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Seepage characteristics of collapse column fillings

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ABSTRACT

With concealment and hysteresis, water-inrush from Karst collapse column has become an important security hazard of lower group coal mining in North China. Based on the MTS815.02 seepage test system, we analyzed the impact of consolidation pressure, initial moisture content and confining pressure on the permeability of fillings in order to study the seepage characteristics of collapse column fillings. The results show that: (1) The permeability of collapse column fillings is of the order of 10^{-16}–10^{-15} magnitude and decreases with an increase in consolidation pressure and decrease in initial moisture content. (2) The essence of filling seepage law change is the change in porosity, and a power function relationship exists between the permeability ratio and porosity ratio. (3) With increasing confining pressure, the permeability of fillings decreases. However, under low confining pressure (1.2–4 MPa), the change of confining pressure has no obvious influence on the permeability.

1. Introduction

Karst collapse column is a special kind of geological structure of the Permo-Carboniferous coal field in northern China, and presents a great danger to safe production in coal mine [1–3]. It is widely distributed over 45 mining areas in 20 coal fields in north China. Karst collapse column is usually concealed under the bottom coal layer, and it is therefore difficult to prevent water inrush disasters due to its concealment and hysteresis. In China, with the exception of Shanxi province, water inrush disasters of large collapse column have happened in many areas [4–6]. The water volume of most water inrushes of the collapse column is huge, with a water volume of more than 10,000 m^3/h. This has caused a great number of casualties and enormous economic losses, such as at Fangezhuang coal mine in Kailuan, the Camel Mountain coal mine in Wuhai and Taoyuan coal mine in Huaibei [7].

To date, many scholars have studied the seepage characteristics of collapse column. In the aspect of laboratory testing, Wang et al. [8] researched the physical laws and characteristics of the water inrush process of collapse column through model tests, and analyzed the effect of water pressure on the seepage mutation process of collapse column and its surrounding rock. Through similar simulation and experimental research on collapse column X15 in Liugou coal mine, Li et al. [9] found that the formation of water channels is associated with water pressure and time. Mao et al. [10] simulated collapse column with broken rock samples, tested the ratio of aggregate and fillings, the axial pressure and sand content of the samples, and analyzed their effect on the seepage characteristics of collapse column and its mutation laws. In the aspect of theoretical research, Yin and Wu [11] established a thick wall cylinder model of collapse column with thin plate theory, and derived the water inrush criterion of collapse column. Based on thin plate theory, Xu et al. [12] set up the criterion of karst cave roof separator collapse with the limit equilibrium analysis method. Bai et al. [13] established a piston model, explained the fundamental cause of water inrush disasters and deduced the water inrush criterion of collapse column. Moreover, some scholars have revealed the water inrush regularity [14–16] by researching the water conduction mechanism of collapse column using numerical simulation methods.

As previously mentioned, predecessors have researched the seepage characteristics and water inrush mechanism of collapse column. However, because of the complexity of collapse column structure, the process of water inrush cannot be predicted and controlled very well at present. Collapse column seepage is determined by the skeleton structure and the fillings in the skeleton. As many collapse columns are in a consolidation state and the interspace of the skeleton structure is filled with the fillings, the degree of compaction and water-rich situation of the fillings are the key factors in determining the seepage characteristics. Collapse column water inrush is a complex process that is mainly reflected in the change from steady seepage to unsteady seepage. In such a process, the filling is gradually being lost which eventually improves the permeability of the collapse column integral

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structure and leads to seepage mutation. Therefore, researching the seepage characteristics of collapse column fillings is significant in explaining water inrush. Based on the consolidation test, permeability test samples of collapse column fillings are generated and, through permeability tests in the laboratory, the influence of consolidation pressure, initial moisture content and confining pressure on the seepage characteristics are studied and the seepage laws of collapse column fillings summarized. This provides a theoretical foundation for the prevention of water inrush disasters.

2. Permeability test of collapse column fillings

2.1. Preparation of test samples

Collapse column is a complex geological structure that accumulates superficially by different sizes of rocks and cuttings. The object of research described in this paper is the fillings widely spread in the rocks. For well-consolidated collapse columns, the permeability of the fillings has a direct effect on the permeability of the whole collapse column. Under the influence of drilling or mining, the structure of collapse column readily becomes loose when disturbed, and it is difficult to obtain samples of collapse column fillings on site. Therefore, according to the methods of soil sample testing, samples of collapse column fillings are created by the consolidation test.

The samples were taken from Sima 2 coal mining area in Changzhi city, Shanxi province, as the collapse column fillings. A 1 mm-seive was used to sieve the samples, producing the density and mineral composition of fillings as seen in Table 1.

In the test, the materials with different moisture contents were first put into a plexiglass cylinder with a height of 160 mm and diameter of 50 mm (see Fig. 1), and then compressed and consolidated in the lever-type high pressure consolidometer. The initial height of the consolidation sample was about 130 mm, and the sample of collapse column fillings was formed under consolidation.

As there is usually a cavity on the top of the collapse column at the site, the vertical load is approximate to 0. With reference to the stress conditions at different depths of the collapse column, the pressures in the consolidation test and loading levels are reflected in Fig. 2. The loading level is classified into 12 levels from 18.8 kN to 6000 kN (referring to the standard design of the soil test). The stable criterion of the test is that when the displacement increment is less than 0.008 mm/h, the next loading level can be applied [17]. Meanwhile, to analyze the influence of a water-rich situation in the surroundings of the collapse column on the regenerative structure of fillings, 5 groups of consolidation tests were conducted with the consolidation pressure set at 3000 kPa and moisture content ranging from 15% to 25%.

The height of samples prepared from the consolidation test is about 110 mm. The upper and lower ends of samples with poor homogeneity are removed, and the samples with two smoothed sides are as shown in Fig. 3. The height of samples in the permeability test of collapse column fillings is 50 mm, the diameter is 50 mm, the consolidation pressure is within 1–6 MPa, the moisture content is within 15–25% and the density is about 2000 kg/m^3.

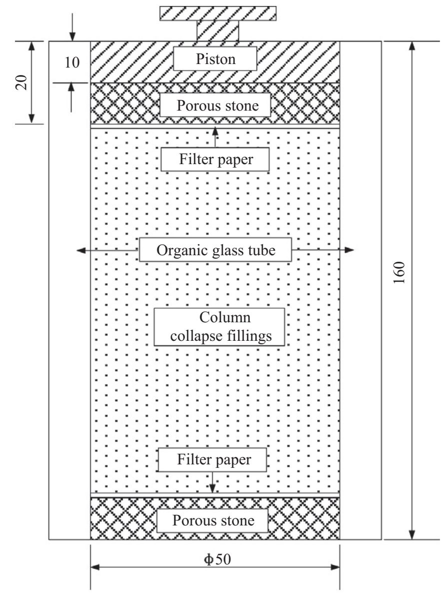

Fig. 1. Consolidation test schematic diagram (mm).

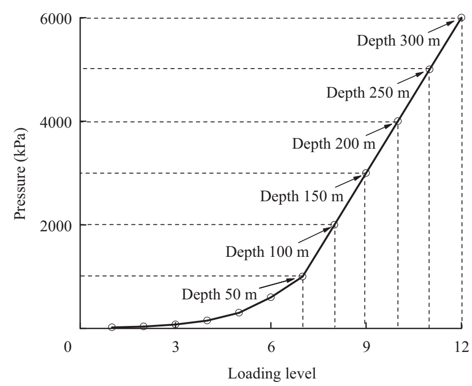

Fig. 2. Grading consolidation pressure.

2.2. Test instrument and methods

The permeability testing of collapse column fillings is conducted with an MTS815.02 electro-hydraulic servo and seepage test system. In the test, the axial load is 1 kN, the confining pressure is 3 MPa and initial osmotic pressure difference is 1 MPa. Each group is tested three times and the average value is taken.

There are generally two methods for the permeability test of rocks, namely: transient permeation and steady permeation. The transient permeation method is used for permeability testing when it is difficult to measure the velocity, and the formula used to calculate the velocity and pressure gradient is as follows [18]:

$$V = \frac{c_f BH}{2A}\frac{d\xi}{dt} \quad (1)$$

Table 1
Density and mineral composition of fillings.

Density (kg/m^3)		Composition (%)						
Relative density	Dry density	Quartz	Kaolinite	Illite	Montmorillonite	Chlorite	Feldspar	Others
2750	1950	5.6	26.3	10.3	45.5	4.2	5.3	Trace