPa	Residual water inflow from borehole, $m^{3/}hr$
1	85	180	742	3,5 - 4,5	6
2	100	6	588	5 - 6	1,5
3	85	1,5	123	7 - 8	-
Total	270		1453		

The total residual inflow of grout water into haulage drift No 28 after driving through grouting zone was 3,5m^3/hr. The fractures in the water-producing fault zone, penetrated by the haulage drift No 28, were filled with compacted bentonite-cement grout.

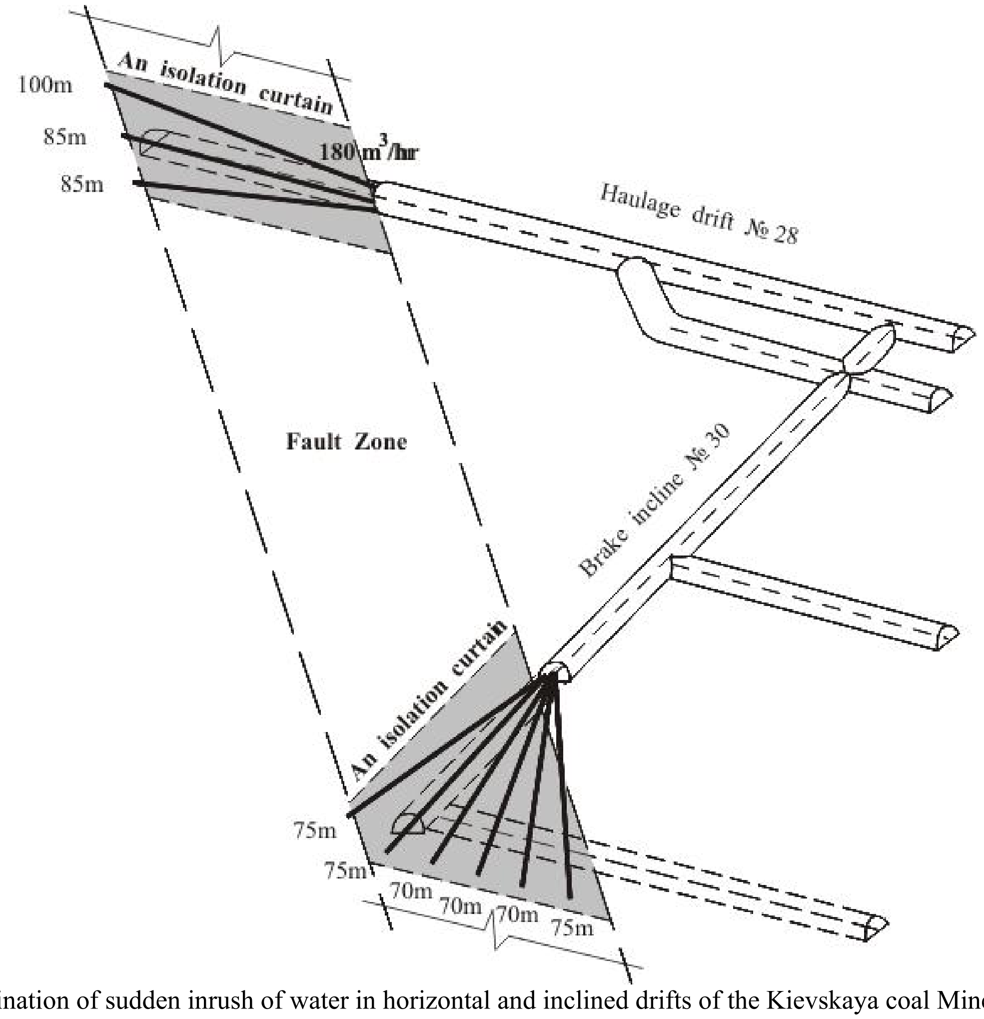

Fig.1 Elimination of sudden inrush of water in horizontal and inclined drifts of the Kievskaya coal Mine in Ukraine

The analogous grouting work DSG implemented at the brake incline No 30 of the Kievskaya coal Mine, Fig.1.

5. RADYANSKA COAL MINE, CROSSCUT NO 6

The mine field of the old Radyanska coal Mine in Ukraine was mapped by large water-bearing faulted zones. For prolongation the life of this mine, the miners try to involve extrapolated reserves of 27 million tons of anthracitic coal behind 400-meters long water-bearing faulted zone, Fig.2. All attempts of miners beginning from 1965 year to 2000 year to intersect this zone by crosscut No 6 using conventional cement grouting and dewatering were unsuccessful.

For providing safe excavation of crosscut No 6 through 400-meters long water-bearing faulted zone, DSG carried out water sealing and consolidation grouting of this zone using different formulations of bentonite-cement grout. The complex hydrological conditions required to divide this faulted zone on five grouting stages with length from 80 meters to 120 meters each, Fig.2.

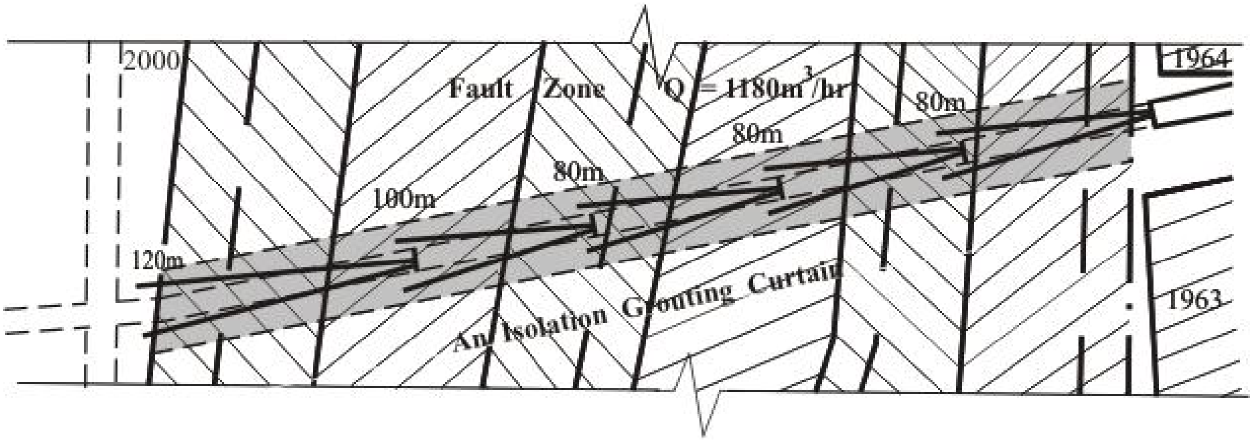

Fig.2 Schematic arrangement of grouting boreholes for ground treatment of water-bearing fault zones at crosscut No 6 of Radyanska coal Mine, Ukraine

In each grouting stage consecutively drilled, investigated and grouted three horizontal holes with length from 80 meters to 120meters, and then drilled checking-grouting borehole for final ground treatment of each stage. The arrangement of the grouting stages and drill holes relative to the crosscut No 6 is shown in Fig.2. Table 2 presents a summary of data for this grouting project.

Table 2. Summarized data for ground treatment of 400-meters long fault zone at crosscut no 6 of the Radyanska coal Mine

Number of grouting stages	Quantity of drill holes in stage	Length of drill holes, m	Inflow of water from first drill hole, m^3/hr	Volume of injected grout into drill hole, m^3	Final pressure in the mouth of the grouting hole, MPa	Residual water inflow into crosscut No 6, m^3/hr
I	4	80	260	1960	7 - 8	0,5
II	4	80	245	1812	8 - 9	1,0
III	4	80	195	1648	9 - 10	0,5
IV	4	100	170	1814	8 - 9	1,5
V	4	120	230	2094	7 - 8	1,0
Total				8326		

Driving of crosscut No 6 through 400-meters long grouted zone provided involving into operation extrapolated reserves of anthracitic coal at the Radyanskaya Mine and prolonged the life of this coal mine.

6. PIN LIN PILOT TUNNEL

Pin Lin traffic Tunnel with length 12,9 km constructed on the north-east of Taiwan in extremely complex hydrologic and seismic conditions. A preliminary estimation shows that the total amount of groundwater inflow into this tunnel was approximately 3,000 l/sec. But usually the initial inflow rate in face of this tunnel always was higher than the long-term inflow.

Excavation of Pin Lin Pilot Tunnel with diameter 4,89 meters carried out by TBM Robbins. During excavation at station 39^k + 078 cutter head of TBM intersected big water produced tectonic zone with water inflow 317l/sec and with flue crushed rock escape, Fig.3. As a result, cutter head of TBM Robbins was squeezed tightly. Hydrostatic pressure of underground water in this tectonic zone achieved 1,8 MPa.

All attempts of drivers to reduce water inflow from the face of pilot tunnel by application of cement grouting and chemical grouting was unsuccessful. Then for dewatering from both sides of cutter head excavated By-Pass A, By-Pass

C and between them By-Pass B, Fig.3. However 12 months of dewatering 10 million cubic meters of ground water from this tunnel resulted in the reduction of inflow from 317 l/s to 260 l/s.

For minimizing this water inflow author proposed to perform water sealing of tectonic zone through three horizontal grouting holes with length from 35 meters to 18 meters, arranged as shown in Fig.3.

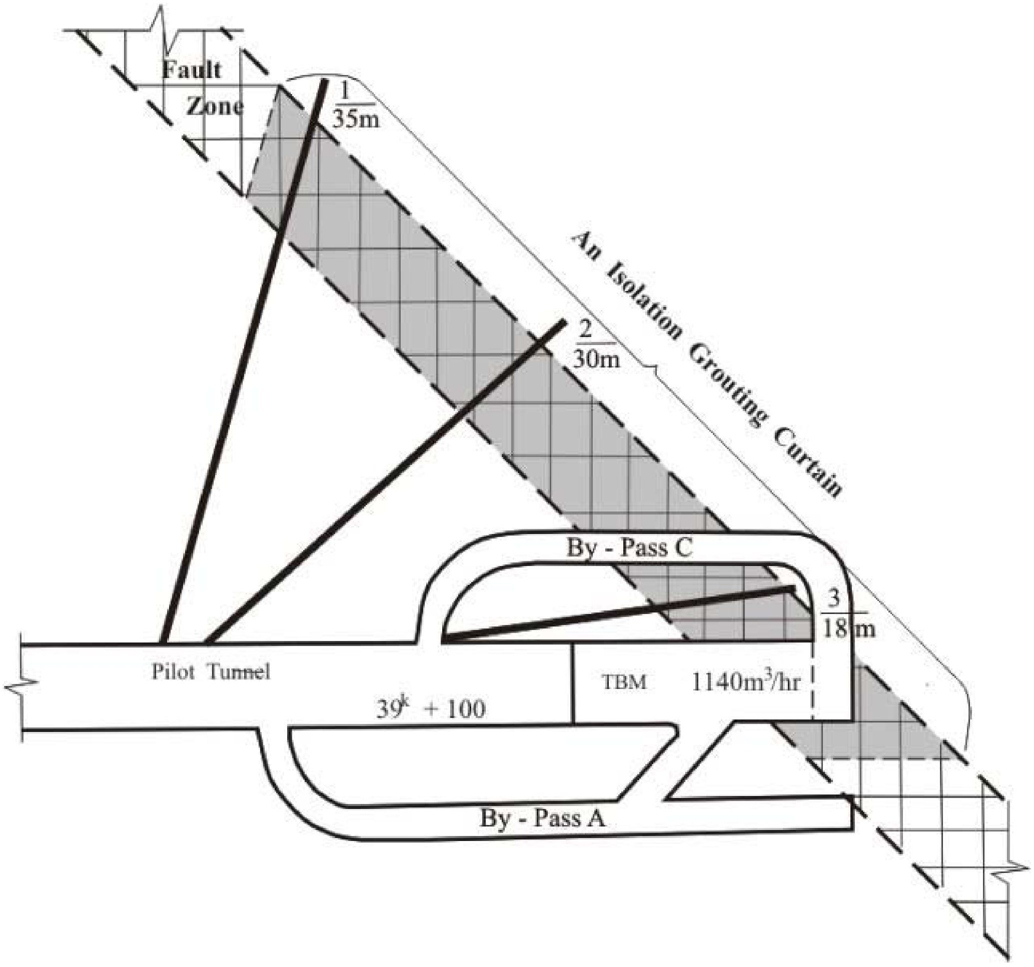

Fig.3 Arrangement of grouting boreholes for elimination sudden inrush of water into Pin Lin Pilot Tunnel

In first borehole executed hydrodynamic investigations to obtain reliable data about hydraulic properties, size and degree of blockage of fissures and joints of tectonic zone. The calculation volume of bentonite-cement grout for elimination underground inflow from the By-Pass C and By-Pass A was 600 cubic meters. Actually, 592 cubic meters of bentonite-cement grout was injected into above enumerated three grouting boreholes. The practical result of ground treatment around cutter head of TBM Robbins are summarized in Table 3.

After injection of calculated volume of bentonite-cement grout into boreholes 1 through 3 water inflows from By-Pass C and above cutter-head of TBM decreased to zero and from By-Pass A reduced to 40 liters per second. Then Client decided not perform grouting from side of By-Pass A for providing dewatering on the site of excavation neighboring Main West Pin Lin Tunnel.

Table 3. Drilling and grouting data of ground treatment of water-bearing fault zone at the Pin Lin Pilot Tunnel

Number of grouting holes	Length of grouting holes, m	Grout volume injected into boreholes, m^3	Final injection pressure, MPa	Residual water inflow from boreholes, l/s
1	35	121	4-5	-
2	30	246	5-6	-
3	18	225	6-7	-
Total		592		0

After the detour-tunnel was driven through the grouted rock. The water producing tectonic zone was broken up by a number of large fractures having apertures of 100mm to 400 mm and filled with compacted bentonite-cement grout.

7. CONCLUSION

Application of the proposed High Bentonite-Based Grouting Technology has been shown in the above and other applications to provide water control and has following advantages:

a. It’s based on the analytical substantiated calculations of the entire process of water sealing the fractured and faulted zones.

b. Application of efficient bentonite-cement grout.

c. Hydrodynamic methods are employed which allow the complete initial information on the fractured and faults seepage properties to be obtained.

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

e. The results of the advanced water control are comprehensively estimated prior to the commencement of driving drifts and tunneling.

The Technology makes it possible:

1. To reduce time while driving drifts and tunnels through water-bearing fractured zones and faults.
2. To reduce overall excavation drift and tunneling costs.
3. To gain considerable savings through the repayment of capital investments because of reducing construction time and putting drifts and tunnels into operation ahead of schedule.

8. REFERENCES

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