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

Key Technology for Grouting behind Wall of Single-formation Shaft Wall in the Surface Soil Segment of Waste Shaft

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Abstract Due to the huge thickness of unconsolidated formation in Huainan mining area, a shaft drilling method was used to construct waste shaft of Xizhuji Coal Mine. After the inspection, Section 54 and 59 of reinforced concrete shaft wall of this shaft located in the lower part of the "third aquifer" was found to have the water inrush point and water seepage phenomenon after the inspection. If the effective treatment measurement is not taken timely, it may cause the expanding water disasters and even mine flooding. Based on the characteristics of early discovery, small water yield, concentrated water seepage etc. of inrush point of the shaft, through comparison and with analytical investigation, a scheme of grouting through shaft wall and key grouting technology measurements were taken to successfully plug the water inrush point of the shaft and achieve preferable results, providing a firm basis for the safety production of mine.
Keywords the third aquifer, shaft, grouting

General situation and hydrogeological condition of the shaft

Located in the north of Huainan Coal Field, the construction of Xizhuji Coal Mine started in 2008, and its designed annual production capacity was 4 million tons. Four shafts of main shaft, auxiliary shaft, air shaft and waste shaft are arranged in the industrial square, among which a freezing method is used to construct the alluvium segment and bedrock weathered zone of the three shafts (main shaft, auxiliary shaft and air shaft), a shaft drilling method is used to construct the alluvium segment and bedrock weathered zone of waste shaft, and a preliminary ground grouting for plugging and an ordinary drilling and blasting method for construction are adopted for the lower part of bedrock segment.

The design net diameter of drilling segment of waste shaft is 5.2 m, the thickness of passing through alluvium is 469.55 m, the drilling diameter is 7.7 m, the drilling depth is 545 m, and the total depth of the shaft is 1,000 m. 0 – 361 m of well depth of waste shaft drilling segment is reinforced concrete shaft wall; 361 – 541 m is double steel plate concrete composite shaft wall (Commonly known as iron shaft wall),the thickness of shaft wall in the unconsolidated formation is 750 mm.

According to the data of inspection hole of shaft, the formation that the shafts of waste shaft pass through is the unconsolidated formation of Cenozoic Erathem and the upper Shihezi Formation of Permian System from top to bottom. The surface soil alluvium can be divided into four aquifers (formations) and three aquicludes (formations). Among which the characteristics of the third to fourth aquifer are as follows:

(1) The third aquifer (formation)

With the well depth of 86.45 - 382.60 m and thickness of 296.15 m, this aquifer is mainly composed of medium sand, fine sand, silt etc. of grayish green - middle and medium thick - thick formation, which are distributed stably in the sand formation area, with the water abundance of medium - stronger. The aquifer is divided by a formation of thick clay in the middle part into the upper and lower part, the thickness of single formation in the upper part is large and the clay content is low. The thickness of single sand formation in the lower part is small, the quality is not pure, and the clay content is higher. The thickness of aquifer sand formation is 159.30 m. According to the data of pumping test, the specific capacity is 0.571 L/m·s .

(2) The third aquiclude (formation)

The well depth is 382.60 - 458.20 m, and the thickness is 75.6 m. It is composed of clay and calcium sandy clay.

(3) The fourth aquifer (formation)

The well depth is 458.20 - 469.55 m, the thickness of aquifer is 11.35 m, and the thickness of sand gravel is 5.1 m. This aquifer is composed of grey white medium and fine sand, gravel formation in the lower part and gravel containing clay. The water enrichment of this aquifer is weaker - medium as diverse. According to the data of pumping test, the specific capacity is 0.042 L/m·s.

Determination of shaft grouting scheme

After three years of completion of waste shaft construction, during the shaft inspection in March of 2013, it was found that Section 54 and 59 of reinforced concrete shaft had the water exit point and water seepage phenomenon, the water yield in half a month was increased from 0.2 m^3/h to 0.7 m^3/h. Through the analysis, it was believed that the shaft at the depth of 313 m and 347m located in the lower part of the third aquifer of unconsolidated formation, among which the formation corresponding to the shaft at the depth of 313 m was a great thickness of fine sand formation with the single formation of 16.4 m; the formation corresponding to the shaft at the depth of 347 m was clay and sandy clay. According to this analysis, the water source of exit point of this shaft was the water of the third aquifer, it was determined as the “third aquifer" water after the analysis through water quality test. The "third aquifer" water level of long-time observation hole of mine is +12.4 m, the water pressure at the two exit points is 3 - 3.3 MPa.

By comprehensive analysis on the situation of water exit of shaft wall, it was believed that water leakage phenomenon was so occurred mainly due to that the combination of construction cold joint or shrinkage crack and steel plate surface with the concrete in the shaft wall was loose, breakstone filling behind wall couldn't plug the water exit point, the high pressure water (3 - 3.3 MPa) of aquifer would directly act on the surface of shaft wall concrete, under the long-term action of high pressure water, the original microcrack in the shaft wall would generate crack, expansion and penetration.

Based on the characteristics of early discovery, small water yield, concentrated water seepage etc. of water exit of the shaft, by comparing and with analytical investigation, it was determined to adopt a scheme of grouting through shaft wall. This method refers to that by conducting the construction of grouting and drilling on the shaft wall, conducting pressure grouting towards the wall after passing the ground producing grout through grouting pipeline, then plug the water exit channel. Combining the bench height of breakstone filling behind wall of shaft in the corresponding place of the third aquifer as well as the lithologic structure of the third aquifer, a scheme of grouting behind wall is adopted within the range of 100m from the upper and lower part of exit point, the construction of grouting is conducted in the uplink way, the bench height of grouting is 10 m. In consideration of a rich aquosity of the “third aquifer”, therefore the first row of grouting hole in the lowest part is arranged in the clay formation at the well depth of about 355 m in the lower part of breakstone filling segment, then it adopts an alternate shield uplink hole drilling for grouting. As a safety precaution, it shall take the technical safety measures.The process includ drill a short hole to install orifice tube and BOP plate, after installing two high pressure ball valves in series, then implement the grouting through the shaft wall.

Technical parameters of shaft grouting

(1) Arrangement form of drill hole

The grouting hole is located at the well depth of 259 – 355 m, the bench height is 10m, a total of 10 rows are arranged with 4 holes per row and 4 m of pitch of holes, two adjacent rows of drill holes are evenly arranged in staggered form.

(2) Drill hole structure and hole depth

The orifice tube of drill hole is made by selecting and using Φ42 seamless steel tube, the length is 500 mm, of which the forepart is processed into a length of 450 mm of Green buckle wrapped with raw hemp, the orifice tube is pushed inside the hole by using a sledge hammer; the rear part is processed into a screw thread of 30 mm, of which 50 mm is exposed. After the pressure test for the installation of orifice tube of drill hole is qualified, then cleaning the bottom of hole and grouting through shaft wall can be conducted, the hole depth is 700 mm.

(3) Types of grout

The grouting behind wall is conducted in the form of single fluid of cement grout. The cement uses No. 425 ordinary Portland cement, sodium silicate uses the one with modulus of 2.8 -3.2, Baumé degree of 40-45, which is used for sealing hole at the end of single-hole grouting.

(4) Grout proportioning

Water cement ratio of single fluid of cement grout is generally 0.75: 1 - 1:1, due to that the breakstone and slurry are filled outside the shaft wall, so after a few barrels of thin grout is firstly poured in, all thick grout is poured in. The volume ratio of cement and sodium silicate is 3:1 - 4:1. It may be diluted with water according to the need of gel time when the water glass is used.

(5) The grouting pressure shall be controlled within the range of 1.5 times of hydrostatic pressure, so as to prevent high pressure from damaging the shaft wall.

Key technology for grouting construction

Technological process of grouting behind wall: drill hole → install orifice tube → install high pressure ball valve → install blowout preventer → carry out pressure test → install grouting pipeline and mixer → fresh water test → measure hydrostatic pressure → grouting → seal hole.

(1) Selection of critical formation for grouting. The waste shaft is constructed by adopting drilling method. It is a single-formation shaft wall, breakstone and slurry are filled outside the shaft wall. The observation is made by drilling hole and found that a large amount of silt and fine sand are contained in the slurry, with no gel. Therefore the selected position of grouting hole at an early stage is critical for safe grouting. Therefore, the first row of grouting hole in the lowest part is arranged in the clay formation at the well depth of about 355 m in the lower part of breakstone filling segment; the third and fifth row of drill hole are also selected to arrange in the corresponding clay area; the second and fourth row are arranged in the corresponding place of sand formation. After grouting in the clay area firstly, then grouting water-bearing sand formation, the grouting order is 1→3→2→5→4, that is the so-called "alternate shield grouting", so as to prevent the drill hole from excessive water yield or causing sand inrush disaster once the shaft wall is broken.

(2) A blowout preventer must be used. The blowout preventer is made of 30 mm×30 mm steel plate with the thickness of 10mm (fig. 1). The aperture diameter of orifice tube is dug up in the center position. A BOP plate is used to lock the orifice tube firmly after the orifice tube

is installed, then the BOP plate is fixed on the shaft wall by four pieces of Φ16×500 mm rockbolts to prevent the orifice tube from being ejected.

Fig. 1 *BOP plate*

(3) The drilling depth must be strictly controlled. After the installation of orifice tube and blowout preventer is completed, a*Φ*28 mm drill bit is used to drill in from the first formation of orifice tube. During the construction of chipping and drilling, the drilling depth must be strictly controlled. The thickness of surface soil segment of waste shaft is 750mm. As 700 mm of hole depth is drilled, it needs to observe the change of the amount of water. Once the amount of water increases or slurry is gushed forth, it shall immediately stop drilling, pull the drill pipe out, finish the drill hole and close the valve.

(4) Prepare grout proportioning well to ensure the quality of grout. During the construction, grout proportioning shall be strictly controlled. The failure agglomerate cement is not permitted. The slurry shall be put into the slurry pool by using transitional sifter and then stirred evenly by using water separator. The slurry produced shall be grouted timely and the storage time shall not be too long.

(5) The pressure changes shall be observed at all time. Due to grouting behind wall, a long time of no pressure rise or a pressure rise abruptly will influence the quality of grouting. Therefore, a pressure meter shall be equipped in the ground grouting station and tube wall of grouting hole under the shaft for observing the pressure change. In case of excessively fast pressure rise, it shall timely stop pumping or reduce the concentration and increase water injection; in case of no pressure rise for a long time, it shall increase the concentration of grout.

(6) The grouting effect shall be analyzed timely and grouting parameter shall be optimized timely. One of the differences between grouting behind wall and grouting between walls in the segment of unconsolidated formation is that the grout for grouting behind wall might be probably penetrated into the drift sand formation, resulting in huge loss of grout. During the actual construction, firstly, the grouting hole at both sides are constructed for blocking grout up, that is for firstly grouting the drill hole with well depth of 259m and 355m, then the uplink grouting scheme is performed, the hole location and construction sequence are adjusted according to the change of grouting pressure.

Problems to note after grouting behind wall

In the process of grouting behind wall of single-formation shaft wall, it needs to notice the following problems:

(1) Shield grouting. Essentially, shield grouting is a segmented grouting and plugging water, and such uplink grouting is conducted in a way of skipping. According to the change of lithologic structure, the adjacent bench heights are generally taken as a grouting unit, the previous bench height is grouted firstly. The hole is located in the place of clay formation to shield the grouting of the next bench height, so as to prevent water or sand inrush disaster.

(2) Staggered grouting. At the time of uplink grouting, the grouting of high drill hole in the adjacent bench heights shall be conducted in the staggered manner, so as to ensure that the grout being grouted is evenly blended with the slurry outside the wall together.

(3) Intermittent grouting. The intermittent grouting shall be done in the manner of stopping for one day after a small shift of grouting, so as to ensure the grout being grouted can be congealed. When grouting for the next time, the previous grouting drill hole or the adjacent drill hole is opened to inspect the grout coagulation situation.

(4) Drawing off the water and slurry is prohibited. In the process of drilling, drawing off water and slurry is prohibited. If a large amount of water and slurry is drawn off, it may cause a turbulent flow of grout behind wall, uneven pressure for the shaft may occur, the stability of the shaft may be destroyed.

(5) Construction of confirmation hole. A certain number of confirmation holes shall be designed and constructed. At the end of grouting engineering, the effect of grouting and water plugging shall be verified, the confirmation hole is generally arranged in the place of drift sand formation.

(6) The quality of sealing hole shall be reliable and ensure absolute safety.

Effect of shaft grouting

A total of 606 tons of cement, 2.135 tons of water glass and 792 m^3 of cement slurry were grouted for the grouting behind wall in the alluvium segment (segment at the well depth of 259 - 355 m) of waste shaft for this time. There was no significant seepage point in the shaft after grouting. The water exit point and water seepage phenomenon occurring to the original reinforced concrete shaft wall of Section 54 and 59 were basically eliminated. By inspecting the shaft after half a year, it was found that all the shaft walls were dry without water, thus the grouting effect was significant.