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Research paper

Structural characteristics and variable mass permeability of fall column broken rock mass

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Abstract: In order to analyze the relationship between the configuration characteristics, variable mass permeability characteristics and the catastrophe mechanism of falling column process, The influence of the permeability was studied by diffraction instrument, And using the seepage test system of the fall column, The seepage instability process of variable mass broken rock mass is analyzed, The findings suggest that, The proportion of coarse particles accounted for 89.86%, Fine particles accounted for 10.14%, Broken rock particles is better, Low compression performance; The fall column, under strong hydrodynamic conditions, Due to its strong characteristics of migration and loss with water flow, It is easy to induce the subsidence column protrusion water disaster; As the ratio between coarse and fine aggregates increases, Porosity and permeability are both increased; When the axial displacement does not change, With the increasing circumference pressure, The permeability of the broken rock samples is decreasing; The fitting of the seepage velocity of the broken rock mass to the pore pressure gradient follows the Forchheimer relationship, The seepage of the broken rock mass belongs to the category of non-Darcy flow under the triaxial stress; The instability of the subsidence column fracture rock mass presents three seepage instability forms: initial seepage stage, seepage mutation stage and piping stage in different stages.

Keywords: porosity, safety of coal mine, seepage characteristics, subsidence column, water burst mechanism

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1. Introduction

There are a lot of overlapping areas in the coal resource-enriched areas and karst developed areas in southern China. Guizhou is one of the main mining areas in southern coal fields, known as the “Southern Coal Sea”, mainly mining the Late Permian Longtan Formation coal measures, mainly mining coal The Changxing Formation karst aquifer is overlying the layer, and the karst water body is rich in reserves [1,2]. At the same time, with Guizhou as the center, a large area of karst landforms dominated by carbonate rocks is formed. The surface karst landforms are mainly sinkholes, karst buckets, karst big springs, etc. There are karst caves and underground rivers developed underground. Atmospheric precipitation penetrates into the karst caves and underground rivers through the surface karst structure, and a large amount of karst water exists in the rock formation. Sufficient supply [3,4]. On the basis of underground karst caves, the overlying rock cavities collapsed under the action of its own gravity, tectonic stress and vacuum negative pressure in the cave, and gradually compacted, filled and cemented in the long-term historical process, forming a cone or columnar broken rock mass structure Such typical buried karst structures are called collapse columns [5,6]. In recent years, through geological exploration and coal mining, it has been found that there are a large number of collapsed pillars in the roof of the coal seam. If the compaction and cementation strength of the filling inside the collapsed column is low, under the influence of external factors such as the mining disturbance of the working face and the water pressure of the aquifer, the collapsed column is very likely to generate activated water conduction, and become the connection between the overlying aquifer and the mining working face. Water diversion channel between them, causing major safety accidents such as water inrush and flooding of wells from collapsed columns [7].

Mining and other activities will cause the stress redistribution of the underground rock mass, and changing the permeability of the surrounding rock will lead to water gushing from the roof and floor or collapsed columns, resulting in safety accidents [8]. Mine water inrush is one of the five major disasters in mine production and construction. The permeability characteristics of broken rock mass is an important research content in rock mechanics and seepage mechanics, and it is also the source of coal mine gas and water inrush disasters [9]. Therefore, it is of great significance to study the permeability characteristics of broken rock mass, whether it is for the development of mechanics or for the prevention and control of disasters in practical engineering [10].

For the study of the seepage test of broken rock mass, Schulze et al. established the relationship between damage and permeability, porosity, and other parameters and permeability based on rock salt [11]. Han et al. based on carbonate [12], Oda et al. based on granite [13]. The triaxial compression test analyzes the evolution law of permeability in the whole process of stress and strain. Zhang et al. used the improved variable mass fractured rock mass seepage test system to obtain the particle change law of the collapsed column fractured rock mass filling under the condition of graded loading, and analyzed the evolution law of porosity and water seepage mutation in the process of particle loss [14]. Ma et al. invented the test method of water injection and axial stress loading around the inner wall of the permeable cylinder, which solved the core problem of the migration of fine substances from the periphery to the center under the action of infiltration [15]. Under the influence of the fluid-solid coupling test of the rock mass in the fault fracture zone, the deformation and seepage characteristics of the rock mass in the fault fracture zone during the variable mass water inrush were obtained [16].

The research of the above scholars is mainly aimed at the time-varying law of the variable mass permeability parameters of broken rock mass. By carrying out different types of seepage tests, the internal mechanism of seepage was revealed from different angles, and the fluid-solid coupling mechanics model of broken rock mass under free particle migration was established. The process in which the skeleton deformation of the broken rock mass and the water seepage influence and promote each other. However, mining engineering practice shows that in the process of water inrush from the collapsed column, the particles of the collapsed column filling will migrate and lose mass with the water flow [17]. Under the action of mining, the well-cemented collapsed column is damaged and ruptured, and the cracks expand, connect and penetrate each other to form a good water conduction channel; under the action of water flow dissolution, erosion and abrasion, the filling of the collapsed column is The migration of particles causes mass loss, and the porosity and permeability parameters of the collapsed column change accordingly; in the process of variable mass seepage, the water-conducting channel of the collapsed column transitions from the well-cemented pores to the fractures after mining activation [18]. Finally, after entering the pipeline with a certain degree of mass loss, the water flow pattern will also undergo the flow transition process of "pore flow-crack flow-pipeline flow", which will eventually lead to the water inrush disaster of the collapsed column [19]. Therefore, in view of the variable mass-fluid-solid coupling problem of water inrush disaster in the roof collapse column, it is necessary to consider the influence of mining on the variable mass seepage characteristics of the roof collapse column and the water inrush disaster induced by fluid state transformation, and the mining disturbance process and collapse column must be considered. Combined research with variable mass seepage mechanics response [20, 21].

Therefore, in order to study the relationship between the structural characteristics of the broken rock mass, the variable mass permeability characteristics and the water inrush mechanism of the collapsed column, the author uses the sieving analysis method to screen the collapsed column broken rock mass retrieved from the field, and obtains the collapsed column broken rock mass. The particle size distribution characteristics of the collapsed column were analyzed by X-diffraction experiments to obtain the physical components and contents of the collapsed column crushed rock mass; based on the particle distribution characteristics and component analysis, the self-developed The variable mass seepage test system for broken rock mass studies the change law of the permeability of the collapsed column broken rock mass under the conditions of different porosity, different confining pressure and different pore pressure gradients, and obtains the influence of the collapsed column broken rock mass permeability on the collapsed column water inrush disaster In order to reveal the catastrophic mechanism of the collapsed column broken rock mass, meta-mass seepage instability.

2. Fabric characteristics of collapsed column broken rock mass

2.1. Occurrence characteristics and spatial form of collapsed pillars in coal mines

The experiment is based on the Qianjin Coal Mine in Guizhou Province. The upper part of the 1908 working face of the Qianjin Coal Mine is the 1906 goaf, and the lower part is the 1910 goaf. The strike length of the 1908 working face is 403 m, the incision length is 104 m, the coal seam dip angle is 8–14°, and the average dip angle is 10°. The 9# coal seam is simple in structure and basically stable in thickness, with an average thickness of 1.8 m and an average burial depth of 245 m. Affected by the structure and depositional environment, local thickening and thinning exist. The hydrogeological conditions of the working face are relatively simple. The top sandstone fissure water is the main filling water source of the working face, and the bottom floor is the Maokou Formation limestone water which is not under pressure.

When the working face was 233 m away from the cut hole, a large amount of water gushing began to appear on the coal wall in front of the working face. With the continuous advancement of the working face, the collapsed column was exposed at a distance of 235 m from the cut hole. Combined with the comprehensive analysis of geophysical and drilling results, the location and overall contour characteristics of the collapsed column can be obtained, as shown in Fig. 1. The diameter of the collapsed column in the advancing direction of the working face is about 30 m, the upper boundary is 54 m away from the nose belt lane, and the lower boundary is 32 m away from the tail track lane. Formation limestone middle.

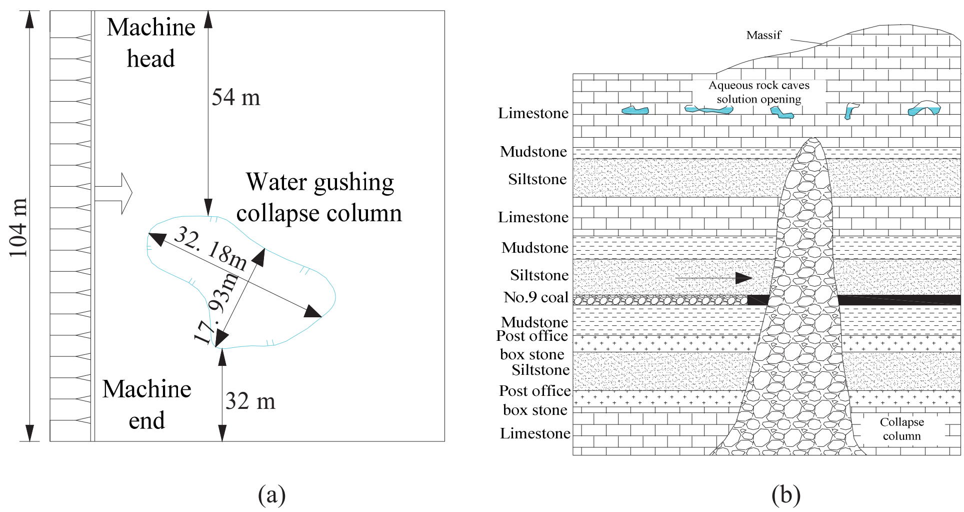

Fig. 1. Schematic diagram of the level profile of the fall column: a) Ichnography, b) Section plan

2.2. Occurrence characteristics and spatial form of collapsed pillars in coal mines

1. Experimental principle
   The particle composition of the collapsed column packing reflects the particle size characteristics of the collapsed column. The sieve analysis method is to use standard sieves with different apertures to screen and group the dried filler particles, then weigh them, and calculate the percentage of the total particle group of each size. The particle size distribution of the crushed rock mass can be obtained by analyzing the particle size of the crushed rock mass by the sieve analysis method.
2. Experimental apparatus
   The grading sieves used are divided into two types: round-hole course sieves (with apertures of 60 mm, 40 mm, 20 mm, 10 mm, 5 mm and 2 mm) and round-hole fine sieves (with apertures of 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.075 mm). Classes, each grading screen is shown in Fig. 3; a balance weighing 1000 g, with a minimum division value of 0.1 g; weighing 200 g, a balance with a minimum division value of 0.01 g; vibrating screen machine, oven, measuring cylinder, funnel, Mortar, porcelain plate, stainless steel spoon, etc.
3. Experimental procedure
   Take out a representative sample from the dry collapse column packing with a particle size larger than 0.075 mm; weigh 500 g of the dry packing, and the error is controlled within 0.1 g; pour the weighed dry packing into the sieves stacked in sequence. Then place the screen on the vibrating screen machine for screening. The sieving time needs to be controlled to be about 10 minutes; finally, the quality left on each sieve can be weighed step by step.
4. Analysis of results
   The particle size distribution characteristics of the fallen column particles are shown in Fig. 2. The particle size range of the collapsed column was obtained through the standard gradation sieving experiment. Those that cannot pass the minimum coarse sieve

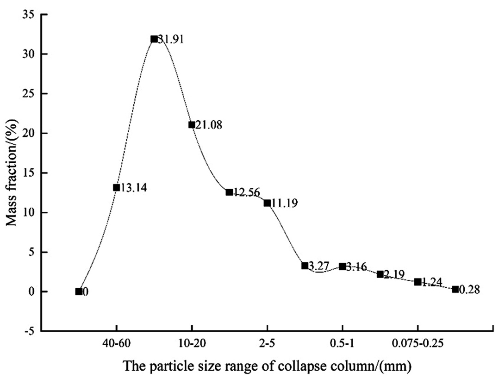

Fig. 2. Grain size distribution of the fall column

(2 mm) can be regarded as coarse particles (greater than 2 mm), and those that pass the minimum coarse sieve can be regarded as fine particles (less than 2 mm), Then the proportion of coarse particles is 89.86%, and the proportion of fine particles is 10.14%.

2.3. Composition and content of broken rock mass in collapsed column

During the experiment, X-ray diffractometer was used for analysis. Before the experiment, the rock to be tested was sampled, and the equipment used was a vertical square planetary mill. Break the rock blocks to be tested with an iron hammer, take an appropriate amount of small rock blocks without debris, put them into a numbered cylindrical barrel, add an appropriate amount of iron balls of different diameters, record the rock name and the corresponding number, and seal it. Good all the iron buckets. Close the safety cover, turn on the switch, rotate for 5 minutes, and then take it out, filter it with a sieve, and obtain a powdered rock sample with a particle size less than 44 μm (350 mesh) for use, as shown in Fig. 3. The sample was taken from a depth of 245 m underground and drilled. After the sample was taken out, it was sealed with honey wax to prevent weathering and ensure the accuracy of the sample.

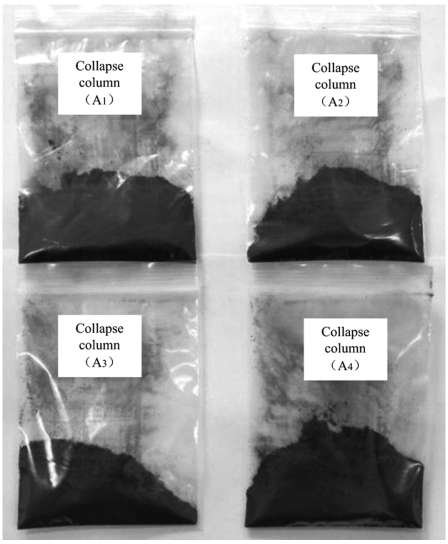

Fig. 3. Dump column mineral powder sample

First fill the powder into the sample holder, then flatten it with a glass plate, turn on the circulating water pump, turn on the high-voltage power supply of the X-ray tube, set appropriate diffraction conditions and parameters, and test the sample. After the test is completed, after the original data undergoes corresponding processing steps, the obtained test result is shown in Fig. 4.

It can be seen from Fig. 4 that the content of illite in the collapsed column samples is relatively high. The reason is that illite is more migratory, so compared with other components, more illite will migrate with the water flow, which will lead to an increase in the porosity

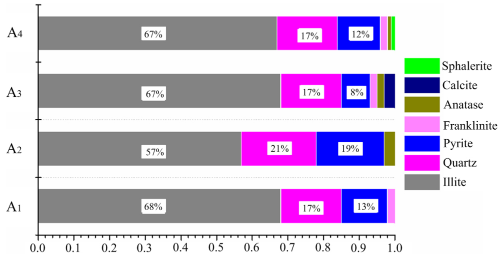

Fig. 4. Composition and proportion of fall column filling sample

and permeability of the column, which further induces water inrush disasters; Under runoff conditions, migrating particles may block the throats of intergranular pores and reduce the permeability of the collapsed column.

2.4. Influence of fabric characteristics of collapsed column fractured rock mass on permeability

It can be seen from the test results of the particle size of the filler that the sample particles are relatively large, the proportion of coarse particles is 89.86%, and the proportion of fine particles is 10.14‰. The largest particle can reach 40–60 mm, and the smallest particle is only 0.075 mm. Dissolution can lead to particle migration, which is also the cause of water inrush disasters. In addition to this, the samples were found to be well graded, which may also account for less permeability and compressibility. It can be seen from the experimental results of the composition analysis of the collapsed column that the mineral composition in the broken rock mass is mainly illite. Because illite is easy to migrate, more illite in the filling of the collapsed column will migrate with the water flow, resulting in the formation of the column. The increase of porosity and permeability will induce water inrush disasters; under weak runoff conditions, the migrating particles may also block the throats of intergranular pores and reduce permeability. To sum up, when the collapsed column is disturbed by mining, the internal filling is in a relatively loose state, and the strong hydrodynamic force is more likely to cause migration and loss, thereby causing water inrush disasters.

3. Variation-mass permeability test of collapsed column broken rock mass

3.1. Experimental principle and method

The penetration test of the collapsed column crushed rock mass is carried out by using the developed seepage experimental system (as shown in Fig. 5). The initial height of the body, the axial displacement, the volume before the rock mass is broken, and the confining pressure series. According to the drainage method, the volume of the liquid discharged under the influence of the confining pressure is the volume reduced by the sample under the influence of the confining pressure, which is collected by the outlet graduated cylinder. Record. The porosity of the sample before infiltration can be calculated under various loads, and the confining pressure is kept stable. Then, the nitrogen cylinder is opened to provide the osmotic pressure, the regulator valve is adjusted, and the data is recorded. At this time, the fine particles of the broken rock mass will flow with the water flow. Flow out from the liquid instrument, if the pressure loss of the pipeline is ignored, it can be considered that the upper pressure of the test specimen is the same as the osmotic pressure, and the lower end pressure of the specimen is the same as the atmospheric pressure, so it is the pressure difference between the two ends of the specimen, and the pressure difference is the same as the flow rate per unit time. The volume flow of the crushed rock mass can be displayed on the screen of the data collection system. According to the height and volume flow of the sample after axial loading, the seepage velocity at all levels of seepage water pressure is calculated. According to the pressure difference and axial loading the pore pressure gradient during percolation is calculated after the specimen height.

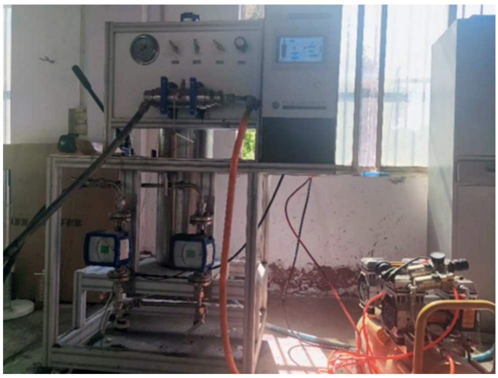

Fig. 5. Broken rock mass penetration test system

3.2. Specimen preparation and test methods

Considering that the crushed rock mass of the collapsed column is composed of coarse-grained skeleton and fine-grained filler, the sample is made of coarse-grained broken limestone as the skeleton and mudstone as the filler, and is formulated into a test sample according to a certain ratio. First, crushed crystalline tuff with particle sizes of 5–10 mm and 2–5 mm and 1–2 mm was mixed in the ratio of 3:2:1 as coarse aggregate, and then 0–0.25 mm, 0.25–0.5 mm and 0.5–1 mm is mixed in a ratio of 1:2:2 as filler particles. In order to analyze the influence of aggregate (skeleton) and filler particle gradation, seepage water pressure, and mass loss on seepage mutation, the designed test scheme is as follows:

1. In order to analyze the pairing of confining pressure and filler particle gradation on the seepage of broken rock mass for the effect of mutation, the mass of each specimen is equal, the ratio of coarse aggregate to filling fine particles is 4:1, 3:1, 2:1, and the confining pressure is 3 MPa, 3.5 MPa, 4 MPa, 4.5 MPa, 5 MPa, respectively.

2. Considering the effect of confining pressure and setting up four levels of axial displacement, they are 4 mm, 8 mm, 12 mm and 16 mm respectively, and the loading time of each level is 60 s. Five groups of confining pressures are set under each stage of axial displacement, and the confining pressure is at least 0.2–0.5 MPa greater than the pore water pressure. The osmotic pressures of three groups were set at 0.5 MPa, 1.0 MPa and 1.5 MPa respectively under each group of confining pressures.

3.3. Analysis of test results

1. The relationship between porosity and permeability
   Porosity is a physical quantity that characterizes the structure of broken rock materials and is an important parameter to describe the permeability characteristics of collapsed columns. According to the test data, the relationship between the porosity and permeability of the broken rock mass with different ratios of coarse aggregate and fine particles under three confining pressures of 3 MPa, 3.5 MPa and 4 MPa was drawn, as shown in Fig. 6.

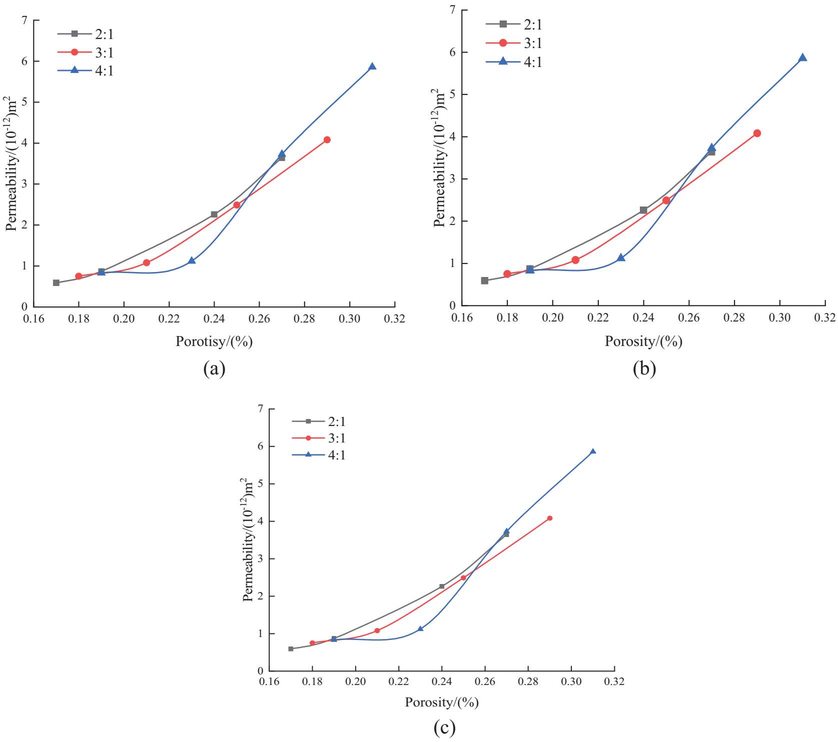

Fig. 6. Porosity-permeability relationship curve, wall rack: a) 3 MPa, b) 3.5 MPa, c) 4 MPa

It can be seen from Fig. 6 that with the increase of the ratio of coarse aggregate to fine aggregate, both the porosity and permeability increase, and the permeability increases faster and faster. Its permeability is better. Crushed rock with a 4:1 coarse-to-fine aggregate ratio has a greater permeability than a 2:1 coarse-to-fine-aggregate ratio. However, as the porosity decreases, the rock sample with a thickness ratio of 2:1 has a higher permeability than the rock sample with a thickness ratio of 4:1. This is because with the compaction of the rock sample, the rock sample with a relatively large particle size is broken. More seriously, the broken small particles fill the pores, block the channels, and reduce the permeability.

2. The relationship between confining pressure and permeability
   In order to analyze the influence of confining pressure on the permeability of broken rock samples, the relationship between confining pressure and permeability was drawn according to the test data, as shown in Fig. 7.

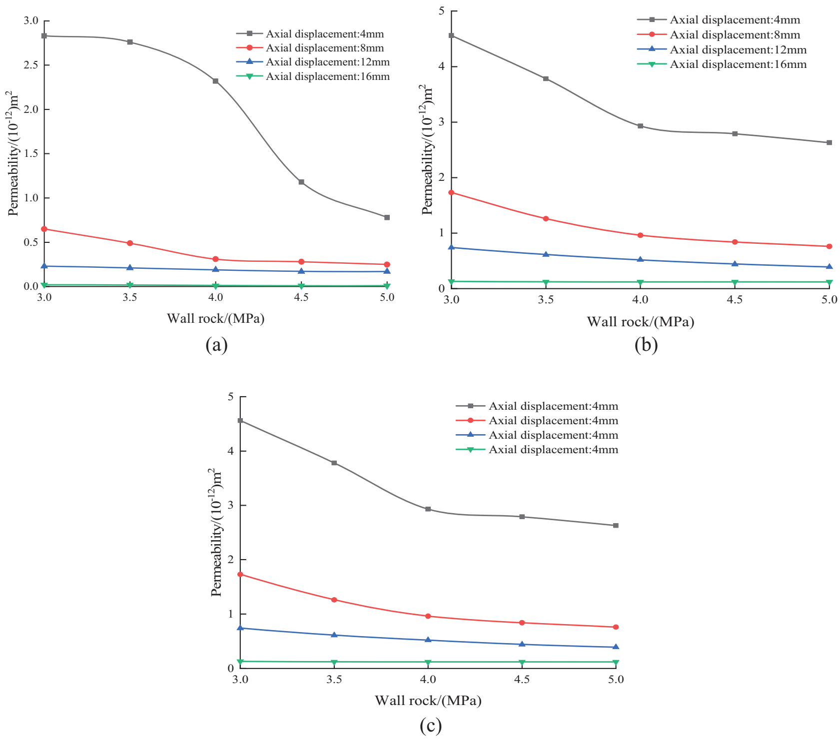

Fig. 7. Wai-pressure-permeability relationship curve, scale of coarse and fine particles: a) 2:1, b) 3:1, c) 4:1

It can be seen from Fig. 7 that when the axial displacement is constant, it can be found that the permeability of broken rock samples decreases with the increase of confining pressure. This is because the axial displacement remains unchanged, the confining pressure will cause the lateral compression deformation of the broken rock sample, the particles inside the rock sample will be compacted, the porosity will decrease, and the permeability of the broken rock mass will also decrease. Under the condition of constant confining pressure, the permeability of broken rock mass decreases with the increase of axial displacement, and it can be found that the larger the axial displacement is, the less obvious the permeability change is. When the axial displacement is 4–8 mm, the degree of compaction of the broken rock mass is relatively small, and there are many pores. Under the action of confining pressure, the seepage channel changes, and the permeability of the broken rock sample changes greatly. The change of its permeability is obvious; when the axial displacement increases to 12–16 mm, the pores inside the broken rock mass have basically been compacted, and the change of the pore channel is small, so the change of the permeability of the rock sample is relatively small, and the change of confining pressure has no effect on the permeability. The effect of permeability is not obvious.

3. Relationship between pore pressure gradient and seepage velocity
   The change of osmotic pressure will cause the change of seepage velocity and pore pressure gradient. Taking the axial displacement of 4 mm and the confining pressure of 3 MPa as an example, the scatter diagram and fitting curve of pore pressure gradient and seepage velocity are obtained, as shown in Fig. 8.

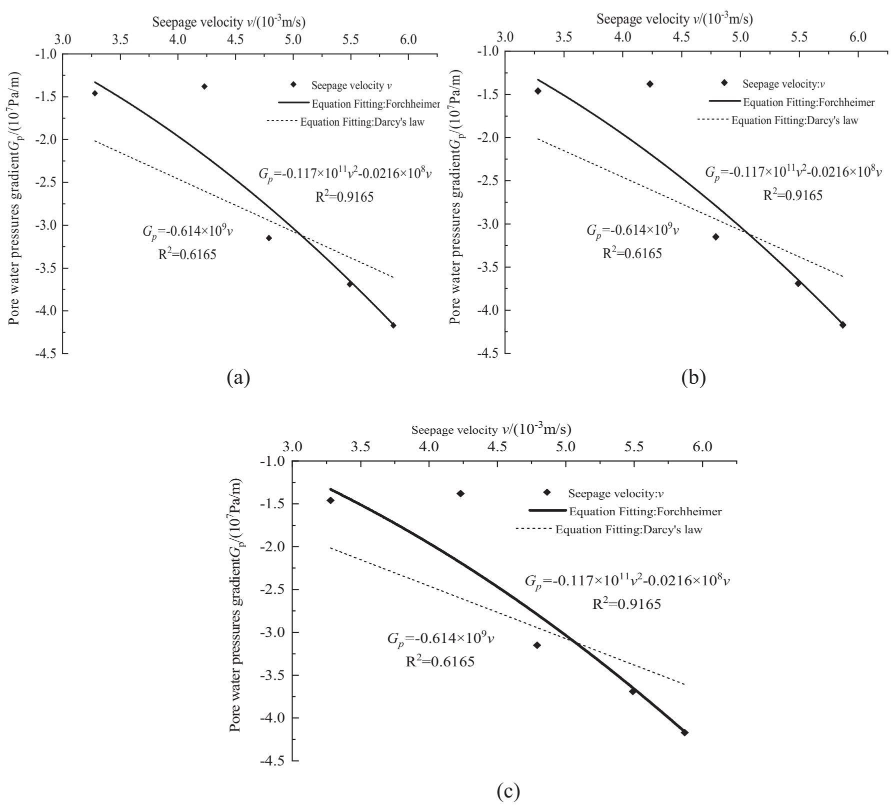

Fig. 8. The relation curve between pore pressure gradient and seepage velocity, scale of coarse and fine particles: a) 2:1, b) 3:1, c) 4:1

It can be seen from Fig. 8 that the value of the correlation coefficient R2 of the curve fitted by the Forchheimer relationship is above 0.93, which is greater than the value of the correlation coefficient R2 obtained by the fitting of Darcy's law, indicating that the fitting of the seepage velocity of the broken rock mass and the pore pressure gradient obeys Forchheimer. relationship without obeying Darcy's Law. The seepage characteristics of broken rock mass under triaxial stress are non-Darcy flow, and each set of data satisfies the above rules. The phenomenon of deviation from Darcy's law is more obvious in the seepage process of broken rock mass with a ratio of coarse to fine particles of 2:1. This is because when the particles of the broken rock mass are relatively dense, the fluid is subjected to greater resistance, so the non-Darcy phenomenon is more obvious.

4. Analysis of seepage and instability process of variable mass broken rock mass, as shown in Fig. 9.

(a) (b) (c)

Fig. 9. Water evolution stage of broken rock mass: a) Initial percolation phase, b) Permetry phase, c) Pipe surge stage

In the initial seepage stage, the dissolution and erosion of water and the abrasion of the original fine particles make the material near the pore wall of the broken rock break away from the parent body and form secondary fine particles; some of the fine particles dissolve with water to form slurry, and the other Part of it forms a suspension, and part of it settles on the pore wall. The fine particles fill the skeleton of the coarse particles, so that the coarse particles inside the sample gradually expand under the influence of the water flow, and the fine particles move from the water inlet along the internal cracks under the action of the water flow. Gradually move to the water outlet, the water flow speed will be relatively small at this stage, the loss of fine particles will be relatively small, and the water flowing out of the water outlet will be relatively clear. In the stable seepage stage, due to the migration and accumulation of fine particles in the pores of the broken rock mass under the action of water pressure, the porosity decreases, the permeability decreases, and the seepage pressure difference between the two sides of the sample increases. To a certain extent, the original structure of the coarse particles will suddenly become unstable, and the water channel will suddenly open, causing the filling particles to be lost in a short period of time. The test phenomenon at this stage is that a large number of fine particles are suddenly lost to the water outlet, and the water flow is relatively turbid. In the piping stage, the skeleton structure of coarse particles is unstable due to the seepage stage, and a large number of fine particles are lost; the test phenomenon in this stage is that the water flow velocity is large, the water inflow is large, and the water body is relatively clear, accompanied by occasional outflow of a small amounts of fine particles, the water flow is relatively stable.

4. Conclusions

1. The experimental analysis of the sieve analysis method shows that the proportion of coarse particles is 89.86%, and the proportion of fine particles is 10.14%. The filling of the collapsed column is mainly composed of illite, quartz, pyrite, zincite and a small amount of anatase, calcite, sphalerite and other minerals. Under the condition of strong hydrodynamics, the collapsed column is very easy to induce the water inrush disaster due to the strong migration and loss of illite with the water flow.
2. As the ratio between coarse and fine aggregates increases, both porosity and permeability increase, and the permeability increases faster and faster. The larger the ratio of coarse aggregates, the higher the permeability. Good; when the axial displacement does not change, as the confining pressure increases, the permeability of the broken rock sample decreases; the fitting of the seepage velocity of the broken rock mass and the pore pressure gradient obeys the Forchheimer relationship, and the Seepage under triaxial stress belongs to the category of non-Darcy flow.
3. The instability of the broken rock mass in the collapsed column presents three seepage stability forms at different stages: the initial seepage stage, the seepage mutation stage, and the piping stage.

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