

## Research Article

# Migration Characteristics of Boring Mud in Roadway Floor Anchor Wire Hole and Test in Coal Mine

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Given the difficulty in drilling the anchor holes in the roadway floor of the coal mine, the characteristics of slag movement in the process of positive and negative circulation drilling are analyzed. It is concluded that the interaction between the three zones of drilling and slag is the fundamental reason restricting the rapid drilling of the anchor cable hole in the floor, and it is proposed that the pump reverse circulation drilling can effectively prevent the formation of the three zones of drilling and slag. According to the actual situation, the relationship between drilling depth, vacuum degree of the pump, and the velocity of drilling fluid and the volume of drilling slag is obtained. The results show that the pump suction reverse circulation is feasible for the rapid drilling of the anchor hole of the floor. A set of pump suction reverse circulation drilling systems has been developed, and floor anchor wire hole drilling and slag discharge operation at the same time were realized. The field test shows that the effective drilling time of the anchor cable hole in the depth of 5.6 m can be controlled within 30 min, which solves the problem of deep hole drilling in the anchor hole of the bottom plate and purifies the working environment.

## 1. Introduction

The large deformation of the deep mine roadway surrounding rock is mainly manifested as a strong bottom drum phenomenon, and the bottom drum volume accounts for 2/3~3/4 of the amount of the roof and floor moving [1, 2]. The research shows that [3, 4] the roof and floor of the deep mine roadway and the two groups of surrounding rocks are an interactive organic unity. The generation of bottom drums aggravates the process of the overall destruction of the surrounding rock of the roadway and is the key to the overall instability of the surrounding rock of the deep roadway. The formation of the bottom drum aggravates the process of the overall destruction of the surrounding rocks of the roadway and is the key to the overall instability of the surrounding rocks of the deep roadway. In deep and high-stress roadways, the type of bottom drum is a stress-type bottom drum. Due to the large scope of floor anchor cable reinforcement, such methods as applying high pretensioned force and

anchor cable grouting can be adopted, which not only are the most effective means to treat floor drum but also play an important role in the overall stability of roadway surrounding rock [5, 6]. Anchor holes in coal mine tunnels basically adopt the positive circulation of flushing fluid to discharge slag into holes. The factors affecting the drilling speed are different floor lithology, the size of the rock-breaking particles of the drill bit, the type of flushing fluid, and the pressure of the flushing fluid. At present, domestic and foreign studies [6, 7] have adopted the use of tunnel drilling rigs to drill the holes in the anchor holes of the floor, flushing the holes with high-pressure wind or high-pressure water. Although these methods can be used for effective drilling, the floor has accumulated water or the roadway is not full of dust. Environmental degradation [7, 8]: more importantly, the depth of the anchor cable hole is large. When the tunnel drilling rig is used for circular drilling, stuck drills, holding drills, and drilling slag cannot be discharged after the drilling depth exceeds 3.0 m [9, 10]. It is

difficult to implement rapid drilling [11, 12]. Holes have become the key to restrict the rapid drilling of anchor holes in the bottom plate [13, 14]. Therefore, it is necessary to clarify the movement rule of boring mud during the floor anchor wire hole, which provides an important theoretical basis for the research on the construction technology of the anchor hole of the bottom plate [15, 16].

## 2. Characteristic Analysis of Deep Hole Drilling and Slag Discharge for Anchor Hole in the Bottom Plate

**2.1. Characteristic Analysis of Slag Discharge during Anchor Hole Drilling in Bottom Plate.** At present, the anchor hole of the coal mine floor mostly uses positive circulation hydraulic or wind slag discharge. The slag discharge power of the slag discharge system does not come from the power of the drilling rig, but from the external flushing fluid, as shown in Figure 1, the schematic diagram of the slag discharge system of the positive circulation flushing liquid [17–20].

The flushing fluid enters the bottom of the hole along the flushing fluid route from the central channel of the drill pipe and rinses the bottom hole and the cooling bit. Then, the drilling slag carried by the washing fluid is discharged out of the hole along the annular clearance line between the drill pipe and the drill hole to realize the positive circulation and slag discharge drilling.

Under the action of the washing liquid, the drilling slag particles will form three zones in the annular space: the upper area of drilling slag, the area of drilling slag accumulation, and the area of drilling and slag extrusion, as shown in Figure 1. When the anchor holes are drilling, the three zones are formed successively in a dynamic way and will eventually exist at the same time. The drilling slag upper return area is directly affected by the formation of the drilling slag accumulation area by the effect of flushing fluid pressure and drilling slag particles. The drilling slag accumulation area, in turn, restricts the fluid pressure of the drilling slag upper return area and the size of the drilling slag particles passing through this area. Once the slag accumulation area is formed, the drilling slag will accumulate quickly. If continuing to drill, the drilling slag pressing area will be quickly formed; when the drilling slag pressing area reaches a certain level, the drill rod will be drilled by the drilling slag pressing area hold on. During the drilling process, the continuous lifting of the drill or increasing the pressure of the flushing fluid destroys the formation of the drilling slag accumulation area to a certain extent and relieves the formation of the drilling slag squeeze area in a short time, so that the drilling can be sustained. But continuously lifting the drill, the slag in the squeeze area will fall back to the bottom of the hole, causing the drill bit to repeatedly break the slag, which is beneficial to the discharge of the slag to a certain extent but greatly reduces the speed of drilling and increases to a certain degree of flushing pressure. The pressure supply equipment needs to be increased but the hole wall is seriously damaged and the working environment of the roadway deteriorates.

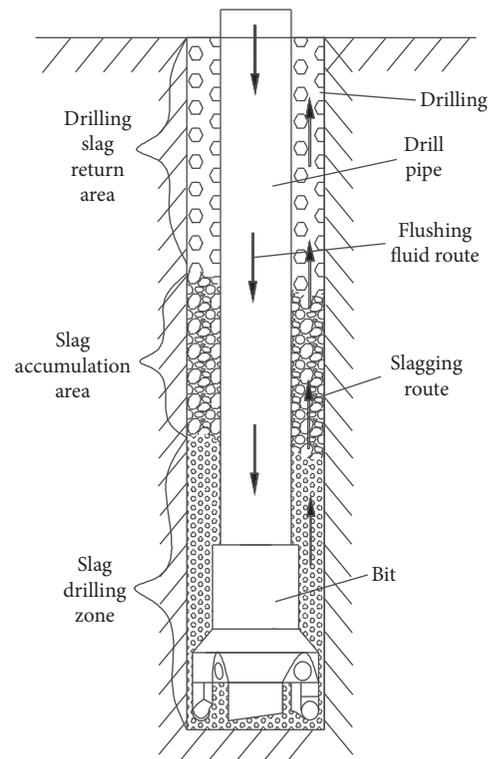


FIGURE 1: Diagrammatic sketch of flush fluid normal cycle deslagging in floor anchoring hole drilling.

To a large extent, avoiding the interaction between drilling and slag, three areas are the key to speeding up drilling speed. However, due to the limitations of drilling tools, it is difficult for workers to predict the formation of drilling and gathering areas due to the operation of machines and tools, resulting in extremely slow drilling speed of floor anchor holes, which cannot meet the needs of the development of roadway floor anchoring technology.

**2.2. Characteristic Analysis of Pumping Reverse Circulation Slag Discharging for Anchor Cable Hole.** Because of the insuperable limitations of the circular drilling and slag discharge in the bottom anchor cable hole, it is difficult to popularize the field. Reverse circulation drilling is divided into pressure feeding reverse circulation and pump reverse circulation drilling. In the reverse circulation drilling, the high-pressure pump is used to send the washing liquid through the drill pipe to the bottom of the hole, and the flushing fluid is discharged from the pores between the drill pipe and the hole wall, resulting in the deterioration of the working environment of the roadway floor. If a double-wall drill pipe is used for drilling, the drill pipe cannot be automatically discharged from the hole because of the poor sealing quality between the hole wall and the drill pipe.

Pump suction reverse circulation drilling slag discharge [15] is based on the suction force of the pump, which can draw out the hole from the bottom of the hole and realize the simultaneous drilling and discharging of the bottom anchor cable hole, as shown in Figure 2.

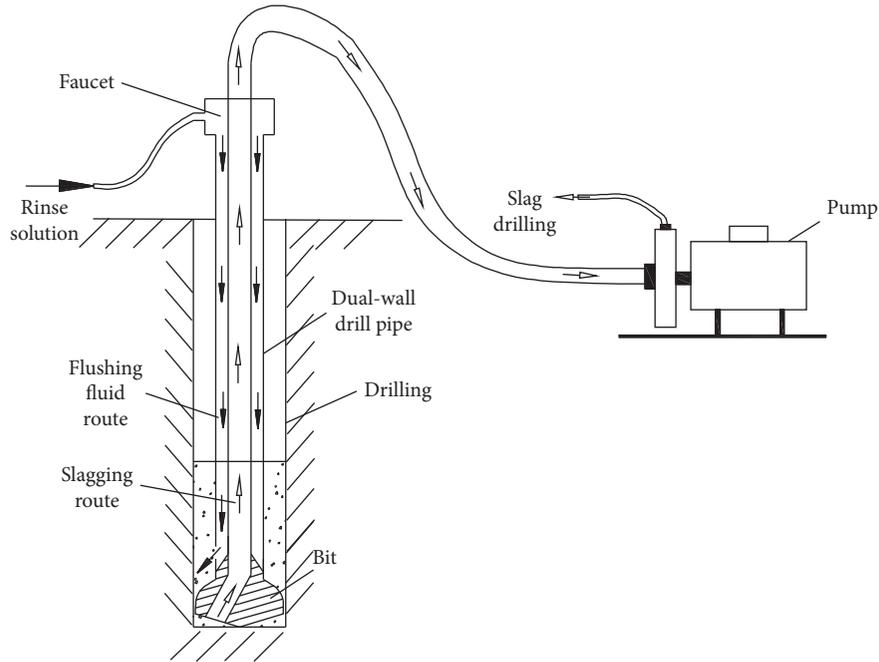


FIGURE 2: Slagging diagrammatic sketch of pump suction reverse circulation.

When drilling the bottom anchor hole, the basic principle of pump suction reverse circulation slag removal is adopted. The flushing fluid is carried through the water tap to carry out the double-wall drill pipe inner wall and then enters the bottom hole, rinses the drilling slag, and cools the drill bit. Under the suction force of the pump, the drilling slag is discharged through the central channel of the double-wall drill pipe. Under the action of atmospheric pressure, the suction force of the pump can reach the 6~7 m water column. Therefore, when drilling and slagging at the bottom of the anchor cable hole, when drilling in the depth range of 0~6 m, the flushing fluid and the drilling slag are discharged by the suction action of the pump near the drill bit to avoid the formation of the three zones in the drilling while drilling. When the drilling depth is greater than 6 m, there will be a mixture of washing fluid and drilling slag in the bottom of the hole. As the drilling depth increases, the length of the section increases. However, with the continuous injection of the flushing fluid, it does not affect the continuous discharge of the drilling residue under the action of the pump and theoretically solves the problem of slag discharge in the drilling of the anchor hole of the floor.

### 3. Theoretical Analysis of Pumping Reverse Circulation Drilling in Anchor Cable Hole in Floor

**3.1. Hydraulic Loss along Flushing Fluid.** The hydraulic loss along the whole process of the rinsing fluid is mainly divided into the hydraulic loss along the rinsing fluid entering the bottom of the hole  $\sum \Delta P_{\text{outer}}$  and the hydraulic loss of the rinsing fluid through the inner tube under the suction force of the pump  $\sum \Delta P_{\text{inside}}$ .

The hydraulic loss along the way of the flushing fluid entering the bottom of the hole is

$$\Delta P = \sum \Delta P_{\text{outer}} + \sum \Delta P_{\text{drill}} = \gamma \lambda_1 \frac{\sum l}{d_1 - d_2} \cdot \frac{V^2}{2g} + m \gamma \xi_1 \frac{V^2}{2g}. \quad (1)$$

The hydraulic loss along the way of the flushing fluid-carrying drilling slag through the inner pipe of the double-wall drill pipe is

$$\sum \Delta P_{\text{inside}} = \gamma \lambda_2 \frac{\sum l}{d} \cdot \frac{V_a^2}{2g}. \quad (2)$$

In the above formula,  $d_1$  is the inner diameter of the outer wall of double-wall drill pipe,  $m$ ;  $d_2$  is the double-wall drill pipe inner tube outer diameter,  $m$ ;  $d$  is the inner diameter of double-wall drill pipe inner tube,  $m$ ;  $\xi_1$  is the coefficient of local resistance of the drill hole,  $\xi_1 = 0.6$ ;  $\gamma$  is the fluid bulk density,  $N/m^3$ ;  $l$  is the length of each drill pipe,  $m$ ;  $V^2/2g$  is the velocity head,  $m$ ;  $V$  is the average fluid velocity in drill pipe,  $m/s$ ;  $n$  is the number of water holes in the drill;  $V_a$  is the average velocity of annulus fluid between the hole wall and drill pipe,  $m/s$ ; and  $\lambda_1$ ,  $\lambda_2$  are the friction coefficients.

**3.2. Drilling Slag Return Speed  $u_s$ .** Derived from the equilibrium conditions of the pumping reverse cycle,

$$\frac{S}{u_s} \cdot \left( \frac{D}{60d} \right)^2 = \frac{\gamma_m - \gamma_a}{\gamma_s - \gamma_a}. \quad (3)$$

In the above formula,  $D$  is the drilling diameter,  $m$ ;  $S$  is the drilling speed,  $m/h$ ;  $\gamma_m$ ,  $\gamma_s$ ,  $\gamma_a$  are the densities of slag

drilling fluid, slag drilling fluid, and flushing fluid,  $\text{kN/m}^3$ ; and  $u_s$  is the drilling slag rising speed,  $\text{m/s}$ .

Let  $\psi = \gamma_m - \gamma_a/\gamma_s - \gamma_a$  be the volume content of drilling slag in the pumping reverse circulation drilling slag drilling fluid, then the drilling speed is  $S$  from the above method (3):

$$S = \psi \left( \frac{D}{60d} \right)^2 u_s. \quad (4)$$

According to the total flow per unit length of pumping reverse circulation drilling,

$$Q_m = Q_s + Q_a. \quad (5)$$

In the above formula,  $Q_m$  is the drilling fluid flow,  $Q_m = (\pi/4)d^2 u_m$ ,  $\text{m}^3/\text{s}$ ;  $Q_s$  is the slag drilling flow,  $Q_s = (\pi/4)D^2 (S/3600)$ ,  $\text{m}^3/\text{s}$ ;  $Q_a$  is the flushing fluid flow,  $Q_s = (\pi/4)\{d^2 - [D^2 S/3600 u_s]\} u_a$ ,  $\text{m}^3/\text{s}$ ; and  $u_m$ ,  $u_a$  are the upward and backward flow rates of slag drilling fluid and flushing fluid,  $\text{m/s}$ .

Bring the above parameters into formulas (4) and (5) to get

$$u_s = u_m - \frac{\gamma_s - \gamma_m}{\gamma_s - \gamma_a} u_g. \quad (6)$$

In the above formula,  $u_g$  is the suspended speed of drilling slag in flushing fluid,  $\text{m/s}$ .

**3.3. Drilling Slag Suspension Speed  $u_g$ .** According to the suspension correction formula of B. A. Uspenski's solid particles in the fluid, under the condition of pumping reverse circulation drilling, the maximum suspension speed is

$$u_g = 2.73 \sqrt{\frac{d(\gamma_s - \gamma_a)}{\gamma_a}}. \quad (7)$$

Then, by formulas (6) and (7),

$$S = \psi \frac{60d}{D} \left( u_m - 2.73 \sqrt{\frac{d(\gamma_s - \gamma_a)}{\gamma_a}} \cdot \frac{\gamma_s - \gamma_m}{\gamma_s - \gamma_a} \right). \quad (8)$$

It can be seen from equation (8) that the drilling speed  $S$  of the anchor hole of the bottom plate varies with the change of the lithology  $\gamma_s$  of the bottom plate. Different lithologies have different drilling speeds of the bottom plate.

**3.4. Drilling Slag Fluid Return Flow Rate  $u_m$ .** According to the Bernoulli equation of pumping reverse circulation,

$$u_m = \sqrt{\frac{P_s - \Delta P_a - \Delta P_t - \sum \Delta P_{\text{inside}}/\gamma_m - h - H(1 - \gamma_a/\gamma_m)}{\alpha(1 + \sum \xi + \lambda_2/dL)}}. 2g. \quad (9)$$

In the above formula,  $P_s$  is the pump vacuum,  $\text{kPa}$ ;  $\Delta P_a$  is the drilling site atmospheric pressure correction value,  $\text{kPa}$ ;  $\Delta P_t$  is the correction value of gasification pressure after drilling site water temperature exceeds  $20^\circ\text{C}$ ,  $\text{kPa}$ ;  $h$  is the distance between pump axis and water level line in hole,  $m$ ;  $H$  is the drilling depth,  $m$ ;  $\sum \xi$  is the sum of local drag coefficients;  $\lambda_2$  is the friction coefficient;  $L$  is the length along

the way,  $m$ ,  $L = H + h_c + l_1$ ;  $h_c$  is the active drill pipe length,  $m$ ;  $l_1$  is the length of the hose from the faucet to the inlet pipe of the pump,  $m$ ;  $\alpha$  is the kinetic energy correction factor;  $g$  is the acceleration of gravity,  $\text{m/s}^2$ .

#### 4. Checking Calculation of Pumping Reverse Circulation Drilling for Anchor Cable Hole

The anchor hole in the floor of a coal mine roadway is pumped by reverse circulation. The inner diameter  $d_1$  of the outer wall of the double-wall drill pipe is  $28 \text{ mm}$ , the outer diameter  $d_3$  is  $42 \text{ mm}$ , the outer diameter of the inner pipe  $d_2$  is  $22 \text{ mm}$ , the inner diameter  $d$  is  $16 \text{ mm}$ , and the active drill pipe length  $h_c$  is  $1.5 \text{ m}$ ,  $l_1$  is  $3.5 \text{ m}$ , and the drilling diameter  $D$  is  $50 \text{ mm}$ . The flushing fluid uses static pressure water with a downhole pressure of  $0.5 \text{ MPa}$ . The kinematic viscosity of water  $\nu$  is  $1.142 \times 10^{-6} \text{ m}^2/\text{s}$ . Drilling slag density is  $2.3 \text{ g/cm}^3$ . The density of water is  $1.0 \text{ g/cm}^3$ . The vacuum degree  $P_s$  of the water pump is  $65 \text{ kPa}$ ,  $\Delta P_a$  is  $3 \text{ kPa}$ ,  $\Delta P_t$  is  $0$ ,  $\sum \xi$  is  $1.4$ ,  $\alpha$  is  $1.1$ ,  $\gamma_s$  is  $21.3 \text{ kN/m}^3$ , and  $\gamma_a$  is  $10 \text{ kN/m}^3$ . Let the volume content of drilling slag  $\psi$  be  $10\%$ ,  $15\%$ , and  $20\%$ , respectively.

**4.1. Flushing Fluid Enters the Bottom of the Hole and Carries the Drilling Slag to Return to the Hydraulic Loss along the Way.** Substitute into formulas (1) and (2) to get the flushing fluid at the bottom of the flushing hole and the process of discharging the fluid outside the hole is turbulent, then the resistance coefficient along the way is  $\lambda_1 = \lambda_2 = 0.012$ :

$$\begin{aligned} \Delta P &= 8.28 \times 10^{-3} + 9.18 \times 10^{-6} H, \\ \sum \Delta P_{\text{inside}} &= 3.44 \times 10^{-6} L. \end{aligned} \quad (10)$$

It can be seen from the formula that, as the drilling depth increases, the loss along the way of the flushing fluid entering the hole bottom and carrying the drilling slag out of the orifice increases proportionally. When drilling the anchor cable hole in the bottom plate, the anchor cable hole in the bottom plate is relatively shallow, generally between  $4$  and  $8 \text{ m}$ , so the hydraulic losses along the way are

$$\begin{aligned} \Delta P &= 8.31 \times 10^{-3} \sim 8.35 \times 10^{-3} \text{ MPa}, \\ \sum \Delta P_{\text{inside}} &= 3.10 \times 10^{-5} \sim 4.47 \times 10^{-5} \text{ MPa}. \end{aligned} \quad (11)$$

The pressure loss of the rinsing fluid into the bottom of the hole accounts for  $1.67\%$  of the static pressure water pressure at the bottom of the injection hole, while the pressure loss of the rinsing fluid outside the hole carrying the drilling slag accounts for  $6.88\%$  of the vacuum degree of the pump. Therefore, the pressure loss along the way of the flushing fluid into the bottom of the hole during the calculation is negligible, indicating that when the bottom plate is drilled in reverse circulation, using this type of drilling tool can smoothly send the flushing liquid to the bottom of the hole, further verifying the design of the double the annular gap between the inner and outer pipes of the wall drill pipe is reasonable.

4.2. *Relationship between Drilling Depth and Height of Flushing Fluid in the Hole.* Substituting the above data into formula (7), the suspension velocity of drilling slag  $u_g$  is

$$u_g = 3.67 \times 10^{-2} \frac{m}{s}. \quad (12)$$

From formula (9),

$$\frac{P_s - \Delta P_a - \Delta P_t - \sum \Delta P_{\text{inside}}}{\gamma_m} - h - H \left( 1 - \frac{\gamma_a}{\gamma_m} \right) \geq 0. \quad (13)$$

Then there is

$$h \leq H \left( 1 - \frac{\gamma_a}{\gamma_m} \right) - \frac{P_s - \Delta P_a - \Delta P_t - \sum \Delta P_{\text{inside}}}{\gamma_m}. \quad (14)$$

Furthermore, the height  $l_2$  of the rinsing liquid in the hole is

$$l_2 \geq H \left( 2 - \frac{\gamma_a}{\gamma_m} \right) - \frac{P_s - \Delta P_a - \Delta P_t - \sum \Delta P_{\text{inside}}}{\gamma_m}. \quad (15)$$

Substituting the volume content of drilling slag  $\psi$  as 10%, 15%, 20% and other parameters into formula (15), as shown in Figure 3, when the plate anchor cable hole is pumped by reverse circulation drilling, linear relationship between the depth of the anchor cable hole and the height of the flushing fluid in the hole.

We can see from the picture that ① when the volume of drilling slag is constant (i.e., when the drilling speed is constant), the height of the flushing fluid in the anchor cable hole increases with the increase of the hole depth; otherwise, the drilling slag cannot be discharged out of the hole with the flushing fluid. When the drilling slag volume content is 10%, the rinsing fluid can circulate at the bottom of the hole before the anchor hole is drilled for 5 m. After more than 5 m, a certain height of rinsing fluid is required in the hole for the pump to successfully draw the slag out of the hole. ② When the pump vacuum is constant, as the drilling slag content increases (i.e., the drilling speed increases), the depth of the anchor cable hole where the flushing fluid circulates smoothly at the bottom of the hole will decrease. When the drilling slag content is 20%, the anchor cable hole depth when it is larger than 4.2 m, there will be a certain column of flushing fluid at the bottom of the hole to make the reverse circulation work normally.

Therefore, when the bottom cable hole pump sucks reverse circulation drilling, choose a water pump with a high vacuum (good sealing) and low drilling speed to facilitate the discharge of drilling slag at the bottom of the hole. When drilling a deeper cable hole, it is necessary to have an appropriate amount of flushing fluid column at the bottom of the hole without affecting the quality of the drill hole. Since the pump with the highest vacuum degree  $P_s$  is less than 80 kPa, the depth of the bottom hole drilled into the anchor cable hole at the bottom of the hole is also less than 6.5 m. When the hole depth is greater than 6.5 m, the flushing fluid and drilling slag in the hole are pumped out of the hole.

4.3. *Factors Affecting the Drilling Speed of Anchor Cable Hole in the Floor.* Suppose that the flushing fluid only circulates at the bottom of the hole, the distance  $h$  of the pump axis from the water level line in the hole is equal to the depth  $H$  of the hole, set the depth of the hole 4m, and substitute the formulas (6)–(9) to get the parameters shown in Table 1.

As can be seen from the table, ① as shown in Figure 4, at a certain drilling depth, the drilling slag return rate is inversely proportional to the drilling slag volume content, and as the drilling slag volume content increases, the drilling slag return rate decreases rapidly. When it is 24.1%, the drilling slag will not be pumped out of the hole along with the flushing fluid, indicating that when the drilling slag volume content is greater than 24.1%, the pumping reverse circulation cannot be completed, and the bottom plate anchor hole will not be able to continue drilling. ② The drilling speed of the anchor cable hole in the bottom plate does not increase or decrease with the increase of the drilling slag volume content. When the drilling slag volume content is 15%, the drilling speed is the fastest, the theoretical value is 5.09 m/s, but the drilling speed of anchor cable holes is also affected by factors such as drilling pressure, lithology, and drilling rig speed. The drilling speed is also affected by factors such as weight on bit, lithology, and rig speed, which makes the drilling speed much lower than the theoretical value of pumping reverse circulation drilling.

4.4. *Pumping Reverse Circulation Drilling Test of Anchor Hole in Floor.* The self-designed reverse circulation drilling tool and diaphragm pump were used to form the bottom plate drilling and slag discharge system, and field tests were carried out at the Donggedu Coal Mine in Inner Mongolia. As shown in Figure 5, the construction site of the bottom plate anchor cable hole pump suction reverse circulation of Donggedu Coal Mine in Inner Mongolia, the bottom slate layer mainly consists of sandy mudstone and mudstone, with low strength and easy to slime when encountering water.

When drilling in the depth of 4 m, no washing fluid was spilled out of the borehole wall. After drilling, the drilling fluid was only less than 0.2 high, and the quality of the drilling hole was better. Figure 6 shows that the sand and paper mudstone of the floor was pumped by reverse circulation drilling, and the drilling slag was formed near the drill bit and then pumped out of the hole, which not only reduced the mud effect of the washing liquid on the hole wall but also avoided the locking of drill mud by drilling and gathering mud.

During drilling, under the condition of certain drilling pressure, the relationship between the drilling time and the drilling depth of the anchor cable hole is as shown in Figure 7.

The curves of drilling depth and time are 6 KN, 7 KN, and 10 KN, respectively. The drill drills 1 time (0.4 m) to record the time. The drill pipe is 1.2 mm root. When drilling the 5.6 m, 4 drill pipes need to be replaced. 4 min is needed for each replacement, 16 min is needed, the effective drilling time is controlled within 30 min, and when the drilling pressure is 6 KN and 7 KN, the drilling pressure increases.

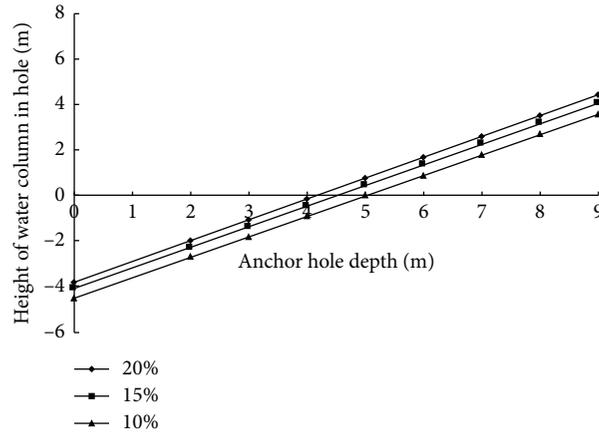


FIGURE 3: Relationship of floor anchoring hole depth and flush fluid height in the hole.

TABLE 1: Arising velocity parameters of intermixture, boring mud, and drilling.

$\psi$	$\gamma_m / (\text{kN} \cdot \text{m}^{-3})$	$u_m / (\text{m} \cdot \text{s}^{-1})$	$u_s / (\text{m} \cdot \text{s}^{-1})$	$S / (\text{m} \cdot \text{s}^{-1})$
10%	11.13	2.588	2.545	4.36
15%	11.70	2.031	1.999	5.09
20%	12.26	1.351	1.322	4.49

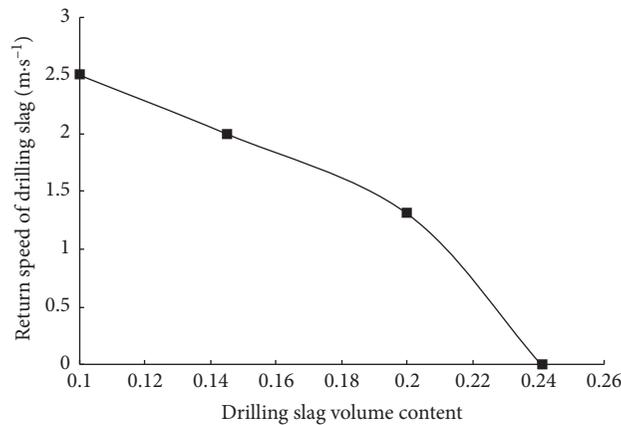


FIGURE 4: Relationship of boring mud content and ascending velocity.

The accumulative drilling time of the anchor hole decreases obviously, which indicates that the increase of drilling pressure is helpful to improve the drilling speed. But when the drilling pressure is steady to 10 KN, the drilling speed will increase suddenly due to the larger drilling pressure and the more soft mudstone, but the sticking phenomenon will

occur. It is indicated that the rock property has a great influence on the drilling speed, and how to effectively control the relationship between the drilling pressure and lithology needs further study. Because the drilling slag in the hole is directly discharged by the pump, the working environment and the hole forming quality of the anchor hole



FIGURE 5: Pump suction reverse circulation drilling test of floor anchoring hole.

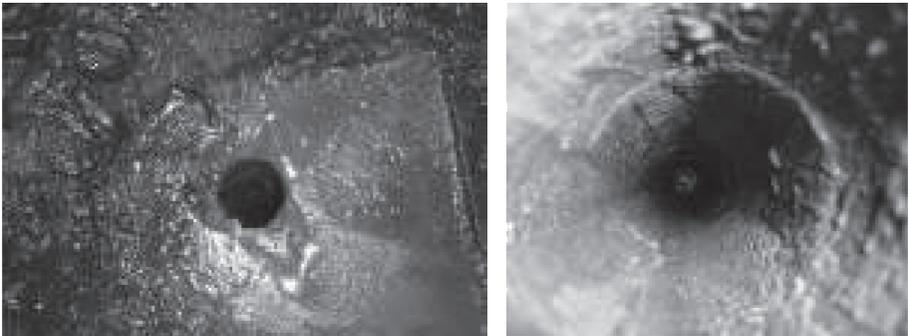


FIGURE 6: The effect of pumping reverse circulation drilling holes.

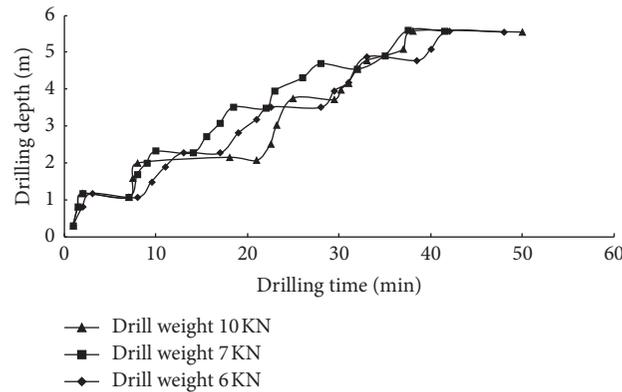


FIGURE 7: Relationship of drilling time and drilling depth.

are greatly improved, which is conducive to anchoring the anchor cable of the floor and avoiding the water damage of the floor rock.

## 5. Conclusion

- (1) Because of the interaction between the “three zones of drilling and slag,” the basic reason for the rapid drilling of the bottom anchor cable is the positive circulation drilling of the bottom anchor cable hole. It is put forward that the bottom of the anchor rope hole is pumped by reverse circulation drilling, and the drilling slag is discharged by the suction force of the pump, thus effectively preventing the formation of the three zones of drilling slag and improving the drilling efficiency.
- (2) Based on the principle of fluid mechanics, the formula for the hydraulic loss of the whole process, the velocity of drilling slag, the suspension velocity of drilling residue, and the return flow velocity of drilling fluid are derived. Through engineering calculation, it can be known that the relationship between the drilling depth, the vacuum degree of the pump, the upward return speed of the drilling slag fluid, and the volume content of the drilling slag during the pumping reverse circulation drilling of the bottom plate anchor hole can be obtained by implementing the pumping reverse circulation. It is feasible to drill the anchor hole of the bottom plate quickly.
- (3) According to the special geological environment of the roadway and the hole forming requirements of the anchor holes of the floor, a set of pump suction reverse circulation drilling tools has been selected for simultaneous drilling and slag discharging. The field test shows that the effective drilling time of the 5.6 m deep hole single hole pumping reverse circulation drilling of the anchor cable hole in the floor of the roadway can be controlled within 30 min, which solves the problem of slag discharge in the anchor

cable hole of the floor, improves the drilling speed, and purifies the operating environment which has laid a strong foundation for the prestressed anchor grouting reinforcement of the roadway floor.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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