An Interdisciplinary Response to Mine Water Challenges - Sui, Sun & Wang (eds)

Treatment Practice for Controlling Water Damage in the Annular Space of Shaft Freezing Hole

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Abstract After unfreezing of frozen wall of shaft constructed by full depth freezing method, the annular space outside the freezing hole and freezing pipe is extremely easy to form conduit pipe which will seriously threaten the safety of mine. West Ventilation Shaft in Qianyingzi Coal Mine adopts the whole freezing method to conduct construction, when the shaft is constructed to the sump of the bottom of the well, due to that partial aquifer of the superior part is unfrozen and the water is effluent, the total water inflow reaches 25 m^3/h, a large part of water "rock" loses, causing an especially large cavern forming along the freezing hole by upward inbreak in one side of the shaft bottom, which will result in the disastrous mine flooding. Through investigation and analysis, this paper boldly adopts "Point to Point Split" grouting method, uses sublevel (gradation), deep hole grouting, effectively treats the flood damage of the annulus of the freezing hole, the water exit channel is effectively blocked, the surrounding rock is consolidated obviously, and the total water inflow of the shaft is reduced to 0.5 m^3/h below. It has created a certain of economic and social benefits on governance effect, time and cost.
Keywords shaft, freezing hole, annulus, water diversion channel, treatment

Overview of the shaft and freezing hole

The shaft depth of West Ventilation Shaft in Qiangyingzi Coal Mine is 327 m, the diameter is 5.0 m, the elevation of the shaft mouth is +25 m, the buried depth of the bottom plate of the ingate is 314.3 m, and the lodgement depth is 12.7 m. The 0-284 section of the shaft adopts three-formation reinforced concrete composite shaft wall; the section from 296 m to the ingate adopts single-formation reinforced concrete shaft wall; and the lodgement adopts plain concrete for pouring.

The shaft adopts whole freezing method to construct, the freezing depth is 332 m, the freezing project started from July 28, 2011, and ends on December 27, 2011. There are 45 freezing holes in total, 30 main drainage holes, among which the depth of 15 holes is 332m, the depth of 15 holes is 287 m/15, and they are arranged alternatively; there are 15 pilot holes (which are frozen targeting at the new formation), and the depth is 230 m.

Hydrogeological condition

According to the column chart of the actually disclosed formation, the thickness of the unconsolidated formation is 228.85 m, and the disclosed thickness of the bedrock is 94.65 m. Combining with the adjacent data of drill hole and the comparison diagram of unconsolidated formation, the unconsolidated formation is divided into 4 aquifers (groups) and 3 aquifuges (groups), the aquifer of oxidation zone of strong and weak breeze, the sandstone aquifer of bedrock section M1 and M2. See table 1 for the main characteristic description of its main aquifer and aquiclude (groups).

The water exit condition of shaft and the preliminary analysis

On January 19, 2012, when the shaft of West Ventilation Shaft is constructed to the lower lodgement depth of 9.2 m, the water becomes effluent from the bottom plate, the preliminary water inflow is about 15 m^3/h, the junction position of the two moulds which are 3.4 m on the top of door of the south ingate, and the amount of water inflow is 2.5 m^3/h. Due to the function of the water flow, the loose rocks in the broken zone of surrounding rock of shaft are

mostly drained to the ground under the drive of water flow, thus, causing one side of the construction lodgement becomes along the freezing hole, the rock mass generates caving, and the range of inbreak cavern is: the height is about 5 m, the width and depth is about 3 m, the water inflow of the lodgement also increases to 20 m^3/h above, plus the water exit of other parts of the shaft, the total water inflow reaches 25 m^3/h.

Table 1 *Schedule of the aquifer and aquiclude division of shaft*

Names of the aquifer and aquiclude	Depth of the bottom plate (m)	Effective thickness (m)	Remarks
No. 1 aquifer	36.13	25.57	The sand formation is loose, and the water abundance is better.
No. 1 aquiclude	47.40	11.27	The plasticity of clay is strong, and the water resisting property is better.
No. 2 aquifer	63.90	14.05	The sand formation is loose, and the water abundance is better.
No. 2 aquiclude	94.20	28.66	The plasticity of clay is strong, and the water resisting property is good.
No. 3 aquifer	164.70	18.65	Containing a little gravel, and the water abundance is ordinary.
No. 3 aquiclude	210.60	45.90	The water resisting property is better.
No. 4 aquifer	228.85	11.93	The water abundance is ordinary.
Intense weathering bedrock	261.60	32.75	The drill core is broken, the water permeability is inferior, and the water abundance is weaker.
Moderate weathering bedrock	270.30	8.70	The drill core is broken, the water permeability is inferior, and the water abundance is weaker.
Fissure of the bedrock section Aquifer of M1 sandstone	281.00	8.00	The water erosion phenomenon of the fissure plane is obvious, and the permeability is good.
Fissure of the bedrock section Aquifer of M2 sandstone	339.00	4.50	The water erosion phenomenon of the fissure plane is obvious, and the permeability is good.

Analysis of water source: Through the comprehensive analysis of water quality, water temperature and water exit formation, it is preliminarily judged that the water source of water exit is of M1 sandstone fissure aquifer water whose buried depth is 281 m.

Reason analysis of water exit: According to the judgment of the downtime of freezing project and the temperature at that time (below -3℃), the freezing hole and the surrounding rock shall not be frozen at the moment, and the water level of the "fourth aquifer" shall also have no obvious changes. The analysis might be caused due to that the local freezing of surrounding rock of the bedrock section is not compacted and the freezing of the shaft bottom is imprecise.

The grouting scheme and the implementation steps

The arrangement of the shaft construction is that after the completion of the shaft bottom lodgement, and then conduct grouting, consolidation and water plugging for the freezing hole and the annulus of the shaft, so as to realize the objective of blocking off each aquifer. But there is a large amount of water exit in the lodgement of the shaft bottom, bringing along the inbreak and running down of most surrounding rocks, meanwhile, the mobilization of the water flow also quickens the unfreezing of the surrounding rocks in the freezing zone, which will definitely cause the further upward inbreak of the surrounding rocks, the onstate occurs from the shaft to the annulus along the freezing hole, and it can cause the bursting of each aquifer of the overlying unconsolidated formation, which will result in the disaster of water bursting and mine flooding. To completely eradicate the occurrence of mine flooding accident, it must conduct grouting, water plugging and consolidation to the freezing hole and annulus surrounding the shaft, meanwhile, conduct grouting, water plugging and consolidation to the surrounding rocks in the water exit area of the shaft lodgement and the ingate etc., so as to ensure the safe and smooth construction of the shaft and ingate. Therefore, conduct comprehensive analysis according to the actual water exit position, the inbreak area, the arrangement of the freezing hole, the buried depth of each aquifer that the shaft passes through etc., through the demonstration of specialists, it forms the following design scheme of grouting, water plugging and consolidation, and implements step by step.

Step I: Conduct grouting to the grout cover and lodgement of the shaft bottom

To provide guarantee for the grouting, water plugging and consolidation of the water diversion channels such as M1 sandstone aquifer, the space behind the shaft wall, the annulus outside the wall of freezing pipe.

It has constructed successively 4 grouting holes at the vertical depth of 305.2 m of the shaft, the hole depth is 3-10 m; 5 grouting holes at the vertical depth of 309.4, the hole depth is 7-9.6 m; 7 grouting holes at the vertical depth of 310m, the hole depth is 3.5-6.5 m; 5 grouting holes at the vertical depth of 313 m, the hole depth is 3.5-6.5 m; 4 grouting holes at the depth of 316m, the hole depth is 6 m; 3 grouting holes at the vertical depth of 318m, the hole depth is 1.5 m; 7 grouting holes at the depth of 327 m, the hole depth is 1.8-6 m. There are 35 holes in total (See fig. 1 for the detailed position). The final pressure of grouting is 5 - 6.2 MPa, the totally grouted cement is 123.15 tons and the water glass is 8.4 tons.

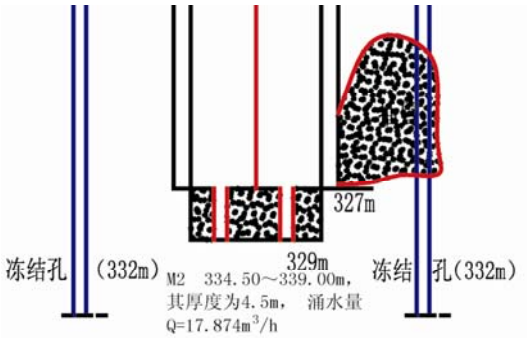

Fig. 1 *Layout diagram of the grouting pad and lodgement at the bottom hole*

Step II: Conduct grouting to M1 (282 m) and the water diversion channel outside the freezing pipe wall (the defreezing section of bedrock)

Aiming at the buried depth of the aquifer of M1 sandstone, in the section of 277.4-287.1 m, it totally conducts 30 grouting holes within the thickness of 9.7 m (See fig. 2 for the specific position), and the hole depth is 10 m. It shall obey the principle of shallow hole with low

pressure firstly and then deep hole with high pressure. The final pressure of grouting is 5-7.3 MPa, the totally grouted cement is 130.05 tons. Meanwhile, it conducts treatment to the leakage section near the ingate and 231 m of the shaft.

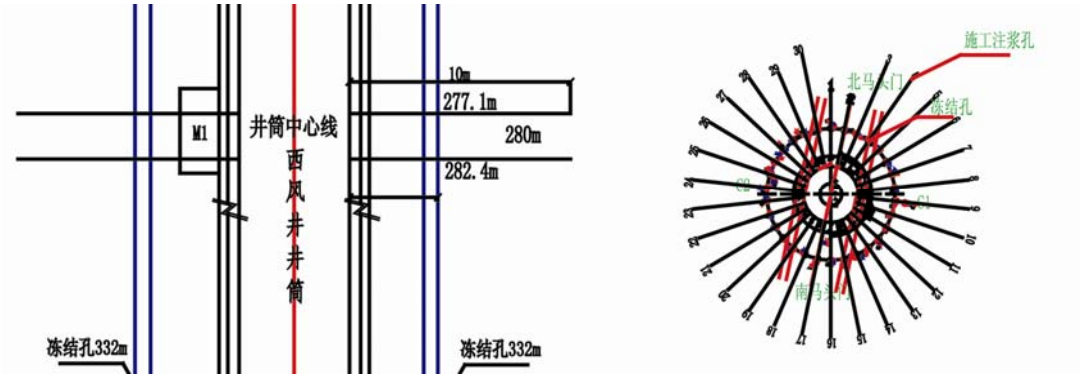

Fig. 2 *Layout diagram of M1 aquifer and the annulus outside the freezing pipe wall*

Step III: Conduct grouting to M1 upper sandstone formation (260 m) and the annulus outside the freezing pipe wall

Aiming at the sandstone formation between M1 sandstone aquifer and the "fourth" aquifer (255.0-261.6 m), the thickness is 6.6 m, and totally 10 grouting holes are laid out (See fig. 1 for the specific position), the hole depth is 10 m, the final pressure of grouting is 5.5-8 MPa, a total of 75.8 tons of cement and 2.5 tons of water glass are grouted.

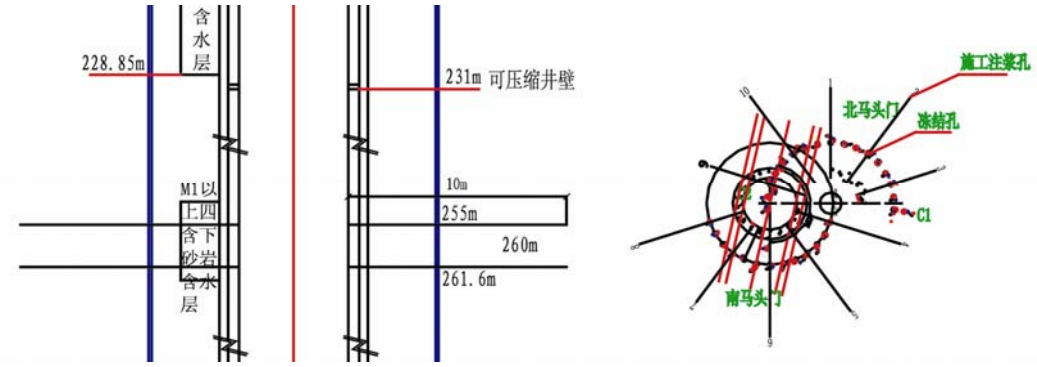

Fig. 3 *Layout diagram of grouting holes in the sandstone formation between M1 and the "fourth aquifer"*

Step IV: Grouting for the annular space outside the wall of the freezing pipe in the upper part (307 m) of ingate

24 grouting holes are arranged in the upper section (307 m) of ingate (See fig. 4 for the specific location), the hole depth is 10 m, the final grouting pressure is 5 - 6.5 MPa, a total of 24.25 tons of cement is grouted. The surrounding rock of ingate is further strengthened at the same time.

Step V: Advanced exploration and preliminary grouting for the deep hole of ingate

Due to the broken surrounding rock at the north and south ingate as well as the occurrence of water exit phenomenon, in order to facilitate the safe and smooth excavation of ingate, the advanced exploration and grouting and water plugging for the surrounding rock at the ingate are conducted for reinforcement. 5 grouting holes are respectively explored and constructed around roadway at the north and south ingate (See fig. 5 for the specific location), there are 10 holes in total, the hole depth is 30 m, the final grouting pressure is 6 MPa, a total of 34.15 tons of cement and 0.4 tons of water glass are grouted.

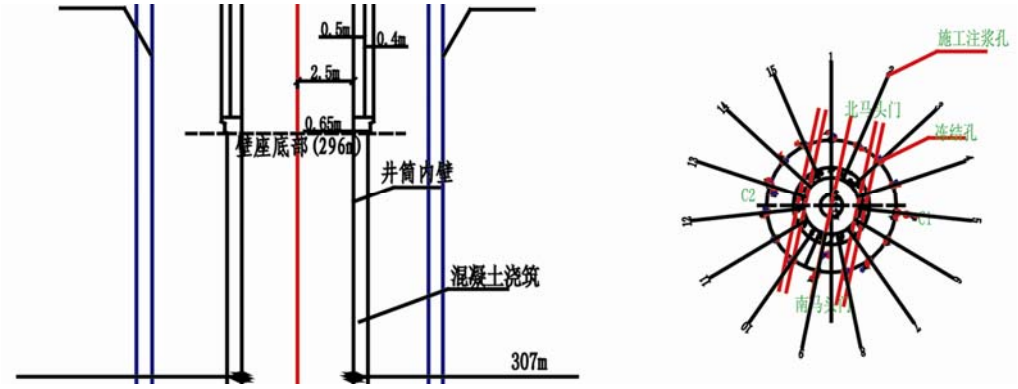

Fig. 4 *Layout diagram of grouting holes in the upper section (307m) of ingate*

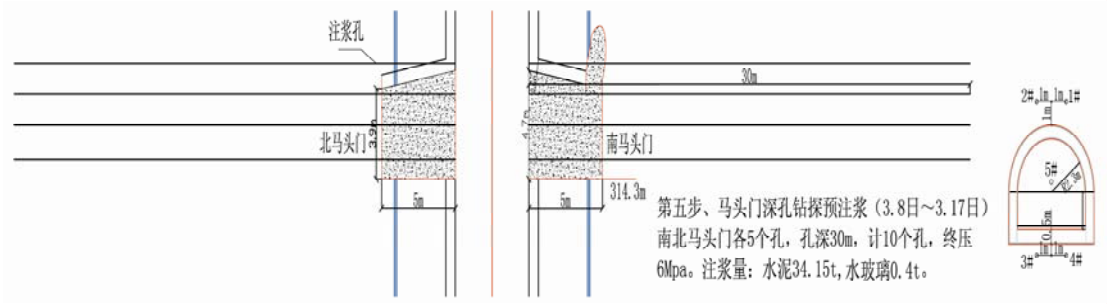

Fig. 5 *Layout diagram of advanced exploration and preliminary grouting holes of ingate*

Analysis of grouting effect

Correlation between water inflow and grouting amount

Upon grouting reinforcement to grouting pad, lodgement and the part near ingate at the bottom of shaft (the amount of cement grouted is 123.15 tons), the water inflow of shaft is reduced from 25 m^3/h to 5.0m^3/h; then upon grouting and water plugging to the upper part of M1 aquifer (282 m) and M1 aquifer (260 m) (the amount of cement grouted is 130.05 tons and 75.8 tons, respectively), the water inflow of shaft is reduced from 5.0 m^3/h to 1.6m^3/h.

In the later stage, the targeted grouting and water plugging for reinforcement is then conducted, the aggregate amount of cement grouted is 387.4 tons, 11.3 tons for water glass, now the water inflow of shaft is less than 0.5 m^3/h (without obvious water exit point). With the decreasing of the water inflow of shaft, the entering of grouting amount while grouting is becoming more and more difficult, the final grouting pressure is also increased gradually. It can be seen that the shaft, annular space of the freezing hole and surrounding rock have been effectively filled and reinforced.

Comparison between grouting amount and grouting space

From the analysis and statistics for the relevant factors of the freezing hole and the annular space outside its wall, the fissure rate of surrounding rock and sandstone, etc. (See table 2). It can be seen that the all kinds of accumulated space volume is 252 m^3, the actual grouting amount is 387.4 m^3. This shows that the grouting effect is significant.

Analysis of grouting diffusion radius

According to the data of the freezing hole of shaft, the inner shaft wall is about 4 m away from the freezing hole, the interval is 1.2 m for the freezing hole of more than 287 m; the

interval is 2.4 m for the freezing hole of 287-332 m. There are 10 holes in the 260m of grouting section of shaft, the interval of hole depth in freezing hole is 3.6 m; there are 15 holes in the 307m of grouting section of shaft, the interval of hole depth in the freezing hole is 2.4 m; there are 30 holes in the 282 m of grouting section of shaft, the interval of hole depth in freezing hole is 1.2 m.

The aforementioned three stages of grouting is split grouting (soft rock and high pressure), the hole depth is 10 m, the final grouting pressure is above 6 MPa, the empirical value split grouting radius is twice of final grouting pressure, which is above 12 m and considerably more than the interval of the freezing hole. The grouting diffusion radius of sandstone fissure aquifer is supposed to be even bigger. This shows that soft rock and hard rock fissure within the range of 22 m outside the shaft wall have been constructed with full and effective grouting, filling and reinforcement.

Table 2 *Statistical table of comparison between grouting amount and grouting space*

Category	Volume (m^3)	Remarks	Comparative analysis
Space in the freezing hole	14	30 holes, with the diameters of 133 – 156 mm	The actual grouting amount is 387.4 m^3, the grout leakage rate is 10%, the grout leakage amount is 23 m^3, and the actual effective grouting amount is 364.0 m^3. It is far greater than the volume of all kinds of spaces: 252 m^3. This shows that the grouting effect is obvious.
Annular space outside the wall of the freezing hole	82	The clearance is taken as 0.05 m	
Fissure rate of sandstone aquifer	133	Sandstone thickness, 14 m in total	
Total	229		

Temperature of thermometer hole

To master the freezing and unfreezing situation of surrounding rock of shaft in a timely manner, three thermometer holes of C1, C2 and C3 are constructed within the scope of freeze outside the shaft in the three directions of east, south and west, respectively. Each of thermometer holes is equipped with temperature probe in the key position (horizon), among which thermometer hole C1 has 17 probes; thermometer hole C2 has 17 probes; thermometer hole C3 has 12 probes. From the statistics and analysis on the temperature of each probe of thermometer hole, it can be seen that when the grouting reinforcement is conducted for the grouting pad, lodgement and the part near the ingate (305-330 m), the probe temperature of each thermometer hole in such a stage is 11°; when grouting and water plugging is conducted for the upper section (307 m) of ingate, the probe temperature of each thermometer hole in such a stage is also 11°; when grouting and water plugging is conducted for the upper section (282 m) of M1 sandstone aquifer, the temperature of each thermometer hole in such a stage is 7 - 17°; when grouting and water plugging is conducted for the upper section (260 m) of M1 sandstone aquifer, the temperature of each thermometer hole in such a stage is 0 - 1°; when the buried depth of freezing hole is above 250 m, the temperature of each thermometer hole in such a stage is 0.2°-3.8°. Thus it can be seen that during grouting, the bedrock section has fully or basically (near the unconsolidated formation) unfrozen, but the unconsolidated formation has not unfrozen yet.

Verification of 30 m slot hole of ingate

Five exploration holes are constructed respectively in the section of 1.0 m above roof, 0.5 m below floor and roadway at the north and south ingate, the diameter of drill hole completed is 50 mm, the hole depth is 30 m, among which there are two holes passing through the wall of freezing pipe (2 for the south and 1 for the north) without water. During the construction of

drilling, there is obvious solid piece of cement, and the grouting can't be conducted after the drill hole is completed. This shows that the grouting is compacted within the range of 30 m away from the shaft wall.

Conclusions

Through the grouting method of "Point to Point Split", after the sublevel (gradation) and deep hole grouting, 30 m advanced exploration and preliminary grouting & water plugging reinforcement engineering for the three bench heights as well as the ingate were completed within 40 days, 387.4 t of cement and 11.3 t of water glass in total were grouted . As a result, it has effectively treated the water disaster in the annular space of freezing hole, the water output channel has been effectively plugged and reinforced, the total water inflow of shaft was reduced from 25 m^3/h to below 0.5 m^3/h (there was no obvious water exit on the shaft wall and at the bottom of shaft), and the water plugging rate was up to 98%.

Through the comprehensive analysis on the factors, such as changing relation of water inflow and grouting amount, the temperature of temperature hole, radius of grouting extent, the exploration and verification condition of deep hole of ingate, etc. The following conclusions can be reached:

(1) The water diversion channel of M1 sandstone aquifer has been closed fully, the surrounding rock has been reinforced obviously.

(2) The interspace between the outer part of shaft wall and surrounding rock has been filled sufficiently.

(3) Freeze the valid replacement which the aperture and annular space outside its wall have got.