Key Technology of Directional Drilling for Water Prevention and Control of Bottom plate Limestone in Zhangji Coal Mine

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Abstract: The coal of group A in Zhangji Coal Mine is seriously threatened by limestone water damage. We use the directional drilling equipment to construct along the strata long drilling and explore the limestone aquifer of the working face bottom plate. According to the characteristics of the formation, the directional drilling casing hole section, rotary drilling hole section, directional bevel hole section, and directional stability. The construction methods and key technology of the inclined hole section are analyzed and researched, and the 1414A working face is selected for directional exploration drilling for practical verification. The results show that the directional long drilling technology realizes the full coverage exploration of the working face bottom plate. The target layer has a high drilling encounter rate. The one-time exploration distance is long, which effectively solves the safety risk caused by the bottom plate limestone water damage to the working face safety production. Realizing the promotion of directional drilling equipment in the field of water prevention and control in Huainan Coalfield.

1. Introduction
As coal mining goes deep, the distance from the limestone water of the high-pressure aquifer is getting closer, and the mining risk increases exponentially. When the water-resistant layer between the coal bottom plate and the aquifer is thin, the continuity of the water-resistant layer of the coal bottom plate will be destroyed under the action of mining pressure, and its water blocking capacity will be reduced. When it spreads to high-pressure aquifers, water inrush accidents from the bottom plate will occur[1]. The coal mine water prevention and control work follows the principle of "prediction and forecast, exploration in doubt, exploration before excavation, treatment before mining", and comprehensive treatment measures of "prevention, blocking, drainage, drainage, and interception" are adopted. The coal mine underground kilometer directional drilling rig is used, and the screw motor is used as the power tool at the bottom of the hole, and the drilling trajectory design and control theory are used to realize the directional drilling of near-horizontal long boreholes. At present, it is widely used in coal mine roadway fire prevention, underground gas drainage, bottom plate grouting reinforcement, geological detection, emergency water blocking and other fields[2].

Zhangji coal mine belongs to the Huainan coalfield area, and coal 1 is located in the lower part of the first coal-bearing section. The thickness of the coal seam is 0〜10.74m, with an average of 6.46m. The coal-bearing area is 57.35km², of which the minable area is 53.59km². The thickness of the coal seam within the minable area does not change much, and it is basically a relatively stable coal seam that can be mined in the whole area. In view of the large proportion of coal reserves in coal mine A, high coal quality and low mining cost, under the current situation, in order to improve the quality and
efficiency of mine development, Zhangji Mine rationally optimized the stope layout according to the occurrence of coal seams, and adjusted the mining center of gravity to Group A coal is a high-quality resource. However, the 1st coal seam bottom plate in the minefield is 17.07m away from the first limestone layer of the Carboniferous Taiyuan Formation, and the maximum underground limestone head pressure is 6MPa, which exceeds the maximum allowable water pressure of the 1st coal seam bottom plate rock. Therefore, the limestone of the Taiyuan Formation is a direct water-filled aquifer in the 1st coal seam bottom plate, especially the fault zone that faces the coal seam and the limestone\cite{3}. It is often a direct channel for water inrush from the 1st coal seam bottom plate, and the possibility of water inrush from the fault zone is greatly increased. Regional data show that the Ordovician water at the bottom can be directly hydraulically connected with the Taihui aquifer due to faults, collapse columns and other structures. That is coal seam 1 is not only threatened by the limestone water of the Taiyuan Formation on the bottom plate, but also threatened by the Ordovician water. According to the production plan, in order to ensure safe mining of the working face, directional drilling technology was used to construct a large number of directional long boreholes in advance of the limestone water hazard in the coal bottom plate of Group A to explore the vertical guiding structure and drain the karst water of the limestone aquifer.

2. Directional drilling equipment and instruments
The underground crawler tunnel kilometer drilling rig in coal mines has the advantages of convenient relocation, controllable trajectory, high drilling accuracy, wide drilling coverage, no blind areas, high target horizon and low comprehensive cost, and can realize parallel mining operations. Directional drilling equipment mainly consists of downhole directional drilling rigs, full hydraulic crawler pump trucks for downhole directional drilling in coal mines, measurement while drilling systems, screw motors, probe pipes, drill pipes, explosion-proof computers, etc. (Figure 1), and main equipment drilling parameters See Table 1.

![Figure 1 Directional drilling process](image)

| Name                  | Model     | Parameters                        | Function                                           |
|-----------------------|-----------|-----------------------------------|---------------------------------------------------|
| directional drilling rig | ZDY-12 000LD | angle adjustment range: -20°~20°; motor power/kW: 132 | external power, trajectory adjustment, composite rock fragmentation, feed/pull |
| mud pump              | BLY460    | pump pressure/Mpa: 0~13.8; flow rate/L·min⁻¹: 0~460; motor power/kW: 132 | hole power, drive motor to rotate and discharge slag |
| screw drilling tool   | φ89mm     | rated output torque / (N·m): 810 | drive the drill bit to crush the rock and make the drilling deviation |
| measurement while drilling system | YHD2-100 0(A) | error range/ (°): Inclination angle:0.2, azimuth:1.5, tool facing angle:1.5 | Data transmission, display, calculation, power supply |

3. Directional drilling design
The directional drilling design mainly includes the opening horizon, the opening dip angle, the opening azimuth, the casing section, the tilting section and the stabilizing section. It adopts a three-level hole depth structure and is drilled in clean water\cite{4}. As shown in Figure 2 and Figure 3.
3.1 Drilling trajectory design

The author takes as an example that the limestone water disaster control of the 1414A working face in Zhangji coal mine. The 1414A working face belongs to the Xi'er 1 coal mining area. The karst fissure aquifer consists of three parts. Among them, the Cenozoic loose porous aquifer developed at the bottom of the composite water barrier composed of a stable partition + "red layer", which can effectively block the hydraulic connection between the Cenozoic aquifer and the lower coal-measure formation. According to the Xi'er 1 coal mining area 1413A The exploration results of the bottom plate failure zone of the working face show that the bottom plate failure zone of the coal face of Group A will not affect the underlying Ordovician ash and cold ash strata after the coal face of Group A is mined. The aquifer (group) basically has no hydraulic connection, but if there are subsidence columns or other water channels developed in the too ash and Ordovician stratum, Ordovician water may threaten the mining of 1st coal. Therefore, the main threat of water hazard in mining at 1414A working face is the limestone aquifer of Taiyuan Formation in the 1st coal seam bottom plate. It is necessary to use downhole directional long boreholes to drill the abnormal area of 1414A working face at the outer entrance of the bottom roadway of 1415A. The hole is located at the lower part of C31 ash, and it needs to pass through 5 layers of mudstone and 5 layers of limestone[5]. Due to the interaction of soft and hard, the mudstone swells and shales in contact with water, and the risk of hole collapse is greater. The target horizon is C36 gray, and the directional drilling is along the C36 target horizon. See table 2 for specific drilling parameters[6].

| Name | Open hole inclination (°) | Open position (°) | Stop stratum | Stop hole inclination (°) | Stop position (°) | Hole depth (m) |
|------|---------------------------|-------------------|--------------|--------------------------|-------------------|---------------|
| K1   | -17                       | 5                 | C36          | 10.00                    | 1                 | 650           |

3.2 Drilling structure design

The bottom plate of 1 coal seam is alternately composed of limestone, mudstone, sandstone, and limestone. There are many sandy mudstones and aluminum mudstones in mudstone, and the risk of hole collapse is higher. In particular, long-term directional drilling, high-pressure mud back and forth circulation and screw motor vibrations greatly disturb the formation, and are very easy to collapse, hold the drill, and produce new holes. In view of the above special stratum, the drilling adopts a
three-level hole structure\cite{7}, as shown in Figure 4. The primary casing is mainly used to protect the orifice, install blowout prevention, four-way equipment, etc.; the secondary casing runs deeper into the hole, and the main function is to protect the wall, penetrate the unstable stratum, and run into the relatively complete limestone section. To protect the safety of the front section of the borehole, avoid the occurrence of directional drilling near the drill bit and the occurrence of hole collapse in the front section of the borehole; the third-level bare hole section is mainly drilled along the target horizon through a directional drilling tool, so as to maximize the target horizon.

The first-level hole structure: the diameter of the hole is 193mm, the construction is 12m, and the \( \Phi 178 \times 8 \)mm orifice pipe is inserted (single length is not less than 1m), the total length of the casing is not less than 10m, and the use label is P.O42.5 ordinary Portland cement cement pipe.

Secondary hole body structure: the hole diameter is 158mm, the construction is 36m, and the \( \Phi 146 \times 8 \)mm orifice pipe is inserted (single length is not less than 1.5m), the total length of the casing is not less than 30m, and the use label is P.O42.5 Ordinary Portland cement cement pipe.

Three-level hole body structure: the hole diameter is \( \Phi 120 \)mm, the hole is bare, and the hole is drilled directionally to the depth of the designed hole.

![Figure 4 Schematic diagram of the three-level hole depth structure](image)

The orifice safety device uses a DN150 gate valve to ensure that the orifice can be closed in time when drilling into a large water and high-pressure aquifer, as shown in Figure 5. To drill the hole, first place the orifice pipe and conduct a pressure test. Before the formal construction, the orifice safety gate valve must be installed to ensure the control of the water release. The pressure resistance of the safety gate valve should be greater than 1.5 times the head pressure of the area. Orifice tube sealing standard test: fix the hole for more than 48 hours, sweep the hole out of the casing 0.5m, use the mud pump to inject water into the hole to hold the pressure, keep the pressure at 1.5 times the maximum water pressure, and observe for a duration of 30 minutes\cite{8}. Whether there is leakage near the hole wall and the orifice pipe, if there is no leakage, the solid hole is qualified; if there is leakage, grouting needs to be continued.

![Figure 5 Schematic diagram of orifice device](image)

4. Key technology for directional drilling

4.1 Drilling design technology
The inclination and azimuth of the borehole opening section is the key to the borehole construction. The coal bottom plate limestone, mudstone and part of the sandstone in Zhangji Coal Mine 1 are soft
and hard. During the drilling process, hole collapse and sticking are very easy to occur, and the old hole section cannot be entered again by the drilling tool, which makes it impossible to continue drilling. Therefore, in the drilling design process, it is necessary to avoid reducing the distance across the interval, and use low drilling pressure, high drilling speed to ensure the safety of the drilling tool, and penetrate the mudstone interval as soon as possible. It is limited to the range of -20°~20° of the drilling rig’s main shaft angle. Therefore, when the drilling inclination meets the on-site construction situation, the hole is opened at a large angle and feeds quickly[9]. By adding straight-keeping drilling tools to ensure that the inclination is in the mudstone and ash, the rock interface changes too much, which affects the distance to the target horizon. Due to the limitation of underground construction space, the azimuth difference with the target should be minimized as far as possible under the condition of meeting the normal production of equipment[10]. Avoid increasing the blind area and reducing the effective footage due to the large difference.

4.2 Drilling craft technology
The Platts hardness of limestone is generally above 6, which is a hard rock. In the process of drilling with conventional polycrystalline diamond composite drill bits, the drilling efficiency is low and the construction is more difficult. The conventional solution is to use rotary drilling instead of directional drilling to increase drilling efficiency, but the drilling trajectory cannot be adjusted. When entering the target layer, it is difficult to use directional drilling tools to correct the deviation, which causes the drilling to deviate from the purpose of pre-reinforcement. Stratum. The combination of sliding drilling and compound drilling is adopted, compound drilling is the main method, and sliding drilling is auxiliary. After the composite drilling technology has penetrated through the hard rock, the measurement-while-drilling directional drilling technology is used to correct the deviation[11]. When the target layer dip and azimuth are stabilized, the composite drilling method is used for drilling again. It not only significantly improves the efficiency of drilling holes, but also allows for proper deflection, ensuring the smooth implementation of measurement while drilling directional drilling in the later stage, forming a rapid drilling technology for rock formations.

4.3 Drilling determine the level technology
Zhangji Coal Mine is part of the Huainan Coalfield, with complex geological conditions, and widespread presence of folds, collapsed pillars, and faults. After the directional drilling reaches the target horizon, due to the existence of the structure, the layer is very easy to emerge during the drilling process, and it is particularly critical to accurately determine the top or bottom. Using the method of 1m one drilling slag, by analyzing the lithological changes and the color change of the backwater, the out-of-layer condition of the target horizon can be judged. The thickness of the limestone formation at the target horizon is small and fluctuates with the terrain. The limestone roof and bottom plate mudstone are soft. After drilling into the target layer smoothly, due to the geological structure or terrain fluctuations, the drilling hole can easily drill out of the target layer and cause the hole wall to collapse. The pump was held back and the directional drilling could not be continued. Since the borehole trajectory of the bedding hole section is nearly parallel to the dip angle of the rock formation, it is difficult to effectively solve the problem by using orifice grouting and reaming methods. A branch point is reserved every 80 m interval during the construction process. When hole collapse occurs and the stuck drill is unable to continue drilling, analyze the horizon of the drilled hole in time, adjust the vertical height of the drill through the judgment result, and then withdraw the drill to the nearest branch point to branch off the side drill[12]. Adjust the borehole trajectory in time to ensure that the borehole extends smoothly in the target layer until the designed hole depth.

5. Conclusion
(1) A set of directional drilling technology has been formed for the treatment of limestone bottom plate water in Huainan coalfield, especially the Ordovician water and too gray water of Zhangji coal mine bottom plate, which provides technical support for the smooth construction of directional drilling for
prevention and control of bottom plate water.

(2) Through the use of large-angle rapid drilling technology, three-stage casing technology, composite drilling and sliding drilling combined drilling methods, and sidetracking and branching process methods, the full coverage of the working face bottom plate has been explored. Integrated technologies of "exploration, dredging, and reduction" such as hidden structure exploration and drainage and pressure reduction have been formed. The directional drilling target layer has a high penetration rate and significant economic benefits, which solves the problem of water hazard detection.

(3) The use of a complete set of directional drilling equipment to prevent water from the bottom plate can improve drilling efficiency, expand effective working face control, reduce mine tunnel excavation costs, shorten working face mining time, and provide a guarantee for coal mine safety production.

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