MINE WATER. GRANADA, SPAIN. 1985.

THE WATER-BLOCKING ENGINEERING IN THREE HORIZONTAL CONNECTION ROADWAYS BETWEEN FANGEZHUANG MINE AND LUJIATUO MINE, KAILUAN MINING ADMINISTRATION, UNDER FLOWING WATER CONDITION

Chen Bing-qiang
Deputy chief engineer of Ministry of Coal Industry, Peking, P.R.C.

Dai Guo-quan
Deputy chief engineer of KMA, Tangshan, Hebei, P.R.C.

ABSTRACT

This article, first of all, briefly introduces the successive mine inundation of Fangezhuang Mine (hereinafter called F. Mine) and Lujiatuo Mine (hereinafter called L.Mine), Kailuan Mining Administration (hereinafter called KMA), and the methods of water treatment for mining area of eastern five mines, and basically relates the 3 - section water-blocking method with small dia. boreholes employed in the three horizontal connection roadways between F. Mine and L.Mine, under flowing water condition (quantity of passing water 388.8m^3/min.). From June 6th, when water inrush occured in L. Mine to Dec. 7, the day the water-blocking engineering succeeded, it lasted 185 days. As a result, water passing through the three horizontal connection roadways was reduced to 1.7m^3/min. (normal mine water inflow not included), the result of water-blocking achieves 99.6%. Thereby, the threat of water flood against the adjacent Linxi (Li. Mine), Zhao gezhuang (Z. Mine) and Tangjiazhuang Mines (T. Mine) was relieved; the preparations for mine restoration could be carried out in L. Mine; And a favourable condition for the water-blocking in water outburst source under standing water in F. Mine was created. At last, the conclusion for the water-blocking engineering is drawn.

1. BRIEFING OF WATER-OUTBURST IN F. MINE

1.1 The course of the incident

When a coal-prewetting borehole parallel to the working face #2171, the fully-mechanized working face in F. Mine, was made in the airway (elevation -311.600m; surface elevation of the auxiliary shaft pit head +29.345m), water inflow of 0.55m^3/min. was from the borehole. To detect water source, 12 more boreholes were made succesively. As a result, the water bearing sinkhole as the water outburst source was preliminaryly determined, and we knew that this sinkhole was connected with Ordorvician Limestone. Because of the water coming from Ordorvician Limestone (elevation of water level +5.98m; water pressure at the mouth of the borehole 317.58m), 5 boreholes (in coal seam) in the airway were washed out and enlarged progressively by the outburst water from water-bearing sink-hole, forming a water passage to the airway of #2171 working face. Consequently, at 10:25, June 2nd, 1984, an exceptionally serious accident in Chinese mining history happened.

1.2 Water-outburst quantity during initial stage

During 100 hours and 35 minutes since water-outburst occured in the face #2171, F. Mine till water inrush was found in L. Mine, the inflow during initial stage is indicated in Table 1. From the table, we can see that after water outburst occured in F. Mine, the inflow increased gradually until maximum peak. Then water inflow decreased step by step with the rise of water level in F. Mine.

INFLOW DURING INITIAL STAGE IN F. MINE

Table 1.

Date	Time interval (min.)	water level in elevation (m)	Aver.inflow (m^3/min.)	Remarks
2/6 10:25				Water outburst took place in the face #2171.
2/6 10:25-3/6 7:09	1244	bellow -311.600	$\frac{534124}{1244}$ - 35.4≅394	1. Elevation of airway in the face #2171:-311.600m. 2. At 17:22, June 2nd, Level -490m was inundated. 3. Normal water inflow below the Level -310m is 35.4m^3/min, (May. 1984)
3/6 7:09-4/6 7:09	1440	-311.600-215.505	$\frac{2155315}{1440}$ - -46.6≅1450	1.After 4:00, June 3rd, in the observation boreholes O_3 and O_4, which are 2130m and 2320m apart from F. Mine on the east, water level

				droped fast suddenly. 2. At 7:11, June 3, Level -310m was flooded. 3. 4:45-6:45, June 3, the average water yield reached to the peak of $2244m^3/min.$, especially during the 10 minutes 6:15-6:25, the max. water yield amounted $3836m^3/min.$ 4. Normal mine water inflow (May, 1984) $46.6m^3/min.$
4/6 7:09- 5/6 7:09	1440	-215.505 - -186.217	$\frac{904833}{1440} - 46.6 \cong 582$	
5/6 7:09- 6/6 7:09	1440	-186.217 - -163.726	$\frac{719953}{1440} - 46.6 = 453$	
6/6 7:09- 6/6 15:30	501	-163.726 - 156.170	$\frac{193994}{501} - 46.6 = 341$	At 15:30, June 6, when the water level was -156.170m in elevation in F. Mine, water inrush was found in adjacent L. Mine.
Average (2/6 10:25- 6/6 15:30)	6065	below -156.170	$\frac{4508219}{6065} - 44.3 = 699$	

Note: The inundation water-filling parameter in goaf area used for calculation of outburst water is checked against the infomation obtained during mine flooding in Tangshan Earthquake, 1976.

2. BACKGROUND AND SITUATION FOR THE WATER-INRUSH IN L. MINE

2.1 Background for the water-inrush.

L. Mine and F. Mine, the two neighbouring mines, are shown in Fig. 1. Since these two mines were put into production, through several modifications of the mine boundary lines, therefore the previously planed 40 m wide safety pillar between F. and L. Mines is no longer remained, only 7m wide pillar being left at the place of -232m coal heading.

After flooding in F. Mine, water level increased constantly. At 15:30, June 6th, when water level reached to -156.170m, water inrush was found in east limb of L. Mine. At last, 7m wide safety pillar was broken and water flowed into L. Mine. Afterwards, at 18:15, June 6th, level -600m was flooded, so was level -425m at 8:30, June 10th.

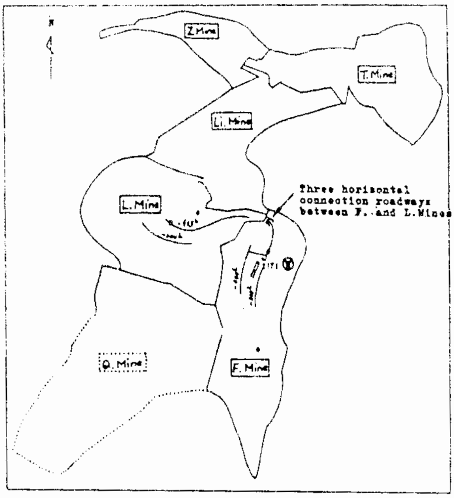

Fig. 1 Sketch map showing the mining area of eastern six mines, KMA.
L.Mine - The mine in production, Q.Mine - The mine under construction;
○ - Main shaft, ● Airshaft, Ⓦ Water outburst source

2.2. Water-inrush quantity during initial stage.

After water inrush in L. Mine, people dared not go imediately into the only water-passing roadway on east limb of Level -425m, so the water inrush quantity could not be measured. Besides, a large amount of water poured down through the main and auxiliary shafts at Level -425m, it's impossible to measure water level in shafts correctly and to convert it into water-inrush quantity. Consequently, in 4 hours after water inrush (19:48, June 6th), water-inrush quantity could be determined roughly in the roadway, east limb of Level -425m. By 0:00, June 9th, a water-level observation station was able to be set up in the dip of Level -425m for the aim of conversion from the dip water level into water inrush quantity. The water inrush quantity during initial stage in L. Mine is shown in Table 2.

2.3. Water leakage in Li. Mine

Li. Mine is the adjasent mine on the north of L. Mine. Water leakage in Li. Mine was mainly caused by mining of Seam 7 which lay on both sides of safety pillar. After mining Seam 7 on both sides of safety pillar, the fracture zones intersected above the safety pillar. The water in L. Mine leaked into Li. Mine through fracture zones when water level in L. Mine reached to -210.881m.

At 9:00, June 25th, water leakage in Li. Mine amounted $6m^3$/min., after that it increased gradually day by day, maximizing up to 14.2m^3/min. on Aug. 14th. If water leakage in Li. Mine increased continuouslly, the water leakage passage between L. and Li.Mines would probably become water-inrush passage. In case water inrush happened in Li. Mine, not only Li. Mine was inundated, but there would be also the danger of mine flooding to both Z. Mine and T. Mine, as there were no actually safety pillars in the three mines, namely, Li. Mine, Z. Mine and T. Mine , due to mining problems in history.

THE WATER INRUSH QUA NTITY DURING INITIAL STAGE IN L. MINE

Table 2.

Date	Mine water level (M)		F. Mine		L. Mine		Remarks
	F. Mine	L. Mine	total water yield m^3/min.	water-outburst quantity m^3/min.	total water yield m^3/min.	water inrush quantity. m^3/min.	
6/6 15:30	-156.170	-	387.2	341.0	12.9	-	Total water yield and water-outburst quantity in F. Mine refer to the average value from 7:09 to 15:30, June 6th.
6/6 19:48	-168.995	-	-	-	-	350.2	Water inrush quantity measured in roadway, east limb of Level -425m, L. Mine.
9/6 0:00-24:00	-139.920- -129.700	-484.500- -441.000	373.9	327.3	235.7	227.5	
10/6 0:00-24:00	-129.700- -124.895	-441.000- -410.283	379.2	322.6	314.1	302.8	
11/6 0:00-24:00	-124.895- -120.305	-410.283- -368.847	434.8	388.2	372.6	359.6	
12/6 0:00-24:00	-120.305- -115.580	-368.847- -334.715	406.1	359.5	365.7	352.7	
13/6 0:00-24:00	-115.580- -117.600	-334.715- -304.126	418.4	371.8	401.8	388.8	
6/6 15:30-24/6 24:00	-156.170- -68.425	below-210.881	257.7	211.1	213.8	200.8	From water inrush occured in L. Mine till water leakage was found in Li. Mine.

Note: Total water yield = normal mine water inflow + water-outburst quantity or water-inrush.

2.4 Distribution of water inflow and pumping water in F. Mine, L. Mine and Li. Mine, on Aug. 14th, 1984 is shown in Fig. 2. At that time submersible pumps were used in F. and L. Mines for water pumping, while water-blocking measures were taken in L. Mine and approved partially effective.

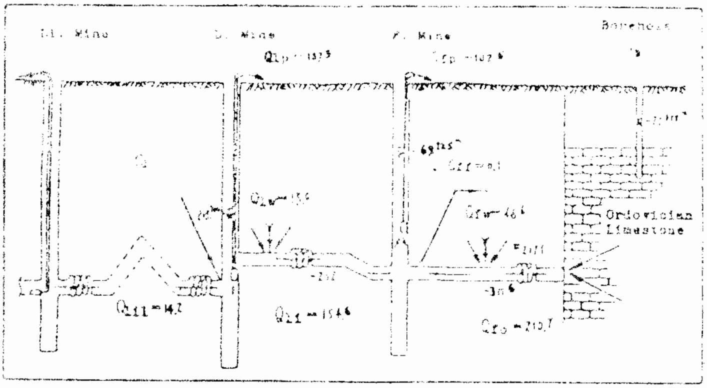

Fig.2 Distribution of water inflow and pumping water in F., L. and Li. Mines on Aug. 14th, 1984 (m^3/min)

Qfo - Quantity of water-outburst in F.Mine; Qfw - Normal water inflow in F.Mine;
Qfp - Water pumped out by submersible pumps in F. Mine;
Qli - Quantity of water-inrush in L. Mine; Qlw - Normal water inflow in L. Mine;
Qlp - Water pumped out submersible pumps in L. Mine;
Qff - Water flowing in roadways and goafs when water level rising in F. Mine;
Qlf - Water outflow from roadways and goafs when water level falling down in L. Mine;
Qlil - Quantity of water-leakage in Li. Mine

3. GUIDING PRINCIPLES FOR WATER TREATMENT IN THE MINING AREA OF EASTERN FIVE MINES

3.1. After water-outburst occured in F. Mine on June 2nd, in succesion, water-inrush happened in L. Mine on June 6th, water-leakage was found in Li. Mine on June 25th, it also threatened the safety of neighbouring Z. Mine and T. Mine. Furthermore, the wells leading to Ordorvician Limestone near the five mines were affected by the incident. Because of the drawdown of the wells, potable water was lacking for some 0.2 million local residents. Therefore, based on the general policy, the water treatment principle in combination with pumping, blocking and damming methods was worked out in order to put the measures into effect at a high speed. The concrete water treatment measures taken by each mine are as follows:

3.1.1. In F. Mine, measures were taken first to ascertain the space form of the sink holes as well as water conduits. Meanwhile, submersible pumps were installed in the shaft to form a water-discharging system, for the sake of reducing passing water quantity into L. Mine in the case of minor water level difference. After successful water blocking in L. Mine, attention would be focused on blocking water-outburst source under standing water condition.

3.1.2. In L. Mine a powerful pumping system was first formed with submersible pumps in a very short time. Water dams were also built in the airway which connected L. Mine with Li. Mine. On the other hand, some selected boreholes were drilled on the boundary between F. and L. Mines, and these boreholes went down through the three water-passing roadways, then by filling and grouting these water-passing roadways were blocked. Thus, the incident was restrained within the range of F. Mine in a short period.

3.1.3 The water treatment method in combination with pumping, blocking and damming was also adopted in Li.Mine. First, mine water discharge capacity was increased while water dams were built at each level in west limb of Li. Mine. Once water leakage took place in the Mine, it's restrained in west limb only. In addition, drilling and grouting were made in the safety pillar between L. and Li. Mines for blocking water-leakage conduit along the fracture zone.

3.1.4. Likewise, water dams were built at each level in one limb of Z. Mine and T. Mine. If water-inrush occured in Li.Mine and water-leakage was found in each level's dams of its west limb, the flood would be limited within some area of Z. and T. mines, minimizing the affected area.

3.2. This article relates specially to water blocking engineering in three horizontal roadways between F. and L. Mines under flowing water condition. For the other related works,a brief account is given only.

4. INTRODUCTION OF THE GENERAL PLAN FOR WATER-BLOCKING ENGINEERING IN THREE HORIZONTAL CONNECTION ROADWAYS BETWEEN F. AND L. MINES UNDER FLOWING WATER CONDITION

The general plan for water blocking engineering covers mainly: aim and significance of water-blocking engineering; necessity of water-blocking under flowing water condition; selection of method (3-section water-blocking method); determination of location for surface operation and underground water blockage;sequence of water-blocking in roadways; selected equipments and system for grout preparation and conveyance; borehole location; drilling process; grouting process; power and water supply; standard and method to examine water blocking effect, etc. The main contents are given briefly as below.

4.1. Aim and significance of water blocking project.

The most important task in dealing with the flood was to block the water-passing roadways between F. and L. Mines. When it was succeeded, Li. Mine would be relieved of flood threat; safety in production could be ensured in Z. Mine and T. Mine; restoration of L. Mine could be carried out; conditions for blocking water-outburst source in F. Mine under standing water condition could be created.

4.2. Background of the water-blocking engineering under flowing water condition.

As it is known to all, it's undoubted that there are extremely great possibilities in success of blocking roadways under standing water condition,its operation is fairly simple as well. If water discharge was not carried out in F. and L. Mines, water-level of the two mines would be progressively level with that of Ordorvician Limestone, forming the condition of blocking roadways between F. and L. Mines under standing water condition. But in upper part of the safety pillar between L. and Li. Mines, the width of safety pillar was comparatively small, only 16m - 23m in places (-175m and -118m). Supposing the water-level in L. Mine rose to -175m or higher, there might be the danger of large water leakage into Li. Mine or of water-inrush caused by gradually-flushed safety pillar. In a word, we faced a fact to choose one of two methods to treat the roadways between F. and L. Mines, namely, water-blockage under standing water condition or flowing water condition. The former had great possibilities in success,but took the risk of flooding in Li. Z. and T. Mines; the latter was more advanced in science and technology, but needed some knacks which should have a well-timed water-blocking operation. Only the operation was successful, could flood be prevented in these three mines. Weighing the pros and cons, the method of water-blocking under flowing water condition was finally adopted in the connection roadways between F. and L. Mines.

4.3 New conception of water-blocking method.

On the basis of lessons drawn constantly during the operation, experiments made in lab and theoretical analysis on them, a new conception of water-blocking method under flowing water condition was taking shape rapidly, that is, sequential "3-section water-blocking method" (water resistance with sand-filling, water blocking with cement-grouting and reinforcement with cement grouting). In order to resist flowing of water entirely in the roadways or to turn the "Pipe stream" into "permeable stream" (when grouting later on, cement grout loss can be reduced greatly), first of all, the sand-filling section for water resistance should be built up. After that a large amount of cement grout was filled under approximately standing water condition to build up the water-blocking section and reinforcement section. Practise has proved that, with the new conception of "3-section water-blocking method" and the three water-blocking sections built with filling materials provided through surface boreholes, speedy results were produced in blocking water passing through the roadways between F. and L. Mines.

4.4. Determination of location for the water-blocking operation.

From Fig. 3 we can see that all goaf areas above Level -425m in L. Mine are connected with each other, so are the roadways of Level -425m and the rise of Level -600m. So, L. Mine side is not the optimum place for the water-blocking operation. Whereas, the area near North No. 4 Crosscut in F. Mine is not coal-getted yet, and there are only three horizontal connection roadways there (-94m airway, -303m tram roadway and -284m leading coal head) being connected with F. and L. Mines. Therefore, the three horizontal roadways were selected as the place for water-blocking operation.

4.5 Water-blocking sequence for the three horizontal roadways.

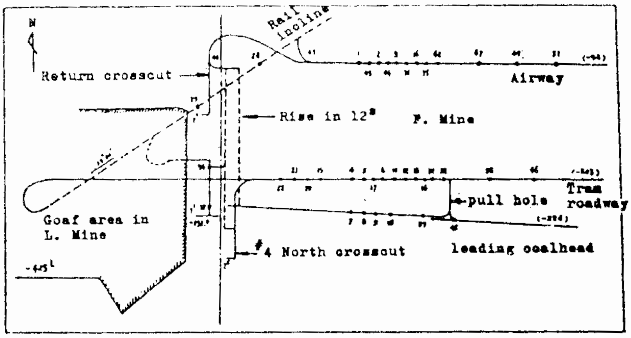

Fig. 3 Plan of water-blocking operation site

To make the last horizontal roadway easily blocked, in an other word, the horizontal roadway with small water pressure should be left to be treated in the later stage of the water-blocking engineering , it was established to block -284m leading coal head first, then -303m tram roadway, at last -94m airway.

4.6. Requirements for boreholes.

Directional drilling was made after determinition of borehole location. During drilling inclination measurement and deviation rectification were carried out regularly to ensure boreholes go through the roadways. Afterwards casing pipes were put down the boreholes. Before grouting, packers were set in the open section of boreholes.

4.7. Selection of main material used in water blocking.

4.7.1. Sand

According to the analysis, sand grain 0.12 - 0.90mm ⌀ makes up 95.2% of local sand in weight, that of 0.05 - 0.12mm⌀ makes up 3.0%, rest is loess (1.8%). The specific gravity of sand is 2.63. It's sediment volume factor is 0.59. In order to fill sand economically, local sand was used as main filling material in sand-filling section for water resistance.

4.7.2. Gravel

Small-and medium-sized gravel (12mm ⌀ and 15 - 25mm ⌀) was adopted. Small-size gravel was used to block the final water-passing cross-sections during later stage in building water-resistance sections, when the water-passing cross-sections became smaller and flow velocity became greater; Medium-sized was used in building boundary wall of the cement grouting section for reinforcement.

4.7.3. Cement

Mainly used in cement grouting sections for water-blocking and reinforcement (#425 Portland cement). Specific gravity of cement grout is 1.6 - 2.0. For quick-setting of cement grout, triethanolamine (0.05% of cement in weight) and salt (0.5% of cement in weight) were mixed with cement.

4.8. Drilling machine

17 sets of 1000m drilling machines were installed at worksite and could be put into operation simultaneously.

4.9. Filling and grouting equipment

In grout station, there were 4 sets of grouting pumps ($P=200kgf/cm^2$, $Q=200-01/min.$) and the necessary equipment, with simultaneous grout capacity of $30m^3/h$; 3 sets of mobile grout pumps ($P=0-300kgf/cm^2$, $Q=800-01/min.$) and the necessary equipment, grout capacity $90m^3/h$; 8 sets of sand pumps ($P=5kgf/cm^2$, $Q=3m^3/min.$) with simultaneous sand-filling capacity of $600m^3/h$.

5. WATER-BLOCKING OPERATION AT -284m LEADING COALHEAD

5.1. Existing condition of the leading coalhead and water-blocking method.

Before beginning of the operation we had visited the personel concerned in F. Mine many times, and known that the leading coalhead was driven in Seam 12 (thickness 3m) in 1975, used as an advanced coalhead for the tram roadway and as air way, with its excavating section of $5.32m^2$. The leading coalhead was abandoned immediately when -303m tram roadway was connected with -94m air way by the incline of Seam 12 and North crosscut No. 4. In it there were original kinds of supports: type 18-U arch (50% of total), concrete supports (30%), wooden supports (20%). 18-U arch supports had been recovered out of the leading coalhead but the concrete ones were put down there only, and the wooden supports being left intact. Soon after the supports fell down, the coal of Seam 12 and the country rock caved. During maintenance of the rise in Seam 12, North crosscut No. 4, a great amount of lump waste were piled up at the entrance of the leading coalhead. Thus a wall seemed to be formed. On the basis of preliminary analysis, the leading coalhead may be sealed off or the water-passing clearance may be very small.

After boreholes No. 7,8,9 were drilled from the surface to the leading coalhead, shown in Fig. 3, a large amount of red water was injected through borehole No. 8. In 21 hours the pink water was found in boreholes 7 and 9, which are 15m apart from borehole 8 separately. It proved that there was a tiny water-permeability in the leading coalhead at most. Therefore it was decided to block water under approximately standing water condition without sand-filling section, but need to establish cement-grouting sections for water-blocking and reinforcement.

5.2. Design for the length of cement-grouting sections for water-blocking and reinforcement.

5.2.1. Cement-grouting section for water-blocking must meet the needs of water-proof capacity and water-blocking steadiness. Here under effect of water pressure P, the compressive and shear stress appeared, shown in Fig. 4. The most dangerous factor is the shear stress F at the interface between water blocking section and its surrounding rock-coal mass, because the compressive strength of condenced cement and the self-weight of the water-blocking section are higher. According to the theory the formulas can be used for the designed length of the upper cement-grouting section for water-blocking (see reference).

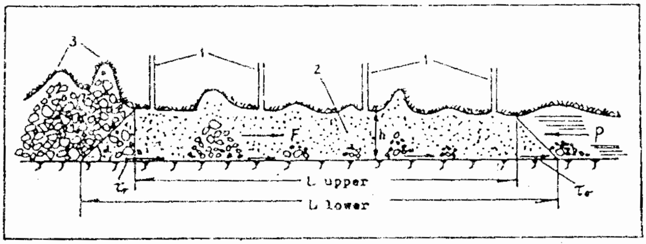

Fig. 4 Sketch showing designed length of the cement-grouting section for water-blocking under water in leading coalhead.

1 - Cement-grouting borehole;

2 - Cement-grouting section of water-blocking;

3 - Caves in leading coalhead after recovery of supports

$$L_{upper} = \left\{ \frac{\lambda H_o W \left[\frac{\pi W}{8} + (h - \frac{W}{2})\right]}{m n \tau_\sigma \left[W (\frac{\pi}{2}+1) + 2 (h - \frac{W}{2})\right]} \right\} \times K - \frac{h}{tg\alpha} = \left\{ \frac{1.2 \times (284+10) \times 2.8 \left[\frac{\pi}{8} \times 2.8 + (2.2 - \frac{2.8}{2})\right]}{0.5 \times 0.5 \times 80 \left[2.8 (\frac{\pi}{2}+1) + 2 (2.2 - \frac{2.8}{2})\right]} \right\} \times 4 - \frac{2.2}{0.7} = 24 \, m$$

$$L_{lower} = L_{upper} + 2 \times \frac{2.2}{7} = 30.3 \cong 31 \, m$$

Where

λ - overload coefficient, in consideration of some impurities in water, taken $\lambda = 1.2$;

Ho - Water pressure, tf/m^2;

h: height of the roadway with semicircle arch section, h=2.2m;

W - width of the roadway with semicircle arch section, W=2.8m;

m - Working condition coefficient of cement-grouting section for water-blocking, m=0.5;

n - considering the resistance-shear stress reduction of interface between cement-grouting section for water-blocking and its surrounding rock-coal mass, taken n=0.5;

τ_σ - 7 days after cement-grouting the calculated resistance-shear strength of cement, τ_σ =80tf/m^2;

α - Anple between the cement-grouting section for water blocking and horizontal plane, α=35°, tgα=0.7;

K - additional safty coefficient of cement-grouting section for water-blocking, K=4.

5.2.2 Design for the length of cement-grouting section for reinforcement.

Considering the leading coalhead was driven through Seam 12, to protect the cohesion between cement-grouting section for water-blocking and the surrounding rock-coal mass against damage, the cement-grouting section for reinforcement was taken twice the section for water-blocking in length, furthermore the end of the cement-grouting section for reinforcement was near to the cross point of leading coalhead and pull hole, so that length of cement-grouting section for reinforcement was taken as 100m.

5.3. Borehole arrangement

Cement-grouting section for water-blocking, 30m long, consisted of boreholes No. 7, 8, 9; section for reinforcement, 100m long, covered No. 9, 15, 39 and 45, indicated in Fig. 2. The total length of these two sections was 130m, the volume of condenced cement 680m^3. The parameters of boreholes are shown in Fig. 3.

PARAMETERS OF THE BOREHOLES AND QUANTITY OF GROUTING MATERIALS FOR -284 m LEADING COALHEAD

Table 3

Hole No.	parameters of borehole: bore-hole length (m)	diam. of casing (mm)	diam. of bore hole (mm)	open length of bore-hole (m)	quantity of grouting material: cement (t)	gravel (m^3)	sand (m^3)	Remarks
7	315.34	168 - 127	110	13.05	631.9	-	15	For cement-grouting section for water-blocking.
8	316.13	168 - 127	110	12.25	623.6	-	16	
9	316.60	168 - 127	110	12.52	391.4	-	38	
15	318.60	168	110	240.03	81.4	-	-	Cement grouting section for reinforcement.
39	318.45	219 - 217	110	15.35	388.4	-	-	
45	322.72	159	91	274.46	130.3	-	-	
Total	1907.84	-	-	-	2247.0	-	99	

5.4. Cement-grouting

Under water cement-grouting section for water-blocking was grouted with cement by mobile grouting pump and mixed a little sand; then using fixed grouting pump, cement was put in until complete full. To build up cement-grouting section for reinforcement, the process was the same as above described, but without sand. The main grouting materials are shown in Table 3.

6. WATER-BLOCKING OPERATION FOR -303m TRAM-ROADWAY

6.1. Existing condition of the tram-roadway and water-blocking method.

The max. quantity of water passing through this roadway was measured and calculated to be 200m3/min. by a self-made borehole horizontal flowmeter in light of pitot tube principle. Inevitably the average velocity of water flow in this roadway should be 0.27m/s, like a "pipe stream", so that 3 - section water-blocking method was adopted, first forming a sand-filling section for water-resistance, then building cement-grouting sections for water-blocking and reinforcement under approximately standing water condition.

6.2. Sand-filling section for water-resistance

Thinking over that water inrush into L. Mine, only in case the water reaches to the coalhead of Seam 7, Level -232m, through a rail-incline with vertical height 71m from -303m tram roadway F. Mine, so the 650m long roadway (total volume 7260m3), located west to borehole No. 4, was taken as a sand-filling section for water-resistance of the roadway, with full utilization of the feature of 71m height difference. To ensure the reliability of sand-filling for water-resistance, in addition to analysis of theory a simple simulation test was made in lab: the water mixed with local sand of size 0.12 - 0.90mm, flushed upward 10m at speed 0.3m/s, under the condition of the stream containing the sand density 2%, lasting 10 minutes, no overflow of sand was appeared.

During sand-filling, gravity method was used first, with a great amount of sand put in, then a sand pump was used with pressure until complete full. Density of filling sand 30 - 70%, filling rate 2 - 3 m3/min.

6.3. Cement-grouting sections for water-blocking & reinforcement.

The designed upper length of cement-grouting section for water-blocking calculated as below (see § 5.2.1, but n=0.6).

$$L_{upper} = 52.35 \cong 53m$$

$$L_{lower} = 53+2x\frac{3.2}{7}=62.14 \cong 63m$$

The length of the reinforcement section was also twice that of water-blocking section. Borehole arrangement is shown in Fig. 3. When the sand was nearly filled up in the roadway through borehole No.4, occured the jet with water and sand out of borehole No. 12, 60m apart from borehole #4,jet was about 40m height above the surface. In order to guarantee the strength of the water-blocking section, the part between boreholes No.4 and No. 12 was used as an additional water-blocking section, Thus, the cement-grouting section for water-blocking consisted of boreholes Nos 12, 13, 32 with a 70m long space. Reinforcement section consisted of boreholes Nos 12, 33, 46 with a space 140m long. The total length of water-blocking and reinforcement sections was 210m, volume 2567m^3.

Cement-grouting sections for water-blocking & reinforcement were proceeding under the standing water consition as the same as 5.4, but the treatment of borehole No. 46 was different from the others, first of all, through it some gravel was put in, when the gravel contacted the roadway roof, the top of gravel was leveled out by a sweeper. The two procedures carried out alternatively until the gravel was filled up, then grouting thick cement to build a concrete wall.

After the concrete wall was formed through boundary borehole No. 46, some cement was grouted through intermediate borehole No. 33 of reinforcement section until complete full.

6.4. Parameters of boreholes & the quantity of grouting materials for -303m tram roadway are shown in Table 4.

7. WATER-BLOCKING OPERATION FOR -94m AIRWAY

7.1 Existing condition of the airway and water-blocking method.

It was the last water-blocking roadway of the three horizontal roadways, and the max. quantity of passing water was measured to be 189m^3/min., and 3 - section method should be taken as well, first to form a sand-filling section, then to build cement-grouting sections for water-blocking and reinforcement under standing water condition.

7.2. Sand-filling section for water-resistance

For ensurance of sealing off water running through the airway, the two sand-filling sections for water-resistance were made by fully utilizing the useful natural conditons: one was the bag-type worked out area in dip district, east limb, Level -425m of L. Mine, with elevation -512m to -416m, water-filling volume 176.792m^3. This was the inevitable passage from F. Mine to L. Mine, from which water inrushed into -425m tram roadway through the bag-type worked out area in dip district. So it was decided to fill sand into the workout area through borehole No. 10; the other was at the 4 dips in Seam 12 below -94m airway, filled fully with sand. Then the whole sand-filling area for water-resistance was built up with the two sand-filling section above mentioned and the sand-filling section in -303m roadway.

PARAMETERS OF BOREHOLES AND QUANTITY OF GROUTING MATERIALS FOR -303m TRAM ROADWAY

Table 4

Borehole No.	Parameter of borehole size				Quantity of grouting materials			Remarks
	borehole length (m)	casing diam. (mm)	bore-hole diam. (mm)	open length of bore-hole (m)	cement (t)	gravel (m^3)	sand (m^3)	
4	333.54	168φ - 127φ	110φ	11.29	232.1	2	15811	sand-filling section for water-resistance
5	333.83	168φ - 127φ	110φ	1.89	82.4	72	-	when sand-filling, No. 4 jetting with water and sand, so it was turned to be an additional borehole for cement-grouting section for water-blocking.
37	334.27	168φ	110φ	267.06	28.9	-	-	
6	333.49	168φ - 127φ	110φ	24.63	10.0	1008	not penetrting into the roadway	
11	336.87	159φ	110φ	279.20	52.1	-	-	
12	333.83	168φ - 127φ	110φ	8.10	365.3	525	-	
13	333.53	168φ - 127φ	110φ	15.90	199.1	-	-	cement-grouting section for water-blocking
14	223.46	254φ	-	-	-	-	-	waste borehole
31	152.40	426φ	-	-	-	-	-	"
32	333.49	273φ	127φ	273.79	984.7		-	cement-grouting section for water-blocking.
33	333.47	219φ	110φ	258.99	579.3	4	-	cement-grouting section for reinforcement
46	335.32	159φ - 127φ	110φ	39.68	209.6	-	-	
19	334.10	168φ - 127φ	110φ	23.00	-	-	-	in primary design they were used for pot-shape caving explosion. but not used because of getting success of sand-filling.
20	334.31	168φ	110φ	267.11	-	-	-	
21	333.33	166φ	110φ	265.53	-	-	-	
22	333.95	168φ	110φ	264.61	-	-	-	
Total	5054.19	-	-	-	2743.5	1611	15811	

Sand-filling section for water-resistance in airway consisted of Nos 41,28,40,29,34 and 10 (see Fig. 3). The procedure of sand-filling was the same as 6.2.

7.3. Cement-grouting sections for water-blocking and reinforcement.

The designed upper length of cement-grouting section for water-blocking was calculated as below (see 5.2.1, but n=0.6):

$$L_{upper} = 11.4 \cong 12m$$

$$L_{lower} = 12+2x\frac{2.8}{7} = 20m$$

As a result of borehole No. 1 jetting with water and sand, and No. 16 beginning gravel-filling with sand, when sand-filling through borehole No. 41, the part of 50m between No.1 and No.16 was used as additional cement-grouting section for water-blocking, which consisted of the boreholes Nos 16, 35, 42, with a space of 22.5m. To ensure the safty and reliability of water-blocking, the cement-grouting section for reinforcement formed by boreholes No.42, 47, 49 and its length was fourfold that of the cement-grouting section for water-blocking. The process of boundary borehole of reinforcement section was the same as 6.3.

Cement-grouting process is the same as 5.4

7.4 Parameters of boreholes and the quantity of grouting materials are shown in Table 5.

Table 5

Bore-hole No.	Parameters of boreholes				Quantity of grouting material			Remarks
	borehole length (m)	casing diam. (mm)	bore-hole diam. (mm)	open length of borehole (m)	cement (t)	gravel (m^3)	sand (m^3)	
10	260.28	168φ -	110φ	204.25	73.8	526	18936	sand-filling section for water-resistance
34	261.31	168φ - 127φ	110φ	53.19	1.0	126	-	
29	231.23	168φ	110φ	171.56	6.7	308	1362	
40	122.90	139φ	110φ	42.08	3.5	-	2608	
28	188.31	219φ	191φ	131.13	10.6	1015	14622	
41	125.25	139φ	110φ	44.77	-	-	4571	
1	129.26	146φ - 127φ	110φ	1.98	412.3	1615	16	additional cement-grouting section for water-blocking.
43	125.57	168φ	110φ	32.12	324.3	724	-	
2	126.04	146φ - 127φ	110φ	3.99	741.2	648	2	
44	127.36	168φ	91φ	39.12	142.7	-	not penetrate into airway	
3	124.98	168φ - 127φ	110φ	12.88	301.1	39	1	
30	126.56	168φ	110φ	40.29	340.1	279	-	
16	126.94	168φ - 127φ	110φ	6.16	541.5	-	124	cement-grouting section for water-blocking.
35	124.70	168φ - 127φ	110φ	34.56	412.6	246	13	
42	125.84	219φ	191φ	26.01	238.2	13742	-	
47	125.55	139φ	110φ	27.35	501.2	-	-	Cement-grouting section for reinforcement.
49	125.61	127φ	110φ	25.60	66.3	44	-	
51	126.42	139φ	75φ	19.17	-	-	-	for inspection
Total	2702.11	-	-	-	4117.1	19312	42255	

8. MISCELLANEOUS

8.1 Total work amount for the water-blocking engineering.

Total work amount for water-blocking engineering of three horizontal roadways under flowing water condition is shown in Table 6.

8.2 Percentage of boreholes penetrating into the roadways:

$$\frac{36}{40} \times 100 = 90\%$$

8.3. Utilization rate of boreholes

$$\frac{34}{40} \times 100 = 85\%$$

8.4 Standard and method for examination of final grouting.

TOTAL WORK AMOUNT FOR THE WATER-BLOCKING ENGINEERING

Table 6

Horizontal Roadways		Number of boreholes					total length of bore-hole	Filling material			Remarks
		total	in-use	un-used	pene-trating	waste		cement (t)	gravel (m^3)	sand (m^3)	
-74m air-way	Water resistance section	6	6	-	-	-	1189.28	95.6	1975	42099	
	Water-blocking section	9	8	-	1	-	1135.25	3454	17293	156	including the additional cement-grouting section for water-blocking.
	Reinforcement section	2	2	-	-	-	251.16	567.5	44	-	
	Special observation holes	1	1	-	-	-	126.42	-	-	-	
-303m road-way	Water resistance section	5	1	4	-	-	1669.23	232.1	2	15811	unused holes #19,#20,#21, #22 are included.
	Water-blocking section	9	6	-	1	2	2715.17	1722.5	1605		additional water-blocking section is included.
	Reinforcement section	2	2	-	-	-	669.79	788.9	4	-	
-284m leading coal-head	Water-blocking section	3	3	-	-	-	948.07	1646.9	-	99	
	Reinforcement section	3	3	-	-	-	959.77	600.1	-	-	
	Total	40	32	4	2	2	9664.14	9107.6	20923	58165	

8.4.1. Boreholes in sand-filling section for water-resistance.

Examination standard: sand-filling with pressure until it's full.

Examination method: By salt tracing, injected salt water into one of the boreholes in the water-blocking section, we could not find salt water from the boreholes around salt water injected borehole, so it proved that there was no water current in the roadway.

8.4.2. Boreholes in cement-grouting sections for water-blocking and reinforcement.

Examination standard: To the boreholes in airway, grout pump pressure reached to 60kgf/cm^2, with final capacity of less than 50l/min.. It lasted 5 minutes or longer. To the boreholes in tram roadway and leading coalhead, kept pump pressure 80kgf/cm^2 and final capicity $<$ 50l/min. for more than 5 minutes.

Examination method: The boreholes were injected with water after cement-grouting, water leakage $<$ 5l/min.

8.5. Water level observation boreholes after completing the water-blocking engineering.

Boreholes #34, #41 in the airway and #22 in the tram roadway were used as water level observation boreholes. First, put filter pipe down to 0.5m - 2.0m below the roadway bottom, then connected filter pipe with inner casing up to the surface. Besides, the advanced borehole #57 in the airway was regarded as special water level observation borehole. After the engineering was completed, these four boreholes were used for regular water level observation. Once there is water rise or the sign of water passing in any one of the boreholes, cement-grouting should be made immediately in emergency cement-grouting boreholes for reinforcement. The four boreholes are protected with iron boxes on surface from falling of some things in.

8.6. Emergency grouting boreholes.

Boundary boreholes #49, #46 and #45 for reinforcement in section of the airway, the tram roadway and leading coalhead were taken for the emergency cement-grouting boreholes respectively. After the water-blocking engineering was succeeded, the three boreholes mentioned above would be drilled further down to the roadway bottom, so as to make cement-grout for reinforcement at any time. These boreholes are also protected with iron boxes on surface.

8.7. Practical time phases of the water-blocking engineering.

June 6th, 1984, Water-inrush took place in L. Mine.

June 11th, 1984, Drilling started after location of the boreholes.

June 15th, 1984, Filling material in the boreholes of -94m airway began.

Dec. 7th, 1984, the water-blocking engineering in three horizontal connection roadways between F. and L. Mines under flowing water condition was finished, lasting 185 days.

8.8 Water-blocking result.

Protected by the water-blocking engineering in three horizontal connection roadways between F. and L. Mines, pumping was carried on in L. Mine without interruption. When the water level in L. Mine fell down to -438m, personnel got into the tram roadway in east limb of -425m (the only water passage from F. Mine to L. Mine) on Oct. 22nd. According to the measurement, water inflow in east tram roadway was 7.78m^3/min. As the normal inflow there was 0.85m^3/min., then passing water amount should be 6.93m^3/min. (including quantity of lagging water when goaf area flooded). On Dec. 8th, the passing water quantity decreased to 1.7m^3/min.. The result of water-blocking came up to 99.6%.

9. CONCLUSIONS

The following conclusions were drawn from the practise of the water-blocking engineering.

9.1. In the three horizontal connection roadways between F. and L. Mines, under flowing water condition (the actual max. quantity of passing water: 388.8m3/min.), the "3 - section method" using small diameter boreholes was proved very effective, with the effect of 99.6%.

9.2. When using "3 - section method" under flowing water condition, a sand-filling section for water-resistance must be formed before cement-grouting sections for water-blocking and reinforcement, thus later two sections can be built under approx. standing water condition.

9.3. It's more economic to use local sand(loess content 1.76%) in building sand-filling section for water-resistance.

9.4. Under approx. standing water condition, the abandoned -284m leading coalhead can surely be water-blocked by "2 - section method" (water-blocking and reinforcement sections with small-diameter boreholes).

9.5. Large-diameter boreholes are naturally benificial in both rate of water blocking engineering and averting accidents during operation, but small-diameter boreholes (110mm ϕ) can be adopted in case of blocking water in short time and lack of heavy-duty drilling machines and large-diameter casing.

9.6. In former design of the water-resistance section, first, a pot-like cave can be shaped by means of explosion of small borehole or by large diameter borehole, then downward directional explosion with large amount of explosive is carried out. Afterwards cement is filled in the blasted-down stone to form concrete section as a water-resistance section. The method is feasible theoretically, but shown to be in practice time-consuming and of influence on the other work. For this reason,sand-filling method with local sand was employed instead of the original one. As soon as the sand-filling method achieved success, the former method was stopped.

Acknowlagement

This article is written based on the remarkable achievements made by the whole staff and workers in Water-blocking Headquarter of Tatuo Worksite, L. Mine under the correct leadership of higher authorities. The authors of this article are merely participants in the engineering. All the materials cited in the article are proofread by Mr. Sun Guiwu, Mr. Gu Wencan and Mr. Yang Wentian. All the sketches are drawn by Mr. Yu Xiou. The authors of this article hereby express many thanks to the participants in the engineering and all concerned who provided help for the article writing, and are grateful to MR. Z.Kesserü, Hungarian expert, for his help.

REFERENCES

"PREVENTION AND CONTROL OF WATER INRUSH IN ROADWAY" - translated by Yan Zheng Fang, etc. Coal Industry Publishing House, 1984.