Surface Water Inrush Mechanisms of Shallow Buried Coal Seams: A Single Crack Experiment and Discussion

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Abstract

The mechanism of water inrush from ground surface channel is a scientific challenge in shallow buried coal mine safety issue, fully understanding the rule of water inrush is substantial to mine water disaster in shallow coal seam.Variable controlling approach is used to discuss crack water volume with different variables including channel slope angle, crack width and flow volume. The experiment results show that crack width has a positive correlation with crack water volume, while channel gradients has a negative correlation with it. The crack water volume can be calculated by the binary non-linear equation. The results may reduce the risk of water inrush accident.

Keywords: mine water disaster; Water inrush; Variable controlling approach; crack water volume; binary non-linear equation

Introduction

Water inrush from surficial channel is a one of mine water inrush disasters and it seriously threatens the safety in mine production of shallow buried coal seam (Hu and Tian 2010). Recently, with the development of coal mining technology, the comprehensive mechanized coal mining method of large-scale working face has been widely used and its disturbance damage intensity to the overburden of coal seam roof has also increased. In the surface gully and other shallow buried coal areas, cracks may develop up to the surface and then lead the channel flow water down to the coal mine, resulting in the mine water inrush accident. Surface water inrush has become one of the four main types of mine damages (Zhu et al. 2014).

The areas, which may cause surface channel water damage, generally with the shallow buried coal seam, high height of water guide crack zone, and good connectivity in fluid flow etc. (Wu et al. 2006; Wu et al. 2007; Wu et al. 2004). The researches on coal mine water damage and control technology mainly focus on the damage of groundwater source but are lack of analysing water damage caused by surface waters. The water damage caused by surface water happened frequently with large water quantity (Wu et al. 2013).

Researchers indicate that the coal seams mining with shallow buried, thin bedrock and thick loose layer is often accompanied by the occurrence of accidents such as broken water and sand and surface step sinking (Hou and Zhang 2005; Zhang and Hou 2005; Xu et al. 2009). Therefore, it is of great significance to analyze the law of surface channel in shallow buried coal seam. The study on the mechanism of surface collapse and the movement law of overburden mining in shallow buried coal seam shows that shallow buried coal seam mining often causes serious overburden failure and surface collapse, forming penetrating fractures and surface cracks (Hu et al. 2012; Wang et al. 2007; Zhang et al. 2002).

Methods

1. Experiment devices

In the experiment, water leakage experiment system has been performed to measure the water inrush volume from ground surficial channel. The system consists of water supply part (Fig.1: 1,2,3,4,5), water inrush part (Fig.1: 7,8,9,12,14,17) and water volume measurement section (Fig.1: 10,11,13,15,16). It is important to correct the water level needle (Fig.1:13) and ensure the needle is back to zero before the measurement.

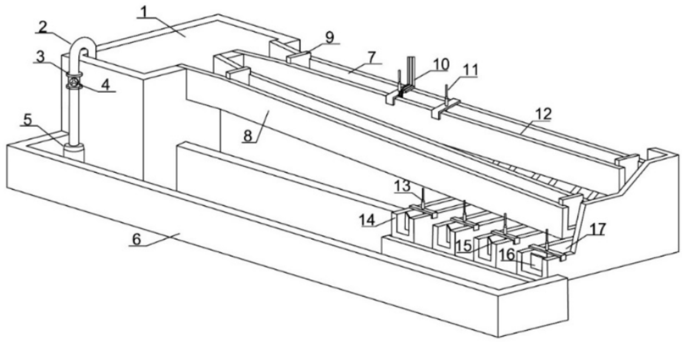


***Fig.1** The experiment device of water insush: 1 Reservoir; 2 Water supply pipes; 3 Flange; 4 Valve; 5 Water pump; 6 Backflow pool; 7 Leaky sink(1); 8 Leaky sink(2); 9 Movable baffle; 10 Pitot tube; 11 Movable needle detector; 12 Changeable crack; 13 Fixed needle detector; 14 Backflow channel; 15 Triangular weir; 16 Rectangle weir; 17 Backflow channel; 18 Steady flow velocity grilling*

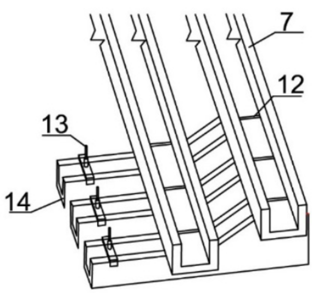


***Fig.2** Schematic diagram of leaking sink device*

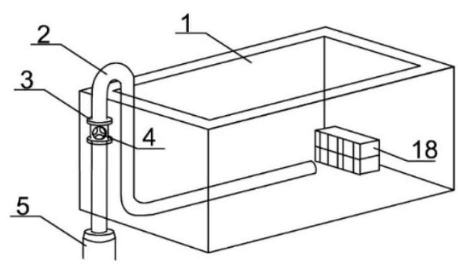


***Fig.3** Schematic diagram of reservoir and water supply system installation*

2. Experimental methods

Variable controlling approach is an effective method to reduce prediction errors of unknowns scientifically. In the paper, variable controlling method is used to analyze the influence factors on crack water discharge quantitively. The crack water volume is affected by many factors, including channel slope angle, crack width, water flow volume, crack roughness and media permeability. But in the same study area, cracks with the same width, their roughness and permeability often have little effect on crack water volume. Thus, crack roughness and permeability are considered as constants in the experiment. In the experiment, two sinks with 5% and 5‰ slope angle were selected, while the crack width at the bottom of the sink were set to 5 mm, 10 mm, 15 mm, 20 mm and 25 mm respectively, and the flow discharge was controlled. Firstly, crack water discharge is obtained by measuring the water flow discharge under conditions of fixed the value of the crack width and slope angle.Secondly, crack water discharge is measured with the change of water flow and crack width. Thirdly, crack water discharge is measured with the change of water flow, crack width and slope angle. Then, the crack water discharge with different slope angle, crack width and water flow can be obtained.

The experimental data of crack water discharge under the experimental conditions of different slope angle, water flow and crack width are obtained, and the crack water discharge has a linear correlation with water flow when the crack width and slope is fixed. The experimental data are standardized to reduce the calculation error. The standardized difference method is used to take the difference between the two groups of adjacent experimental data under the same experimental conditions.

Calculation methods

The water height H_1 and H_2 in the triangular and rectangular weir on the reflux channel are obtained respectively by needle reading in the experiment. Based on the triangular turbulent flow calculation formula (Eq. (1)), the crack water discharge Q_1, Q_2, and Q are calculated. Based on the rectangular turbulent flow calculation formula (Eq. (2)), the water volume in return channel Q_2 is calculated. Then, the total water volume Q_3 in the leakage can be calculated according to equation 3.

$$Q_1 = \frac{8}{15}\tan\frac{\alpha}{2}\sqrt{2g}H_1^{5/2} \qquad (1)$$

$$Q_2 = \frac{2}{3}B\sqrt{2g}H_2^{3/2} \qquad (2)$$

$$Q_3 = Q_1 + Q_2 \qquad (3)$$

Where α is the angle of the top of the triangle weir; H_1 is the water depth in triangular weir; B is the width of the backflow channel; H_2 is the water depth in a rectangular weir; g is the gravitational acceleration.

The experimental data of channel crack water volume under the experimental conditions of slope angle, water flow and crack width, and the crack water discharge has a linear correlation with water flow when the crack width and slope angle value are fixed.

The experimental data are standardized to reduce the calculation error. The standardized difference method is used to take the difference value between the two groups of adjacent experimental data under the same experimental conditions. The standardized experiment value can be expressed as

$$\lambda = \frac{m\left(\frac{b-\delta}{\delta-a}\right)+n}{1+\left(\frac{b-\delta}{\delta-a}\right)} \qquad (4)$$

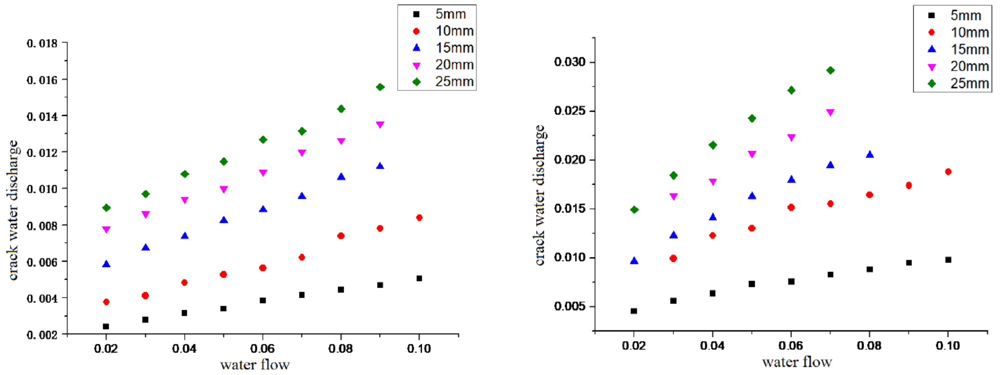
Where (α, m) and (b, n) are coordinate of two separated experimental value; (δ, λ) is the coordinate on the line of (α, m) and (b, n).

The standardized experiment results are shown in table 1.

The standardized data of crack water discharge has a linear relationship with its influenced factors as shown in Fig.6. Therefore, we can use the crack water discharge (Q) data and the water flow discharge (x) with different crack width in the channel to establish a one-dimensional linear

***Table 1** Leakage water volume of trench crack*

Channel slope	Crack width (m, 10^{-2})	Water flow (m^3/s, 10^{-2})								
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
5‰	0.5	0.453	0.559	0.635	0.730	0.756	0.828	0.879	0.947	0.977
	1.0		0.993	1.228	1.302	1.514	1.554	1.642	1.858	1.879
	1.5	0.964	1.230	1.412	1.629	1.797	1.946	2.050		
	2.0		1.709	1.785	2.069	2.238	2.498			
	2.5	1.392	1.845	2.154	2.428	2.716	2.920			
5%	0.5	0.241	0.280	0.316	0.339	0.384	0.413	0.444	0.468	0.505
	1.0	0.376	0.410	0.483	0.526	0.563	0.621	0.738	0.781	0.839
	1.5	0.582	0.673	0.737	0.825	0.883	0.957	1.062	1.120	
	2.0	0.778	0.861	0.939	0.998	1.089	1.200	1.264	1.354	
	2.5	0.894	0.969	1.079	1.148	1.267	1.313	1.437	1.556	1.677



a Channel slope angle is 5%   *b* Channel slope angle is 5‰

Fig. 6 *Standardized differential data diagram for Channel water break experiment*

correlation equation sets respectively which can be expressed as $Q = a_0 + a_1 x$, then α_0 and α_1 can be expressed as

$$\begin{cases} \dfrac{\partial s}{\partial a_0} = -2\sum_{i=1}^{m}(y_i - a_0 - a_1 x_i) = 0 \\ \dfrac{\partial s}{\partial a_1} = -2\sum_{i=1}^{m}(y_i - a_0 - a_1 x_i)x_i = 0 \end{cases} \quad (5)$$

Then the equation can be simplified as

$$a_1 = \frac{\sum_{i=1}^{m} x_i y_i - \sum_{i=1}^{m} x_i \sum_{i=1}^{m} y_i}{m\sum_{i=1}^{m} x_i^2 - \left(\sum_{i=1}^{m} x_i\right)^2}$$

$$a_0 = \frac{1}{m}\sum_{i=1}^{m} y_i - \frac{a_1}{m}\sum_{i=1}^{m} x_i \quad (6)$$

By the same way, the relationship between crack water volume and crack width can be calculated. Then combining the equation (6), the crack water discharge can be expressed as a binary linear equation with variables of crack width and water flow volume.

The relationship between crack water volume and its influenced factors can be divided into two types, according to the crack water volume in the field. When water flow discharge is small in the channel, we assume that crack water volume is equal to water flow discharge in the channel. The crack water volume can be expressed as

$$Q = x \quad (7)$$

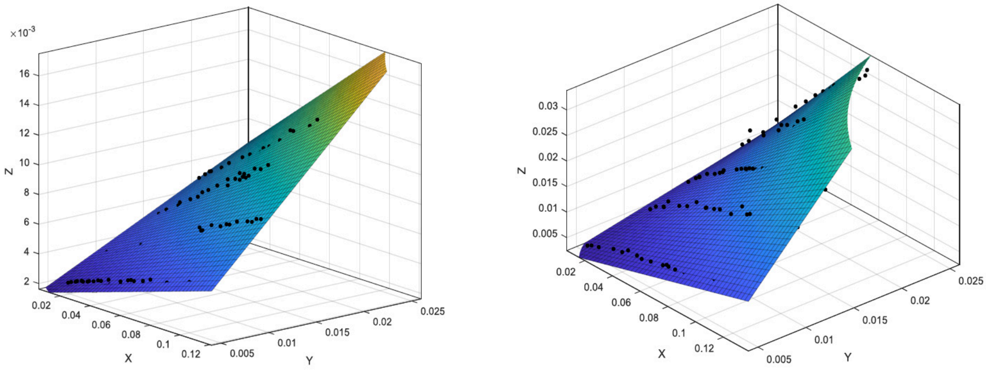
Whereas, when water flow discharge is larger than that water volume in the crack, the relationship between crack water discharge and water flow discharge and crack width can be expressed as following equations:

$$Q_{5\%} = f(x, y) = (3x + 0.3)y + 0.02x \quad (8)$$

$$Q_{5‰} = f(x, y) = (12x + 0.3)y + 0.03x \quad (9)$$

Where, Q is crack water discharge, Q5% and Q5‰ is the discharge when slope angle is 5% and 5‰ respectively, x is the water flow discharge, y is the crack width.

Matlab stands for matrix laboratory, it is a technical computing environment for high-performance numeric computation and visualization. In the paper, it is used to verify the accuracy of the fitting formula. When the slope angle is 5% degree, the fitting coefficient is 0.986 indicating that water leakage volume has an obviously nonlinear relationship with channel water volume and cracks width, as shown in Fig.7(a). As shown in Fig.7(b), it can be concluded that when the slope angle is 5‰ degree, the fitting coefficient is 0.956



a Channel slope angle is 5% *b Channel slope angle is 5‰*

Fig. 7 Relationship between Q and x, y

indicating that water leakage volume has an obviously nonlinear relationship with channel water volume and cracks width.

Conclusions

In this paper, we qualitatively conclude that the main influenced factors of the crack water break are channel rock types, channel slope, channel width and channel water volume, etc.

Experiments are carried out by means of the control variable method. The crack water volume in the channel cracks is negatively correlated with the slope of the channel whereas it is positively correlated with the crack width and flow volume at the bottom of the channel.

The functional relationship between channel flow volume (x), channel crack width (y) and crack water discharge (Q) are obtained. When the channel slope angle are 5% and 5‰, crack water volume are expressed as :

$$Q_{5\%} = f(x,y) = (3x+0.3)y+0.02x$$

and $Q_{5‰} = f(x,y) = (12x+0.3)y+0.03x$

respectively.

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