Grouting Technology for Control of Ordovician Limestone Water

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ABSTRACT

The main incline, two coal bunkers and a vertical air shaft that intersect the main incline in Malan Colliery, Gujiao mine area, had to pass through Ordovician limestone. Excavation was difficult, because the stratum was rich in water and Karst cracks and fissures were not well-connected. The Headquarters of the mine area decided to introduce a grouting method Effective measures were taken in time to suit local conditions based on the characteristic features of Ordovician water-bearing limestone, and based on the experience with conventional grouting method. Alternate grouting and excavation were carried out in more than eight months, starting from April to Dec., 1987. As a result, the difficulty of passing through the water-bearing limestone was overcome, and satisfactory results and rapid excavation were achieved. The paper only describes briefly the grouting technology for water control.

1. ENGINEERING GEOLOGY AND HYDRGEOLOGY

Malan Colliery is a large-sized mine with an annual coal production of 4 million tons. The main incline with an inclined length of 1,148.765 m dipping at an angle of 14^{o}, was equipped with a belt conveyor, and was mainly for coal transportation. In addition, Nos. 1 and 2 bunkers at the level of shaft station, and an air shaft(staple) intercepted the main incline, as shown in Fig.1. When the main incline was driven to a length of 1,036 m, close to the interface of Ordovician limestone, water rushed out from the floor. Development stopped, and a borehole was drilled along the centre line of the incline to explore water. The hole intersected the interface of the limestone at a depth of 4.65m of the hole. The water inflow was 155.65 cu m/h at the depth of 74.21 m of the hole, and drilling then stopped(see Fig.2).

The grouting projects that passed through Ordovician limestone were 112.765 m long in the main incline,starting from 1,036 m to 1,148.765 m, 8 m long in No.1 coal bunker, 30 m long in No.2 coal bunker, 35 m long in ventilation shaft. The coal measures above the Ordovician limestone in the staple shaft were affected by geological structures. There was water connection between the Ordovician limestone and the coal measures.

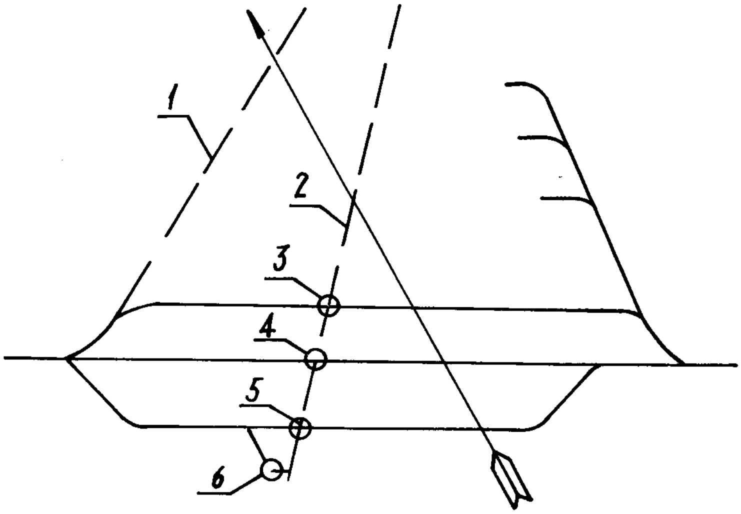

Fig.1 The layout of grouting projects
1 - auxiliary incline; 2 - main incline; 3 - coal bunker for development; 4 - No.1 bunker; 5 - No.2 bunker; 6 - ventilation shaft

The Ordovician stratum was mainly hard and compact limestone. It was filled by calcite dykes in radial pattern. Karst caves were found in some places,1.2 m x 0.4 m in size. There were many smaller ones. The width of cracks were, 50-60 mm in maximum, and 0.5-1.0 mm in minimum, which were partly filled with soft mudstone. The hard limestone was intercalated by marl or mudstone layers. Therefore, cracks and fissures themselves, or cracks with Karst caves were not well connected, and there were no rules could be found.

Faults. There were three major faults near the main incline, and they are $215^{\circ}\angle 30^{\circ}$ H 0.3 m, $260^{\circ}\angle 37^{\circ}$H 2.6 m, and $150^{\circ}\angle 44^{\circ}$ H 1.7 m. Three staple shafts were sunk to the main incline from a roadway at the shaft bottom. Strata occurrence conditions, see Fig.3.

The size of grout roadway. It was 5.83 m x 4.25 m in the main incline, the excavated diameter of both Nos. 1 and 2 bunkers was 8 m and the finished diameter of ventilation shaft, 2m. The width of roadway at the upper mouth of bunker was 5.7 m, and that of roadway at the upper opening of ventilation shaft, 4m.

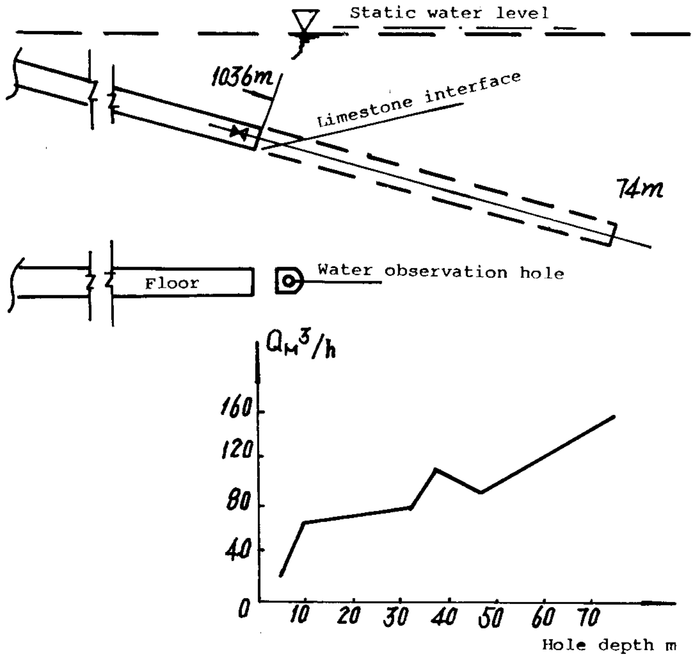

Fig.2 Curves showing variation of water-make from holes in main incline

2. TECHNICAL SCHEME FOR GROUTING

Geology and hydrogeology provided basic information for drawing up a grouting scheme. Because the colliery was to put into operation soon, and it was requested that grouting period to be shortened. An optimal grouting scheme was finally chosen, after careful comparison of several proposals.

For pre-grouting from within the main incline, the length of incline passing through the limestone was divided into three sections. The treatment of injection was carried out alternately with excavation. That is to say, when grouting of the first section was completed, excavation of incline started, leaving 10 m as the grout pad for the next section. Then, injection was conducted in the second section, and so on. The lengths of each section are shown in Fig.4. In addition, the section from 1,026 m to 1,036 m was grouted to

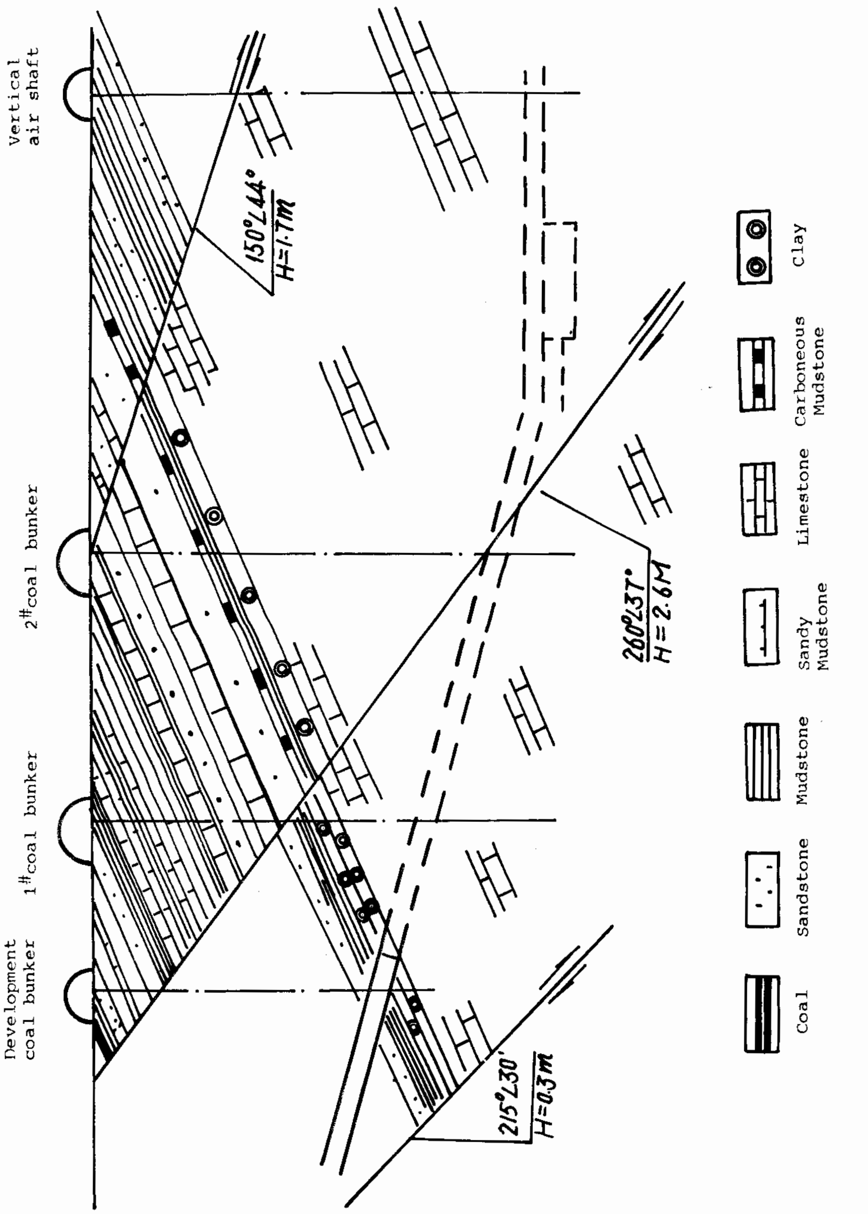

Fig.3 Geological section

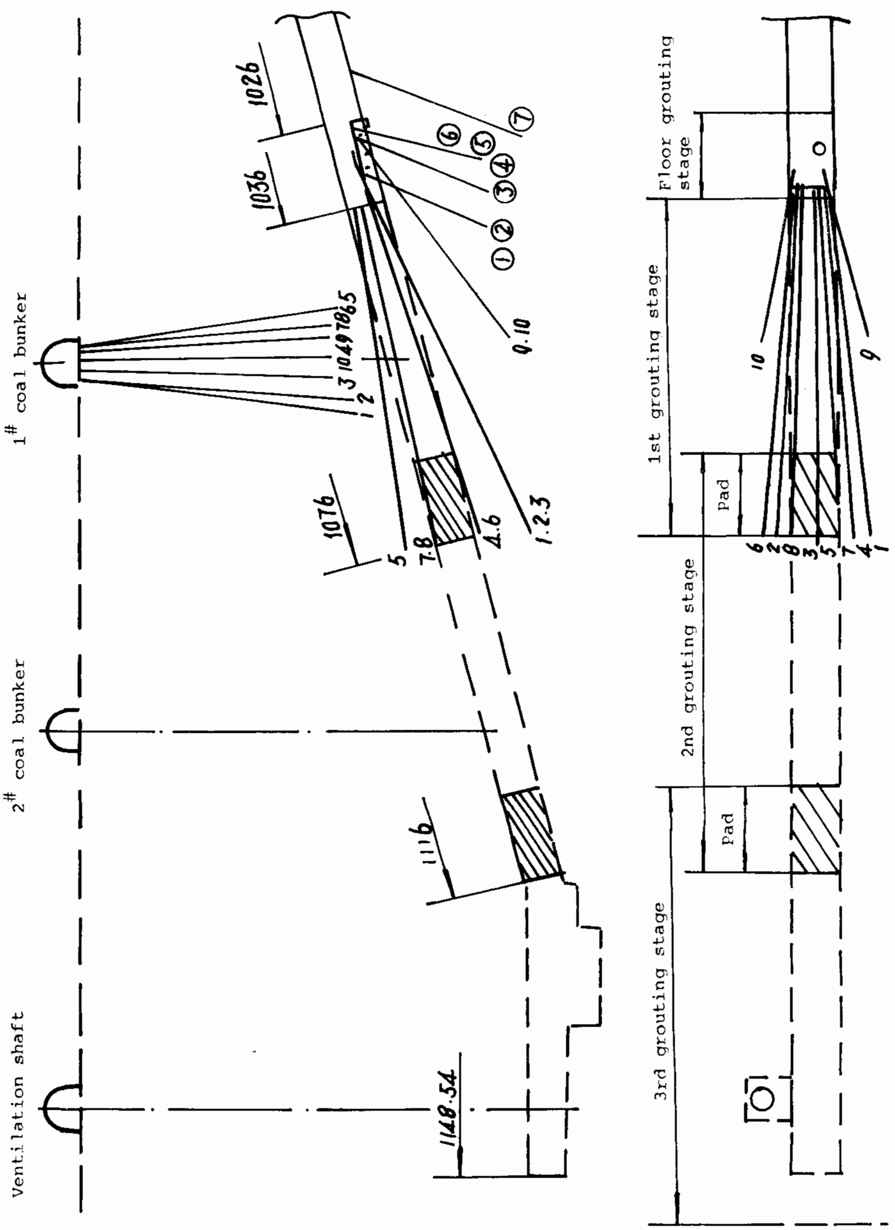

Fig.4 Grout holes pattern

shut off water from the floor, and concrete was placed on the main incline, rock pillar were left and treated with injection techniques as grout pads.

Treatment of staple shaft was similar to pre-grouting from the surface. Injection holes were drilled vertically from a roadway at the shaft bottom to the main incline, so that curtain walls were built around the shafts.

Division of grouting sections. A section of a hole is the hole length at each time of grouting. In general, it was 20-30 m. However, the length of a grouting section in the main incline was not strictly specified, which was simply determined by water inflow from holes. When water-make reached 10-20 cu m/h, drilling was stopped, and grout was injected.

For staple shafts, grouting sections were divided at the interface between coal measures and Ordovician limestone. The upper part above the interface was again divided into 1 to 2 sections, and the lower part below the interface,into 1 to 2 sections too. The length 5 m above and below the interface was regarded as an individual section. Efforts were concentrated on grouting at the interface and limestone section.

Grouting hole pattern. The layout and number of holes were dependent on factors, such as fissures in rock, development of Karst caves, cross-section of roadways, capacity of injection equipment,etc. Grouting holes were drilled radially along the axis of main incline. Bottom hole spacing and distance from bottom hole to the edge of the roadway were all 3 to 4 m. The number of holes in the floor was 7 to 10; 10 holes in the first and second sections; 19 in the third section.As regard to hole pattern for the subvertical shaft since the width of the roadway was smaller than the diameter of coal bunker, and the distance between their centre lines was 0.9 m, all the grout holes were arranged on an ellipse. In general, the apex angle was 2-5^{o}, so that the bottom of holes might be located on the periphery of the excavated diameter of the shaft. The number of grout holes for Nos. 1 and 2 were 10-12 respectively, and 4 for ventilation shaft (Fig.4). The hole pattern basically satisfied the requirements specified in the original design. Holes were found in excavation. Two to three grout holes of No.1 and No.2 coal bunkers were found respectively in the main incline. The position of bottom of holes was basically accurate.

Grouting equipment and flowsheet. All the grouting and drilling machines were installed underground along the strike of the roadway. The grouting station in the main incline was 10 to 14 m away from the heading face.The order of the equipment in the roadway was grouting pump,secondary mixer, primary mixer and cement sacks. The grouting station for staple shaft was installed in a roadway, downstream of the main airflow, so as to reduce possibility of operators exposing to the dust. Four drilling machines and five grouting pumps were employed, e.g. MAZ-200 hydraulic drilling machine, YSB-200/120 speed-adjustable hydraulic pumps and TGZ-60/210 grout pumps, 1 cu m vertical mixer and KWS packers. The grouting system was based on the flowsheet of a combination of cement and chemical grouts, see Fig.5.

Grouts. The grouts were 425# portland blast-furnance cement, 525# regular portland cement, early-strength admixture for cement. The chemical grouts were water-glass and MG 646 grout.

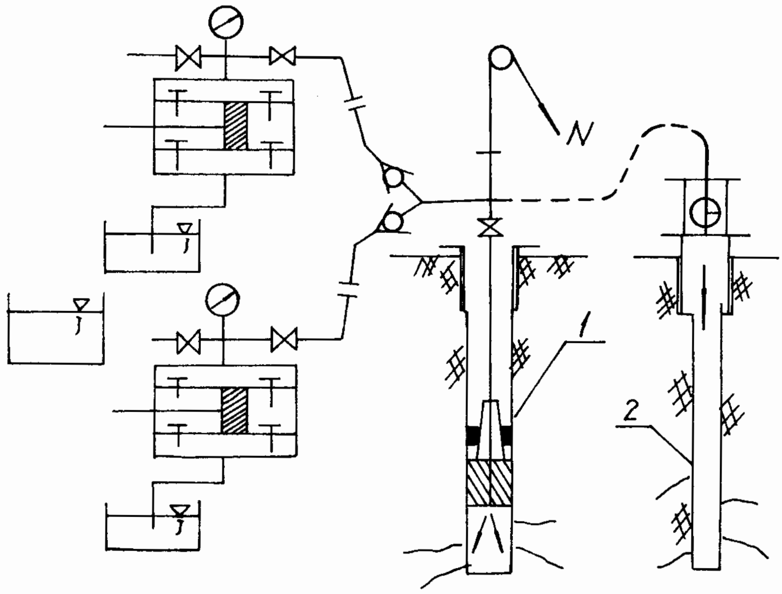

Fig.5 Grouting flowsheet
1 - grouting in staple shaft; 2 - grouting in the main incline

3. DRILLING AND GROUTING

Installation of drilling machine. It was required that drilling machine should be installed properly with jack screws holding the crown of the roadway to keep it stable and reliable. At the heading face on one side of the main incline, a water sump was dug to a depth of 0.5 m. A drilling platform was built with planks at a place 0.4- 0.5 m from the floor. The drilling machine and hoisting winch shall satisfy the application of packers.

Structure of grout holes. The grout holes was 108 mm in diameter at the mouth, 3-4 m long. The injection pipes were inserted directly into the standpipes with flanges. Consolidation and testing of pipes was carried out by special persons. The diameter of grout holes below the standpipes was 75 to 90 mm.

Drilling. The grout holes were not long. No measurement and correction of deviations was necessary. Erection of drilling machines and selection of hole position was conductes strictly according to the design. Water flushing was adopted to clean the holes and to reduce dust to the minimum. The drilling parameters were properly selected.

Sequence of grouting. The principles for grouting in the main incline was to inject first the holes in difficult conditions, then holes in better conditions; to inject first the floor holes, then the upper holes; to inject first holes in two sides and then holes in the middle; and to consolidate first the rock pad, then to start routine grouting.This not only facilitated treatment at floor holes, but also created favorable conditions for the upper holes. When injection of floor holes was finished, the water-sealing results were examined in the upper grout holes in order to find out the weak points and to adjust the position of holes. In drilling floor holes two drilling machines were erected wich worked alternately to reduce the quantity of water suddenly rushed in. When condition permitted, two drills worked simultaneously. Two floor holes were injected concurrently. The sequence of drilling holes in staple shafts was basocally similar to that in surface pre-grouting. Grout holes were divided into two groups, i.e. the first group consisted of holes with odd number, $1^{\#}$, $3^{\#}$, $5^{\#}$, $7^{\#}$, $9^{\#}$; and the second group consisted of holes with even number, $2^{\#}$, $4^{\#}$, $6^{\#}$, $8^{\#}$, $10^{\#}$. Several drilling machines worked simultaneously, and two holes were injected concurrently.

It was required that the holes in the floor should be treated first.This was the major measure for stopping water, and also a reliable means for safety in grouting. Heavy water inflow from the floor occured in all three grouting stages in the main incline. In the first grouting stage, water from inspection hole was stopped until second injection was finished. Later, water seeped from four floor holes at a rate of 2-40 t/h, the hole spacing being only 3-4 m. Fissures and cracks nearby were not sealed by the 1st group of holes injection. Practical experience full demonstrated that heavy inrush of water was an indication of bad connection between fissures and cracks.

Injection in stages. Nos.1,2,4, 6 holes in No.1 coal bunker were treated first to full depth and hole mouths were protected by covers. Due to great difference between cracks and fissures in coal measures and those in limestone, the results could not satisfy the requirements of the design,and the requirements for water-sealing neither.Therefore, forced injection in upward stages, or in downward stages, or a combination of both was introduced to the rest of grout holes and KWS type packers were employed in injection. To operate KWS packer, a water-sealing rubber was lowered to the desired position by a drilling tool. The rubber was expanded and retracted by pressurized and pressure-relief mechanism in order to inject the grouts.

Grouting pressure and concentration of grouts. The designed grouting pressure was 2.0-2.5 MPa, which was already 3-4 fold of the ground static pressure. However, the grouting pressure increased to 5-7 MPa based on operational conditions of the grout holes. The water-cement ratio were 0.6:1, 0.8:1, 1:1, 1.5:1, 2:1, 3:1. The rule for controlling grout concentration was to inject first thick and then thin grouts. For small fissures thin grout was mainly applied. High pressure injection was employed.

Treatment of rock pad. No matter treatment was carried out in the main incline or in staple shafts, normal drilling and injection could only started until all the fissures in the pad were filled with grout and could stand the final pressure specified in the design. For consolidation of standpipes, quick-setting mortar or quick-setting cement grout was used. Grouts were squeezed into fissures through shotholes. Standpipes were consolidated by repeated grouting. It was difficult to consolidate the pads in the staple shafts, so it was not treated. A packer was lowered directly to a depth of 5-7 m for grouting, and the standpipe was used only for protection. Proper treatment of the rock pad was a technical key problem to the quality of injection.

4. GROUTING PERIOD AND RESULTS

From April to Dec., 1987 grouting projects, including main incline, No.1 bunker, No.2 bunker and ventilation shaft, were completed. Grouting and excavation was carries out alternately. The total of 306.785 m grouting projects was completed, and 3,338.96 m of small holes was drilled and treated. The results met the specific targets which created favorable conditions for quickening the pace of mine construction. About 1,200 tons of cement and 50 tons of waterglass were used in the projects. Labour efficiency in drilling and grouting in different stages are shown in Table 1.

5. CONCLUSIONS

The high pressure forced grouting technology adopted in treatment of main incline and staple shafts of Malan Colliery was a success. A grouting method for Ordovician water-bearing limestone with Karst caves, partially developed and poorly connected fissures and cracks was studied. The technical measures are: leaving a rock pad as a grout pad; grouting with packer & grouting in stages; controlling in stages according to the size of fissures;geological control of holes before grouting; simultaneous operation of many drilling machines; simultaneous injection of two holes. To sum up, the grouting measures were effective which controlled the Ordovician water-bearing stratum, and achieved the expected water-sealing target. The grouting period was shortened, which created favorable conditions for quickening the speed of construction.

Table 1

Grouting position	Main incline			Staple shaft		
	1st stage	2nd stage	3rd stage	1st stage	2nd stage	3rd stage
Length of grouting stage, m	50	50	48	62	78	79
Drilling and grouting period, days	35	28	35	30	28	15
Grouting unit time day & night/m shaft	0.7	0.56	0.72	0.48	0.35	0.19