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Characteristics of Typical Shaft Engineering Water Hazards and The Key Control Techniques and Processes

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Abstract Shafts are the key projects of coal mines. Shaft engineering water hazard which can influence coal mine construction period and production is a common hazard phenomenon during coal mine construction process. Shaft engineering water hazards can be classified into original hazards which include pore water hazard, fracture water hazard and secondary hazard which is freezing pipe thawed water hazard. This paper highlighted pore water hazard, fracture water hazard and freezing pipe thawed hazard. Occurrence characteristics of highlighted hazards were analyzed. Key techniques and processes of typical shaft engineering water hazard control were put forward. Key techniques and processes of shaft engineering water hazards include rotary jet grouting technique applied to shafts through confined quicksand layers, low aperture coal fracture network osmotic grouting process and freezing pipe thawed hazard aquifuge mend technique etc. Actual application effects of different grouting technique and process were illustrated by engineering practices which provide references for similar projects to prevent and control shaft engineering water hazards.
Keywords shaft engineering water hazard, rotary jet grouting, osmotic grouting, aquifuge mend

Introduction

Shaft water inflow is a main factor which restricts shaft construction and coal mine normal production. As a special underground structure, shafts cut through all aquifers from surface to underground. During construction process, shafts were influenced by different types of water hazard such as pore water hazard, fracture water hazard and thawed water hazard. These water hazards can influence normal safe use of shafts and even can cause serious personal casualty accidents. Flooded accidents in shaft building practices also bring huge economic losses. Hongling coal mine and Chenjiagou coal mine were influenced by confined water quicksand and gravel layer pore water hazards. Ningtiaota coal mine, Zhangji Coal mine were plagued by facture water hazard during shafts building processes. Hujiahe coal mine, Mengcun coal mine and Tarangaole coal mine were affected by thawed water hazard on varying levels. These water hazards extended shaft construction period and caused above mines can't be put into production timely. According to different type water hazards, a lot of scientific experiments and engineering practices were put forward by coal mine engineering technicians. Key control techniques and processes of shaft engineering water hazards were formed and developed. The technology has played a positive role in shortening shaft construction period, improving shaft engineering quality and ensuring safe operation after constructions completion.

Shaft water hazard types and water inflow characteristics

Shaft engineering water hazards include original water hazards and secondary water hazards. Original water hazards such as pore water hazard and fracture water hazard are caused by nature factors. Secondary water hazards such as thawed water hazard are caused by shaft construction processes.

Pore water hazard

The pore water hazard is a common water hazard type while shafts pass through confined water quicksand layer. Usually, quicksand layers have characteristics of loose structure, poor cementation, good permeability, big water inflow, high water pressure and liquidity. If shafts encounter confined water and sand inrush, normal excavation engineering will be affected.

Fracture water hazard

If ground water flows into shafts through fractures, water inrush points generally relatively scattered. When water inrush points have hydraulic connections with strong aquifers, water inflow increases suddenly. Generally, while grouting boreholes drilled into fracture aquifers, there will be a large water inflow. Water inflow increases with borehole depth increases. Fracture water hazard may occur during excavation period and also can occur after shaft building period behind shaft walls.

Thawed water hazard

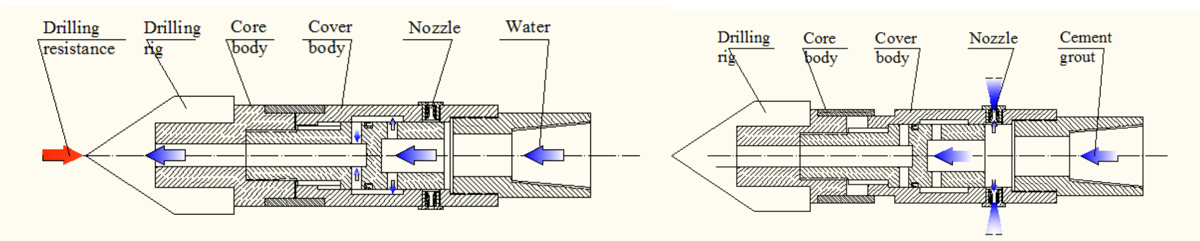
As a special construction method, freezing shaft sinking method was applied widely. But as freezing depth increasing, thawed water hazard became more and more important. Thawed water hazard is a typical water hazard which can affect mine normal production and shaft safe operation. Hydraulic pressure differences between aquifers and underground structures are formed by artificial water channel formed by annular gaps between freezing pipes and freezing boreholes. Hydraulic pressure differences can deform underground structures and even can lead to flooded accidents. Thawed water channel has a large vertical depth which causes inrush water has high velocity and large scouring force. Inrush water tends to carry large amounts of sediment and hollow out surrounding rock behind the shaft wall. The water inrush process threats water hazard global stability and lead to uneven subsidence and cracking accident. If annular gaps between freezing pipes and freezing pipes can't be dealt timely, the ingate and wall weak spots damage will be serious.

Key control techniques and processes

Confined water quicksand layer pore water hazard rotary jet curtain grouting tools and processes

(1) Drilling jetting integrated tool

Drilling and jetting integrated tool was developed to solve borehole collapse and tool sticking problems during secondary drilling process in confined quicksand layers. In drilling process, rotary jet nozzles are sealed by formation resistance. Drilling cuttings removal, cooling and lubrication processes use drilling fluid which flow from the drill rod center to core body connection cavity through combination holes in core body then flow to the drill bit through front combination holes in core body. When rotary jetting, core body connection cavity is closed and rotary jet nozzles are opened by gravity and grouting pressure. High pressure cement grout will be jetted by nozzles to form the jet grouting pile, as the fig. 1.



a: drilling condition ***b: jet grouting condition***

Fig. 1 *Drilling-jetting integrated tool schematic*

(2) Grout protected process under pressure at orifice

In confined quicksand rotary jetting process, if the orifice can't be controlled by a special process, cement grout will be washed away by water then the pile can't be formed. To solve this problem, a special device to protect cement grout at orifice under pressure was developed and used. The grouting valve is opened to discharge circulation liquid and drilling cuttings as the fig. 2.

If cement grout leaked at orifice, the damping body should be tightened to form radial deformation which can seal gaps between borehole walls and drill pipes. Then the grouting valve should be opened slowly to discharge extra grout. After rotary jet grouting, cement-sodium silicate double grout should be grouted through the grouting valve. The orifice device then can be dismantled after grout solidification.

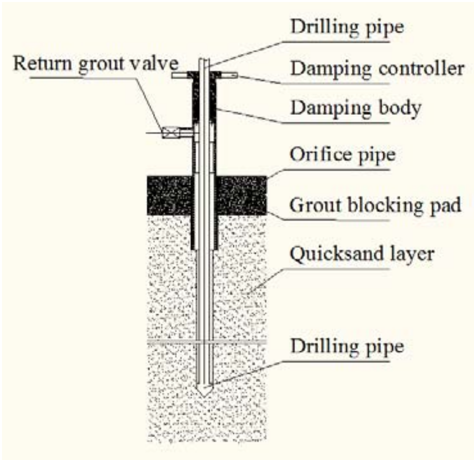


Fig. 2 *grout protected orifice device schematic*

A water and sand inrush accident happened when the east ventilation shaft of Hongling coal mine was excavated at -84 m where there is a confined water quicksand layer in March 2008. The excavation work was stopped because of the accident. A double cycle triple layer jet grouting curtain was formed as the fig. 3. First cycle grouting has two layers, after first cycle grouting the shaft was excavated about 7.5 m. Second cycle grouting pile was grouted after second cycle grout was formed(Zhu 2009). Rotary jet grouting curtain was constructed by the grout protected process under pressure and the Drilling-jetting integrated tool. According to excavation verification, single pile diameter is larger than 600 mm, the consolidation compressive strength is bigger than 4 MPa. The ventilation shaft was successfully excavated to the designed depth safety with no water and sand inrush at confined water quicksand layers.

Low aperture fracture network osmotic grouting technique

The bedrock fracture aperture and fracture connectivity are controlling factors for grouting technological conditions and parameters. Bedrock fracture which is inhomogeneous has obvious development and distribution directivity. Bedrock fractures Osmotic grouting technique use grout to fill bedrock fractures and replace fracture water. Grout diffusion along fractures is affected by bedrock fracture aperture and connectivity which are key factors to determine if the rock body can be grouted. The grouting applicability, grout performance and grouting pressure should be studied synthetically to ensure fracture rock mass grouting quality.

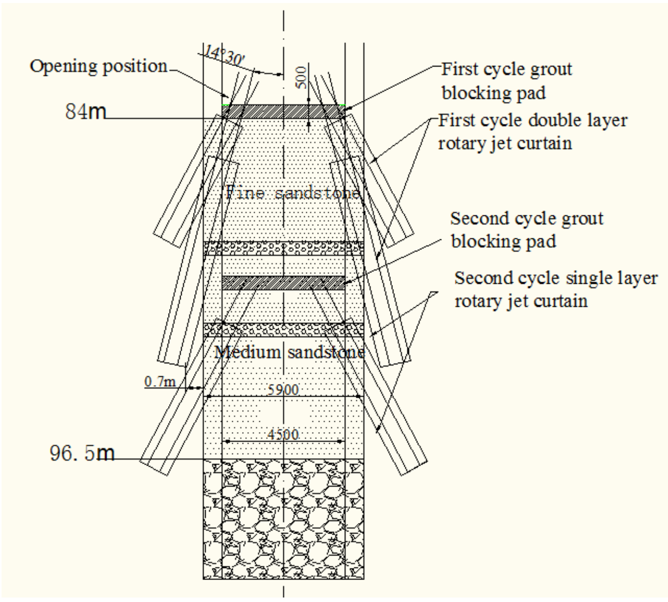


Fig. 3 *Double cycle rotary jet grouting curtain schematic*

For low aperture fracture networks, grouting quantity is very limited. Osmotic grouting technique is an effective approach to ensure grouting quality. Osmotic grouting process presses certain amount of grout to boreholes. If the grout inflow is larger than the fracture grout absorption, part of grout will diffuse in fractures, the rest will return to outside of the borehole through the return grout pipeline. When the grouting pressure increases suddenly, grouting process should be immediately stopped. After the grout diffuse in fractures for a period of time, grouting again with low pressure and small flow. Intermittency, low pressure, low permeability, small flow and repetitive grouting are base characteristics of osmotic grouting.

On April 22 2006, a water inrush accident happened when the 3-1 coal seam central transportation roadway of Ningtiaota coal mine excavated at the 3-1 coal seam with the elevation about +1068 m. Water inflow increased from 10 m^3/h at the beginning to 300 m^3/h. H_2S gas concentration increased and the excavation work was stopped. Osmotic grouting boreholes were arranged along two sides of the roadway at 110 m position. Thin grout with water cement ratio 1-2, low pressure which is not bigger than 1.5 MPa, low flow which is not bigger than 60 L/min, slow seepage and intermittent osmotic grouting technique was used to seal coal seam fracture network(Zhou 2008). The water inflow was decreased significantly and the roadway was excavated safety in 3-1 coal seam with a length of 400 m.

Freezing pipe thawed hazard aquifuge mend technique

(1) Perforating grouting technique

Perforating grouting technique is based on the shaped blasting perforation technology. A specialized perforating gun is placed at a predetermined grouting layer along a freezing pipe, then certain amount of perforating bullets in the perforating gun are directional blasted simultaneously by the electric detonator in the perforating gun to penetrate the gun body and the freezing pipe then go into a certain depth to ground as the fig. 4. Freezing pipe and ballistic holes are used as surface grouting pipes to seal the target layer.

Perforating grouting process flow is from installing and placing perforating gun to perforating broking pipes to placing grouting pipe to sealing orifice to grouting to quantitative water injection to orifice unsealed to lifting up grouting pipe.

After freezing holes thawed, annular space is unblocked, surrounding rock of shafts is easy to absorb grout. Perforating grouting is effective to form water proof body. If the perforating grouting is only applied in aquifers, upper aquifers groundwater still can flow around the water proof body to lower annular space after fully thawed. So the perforating grouting also should be applied in aquifuges to achieve the purpose to mend aquifuges. Meanwhile forced thaw measures of freezing pipes should be used to satisfy perforating grouting conditions (Wang et al. 2004; Qiu 2007).

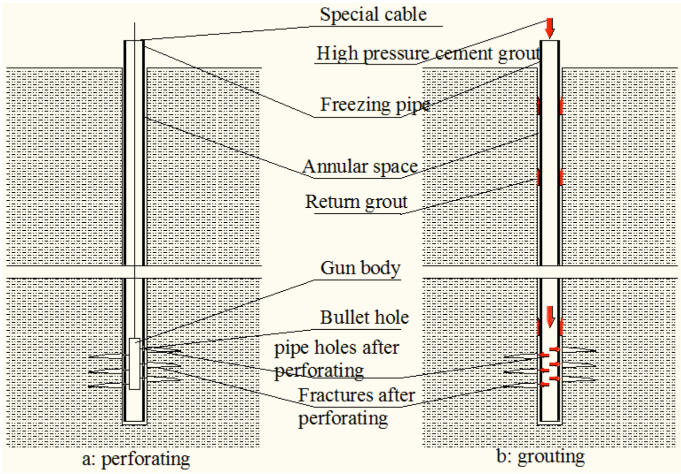


Fig. 4 *Perforating grouting principle schematic*

Perforating grouting technique was applied in Mengcun coal mine to deal 77 freezing holes of the main and auxiliary shafts. Segmented grouting method was used in each borehole. Each borehole was divided to two segments from top to bottom to apply perforating grouting. In the whole grouting process, 562.7 t cement grout was grouted at the main shaft and 1026.4 t cement grout was grouted at the auxiliary shaft, in total 1589.1 t and 154 times. Annualr space water conducted problem was solved to ensure mine normal construction. According exposed freezing pipes by the loading chamber and the ventilation connection roadway, annular space and freezing pipes were filled with cement and there is no water conducted phenomenon. Perforating grouting is effective to seal annular space water channels and auqifer fractures near shaft bottoms.

(2) Annular concrete water proof body constructed technique

The technological flow of annular concrete water proof body constructed technique is from annular measure roadway and chamber excavation to water exploration pre-freezing pipes explosion to consolidation pre-treatment to freezing hole and annular space treatment to concrete pouring of chamber and measure roadway, as the fig. 5.

A water inrush accident with water flow 100 m^3/h was happened when No.9 freezing pipe was exposed at ventilation connection roadway connected process in Hujiahe coal mine on January 23, 2011. Main shaft equipments installation and mine production were affected by the water inrush accident. Annular measure roadway was used as the solution to solve freezing pipe and annular space water conducted problem. Annular measure roadway was built at grit stone layer where -432 m ventilation connection roadway connected with the main shaft. The distance from the inside of annular measure roadway to the main shaft center line is L=10.75 m. Thirty six freezing pipes were dealt by the annular concrete water proof body constructed technique. The threat of freezing pipe water hazard to the main shaft and its auxiliary equipments was solved thoroughly.

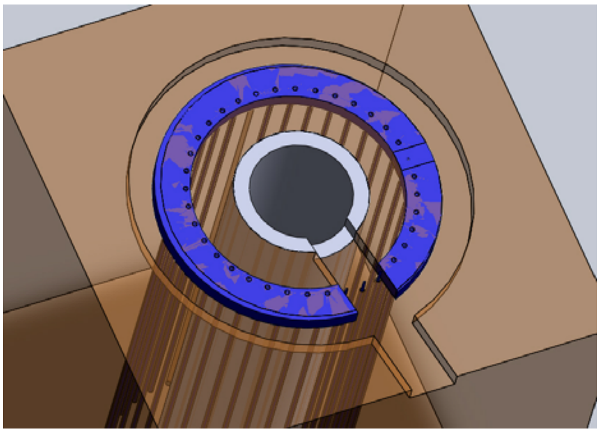


Fig. 5 *Freezing borehole water hazard dealt by annular measure roadway and chamber*

Conclusions

(1) Shaft engineering water hazard can be classified into original water hazard and secondary water hazard. According to water source, original water hazard includes pore water hazard and fracture water hazard, secondary water hazard mainly refers to freezing pipe thawed water hazard.

(2) Rotary jet curtain grouting technique is effective to deal shaft confined loose sandstone water. Drilling and jetting integrated tool can solve borehole collapse and tool sticking problems during secondary drilling in confined quicksand layers. Confine grout protected rotary jet grouting process solve the grout leaked problem under confined water condition at the orifice. The jet grouting pile constructed by previous technique has high strength and can ensure shafts excavated through confined water quicksand layer successfully.

(3) High concentration and low aperture of coal mass fracture, low pressure, intermittency and small flow osmotic grouting process was applied to decrease mine water inflow. The grouting effectiveness is significant. The shaft was excavated in coal seam for 400m successfully.

(4) Thawed water hazard is a kind of shaft water hazard induced by freezing pipes and annular space conducted with upper aquifers as vertical water channels. The basic ideal of this kind water hazard control is choosing a proper layer to mend the aquifuge to eliminate water conducted effectiveness of vertical water channels. Perforating grouting technique and annular concrete water proof body constructed technique are two grouting techniques to deal thawed water hazard from surface and under the shaft.

Acknowledgements

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