PREGROUTING DURING DEEP SHAFT SINKING

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ABSTRACT

In order to accelerate shaft excavation rate and to enhance safety during shaft sinking under complex hydrological conditions, the Donbas Special Grouting Co., Ltd. (former government STG Co.) has developed and implemented a new High Bentonite-Based Grouting Technology. This Technology provides water control of underground flow in deep mines as an alternative to dewatering and mine drainage.

This paper presents case histories of elimination the inundations and sudden inrushes of underground water by bentonite-cement grouting of large faulted zones and fractured rock during sinking vertical ventilation shafts of long Pin Lin Tunnel in Taiwan.

1. INTRODUCTION

The Taipei - Ilan Expressway in Taiwan is about 31km in length, including 5 tunnels. The Pin Lin Tunnel with length 12.9 km was the critical part of this project.

The Pin Lin Tunnel includes two Main Tunnels, Pilot Tunnel and three twin-ventilation Shafts, Fig1. Main Tunnels with outside diameter 11.8m, the Pilot Tunnel was 4.9m in diameter.

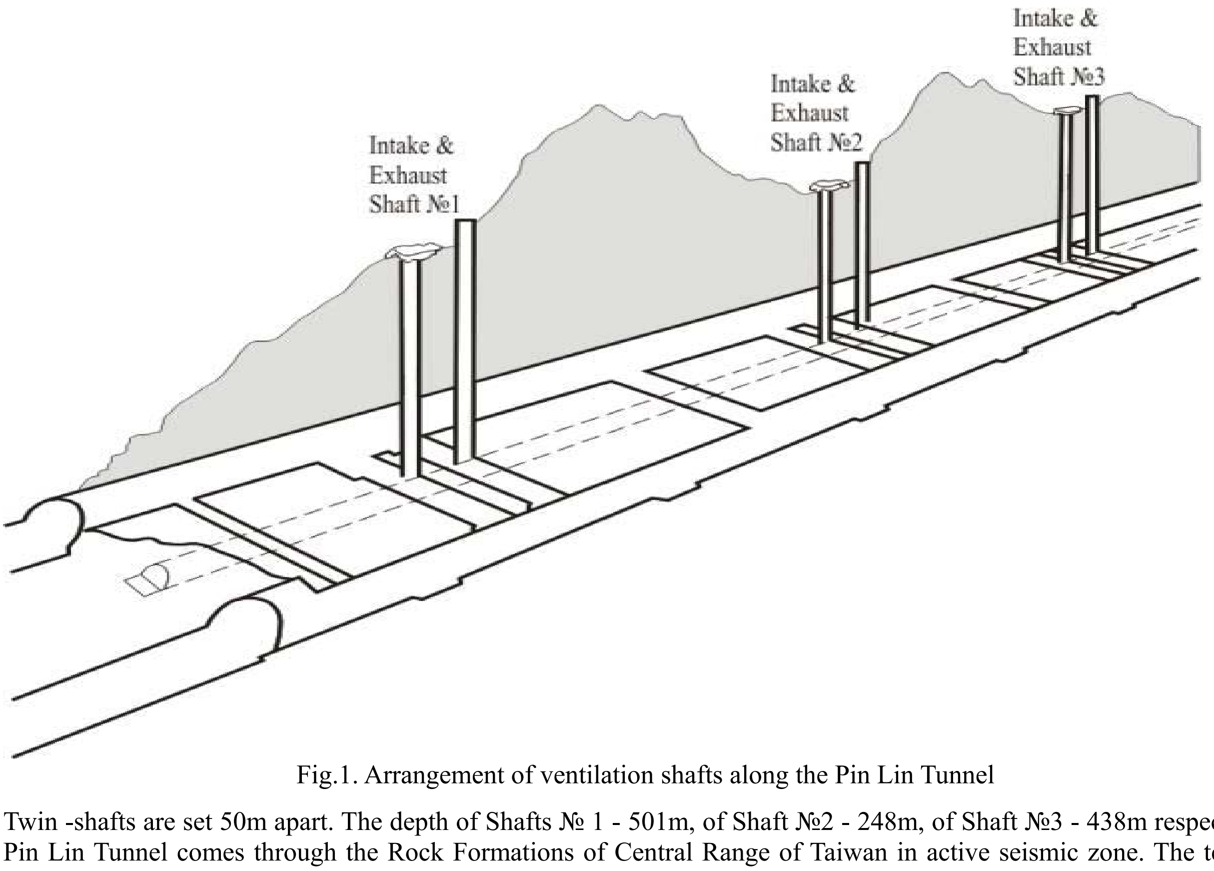

Fig.1. Arrangement of ventilation shafts along the Pin Lin Tunnel

Twin -shafts are set 50m apart. The depth of Shafts № 1 - 501m, of Shaft №2 - 248m, of Shaft №3 - 438m respectively. Pin Lin Tunnel comes through the Rock Formations of Central Range of Taiwan in active seismic zone. The tectonic and hydrologic conditions along the tunnel and his shafts enough complicated.

For watersealing of Pin Lin Tunnel and his Shafts the conventional cement and chemical grouting was accepted. As a result during excavation the Shaft N3 was flooded on depth 157 m.

For providing safe and fast shaft sinking through water bearing fractured and fault zones, author proposed to use new High Bentonite-Based Grouting Technology of the Donbas Special Grouting Co. Ltd. (DSG) at Pin Lin Project.

Below are presented methodology and case histories of application this Technology at Pin Lin Project.

2. METHODOLOGY

The Bentonite-Based Grouting Technology is distinguished by the following:

- preliminary water sealing around shaft through vertical directional grouting holes drilled from the ground surface;
- significant increases in the rate of shaft sinking;
- better estimation of deadlines, schedules and construction costs;
- minimization of power consumption and labor use in grouting operations;
- minimization or elimination the rate of production of shaft drainage.

The key elements in the High Bentonite-Based Grouting Technology revolve around new grouting philosophy and approach, on integrated design procedure and new bentonite-based grout compositions. The general principles of the High Bentonite-Based Grouting Technology is the following:

1. the Technology is based on analytically-founded theory and calculations throughout the entire grouting process including:

a. the rheology of the bentonite-based grout;

b. the dimension and shape of the isolation curtain around the shaft;

c. taking into account anisotropy of permeability;

d. specification of the number and design of injection boreholes;

e the injection pressure modes;

f. the evaluation of the volume and effectiveness of the completed grout curtains.

2. Quantitative information is obtained on the character of the fracturing and the permeable properties of the rock. These hydrodynamic characteristics are obtained from direct measurements and hydrologic investigations in the first exploratory-grouting borehole.

3. The grouting is implemented with calculated volume of visco-plastic bentonite-based grout. Currently the bentonite-cement grout composition runs approximately 85 - 90 percent bentonite slurry, 10-14 percent portland-cement and 1 percent additives. The bentonite-based grout formulation and its application are customized for each project and the entire process is integrated, based on the nature of the problem, the objective of the application, and the detailed site specific information on geology, geochemistry and hydrogeology of the host ground.

Important feature is that bentonite-based grout remains plastic and unpermeable throughout its history.

4. The production layouts for implementing ground treatment operations stipulate the use modern grouting equipment and instruments.

5. Deep directional vertical grouting holes with final diameter 112mm to use for preliminary watersealing of saturated rock around future shaft.

7. The results of watersealing are evaluated objectively prior to the beginning of shaft sinking using special quality control methods.

3. ELIMINATION OF SUDDEN INRUSHES IN PIN LIN INTAKE SHAFT № 3

Shaft sinking of Pin Lin Intake Shaft No3 began in 1996. Expected water inflow to this Shaft was 1930m^3/hr. In complicated hydrological and seismic conditions the conventional cement and sodium silicate grout was accepted. As a result during sinking of Intake Shaft No3 to depth 157 meters after cement grouting were several sudden inrushes of high pressure underground water inflows from the face of this Shaft and he was flooded until hydrostatic level 23 meters.

In 2000 author proposed to carry out preliminary ground treatment of waterbearing stratums in interval 157m - 438m of Intake Shaft No3 through 3 grouting holes and one checking-grouting hole with depth 281 meters each, drilled from face of this Shaft by drill rigs, located on the ground surface, using bentonite-cement grout, Fig.2 .

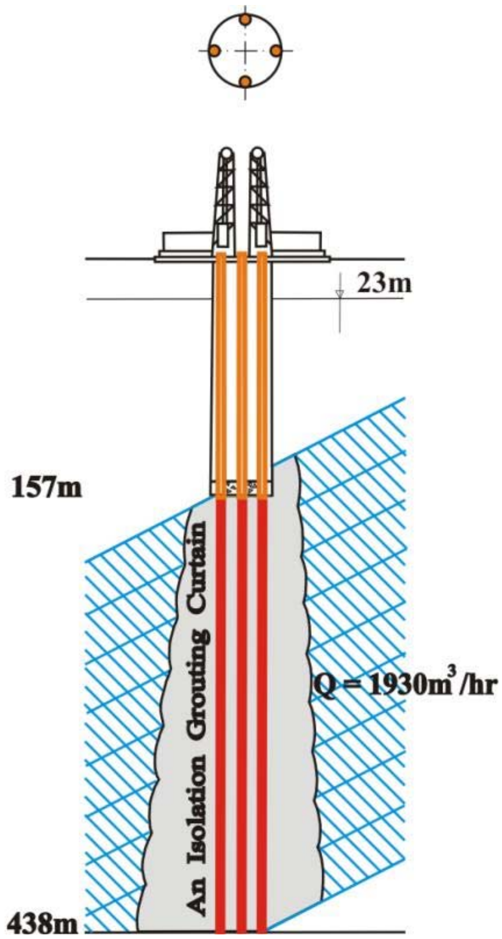

Fig.2. Schematic of elimination sudden inrush of water into Pin Lin Intake Shaft No3
through grouting holes drilled from the ground surface

In order to realize this grouting plan, from ground surface to face of Intake Shaft No3, DSG together with Taiwanian company DGE installed in this Shaft and fixed 4 guide pipes with outside diameter 114mm each for providing drilling from the ground surface of 4 vertical grouting boreholes in interval 157m - 438m. The pregrouting of the Intake Shaft No3 performed in 9 target zones, as presen-ted in Table 1.

According Agreement pregrouting of waterbearing stratums from 157m to 438m of Pin Lin Intake Shaft No3 DSG and DGE executed during 7 months.

Table 1. Principal data of pregrouting around Pin Lin Intake
Shaft № 3 through boreholes drilled from the ground surface

№	Waterbearing stratums or grouting intervals, m	Calculated dimension of grouting curtain around shaft, m	Quantity of vertical grouting holes	Quantity of vertical checking holes	Volume of grout injected through each hole, m^3	Actual total volume of grout, m^3	Final injection pressure, bar
1	157-198	8	3	1	210-215	852	50-55
2	198-238	10	3	1	205-215	840	55-60
3	238-272	12	3	1	175-180	708	60-65
4	272-300	14	3	1	150-155	612	65-70
5	300-334	16	3	1	165-170	670	70-75
6	334-363	18	3	1	145-150	598	75-80
7	363-395	20	3	1	150-155	604	80-85
8	395-417	21	3	1	120-125	484	85-90
9	417-438	22	3	1	95-100	392	90-95
	Total					5760	

Upon completion of the bentonite-cement grouting, the Pin Lin Intake Shaft №3 was sunk successfully during 4,5 months using drilling-blasting method. During the sinking of the shaft through the fault-controlled aquifer, a big number of fractures with apertures as large as 0,1m-0,2m were encountered. All of them were filled with compacted bentonite-cement grout.

4. PREGROUTING OF EXHAUST AND INTAKE PIN LIN SHAFT №1

New High Bentonite-Based Grouting Technology has been applied widely in the sinking of vertical shafts in fractured and faulted saturated rock. Grouting operations preferably carried out from the ground surface where they are integrated into the schedule of the setting up of the shaft excavation and construction equipment. Such integration reduces significantly the length of time, required for preparation of shaft construction and the time required to sink 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 consumption during shaft sinking are minimized because the more complicated and labor-intensive work is carried out at the surface section.

At Pin Lin Shaft №1 site DSG prior to grouting drilled from the mountain surface exploratory borehole on full depth of this shaft, Fig.3, for conducting Flowmeter Investigations, the Recovery Method and for determining:

- the number of water-bearing zones;
- thickness of each water-bearing strata;
- depth of occurrence of each water-producing horizon;
- type of an aquifer;
- size and degree of blockage of fissures and joints;
- voidage of water-bearing zones;
- permeability;
- hydrostatic pressure;
- expected water inflow in shaft.

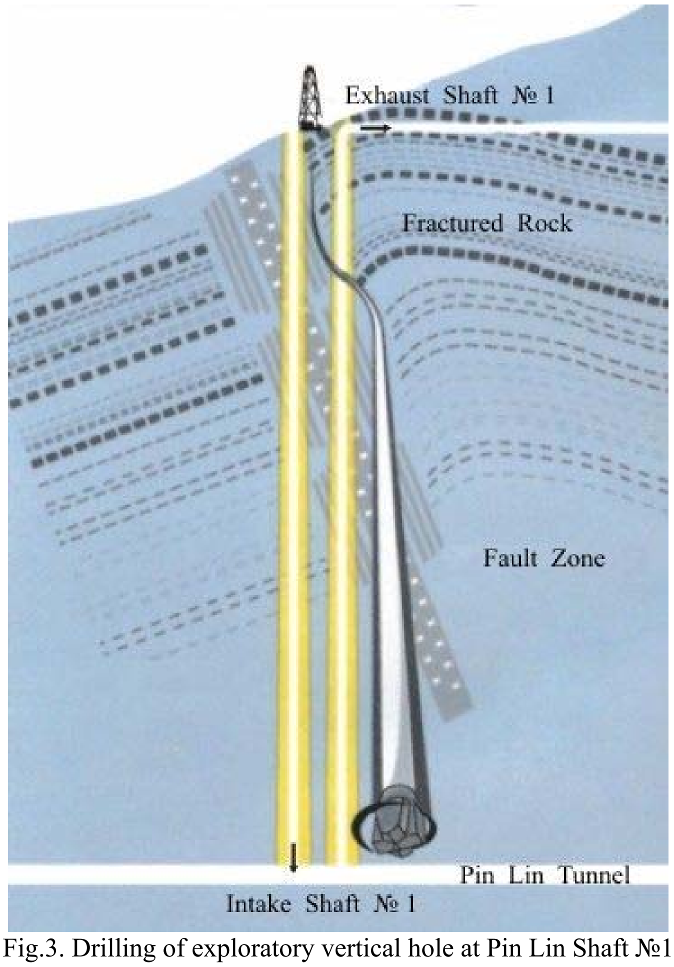

Fig.3. Drilling of exploratory vertical hole at Pin Lin Shaft №1

Obtained reliable quantitative information about expected water inflow 1980 m^3/hr in each Shaft constitutes the basis for designing the correct grouting program.

According plan of grouting operations pregrouting of Pin Lin Exhaust Shaft №1 carried out in two stages.

First stage - it is pregrouting of waterbearing rock around shaft through three vertical grouting boreholes with depth 480 meters each. An actual arrangement of drill rigs on the ground surface around this Shaft is shown in Fig.4.

Second stage - it is drilling of checking - grouting hole №4 through center of future shaft and final grouting of fractured and faulted rock before Raise-Boring of this Shaft.

Fig. 4. Arrangement of drill rigs on the ground surface for drilling vertical grouting holes around Exhaust Shaft №1 of Pin Lin Tunnel

Principal grouting data for Pin Lin Exhaust Shaft №1 are presented in Table 2.

Table 2. Actual data of the grouting operations at Pin Lin Exhaust Shaft №1

№	Grouting Interval, m	Calculated dimension of isolation curtain around shaft, m	Quantity of grouting holes	Volume of grout injected through each hole, m^3	Total volume of grout, m^3	Final injection pressure, bar
1	78*-106	6	3	200-210	616	50-55
2	106-150	8	3	320-325	968	55-60
3	150-200	10	3	365-370	1098	60-65
4	200-255	12	3	400-405	1210	65-70
5	255-300	14	3	325-335	990	70-75
6	300-346	16	3	300-305	912	75-80
7	346-377	17	3	260-265	782	80-85
8	377-420	18	3	315-320	946	85-90
9	420-450	19	3	215-225	660	90-95
10	450-480	20	3	215-220	648	90-95
	Total:				8830	

* Hydrostatic level at site of Pin Lin Exhaust Shaft №1 was - 78 meters and pregrouting started from this depth

For watersealing of fractured rock and faulted zones around Pin Lin Exhaust Shaft №1 used bentonite-cement grout. Initial bentonite slurry with designed viscosity and density prepared in colloidal mixer. For preparation of bentonite-cement grout used double-mixer and agitator. Injection of bentonite-cement grout into vertical grouting holes carried out by double-piston pump with calculated flow rate and pressure.

The pattern of the designed isolation curtains around the future Pin Lin Exhaust Shaft №1 is shown in Fig.5.

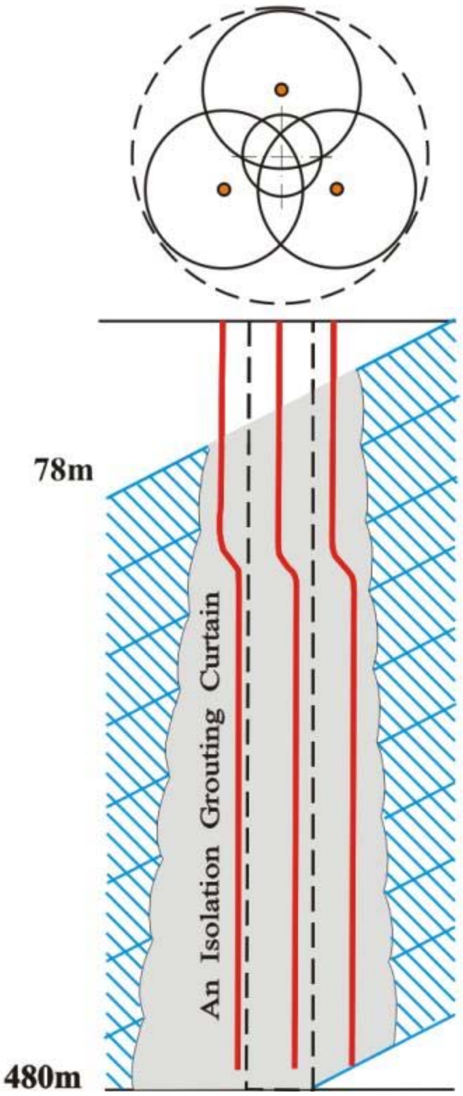

Fig.5. Schematic for creating isolation curtain through vertical grouting holes around Pin Lin Exhaust Shaft №1

An assessment of the quality of grout isolation curtains by injecting grout through holes, drilled from the ground surface around future shaft, made using three criteria:

1. monitoring the change in the permeability of the rock as the bentonite-cement grout is injected into the boreholes;
2. checking the strength and stability of the grout curtains by conducting an injection test of the curtain at the calculated design pressure;
3. checking for adherence to the final calculated modes of injecting the bentonite-cement grout into the hole.

At Pin Lin Intake Shaft №1 all drilling and grouting operations performed by same manner as at Pin Lin Exhaust Shaft №1. The arrangement of the grouting holes on the ground surface relative to the Pin Lin Intake Shaft №1 is shown in Fig.6.

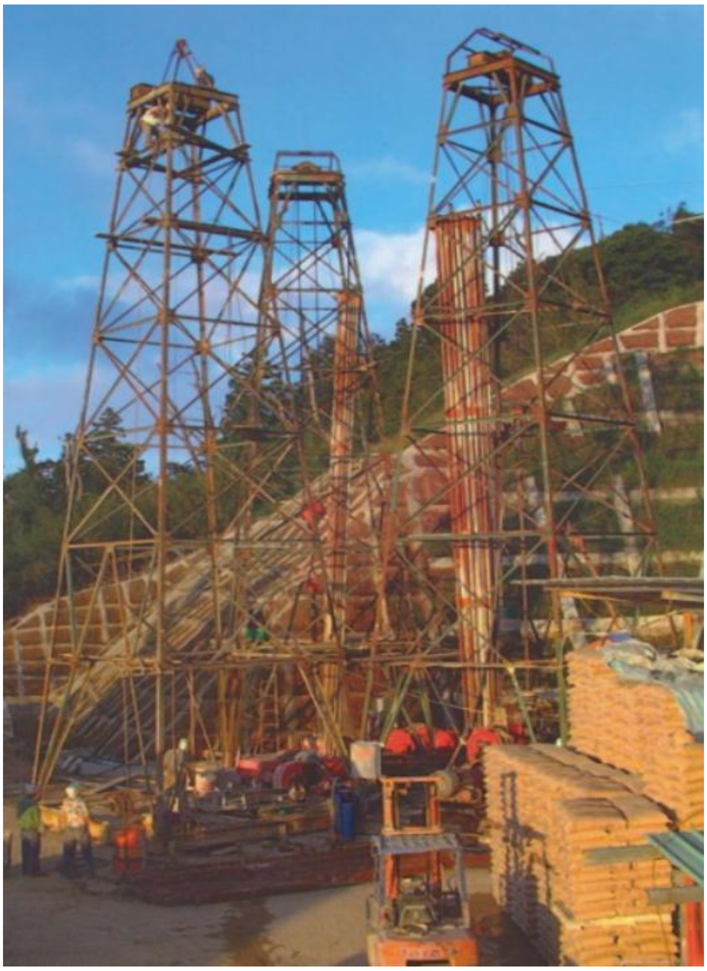

Fig.6. The arrangement of grouting holes around Pin Lin Intake Shaft №1

According agreement DSG and DGE carried out drilling, investigation and grouting work at Pin Lin Exhaust Shaft №1 during 7 months, and at Pin Lin Intake Shaft №1 during 6 months.

5. RAISE-BORING OF PIN LIN EXHAUST AND INTAKE SHAFT №1

After completion of pregrouting at Pin Lin Exhaust Shaft №1 DSG and DGE demobilized all drilling equipment from site of this shaft and made mobilization of special drilling equipment of Austrian company Universal Bau GmbH for Raise-Boring.

During drilling of vertical pilot-hole with diameter 394mm through center of Pin Lin Exhaust Shaft №1 to depth 501 meters DSG and DGE executed Second stage of pregrouting, using this pilot hole for final checking grouting of fractured rock and faulted zones on site of construction future Pin Lin Exhaust Shaft №1.

After completion of drilling pilot hole with depth 501 meters, the Universal Bau GmbH drilled pilot shaft with diameter 2,44 meters by Raise-Boring method during 15 days. Residual water flow from pilot-shaft into tunnel was 0,9 m^3/hr only.

Then Taiwanian mining company expanded and sunk this shaft to diameter 7,5 meters using drilling and blasting method.

After completion this shaft sinking to diameter 7,5 meters residual water inflow on his bottom was same 0,9m^3/hr due to application of new High Bentonite-Based Grouting Technology.

Drilling of pilot-hole, implementation of Second stage of pregrouting and Raise-Boring of Pin Lin Exhaust Shaft №1 DSG and DGE carried out at the same time with performing drilling and grouting work at Pin Lin Intake Shaft №1.

After completion Raise-Boring at Pin Lin Exhaust Shaft №1, the Universal Bau GmbH with assistance DSG and DGE implemented Raise-Boring of Pin Lin Intake Shaft №1. Residual water flow from pilot shaft to tunnel was 1,1m3/hr. After sinking this shaft by drilling and blasting method residual water flow to tunnel was the same.

6. CONCLUSION

1. Application of Bentonite-cement grouting instead conventional cement grouting allowed to eliminate inundation and sudden inrush of underground water in Pin Lin Intake Shaft №3 and provided his safe excavation in interval 157m-438m with average monthly rate 60 meters per month. Twin-Pin Lin Exhaust Shaft №3 sunk with cement grouting from the face of this shaft with average monthly rate 6 meters per month.

2. Use of new High Bentonite-Based Grouting Technology at Pin Lin Exhaust and Intake Shaft №1 guaranteed decreasing of initial underground water flow in each shaft from $1980m^3$/hr to $0{,}9m^3$/hr.

3. Application of High Bentonite-Based Grouting Technology allow to improve the efficiency of environmental protection, including:

□ protection of aquifers from depletion as an alternative to dewatering and mine drainage under complex hydrological conditions;

□ localization (grouting) of acid mine water flows to prevent their migration into surface and subsurface water basins.

4. Donbas Special Grouting Co. Ltd. propose own following practical services:

4.1. Pregrouting during:
- deep mine shaft sinking;
- drifting and tunneling;
- large diameter drilling;
- shaft insets development.

4.2. Elimination of inundations and sudden inrushes of water in mines, pits, open pits and quarries.

4.3. Implacement of sealing grout curtains around open pits:
- in fractured and tectonically broken rock;
- in karst environment.

4.4. Coal seams fire control.

4.5. Grouting of dams, embankments.

4.6. Implementation of bentonite-cement grouting techniques for mining environmental protection.

5. REFERENCES

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