Deep Bore Sealing Grout Technique to Strengthen and Suppress Water in Cracked and Faulted Zone of a Tunnel

By G.L. Wen[1], J.H. Du[2], Z.H. Wang[1], D.M. Shi[2] and L.Y. Chen[3]

[1]Bureau No. 19, Railway Department, China
[2]Northeastern University, China
[3]Bureau of Northeast Coal Industry, China

ABSTRACT

With special problems in tunnel or underground construction engineering such as fractured ground, high pressure waterbearing ground and ground with large water inflow, sealing by deep bore grouting to strengthen and suppress water is one of the effective construction methods. This paper presents experience and practice of drilling deep boreholes and cementitious grouting materials. It discusses deep bore drilling by a hydraulic shaft jumbo, it solves quick pilot jumping and deep bore grouting jumping problems. Moreover, from the experiments with cementitious materials in this paper some new ideas on the physical process of cement - sodium silicate grout hardening are presented.

The equipment, materials and grouting parameters used in the experiments noted above have been used in Benxi Bapanling Railway Tunnel in a 250 m long stretch of waterbearing joint and fault zone with encouraging results.

INTRODUCTION

Water seepage in railway tunnels is still a big problem to transportation. In the past design and construction of a new tunnel always combined taking suppression of water flows with provision for drainage, meanwhile more attention has generally been given to drainage. Because of the complexity of hydrogeologic conditions large amounts of water can be pumped from underground tunnels and so result in the drying up of the water resource. This affected plants and villages, economic waste was large, and underground water made it much more difficult to excavate tunnels. During excavation collapse always took place earlier than support erection and construction became extremely difficult.

All the above problems can be solved by using the grouting method of injection first and excavation second.

Bureau No. 19 of the Railway Department met a troublesome problem during construction of Bapanling Tunnel. The problem was a water bearing joint and fault zone 250 m long. The underground water level is 137 m higher than railway roadsign with a long jointed zone and a high water pressure. There are three springs at the surface above the jointed zone, they are used to provide water to villages and plants on the top of a hill which must be protected.

Deep bore sealing grouting technique to strengthen and suppress water (DBSGSSW) was adopted after discussion.

In domestic tunnel engineering using this kind of construction is not well known. There is no experience which can be used and we can only draw lessons from some limited domestic data and foreign tunnels constructed. A group was formed to carry out experiments to study key techniques and parameters of deep bore sealing grouting to strengthen and suppress water inflows. This paper only presents some of the problems of the technique. It is hoped to prepare a series of papers on the design parameters and construction experience using this technique.

EXPERIMENTAL STUDY OF DBSGSSW

Equipment and technique of high speed deep boring

Equipment and technique of high speed deep boring of horizontal holes is the first key problem of the technique, solving this problem is pre-requisite to implement this technique. In domestic tunnel, geological drilling machine have been adopted commonly to drill deep horizontal hole. This kind of machine has a fundamental weakness, the base of the machine cannot move automatically, and it has no drilling elevating arm mechanism, auxiliary work takes up about 50% of the total time, etc. This is unacceptable. The height of the machine is also not suitable. To solve this problem a hydraulic drilling jumbo made by Sweden Atlas Copco Company was used. The machine is flexible and fast moving from hole to hole and it has an independent two-sided rotary system, with a large variable torque.

The depth of hole is about 5 m normally. Experiments were made to test if the depth of hole could be raised to 25 m. Experiments were made four times. The diameter of drilling rod is 76 mm, the largest depth of hole achieved was 28.1 m and drilling machine worked normally and experimental data are all within the rated parameters of drilling jumbo (shown in Chart 1). According to the experiments Sweden's hydraulic drilling jumbo has the capacity of drilling deep hole with more than 25 m depth successfully and safely.

Mating experiments of cement and sodium silicate

Cement sodium silicate grout is characterised by quick solidification and a high proportion of hardening. Accordingly to meet engineering requirements a series of theoretical analysis and experimental study was done.

Experiments found that with the increase of the water cement ratio decreasing the proportion of grout or decreasing of sodium silicate concentration, coagulant time stopping does not mean that grout really reaches solidification and hardness state. Sometimes continuing agitation will increase the plastic quality of grout after the coagulation time. The whole solidification process of two liquid grouts should be in two coagulation phases (first coagulation, end coagulation) and solidification (strength). Measurements of coagulation time (the first and end coagulation time) and submerge degree of grout body were also measured to clarify physical process of solidification of grout.

Materials used in experiments are: Portland cement No. 525, Seaqull general cement No. 425, sodium silicate with Baume degree 45 Be', modulus 2.75 and slow coagulant of Na_2HPO_4.

Rock in Bapanling tunnel fault zone is broken heavily and has large amounts of flowing water. Design grouting target required every grouting operation must be 20 m long and the spread of grouting diameter of every hole must be 4 m. Coagulation time of grout is 3 minutes, and 1 ~ 2 minutes in water bearing zone, considering spread of grout in rock body. The original plan adopted a method of mixing slow coagulant into grout to prolong coagulation time. According to large amount of water inflow and gaps in rock body varying during coagulation found in experiments, L_{16} (4^5) regular intersection design and part special qualities experiments are adopted to search varying rules between diverse elements and diverse qualities. Results of L_{16} (4^5) regular intersection design are shown in Map 1. Grout sedimentary degree in coagulation are shown in Chart 2 and Map 2.

Experimental results shows that two liquid grout has the following characteristics. After cement was added to the sodium silicate and mixed, for several seconds, sudden change occurred to grout body. This kind of sudden change occurred very fast, from flowing state to non-flow state and coagulation produced. During experiments because w/c, c/s are different from each other, coagulant speed and solidification time are also different (as shown in Chart 2 and Map 2). There are three kinds of experiments in Chart 5. Keeping w/c at 0.75 beume degree of sodium silicate fixed, changing proportion of two grouts (by volume), amount of sodium silicate from max to min and changing coagulation time from long to short, then to determine submerge degree (by cement standard cone) from shallow to deep determine first and end coagulation time, from fast to slow.

Keeping beume degree of sodium silicate unchanged, proportion of two grout fixed changing w/c ratio gradually from min to max changing coagulation time from short to long the submerge degree also changes from shallow to deep, and coagulation time changes from fast to slow.

Experiment shows cement grout density has a linear relation with coagulation time. That is accompanying with gradual variation of w/c. w/c becomes smaller, cement grout density increases, reaction between cement and sodium silicate becomes fast, coagulation time decreases for certain range. Cement grout is more concentrated, reaction becomes faster but sodium silicate is more watery.

W/c of two grouts is smaller, sodium silicate density is higher, proportion of two grouts is larger, then grout begins first coagulation after gelation. Conversely, the difference between gelation time and coagulation time will be enlarged and grout body will also vary from hard plastic state to soft plastic state.

Grouting technique and skill

Grouting holes are arranged along excavation outline in a radial pattern (shown in Map 3).

Commonly pumping water experiment should be done before grouting to wash gaps in rock, englarge passage of grout, increase density of grout filling body and to probe permeability of ground. It is not suitable in waterbearing zone. Water should be replaced by cement grout directly, then pump two liquids into the fault ground. To reinforce ground with large inflows and porosity, two liquids grout should be pumped directly.

During grouting amount of grout and grouting pressure are two key parameters and should be controlled effectively to attain grouting quality. During the whole grouting, grouting amount and pressure are all controlled according to design requirements. Finished rule of every hole is that end grouting pressure should reach 80 per cent of designed quota.

ENGINEERING EXAMPLE

In April 1991, in constructing Benxi Bapanling tunnel a waterbearing joint/fault zone was treated by deep sealing grout strengthen and suppressing water techniques. Success was achieved. Technical, economic and social effects are all ideal.

In the middle of Bapanling tunnel, there was a 410 m long joint/fault zone. Within this zone there is a 250 m long section which is intersected by F6, F7, two regional main faults. Under the effect of main stress acting east-west, rock body is pressurised to break to a crushed stone state. In the fault zone, structure water inflows is large with 10000 m^3/d. The water is corrosive. There is good agreement between surface water and underground water. The two faults appears on the surface, their outcrops are in a low valley with large area of water inflow. The level of underground water is 137 m higher than the designed elevation of road. Construction was very difficult.

The key problem in the fault zone is to seal off water so that the condition of underground water inflow is not be destroyed by excavation. Based on large amount of experimental data and spot construction condition, while according to some grouting parameter designing requirements of spread diameter of grout. Length on grouting part, strength of solidification, basic proportion, basic w/c sodium silicate density and ration of cement and sodium silicate (in volume) are determined and drawn up as spot operative charts of grout making and adjusting chart to adjust for spot grout density. After grouting and solidifying through examining digging hole radially, effective grouting solidification range was determined as 4 - 5 m by measure and calculation of depth of digging hole, and location of inflow. After excavation there is no flow, but a little amount of dripping water in a special zone, total rate of sealing reaches up to 90%. Through large amount of indoor and spot experiments and engineering practice, the parameters were chosen and used in construction are:

effective range of grouting	4 m out of excavation outline (5 m in collapse zone).
length of grouting part	20 m.
grouting way	no flow, all hole pressured one time flow, power advance.
grouting pressure	4 - 5 MPa.
flow of grout	60 - 120 L.
rock plate to block up grout	3 - 4 m.
w/c	0.75 : 1 1 : 1.
sodium silicate density	25 ~ 35 Be'.
ratio of cement and sodium silicate in volume	1 : 0.5.

arrangement of hole	In radiative one row along with excavation outline of working face, overlapping of two thicknesses at bottom of hole, general 19 ~ 23 hoses. In large flow zone, two row holes in arch port.
drilling machine	Made by Sweden Atlas Company H174 H178 hydraulic drilling jumbo.
grouting pump	2TGZ - 60/210, 2TGZ - 120/60 two liquids grouting pump made by Jinxi grouting pump plant.
accessories	mixing barrel made by ourselves, tee mixer, rubber stopper.

Through experimental study, spot experiment and engineering practice we have following realizations.

Choosing drilling jumbo to increase length of grouting part and increase working power. Using hydraulic drilling jumbo produced by Sweden Atlas Company it is feasible to drill holes with diameter of 76 mm and depth of 25 m (max depth of hole is 28.1 m). The machine can be easily moved and fixed, and it has high operating efficiency. It is an ideal tool to drill deep horizontal holes. Deep hole sealing cuts down the time of grout circulation and increases the rate of tunnel advance.

Choosing a drilling pattern improves the quality of grouting. Drilling pattern includes diameter and depth of drilling hole. After several experiments using drilling head with diameter of 76 mm hole depth of 25 m can be successfully grouted. Depth of grouting part has been determined as 20 m. Excavation practice prove grouting result is successful with no leakage problems.

Necessary measures taken in drilling and grouting construction to limit inflows. Sudden inflow in construction of Bapanling tunnel would create serious problems. Measures to prevent this are as follows. (1) Strengthening geological prediction. (2) Prevention in drilling. One way is to drill through a special head tube. If a sudden flow occurs, drilling rod is withdrawn from head tube quickly and the head tube valve closed and connect grouting tube to grout. During drilling this equipment solved several sudden flow with large flow or high pressure water effectively. (3) Prevention in excavation. If construction is using explosive excavation exploratory holes were drilled twice the length of the explosive holes in the centre of the excavation. If there is no unusual flow in examination holes explosive operation proceeds.

CONCLUSIONS

1. Experiments and engineering practices proved that deep hole sealing with grout to strengthen and suppress water inflows was successful. The selection of grout material through the adoption of the L_{16} (4^5) regular intersection design and the special qualities of the experiment has shown major advantages. The regularity of coagulation can be determined by using a cement standard cone for determining the submerged degree of grout coagulation.

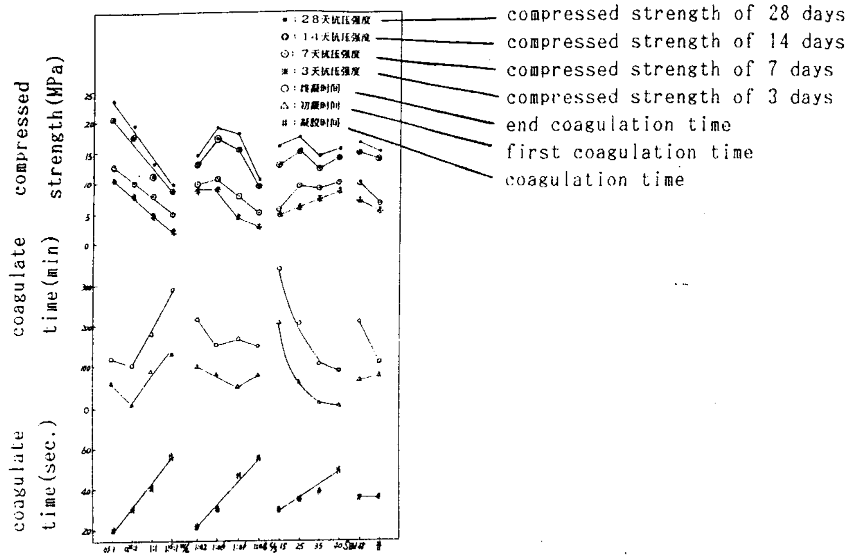
All of these factors constitute a new breakthrough in technique. This technique is very effective for tunnel construction through soft, cracked and highly water pressured zones.

2. The development of a deep bore drilling apparatus and drilling skills. By using a hydraulic drilling machine the depth of hole can be raised from 5 m to 28 m, average rotary speed is 0.37 m/min and the working efficiency is 26 times as that of an ordinary compressed air drilling machine.

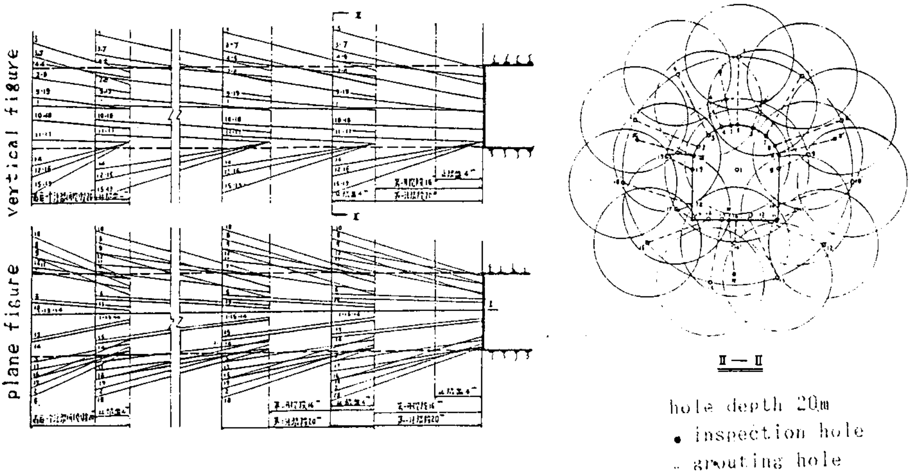
3. In comparison to shallow bore sealing grouting the proposed technique reduces drill operating time and cuts the grouting cycle time significantly. Construction through the faulted zone was cut by three months by adopting the technique.

4. Under conditions of a wide fault zone with high water pressures, large potential flow and no opportunity to pre drain. The ideal grouting system would utilise a grout wall 4 ~ 5 m thick, with a liquifaction strength of 5.6 MPa after seven days and with a 90% coverage. Under these achieved conditions it was possible to break previous drivage records with an advance of 26.5 m in a month (appraised by Railway Department of China in October 1992).

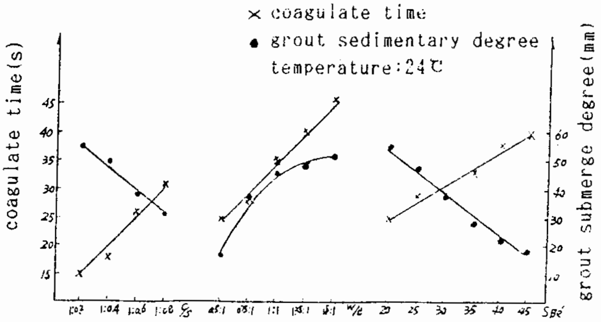
5. The application of hydraulic drilling machines in China is rapidly increasing with over seventy in use within the railway system. The deep bore sealing technique is increasing in application and has proven itself environmentally and practically sound.



map 1. the influence of some facetors for characteristic of grout



map 3. the design of DBSGSSW



map 2. the influence of some factors for coagulate time and grout submerge degree

Experimental parameters of hydraulic drilling jumbo

chart 1

Number	drilling rod	diameter of drilling head (mm)	depth of drilling hole (m)	drill time (min)		drilling speed (m/min)		oil-pressure of jumbo (MPa)		
				net time	total time	net speed	total speed	rotary	power feed	pusher feed
1	2	76	10.8	10.6	24.3	1.02	0.44	5-6	18.5-19.5	3
2	2	76	10.8	10.83	24.9	1.0	0.45	5-6	18.5-19.5	3
3	4	76	18.2	23.58	49.3	0.77	0.37	5-6	18.5-19.5	3.5-4
4	6	76	28.1	32.42	75.0	0.87	0.37	5-6	18.5-19.5	3.5-4
total	14		67.9	77.41	173.1	0.88	0.89			
comment: total time and speed includes:connect rod,retreat rod, unload rod ect and raletive speed.										

Effection of divers elements to gelation and coagulation time of two liquids grout

chart 2

V/C (gravity)	C/S (volume)	density of sodium silicate (Be')	gelation time (s)	submerge degree (mm)	first coagulation time (min.-s)	end coagulation time (h.-min.-s)
	1:0.8		23	31	1-25	1-31-20
0.75:1	1:0.6	30	28	38	1-55	1-48-10
	1:0.4		18	50	2-03	0-59-10
	1:0.2		15	56	32-15	1-2-15
0.5:1			23	17	0-25	0-15-40
0.75:1	1:0.5	30	28	33	1-55	1-48-10
1:1			35	46	2-55	6-42-30
1.25:1			42	49	5-25	11-32-45
		45	40	18	1-10	0-9-0
		40	38	23	1-15	0-18-0
0.75:1	1:0.6	35	23	28	1-25	0-40-0
		30	28	38	1-55	1-48-10
		25	28	47	0-25	2-24-0
		20	25	55	60-00	3-04-0