Improving Efficiency of Sealing Off Water by Pregrouting

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ABSTRACT

In order to improve efficiency of surface pre-grouting in sealing off water in heavily water-bearing strata, such as sandstone, siltstone and limestone, several methods have been used in China, they are ; intermittent pre-grouting, adjusting pre-grouting parameters and stepwise repeated pre-grouting methods. The paper describes effect of deviation on water sealing in pre-grouting. Deviation correction measures, like mechanical, technological and changing hole position methods have been introduced with satisfactory results in practical engineering projects without increasing the volume of engineering project and without causing delay.

INTRUDUCTION

Ground water is the main hazard to deep shaft sinking. Therefore, pre-grouting of the major aquifers before shaft sinking is a necessary measure for successful shaft sinking. Otherwise, inflow of water in shaft sinking will not only worsen sinking conditions, cause delay, but also flooding, injury and fatal accidents.

The paper mainly discusses some aspects of surface pre-grouting in order to improve efficiency of water control.

I. INFLUENCING FACTORS OF SURFACE PRE-GROUTING

When pre-grouting is conducted from surface to water-bearing strata, e.g. sandstone and siltstone and limestone of different grain size, the major targets are fissures and cracks, joints, Karst caves and loosely cemented bedding planes, pores and faulted zone in the strata. They provide space for ground water occurrence and migration paths. When these paths surrounding the excavation stages are filled, ingress of ground water into the shaft can be prevented.

However, there are many factors that affect effectiveness of water control. The geological and hydro-geological characteristics of the aquifers are always changing, which require different types of grout materials. In addition, the level of operational technology has also great effect on the result. That is to say, whether or not three parameters, namely the final injection pressure, final delivery of mud pump and total volume of grout injected can be strictly controlled according to the design, whether or not the technical problems that occur at any time in operation can be scientifically solved, have direct bearing on the success of pre-grouting. We have successful experience and lessons of failure.

From Fig. 1 we can see if the average dispersed distance of the grout in the strata is calculated to be 6 m, the cental hole in the shaft is ineffective, because the grout could not penetrate outside the gross diameter of the shaft. The situation of rest of four holes at depth of 200 m was as the following; the minimum dispersed distance of a hole to the east of the shaft was about 7 m, that of a hole in northwest direction was about 3 m, and that of a hole in southwest direction was only about 0.4 m. i.e. the thickness of the curtain wall in the eastern part of shaft was at least 7 m, and that in the northwest direction 3 m. And the curtain wall in direction of southwest was not closed, and there was a big window. And this window became larger and larger at depths.

In addition, the work team was not familiar with pre-grouting technology, and could not control properly the standards for finishing injection. In some stages, the final delivery of pump at the end of injection was too big, so fissures were not properly filled. In addition , the quality of cement was inconsistent, and no remedial measures were taken to solve the quality problem that might occur in operation. When excavation of shaft reached about 190m, water rushed in, and excavation had to stop. And grouting was conducted again from within the face. This proved that result of surface pre-gouting was not good.

However, surface pre-grouting obtained satisfactory results in many other shafts in Hebei and Shandong provinces due to meticulous construction according to the design and timely introduction of various methods, such as intermittent pre-grouting, stepwise repeated pre-grouting and adjustment of technology to solve all the technical problems that encountered by the constructional unit. Although evident deviation like those of air shaft in Henan was found, the quality of pre-grouting was ensured.

II.METHODS FOR IMPROVING EFFECTIVENESS OF PRE-GROUTING

(I)Technological Methods

1.Intermittent Pre-grouting Method

The intermittent pre-grouting method represents that injection starts and stops many times in one pass of in jection.

When big cracks or Karst caves in the strata to be pre-grouted near the shaft or fissures are well-developed and well-connected., or when the maximum pump pressure is very low, thick grout should be injected at the initial period. If after injecting 2-3 cu. m of grout, the pump pressure still does not go up, we can introduce intermittent pre-grouting method as an alternative of thickening of grout material. That is to say, small amout of clean water is pumped into holes after injection of 2-3 cu. m, and then stops for about 10 minutes, and then injection resumes and stops. This continues for 3 to 4 hours, or when the requirements are met, this time of injection can be ended.

2. Stepwise Repeated Pre-grouting.

The stepwise repeated pre-grouting represents that the standards for each stage are met by several times of injection.

In pre-grouting a deep shaft, usually the entire length of the shaft is divided into several small stages in the range of 20 to 30 m. Injection is conducted stage by stage. When reaching the final depth, injection is repeated upward in great lengths. This method is also called dowward stepwise pre-grounting. When this method is introduced, several or even more than twenty times of injections are necessary in order to meet the standards. This is why it is called stepwise repeated injection. Tables 1 and 2 are statistic figures of 6 grout holes in two groups in stepwise pre-grouting of a central air shaft of a colliery in Shandong province.

In the tables, No.s 1, 3, 5, holes of group 1 were injected in 14 stages. Injection commenced first in No. 1 hole, then No. 3 and No. 5 holes. Holes were kept apart at a distance of about one injection stage from the previous holes, so as to prevent inter-connection of cement grout. No.s 2, 4, 6 holes of group 2 were divided into 12 stages. Of which No. 2 hole was used for pumping water to check the result of stage injection. Water pumping was carried out from 153m to 467 m in five stages. After one stage was drilled downward and water was pumped, then cement grout was injected. The predicted water inflow from each stage based on results of water pumping were 0.66, 0.73, 0.90, 0.54 and 0.91 cu. m respectively.

From tables No. 1 and 2, we can see, the times of injecton of the same stage reduced gradually in the sequence of pre-grouting. And the total quantity of grout injected also reduced remarkably. It indicated that the amount of cement grout absorbed by ground strata reduced after cracks and fissures being filled, and that the technology was successful.

3. Adjusting Pre-grouting Parameters

In surface pre-grouting, the grout material used was mainly cement grout. Accelerator and early strength agents are added, such as, triethannolamine $N(C_2H_5O)_3$ and sodium chloride, NaCl. The proportions of the agents are 0.05-0.1% and 0.5-1.0% of the cement by weight respectively.

As mentioned above, it is necessary to test the borehole with pressure water for 20-35 minutes before pre-grouting. When water absorbed by holes in a stage is greater than 200 l/min., cement and water glass are used. Also several pre-grouting methods, such as intermettent method, stepwise repeated pre-grouting and adjusting parameters, can be adopted when necessary. When parameter adjusting method is used, the initial concentration of grout is selected based on amout of water absorbed by grout strata in pressure water test in the holes. That is to say, when water absorbed is greater than 200 l/min, single cement grout is used instead of two solution process, thick grout should be employed in the initial period, the water and cement ratio of the grout being 0.6:1 or 0.8:1; when the amount of water absorbed is 200-150 l/min, water and cement ratio of 1:1 or 1.25:1 is employed; when amount of water absorbed is 100-150 l/min, or less than 100 l/min., thin grout with water and cement ratio of 1.5:1 to 2:1 is aplied.

When the initial injection concentration is determined, the concentration of grout material should be adjusted in the injection process to suit the concrete conditions, e.g. if after about 20% of the predicted quantity of grout at initial concentration is injected and the pump pressure does not go up, the concentration of grout can be thickened by one grade; if the pump pressure rises too fast, concentration of grout can be thinned by one grade, and so on. i.e., the volume of grout injected is controlled by adjusting concentration of grout material. If a small amount of the thinnest grout is injeted, and if the pump pressure goes up rapidly, certain quantity of clear water may be injected. If necessary, water glass may be injected for pre-treatment. And then a certain amount of water is injected, which is followed by cement grout in order to increase the quantity of grout injected. On the contrary, if great amount of thick grout is injected, the pump pressure does not raise, and can not reach the final pressure and final delivery of pump, injection should stop and wait until next injection commences, i.e, stepwise repeated pre-grouting should be employed.

The dispersed distance of grout can be roughly controlled by changing concentration and pressure parameters, such that the grout may not go too far and cause waste. At the same time, the grout should not be too thick to penetrate cracks or fissurs, or block the water passage, and result in bad quality.

In general, single cement grout is used in pre-grouting. Water to cement ratio falls into 8 grades, namly, 2:1, 1.75:1, 1.5:1, 1.25:1, 0.8:1, 0.75:1, 0.6:1. The ratio is controlled by amount of grout absorbed, which is indicated by pump pressure and delivery. Just as mentioned above, concentration of grout may change many times in one injection until the predicted quantity of grout is injected. The rest will be finished by repeated injections. There is no limit to the times of injection, until it reaches the final injection pressure and delivery.

(II)Method for Overcoming the Influence of Deviation

1. Influnce of Hole Deviation on Injection Results

From Fig.1 we can see bad quality of pre-grouting in a colliery in Henan is mainly due to deviation. Except the special inclined holes, all the parameters for surface pre-grouting are designed for vertical boreholes. Taking into consideration of capacity of machine and technical level of the work team, the permissible deviation is not more than 0.8% of the hole length. If deviation is too high, the grout injected through boreholes may not meet (Fig. 1, southwest direction), and a continuous cylindrical curtain wall can not form, or the curtain wall is too thin to withstand machine vibration in shaft sinking, and can not prevent the pressure water from flowing into the shaft. Therefore, excessive deviation will seriously affect the result of pre-grouting, or even cause flooding of shaft, the downcast air shaft in a colliery in Henan is an example.

Besides, to remedy the effect of deviation, two additional holes were drilled at the auxiliary shafts in two mines in Shandong province. We can take one of the shafts as an example, in the original design, three boreholes were planned to shut off water in Permian red sandstone and limestone of coal measures. All the holes wandered in southwestern direction. The eastern part of shaft was not blocked. A window was found. To prevent the ground water from ingressing into the shaft one additional hole was drilled 8 m from the shaft centre in NE45 deg direction (obviously one hole was not enough), which was No. 4 hole in Fig. 2. The 4-grout-hole scheme not only increased the volume of work, but also caused delay of the project. After excavation, it was proved the result was not so pronounced.

In addition, for correcting deviation, drilling had to stop in many holes, for example, in an air shaft of a colliery correction was made in five of the six holes. The percentage of time for correction as against to the total drilling time (including lowering and lifting of drill tool, drilling with water flushing, and re-drilling) was 25.36% for No. 1 hole, 22.80% for No. 5 hole, 14.52% for No. 2 hole, 51.68% for No. 3 hole, and 7.51% for No. 4 hole. From this we can see deviation not only affects the results of pre-grouting, but also progress of the project.

2. Methods for Overcoming Effects of Deviation

The above- mentioned are only two examples, in fact, deviation causes troubles in pre-grouting in many shafts. In 1983 when surface pre-grouting was conducted in a central air shaft of a colliery to seal off ground water in sandstone, siltstone, Permocarboniferous limestone, several correction methods, such as, changing hole position, the mechanical method, technological method and hole deepening methods, were applied with satisfactory results. These methods are described as the following one by one,

(1) Changing hole position method

a. Determination of hole pattern and optimal diameter of grout hole circle

In the organizational design, all grout holes are equally spaced on a circle with a diameter 1 m greater than the excavated diameter in order to seal off grout water outside the excavated diameter. However, there is flexibility in hole layout, because the grout holes are usually divided into two groups for pre-grouting, i.e. three drill rigs work simultaneously, except high pressure pre-grouting scheme with very few holes(see Fig. 2).

When the optimal number of grout hole is fixed, the greater is the diameter of grout hole circle, the greater is the hole spacing, and the longer the grout dispersed distance. The is irrational, because a series of high pressure equipment and pipelines are necessary, and the material consumption is too high. If the diameter of grout hole circle is too small, e.g. within the net diameter of the shaft, the hole spacing as well as grout dispersed distance becomes too small, and the thickness of curtain wall outside the gross diameter of the shaft is also small. It is unsafe in shaft sinking, and will bring about difficulties in operation due to limited space, and thence, delays progress of the project. In addition, pipes abandoned in the grout holes bring about troubles in shaft excavation.

Fig. 3 is a 6-hole pattern and an ideal curtain wall. Fig. 4 shows the actual grout hole position and deviation plan.

b.Neccessity of Changing Hole Position

If the number of grout holes is more than 3 for a equally spaced hole pattern, holes are drilled in two groups. The first group of holes are drilled according to the design. Then based on deviation regularity and degree of deviation, the position of the second group of holes are adjusted so that the position of all grout holesat each level is evenly spaced, and that a continouns curtain wall may form around the shaft. As shown in Fig 4, No. 1.3.5 holes of 1st grout wander towards the west. The position of No.s 2,4,6 are adjusted, so that holes may wander eastward, and prevent the water inflow during excavation.

(2).Mechanical method

Forced correction method can be applied ,if all the preventative methods are ineffective. Grout hole is sealed at the inflexion poit, where deviation takes place or a kick-sub is lowered. These are called mechanical correction method in general.The former is to seal the hole above the inflexion point.The packer is lowered first, and cement grout is injected. When the cement grout is set. Drilling is made at light weight and low speed. When the course is orientated,normal drilling resumes.

The mechanical correction is applied in two conditions (1)for sealing the hole by lowering the kick-sub to the inflexion point; (2) for guiding purposes, so that the hole will wander toward the pre-determined orientation. For example, kick-sub are used in No. 2 and 4.

(3). Technological method

In Fig 4 the hole spacing at depth in the east and northeast direction of the shaft.additional holes can be drilled. However, this would not only increase the engineering fee by 50,000 Yuan RMB, but also cause delay. After careful consideration it was decided to intensify pre-grouting technology to overcome the effect of diviation.

The main characteristics of this method is to raise the injection pressure and final pump delivery thus to increase the dispersed distance and volume of grout injected.

Again we can take the central air shaft as an example when excessive deviation was found. We increased the final pressure in each stage of injection by taking the upper limit of design pressure, and the final pressure was 0.3-2.5 MPa higher than the design pressure in many stages. The final injection volume for each stage was originally 60 l/min or less. When excessive deviation was found, the final volume for many holes increased to 40-50 l/min. which reached or exceeded the requirements of each stage. The filling propability of cracks and fissures also increased, and they were adequatedly filled. This indicated that the constructional team was meticulous in construction and had high technical level.

(4).Hole Deepening Method

This method is applied to inclined strata, i.e., for grout holes drilled in inclined strata. Although grout holes have reached their designed depth, they actually have not penetrated the final horizon due to deviation. Therefore, the hole length has to be adjusted. And depending upon inclination of the rock strata. Grout holes may be shortened or lengthened.

To sum up, as shown in Fig.4, although deviation of six holes occurred to a different extent, various measures were taken. As a result, the predicted water inflow reduced from 600-112.08 m^3/h to 3.74 m^3/h, and rate of water sealing reached 99.38-96.66%.

In 1985, the shaft reached the bottom, the meassured water inflow at the walling stage being 0.30 m^3/h in minimum, and 2.00-3.5 m^3/h in maximum. This proved that all the technical measures taken were correct. It was one of the best shafts which were treated successfully with surface pre-grouting in the recent years.

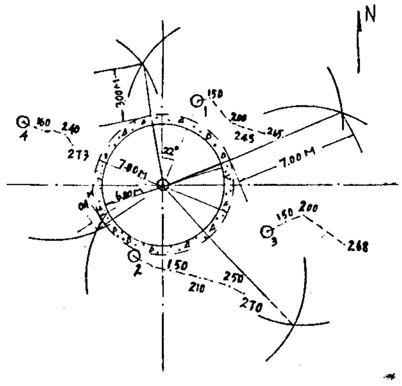

Fig.1 Geometry of grout hole pattern and deviation plan

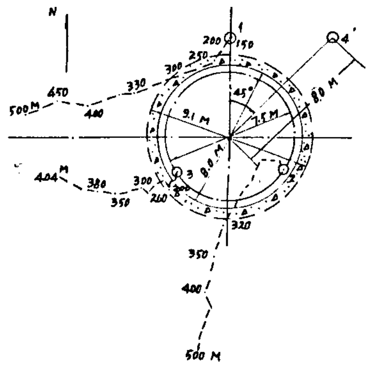

Fig.2 Grout hole pattern and deviation plan of a colliery in Shangdong province

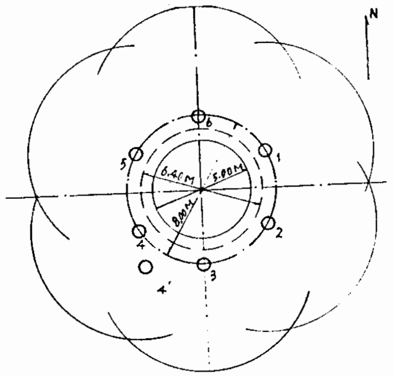

Fig. 3 Grout hole pattern and design of an ideal closed curtain wall for certral air shaft in Shandong

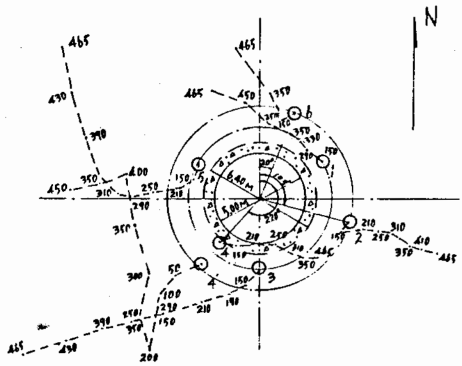

Fig. 4. Actual grout hole pattern in operation and deviation plan of central air shaft of a colliery in Shangdong

Table 1 Injection times of 1st group holes

Hole No.	Stage No.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total grout volume m^3
	Depth m.	0-153 casing	153-168	168-193	193-216	216-241	241-271	271-297	297-322	322-342	342-362	362-385	385-410	410-427	427-452	452-469	
1	Injection times		5	3	3	4	4	6	4	3	3	4	10	5	5	5	108.8o
5			4	3	2	3	4	3	3	3	4	5	6	5	4	2	746.50
3			3	3	3	3	3	3	4	4	4	4	3	3	4	4	628.00

Table 2 Injection times of 2nd group holes

Hole No.	Stage No.	0	1	2	3	4	5	6	7	8	9	10	11	12	Total grout volume m^3
	Depth m.	0-153 casing	153-168	168-193	193-216	216-246	246-270	270-296	296-331	331-362	362-385	385-410	410-435	435-467	
6	Injection times		2	2	3	3	2	4	3	2	2	3	1	1	384.00
4			1	2	2	1	1	2	2	1	3	3	2	3	373.00
2			2	2	2	2	2	2	2	2	2	2	2	2	181.00