International Journal of Mine Water, Vol. 5, No. 2, (1986), 57-66
Printed in Madrid, Spain

APPLICATION OF GROUTING TECHNIQUE TO RESTORE SUBMERGED SHAFTS IN CHINA

Huang Shuxun, Wang Ling and Chen Qinshu
Changsha Institute of Mining Research, China

ABSTRACT

A brief introduction is given to the development of grouting technique in China. Based on the authors' experience, detailed description of two typical water-controlling projects with grouting is given together with their technical and economical results.

INTRODUCTION

As the Chinese economy develops, it is unavoidable to build a number of coal mines and metal mines in the area with more complicated hydrogeology and engineering geology conditions. Limestone is widely dispersed over China and buried at great depth, especially in the coastal area and southern provinces such as Shandong, Liaoning, Jiangsu, Hubei, Hunan, Guangdong and Guangxi, all of them are abundant in mineral resources and meanwhile limestone pervails there. Amongst the shaft-flooding accidents in the recent 20 years about 80% are due to sinking through the limestone statum with well-developed karst and some are caused by permeation of stored mined-out areas of the fault zones in fissured strata.

According to the time of flooding, water permeating mode and control measures, the accidental inundation in shafts can be roughly divided into the following two kinds: shaft and incline are partially submerged at the initial stage of capital construction; drift and stope wholly submerged for water permeation at the development and production stage.

The control measures may be also divided into two kinds: Under the circumstances of small water-inflow quantity or less kinetic water reserve, a mandatory drainage approach is generally adopted. With the exception of the above circumstances grouting is normally used to block up the water or seal off the permeable strata. Recently, as the grouting techniques are becoming increasingly popular, the water-control grouting program will be widely adopted so as the restore the submerged shafts quickly and reduce the power consumption for drainage.

Since the beginning of the 1950's, grouting technique to control mine-water in China has rapidly developed, particularly in the recent 20 years. Among the grouting materials, cement slurry and cement-water glass slurry are in common use; water glass, acrylamide, lignin, urea-formaldehyde resin, epoxy resin, furan resin and polyurethane chemical slurries are also used

Table 1: Summary of Some Submerged Mines Restored by Grouting

Names	Descriptions	Water-gushed Qty (m^3/hr)			Grouting Parameters Material Consumption						Notes
		Max.	Water Press. kg/cm^2	After Grout.	Hole Depth m	Final Press. kg/cm^2	Grout. Hole No.	Cement t	Water-glass m^3	Sand-stone m^3	
South Gaoyu Mine in Shandong	flooded by water from limestone at -50 m level in the incline	114	11.5	5	118	20-60	4	105	64.5		
Jinzhou Asbestos Mine	water permeating from 1509 stope roof	233		154	129	5-20	6	92	32.5		additional cal-cium chlo. TEA & tailing used
Wafeng Mine in Jiaozuo	water bursts out from floor of -115 m level in 117 area	3060		420	270-300	28	5	366	6	1030	
Zhongmacun Shaft in Jiaozuo	water bursts out from floor of temporary sump	105	27			30		320			
Xinhua Coal Mine in Jiangxi	water permeats from face at -94 m in main incline	435 (aver.)		1	120-176	35	4	872			

Table 1: Summary of Some Submerged Mines Restored by Grouting (continued)

Names	Descriptions	Water-gushed Qty (m^3/hr)			Grouting Parameters			Material Consumption			Notes
		Max.	Water Press. kg/cm^2	After Grout.	Hole Depth m	Final Press. kg/cm^2	Grout. Hole No.	Cement t	Water-glass m^3	Sand-stone m^3	
Dafeng Mine in Feicheng	9204 working face is permeated by water	1628	6.7-10.6		180	30	9	500	400	102.4	
Xiezang Mine in Shandong	water permeats through 31104 working face	1960			180	20-50	16	772	433	776.7	
Taoyang Mine in Feicheng	water permeats through 9901 working face	924 (aver.)		5	170			714	700t	510	
Liejiaqiao Shaft of Wangjiashan Coal Mine in Xiangtan	see No 2 example in text	4000	15.7	1.8	170	30	2	191			triethanolamine (TEA) 28 l., salt 280 kg and calcium chlo. 200 kg used

especially in some groundwater-control or sand-consolidation projects. For the purposes of solving environmental pollution and reducing cost, some nontoxic and new chemical grouting materials have been developed utilizing industrial wastes.

From the early part of the 1950's - 60's, slurry pumps for geological exploration and simple mechanical mixing devices were used as basic grouting equipment. Originally grouting techniques were used on such a level as a simple and temporary measure. Since the beginning of 1960's, with the appearance of professional grouting operations and research organizations, special grouting machines have been developed on the favourable conditions, such as 2MJ - 3/40 diaphragm metering pump, YSB-250/120 hydraulic grouting pump with speed-control, and SNC - grouting unit etc. During the 1980's, some professional grouting companies have emerged in China, which are engaged in contract design and scientific research of grouting projects.

Since 1956 when Shajialing coal mine in Shandong province first adopted surface grouting to restore the submerged shaft for more than 20 years, some thirty mines have used grouting methods to control groundwater inflow and restore shafts (see Table 2).

Taking one submerged shaft and one submerged mine as examples (the latter was developed with an incline), detailed case histories are described.

THE SOUTH VENTILATION SHAFT IN XIANGUANZHUANG IRON MINE, SHANDONG PROVINCE

Xianguanshuang iron mine is a medium-size iron mine. The south ventilating shaft with 4 m net diameter and 4.7 m gross diameter had sunk to 424 m depth as it was flooded developing a water pressure of 37 kg/cm^2. The rock mass above 400 m depth is the Triassic system comprising red clay slate, between 400 m - 405 m sandy bibbley-rock and below the point altered-diorite fractured zone with fissure well developed and dipping to 70°. Although the final depth of the shaft was 424 m, a major fault intersected the Ordovician limestone in the hanging wall causing a water inflow at the rate of 259 m^3/h and flooding the shaft upto 32 m from the shaft collar. The solution of the problem, was first to seal the underwater shaft bottom by concrete and then followed by face pregrouting. With this procedure, the shaft was successfully sunk through the water-bearing stratum.

In the process of sinking waterlogged shafts, how to seal the permeable strata at the bottom of shaft is very critical. The normal practice is to use concrete-transferring pipe to convey the premixed concrete from surface to the face for building up a water seal; but bottom-dump hopper is also used to transport concrete to working face through a winch, which automatically unloads as the shaft bottom is touched. Both methods have relative advantages and disadvantages. In the former method, although it is easy to mix concrete in batches, there is a danger of pipe blockage. However, the latter techniques are inherently inefficient and the quality of concrete is poor. With this view, crushed-stone cushion grouting method was adopted to build up a water control plug successfully and seal off inrushing water from the shaft bottom completely.

Operation Procedure

Water is drained to the point of 8 m below the lower floor of work deck (22 m from permeable face) with submerged pump, then the slurry ejector and associated grouting pipe are lowered down from the surface with two 8 ton

Table 2: Summary of Surface Grouting for Leijiaqiao Shaft

Hole No	Grouting Times	Grouting Date (1985)	Hole Depth m	DOSS*1 m	UFBG*2 l/min-m	Mixture Ratio of Slurry W/C	TEA	Salt	Calcium Chloride
No 1 Hole	1	night shift 29/1				1.80:1			
					193	1.00:1			
						1.00:1	0.05%	0.5%	
	2	morning shift 30/1				1.80:1			
						1.00:1			
						0.70:1			
						0.85:1			
						1.00:1			
	3	night shift 30/1				1.00:1			
						0.70:1	0.05%	0.5%	
	4	afternoon shift				0.70:1	0.05%	0.5%	
	5	afternoon shift 3/2	161.4	128	4	1.00:1			
						0.70:1			
						0.60:1			
	sub-total								
No 2 Hole	1	night shift 30/3				1.00:1			
					13.49	1.80:1			
						1.00:1			5%
						0.70:1			3%
	2	afternoon shift 31/3				1.00:1			
					4.63	0.70:1			
						0.70:1			3%
						0.60:1	0.05%	0.5%	
	sub-total								
Hole Sealing		4.1							
Total									

*1 - depth of slurry stopper   *2 - unit flow before grouting

*3 - grouted quantity   *4 - calcium chloride

Table 2 (continued)

Grouted Quantity						Grouting Pressure kg/cm²		Remarks
GQ*3 m³	Cement t	Salt kg	TEA l	CC*4 kg	Pebble l	Pumping Pressure	Permeable Point Pressure	
76.2	48.05	120	12			0		
51	38.85					0		
31.2	29.3	120	12			0		
6.6	5.9	30	3			0	10.4	*5
55	42.8					1-20	9-31.2	
220	164.9	270	27					
29	15.3			130		3-6	9.1-16.4	
13	9.85	11	1.1	70	100	0-20	10.4-30.4	*6
42	25.15	11	1.1	200	100			
	0.95				900			
262	191	281	28	200	1000			

*5 - slurry stopper used for slurry spring out the near surface and grouting interval

*6 - 100 litre of ¢5 - 10 mm pebble throwm in before grouting low-speed winches. The slurry ejector was 6.5 m long and the grouting pipe was of 68 mm outer diameter and 9 mm wall thickness. The operator lowers the wire rope while lengthening the grouting pipeline at the collar surface until bottom mouth of the ejector is 0.3 m from the face.

Select four points on the face and separately measure out the heights from each point to the bottom surface of the lower floor with measuring-line and plummet to determine the muckpile distribution situation on the face. The actual measured results indicate that the depths of the four points are respectively 26.70 m, 26.85 m, 26 m and 26 m. As the above preparatory work is completed, estimate the required pebble quantity for the water-seal layer of 6 m thickness. After being cleaned on surface, the quantified pebble is transferred to shaft bottom by conveying pipe through the work deck; then the second measurement is made to determine the relevant heights from the four points to the lower floor, the actual measured results are 20 m, 18.20 m and 18.80 m respectively. The height difference of corresponding points, ie the thickness of water-seal layer, should not be less than 6 m. After this requirement is satisfied, water pumping is stopped. As the water level in shaft returns to static level or water in shaft bottom is artificially stabilized, cement slurry or cement-sand slurry with accelerator additive is grouted into the pebble layer with grouting pump from the surface.

Grouting Materials

Before the shaft is submerged, on the face remains 2 m thick muckpile, which is about 34.66 m^3 volume with 30% porosity and requires 11.5 m^3 grouted cement slurry calculated according to 90% slurry calculated rate and 6 m thick pebble layer also needs 58 m^3 cement slurry grouted, so 60 ton cement is totally required. The operation result shows that the actual cement consumption is 180 tons, equal to three times of the calculated quantity. It is shown after the shaft excavation that owing to the face that the shaft is connected with a 400 mm wide diorite fissure while sinking, the slurry pressure in grouting is much higher than underground static water pressure so as to force the slurry into the fissure. Therefore, such a phenomenon happens that the height of water-seal layer in shaft remains unchangeable, but the grouted cement slurry quantity has considerably increased. In the process of sinking, 400 mm thick concrete gouge with rock cemented together has been taken out.

Observation in the Process of Grouting

Three methods are used to determine whether the grouting is completed.

1 If the shaft bottom has been sealed by grouting is completed slurry or injected water should not permeate into the shaft bottom and the grouted quantity should be reflected by the increasing height of water level in shaft. So the interval time of grouting or water injection and the measured value of the increasing height H of water level in shaft can be used to determine whether the shaft bottom has been sealed. The value H can be derived from the following expression:

$$H = \frac{Q_1 + Q_2}{60\pi r^2} \cdot t$$

where, Q_1, Q_2 - the quantities of injected water and grouted cement slurry into shaft per hour respectively, m^3/hr

r - net radius of shaft, m
t - interval time between water level measurements, minute

Take t = 20 minutes, then the above expression can become

$$H = \frac{Q_1 + Q_2}{3\pi r^2}$$

2 In the process of grouting, use a sampling pail with a check valve on bottom to take samples periodically on the pebble layer surface in shaft. As cement has been found on the pebble layer surface, stop grouting immediately.

3 By the end of the 24 hours grouting, inject water into the grouting piping from surface, of the time from starting water-injection to the injected water back to the surface is equal or less than the time for filling the pipeline, it is indicated that the water-seal layer in shaft is not permeable. Otherwise, grouting should be carried on.

After drainage, it is confirmed by site observation that the permeable face has been sealed completely. This operation procedure is simple and easy, without complicated equipment, all work done on the surface and capable of resuming submerged shaft in short time.

CONTROL OF WATER AND MUD INFLOW IN THE LIEJIAQIAO SHAFT INSET AT WANGJIASHAN COAL MINE IN HUNAN PROVINCE BY GROUTING FROM SURFACE

Liejiaqiao shaft, located in Xiangtan county, Hunan province, is a coal mine developed with a pair of inclines, which was completed and brought into production in 1972. In 1973 while a crosstunnel was being drifted, it penetrated into karst water in the limestone of Maokou Group, the Permian System, resulting in flooding for 12 years. While the instantaneous water-inflow quantity of accompanied mud was up to 4000 m^3/hr with 15.7 kg/cm^2 water pressure, the quantity of accompanied mud was also up to 2000 m^3 so as to fill several hundred metres of drifts, sump, pump room, and partially inclines.

In November 1984, a research group from Changsha Institute of Mining Research with the co-operation of Xiangtan Coal Geology Team in Wangjiashan coal mine adopted grouting holes (drilled from the surface) to grout cement slurry towards the flooded tunnel, resulting in successfully sealing off the underground permeable face with up to 99.7% efficiency. With the exception of drilling, the grouting work only took six days and with total cost 203 thousand Chinese yuan to restore the submerged mine.

As a rule, the karst development of limestone in China can be generally divided into the southern type and northern type; the former takes karst cavern as a main feature, containing rich underground water and high mud-filled rate in cavern; but the latter is mainly of water-bearing fissures. As the southern limestone is permeated, a lot of mud will pour into the openings with inflow water so as to make groundwater control difficult.

In the past 12 years of Liejiaqiao submerged shaft, various mandatory drainage methods had been tried to resume the submerged mine, but all resulted in failure due to the face that the mud/sand caused pump damage and the depth of water level which lowered ignificantly with mud/sand inrush resulting in surface subsidence and sudde ncrease of water inflow quantity.

For the grouting project, only two grouting holes (No 1 and No 2) had been used. They were located at the surface above the permeable cross-tunnel with the No 1 being 7 m away from the permeable face and the No 2 at 10.5 m from the working face. These boreholes were 146 mm diameter at the surface and 73 mm in final diameter, and of 170 m depth, with their bottoms 10 m over the tunnel floor. No 1 borehole was used as a grouting hole and No 2 as reinforcement borehole for grouting the fissures which may be connected with the permeable tunnel in the weak country rock.

Cement slurry with suitable amount of accelerator was used to grount quantitatively and intermittently. The grouted quantity for each batch was successively reduced and the interval time was based on the initial setting time of grouted slurry. The final pressure of grouting was up to 31 kg/cm^2. Under the circumstances of final pressure, as the absorbing capacity of grouting hole is less than 20 litre per minute, the hole should stop grouting.

For the operation of sealing underground permeable drift with surface grouting, the key point is to make the drill hole to be connected with the drift. In practice both grouting holes deviated about 2 metres from one side of the tunnel. For the connection between the drill hole and tunnel, down-hole-blasting had been carried out at the tunnel elevation with the change made of ¢ 73 mm core tube with 1.5 m total length, and 4.5 - 5 kg 2# type rock explosive. Before and after blasting, water-injection tests were carried out to measure out the unit grouted quantity (litre/min-m) of the two drillholes, which increased respectively from zero to 193 l/min-m and 13.49 l/min-m. For No 1 borehole 220 m^3 cement slurry (containing 165 ton cement and 300 kg compound accelerator) was grouted in 5 grouting operations. For No 2, 42 m^3 cement slurry (25 ton cement and 212 kg accelerator contained) was grouted.

The summary is shown in Table 2 and the final grouting operations for No 1 borehole is illustrated in Fig 1.

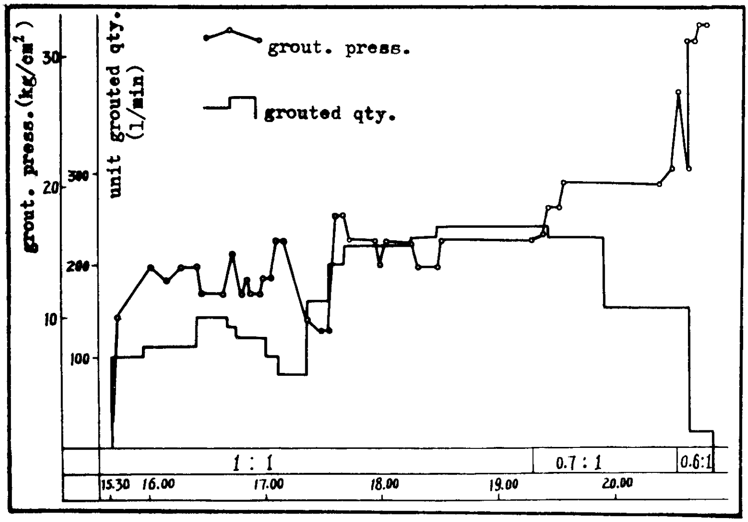

Figure 1: Grouting process curve of No 1 hole

After the resumption of the shaft, the residual water-permeation rate from the permeable face was only 1.8 m^3/hr. Before grouting the water inflow quantity was 600 m^3/hr, thus giving water sealing efficiency of 99.7%. Through drainage and cleaning of the tunnel after grouting, it was found that 2/3 work face (from top to bottom) in the 2 metre high tunnel was filled by cement upto a distance of 60 m from the point of inrush, the cement plug and the tunnel roof were firmly cemented together and mud in the karst cavern was in a stable state.

During the process of cleaning the tunnel, the following in-situ observations were made:

1 When a permenent water-seal wall was built up at a distance 50 m from the permeable point in the tunnel, it was found that on the level 300 mm above the tunnel roof existed a clear trace of water mark with a pronounced line, above the line was a yellow-red water mark and below it was light grey rock. It is apparent that the space with 300 mm height in the upper part of the tunnel is basically the passage of inrush water after the shaft submerged. The key point of success or failure for the grouting project depends upon whether the water passage can be completely sealed.

2 At a distance of 60 m from the point of inrush in the tunnel, cement grout start to be distributed in layers at the upper part but on the tunnel floor there was no traces of any cement. The loess between clayey layers is dehydrated and lumped by compression under the grouting pressure, but the clay at the bottom is still in colloidal state.

3 At a distance of 50 m from the point of inrush in the tunnel, the upper cement layer about 0.8 - 0.9 m thickness is firmly cemented, which can not be broken off without blasting. At the top of the tunnel there appear cement layers in block formed with a smooth curved surface, about 0.04 - 0.07 m^3 in size for each, which are embedded in loess. It is evident that while grouting, the slurry firstly spreads out toward the less resistance interfaces such as the water passage in the upper part of the tunnel, clay and rock interface etc. After the above voids have been filled, the slurry, with the increase of grouting pressure, starts to squeeze into the karst cavern clay which has poured in the tunnel and tightly wedge in. Various cement patches in combination with the clay pouring into the tunnel results in partial dehydration of clay, increase of density, loss of flowability and improvement of shear strength so as to cut the water source and prevent water and mud inrush. This is quite different in mechanism from the sealing of drift in simple flooded mine with grouting.

4 Under the circumstances of water inflow accompanied with mud (poured mud volume up to 2000 m^3 and 85% of tunnel cross-section filled by karst cavern mud), it is decided to adopt simple grouting procedure from the surface rather than time-consuming and expensive freezing method with emphasis on the research in grouting parameters and the control technique of grouting process. This grouting procedure not only costs less because of shorter period of time to seal permeable tunnel successively but also simplifies working procedure for the resumption of submerged mine. Therefore, there is no doubt that it sets a good example for reference to the similar engineering projects at home and abroad, especially in medium and small mines.