Development and Application of Series Physical Simulation Test Equipment for Water Inrush in Coal Mine

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Abstract With the increase of the depth and intensity of coal mining, the mine has faced a number of challenges such as floor water inrush, roof water inrush and structural water inrush. Different types of water inrush mechanism and disaster mode are difficult to carry out the research by means of the field, so indoor test has become an effective means to solve this problem. The simulation test system for floor water invasion in coal, the simulation test system for water and sand inrush across overburden fissures and the true triaxial rock test system of coupled stress-seepage were developed.

Keywords physical simulation, non-hydrophilic material, water inrush phenomenon, geological structure, data monitoring

Introduction

Mine water-inrush hazards account for the major proportion in the numerous disaster accidents occurred during the mine production and construction. There were 1089 water in-rush accidents with the casualty of 4329 from 2010 to 2011(James W 2014), while the hydro-geological environments in the mine production will be more complicated along with the continuously deepening mining depth and improving mining intensity in the recent years. Based on the deep mineral resources which account for 27% of the national coal reserve, scholars have to take up various challenges like water-inrushes from mine floors, floors and structures in the fight against water hazards.

Due to the concealment of underground mining engineering, simulation experiment inside the mining laboratory turns to be the effective means to solve such problems for the different types of water-inrush mechanisms and catastrophe modes are difficult to research by means of on-site monitoring etc. Many scholars have made researches on this aspect earlier, Liu (2009) adopted the similar physical model experiment system for water-inrush mechanism in deep mining to research the stresses, deformation (displacements) and failures in surrounding rock influenced by factors i.e. water pressure, mining and complex stress. Li (2010) developed the physical model experimental system for water-inrush (water-inflow) in underground engineering, they adopted the similar materials to simulate the water-inrush supporting during the underground tunnel engineering and successfully explored the catastrophe evolution process for the roadway water-inflow.

Sui (2008) adapted the TST-70 permeameter and conducted simulation test research on the top caving zone of mining working surface for mine production and the seepage deformation failure characteristics of rocks in the fissure zone . Yang (2012) developed the experimental device for mixed water and sand flow and inrush to reveal the variation characteristics of pore water pressure at the different positions in the fracture channels. Hu (2007)developed the simulation test-bed for3D solid coupling to simulate the mining above aquifer and provide the theoretical and experimental basis for water-inrush control.

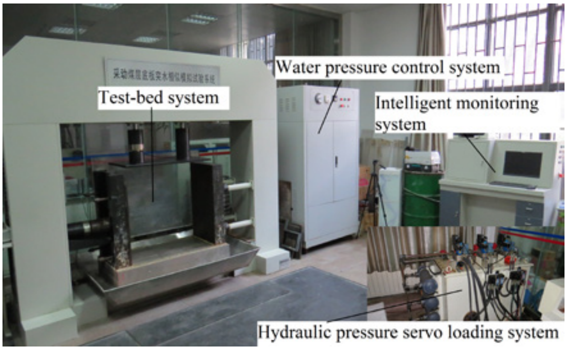
However it can be seen by analyzing the above device that this kind of equipment fails to realize the simulation of the whole process of incubation, development and occurrence for the mine water-inrush hazards; or simulate the complex crustal stress in sealed environment; or directly observe the evolution of the water-inrush channel in the mining process. At the same time, despite the extensive researches(Chang Z 2004, Chen W 2009) the scholars have made focusing on the stress-seepage coupling of the fractured rocks, there is still lack of research on the experimental objects i.e. Large-size test piece (400mm×200mm×200mm) and high seepage pressure etc in addition to the rare researches realizing the tracing monitoring to the expansion and evolution process of the test-piece fractures.

To solve the above problems, Shandong University of Science and Technology has independently researched and developed a series of test equipment such as the similar simulation experiment system for water-inrush from the mining coal seam floor, roof water and sand inrush of mining simulation system as well as the true triaxial rock test system of coupled stress-seepage. It has also established the research lab for water-inrushes and realized the exploration of mine water-inrush by means of lab test; this is of pretty important significance at the same time of providing the multiple means for obtaining the diversified information in the evolution process of mine water-inrush hazards. In this article, it mainly introduces three groups of experiment device, expatiates characteristics of the systems and lists part of the test applications so as to provide the new methods for the researches on the mine water-inrush.

Similar Simulation Experiment System for Water-inrush From the Mining Coal Seam Floor

System Compositions

The similar simulation experiment system for water-inrush from the mining coal seam floor(Sun W 2015 2017, Zhang SC 2017) adopts the 3D solid coupling simulation and computer control technology to obtain the evolution law of the floor mining seepage field under the effects of high water pressure and high confining pressure so as to provide the new research methods for the research on instability and fracture disaster-causing mechanism of seepage channels. The simulation experiment system consists of four subsystems; water pressure control system, servo laoding system, test-bed system and intelligent monitoring system as shown in Fig. 1.



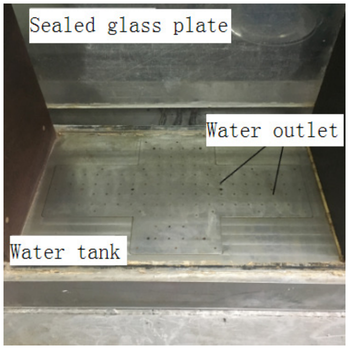


***Fig. 1** Similar Simulation Experiment System for Water-inrush From the Mining coal seam floor*

***Fig. 2** Water-tank Pad*

The laying dimension of test-bed model can be as large as 900mm×500mm×800mm (L×W×H). The crustal stress of the simulation mining field during the experiment is realized by the vertical loading system and lateral loading system with the two loading methods of displacement control and load control; the maximum load of the loading unit is 300kN, the displacement sensor range can be 30mm; loading rate of the two subsystem loads shall be 0.01≈100kN/s while the displacement loading rate shall be 0.01≈100mm/min.

The water pressure control system is connected with the test-bed water-tank by the high-pressure hose; the water injection tube and ram-type pump are also connected by the high-pressure hose so as to inject the water into the model from the water-tank through the pad outlet hole (Fig. 2) on top of the water-tank, the maximum water pressure can be 1.5MPa. The front and rear of the test-bed are the new high-strength sealing material--organic glass plate, the adjacent glass plates are closely joined with gasket cement so that the simulation confined water cannot flow out of the model in between the glass plates; in the meanwhile, the whole process of internal water-inrush and fracture evolution can be observed through the organic glasses. 96 fiber optic sensors are equipped on the pad outlet holes on top of the test-bed water-tank in the model to monitor the variations of water pressure and deduce the variation law of the seepage field on the coal seam floor according to the water pressure variation data collected by sensors in combination with the rock fracture positions.

System Characteristics

The similar simulation experiment system for water-inrush from the mining coal seam floor has the following characteristics:

(1) Full process.

The various phenomena during the simulation of water-inrush from the floor i.e.confined water rise, water-resisting floor failure, water-inrush fracture coalescence, formation and evolution as well as formation of structural water-inrush channels etc can be directly observed through the transparent glass plates on both sides of the test system;

(2) Variety.

The diversity of system is seen at the simulation of multiple water-inrush types, multiple-mode control and loading of displacement stress as well as the various ways of data collection. Simulate the different types of water-inrush mode like fracture water hazards, goaf water hazards and surface water hazards by closing the water bags and water manifolds; adopt the different loading modes to simulate the different stress field conditions i.e. submarine tunnel engineering and in-dept exploration etc;

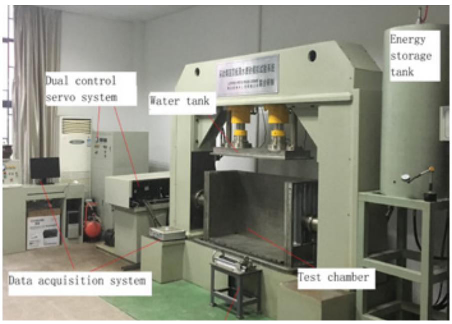
(3) Reliability.

The system is capable of realizing the simulation of water-inrush from the floor under the factors such as different floor structures, mining technologies and water-resisting floor properties etc; through biaxial loading and restraints of organic glass plates, it could realize the simulation of effective crustal stress; by means of water pressure control system, it realizes the pressure preservation of confined water and dynamic water pressure effect in the state of high water pressure; with the help of soil pressure and water flow, the sensor could monitor the variations of stress and seepage field all-around with high precision.

Roof Water and Sand Inrush of Mining Simulation System

System Compositions

Roof water and sand inrush of mining simulation system(Guo W 2016) makes use the closed 3D mining and diversified data acquisition to obtain the overlying strata deformation and failure characteristics, fracture development law, formation of water and sand channels and inrush parameters on the working surface during the mining process, intuitively displays the overlying strata space and the distributional patterns of the water and sand inrush channels after mining the coal, represents the simulation research on the whole process of water and sand inrush hazards on the working surface. This system mainly consists of 7 systems: main bearing support, test chamber, pressure-bearing water tank, mining device, water pressure-water volume dual-control servo system, displacement-stress dual-control servo system and diversified data acquisition system as shown in Fig.3.



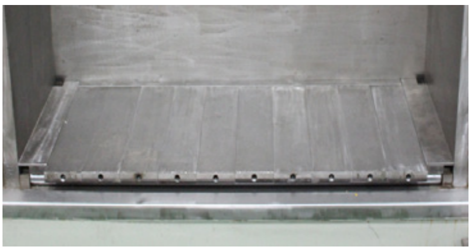


Fig.3 *Roof water and sand inrush of mining simulation system*

Fig. 4 *Coal seam drawing board*

The effective simulation dimension of the test chamber in the test system is 1200 mm×700mm×400 mm (L×W×H); the water pressure-water volume dual-control servo system could provide the water pressure required by the design as large as 0.8MPa while maximum measuring range of the flow meter is 150L/h and the monitoring precision is ±1.0%; the displacement-stress dual-control servo system could carry out the multiple-mode control of displacement and stress, maximum stroke of the loading device is 400mm, the monitoring precision is 0.01mm and the maximum load is 1000kN; in order to reduce the influences of the non-mining factors on the test, the simulated coal device is designed and made, the coal seam drawing board is as shown in Fig.4; variations of overlying strata stress and water pressure in the overlying strata fractures during simulating the mining process on the working surface are directly monitored by the BX-1 soil pressure sensor with the specification of 0.8MPa and the BS-1 osmometer with the specification of 2.5MPa respectively. To maintain the test conditions of stable water pressure and water flow, energy storage tank is installed in between the water pressure system and test system, the pressure-bearing water tank connected to it is evenly distributed with 28 outlet holes in the bottom with the diameter of 4mm.

System Characteristics

(1) Whole process.
Through the totally-closed and digitized control of this system, the structure, shape and dimension of the water and sand inrush channel under the mining and water pressure effects form spontaneously, conduct the whole-process monitoring on the overlying strata deformation and failure characteristics, fracture development law, formation of water and sand inrush channels as well as the inrush parameters by means of system displacement, mine pressure, water pressure and flow sensor;

(2) Visibility.
The structural configurations formed in the overlying strata space and the distributional patterns of the water and sand inrush channels can be intuitively displayed through the entire piece of transparent glass plate so as to reveal the formation mechanism of the water and sand inrush hazards on the coal working surface and provide the quantitative support for the water and sand inrush hazard evolution mechanism and basic theories estimating the water and sand inrush hazards;

(3) High sealability.
The entire piece of glass plate used in this test, the pressure-bearing water tank and test chamber are sealed by the high-pressure seal ring so that the environment of simulated mining field is fully sealed to realize the flexible loading to the overlying rocks.

True Triaxial Rock Test System of Coupled Stress-seepage

System Compositions

The true triaxial rock test system of coupled stress-seepage(Yin L 2014) makes use of the acoustic emission detection technology to trace and observe the fracture expansion and evo-

lution of the large-size rock test piece in real time under the 3D high-stress and high seepage water pressure effects. The test system consists of 6 major parts: the axial loading subsystem, lateral loading subsystem, high-pressure water flow subsystem, acoustic monitoring subsystem, data acquisition and control subsystem and triaxial test box subsystem(Fig.5)
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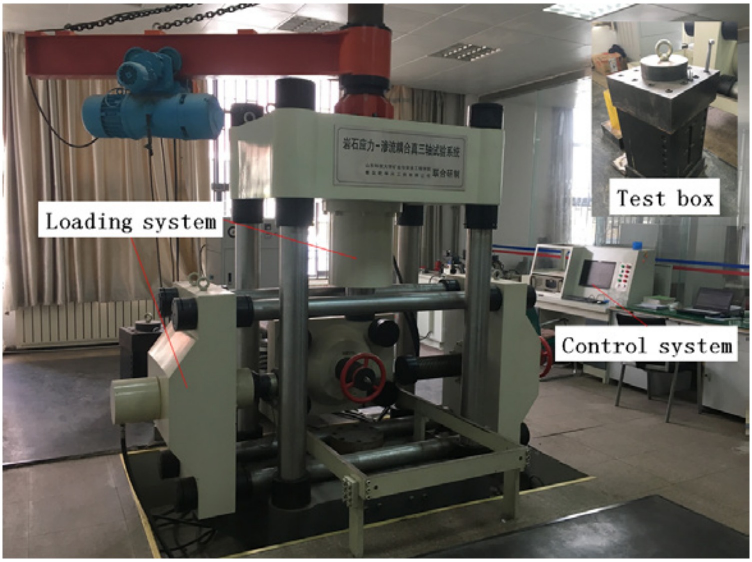

Fig. 5 *True Triaxial Rock Test System of Coupled Stress-seepage*

The maximum load of the axial loading system can be 1600kN while the two lateral exerted loads can be as large as 1000 and 500kN. The test piece used in this test is rectangular; put the test piece inside the cubic test box made of rigid-flexible hybrid structure, seal the test piece with gasket cement all around evenly; use the high-pressure water seepage subsystem to conduct the water-addition test on the test piece from below. The maximum sealed water pressure can be 5MPa, the stand-up pressure time of the seepage pressure is 10d and the measuring range of water flow is 0.001-2mL/s. Paste 6 sonic probes on the positions of the test piece where the minimum stresses are exerted, arranged in 3D space so as to trace and monitor the acoustic emission events during the test and describe the process of fracture expansion and evolution.

System Characteristics

(1) True triaxial.
It could realize the independent 3D stress loading and deformation displacement measurement on three directions and the true trixial test is realized by regulating the servo controller so as to change the triaxial principal stress.

(2) Large dimension.
The test system has the test boxes in three different dimensions, the corresponding rock test dimensions are 400mm×200mm×200mm, 300mm×150mm×150mm and 200mm×100mm×100mm;

(3) High seepage water pressure.
The system could provide the maximum sealed water pressure as 5MPa;

(4) Acoustic monitoring and tracing.
During loading and unloading the test piece, the sensor will monitor the micro cracks inside the rocks in real time and transform them into electrical signals to be transmitted to computers and realize the analysis and quantitative description of the fracture expansion process.

Conclusion

(1) The similar simulation experiment system for water-inrush from the mining coal seam floor realizes the simulation of the floor rock failure and evolution under high water pressure and high stress effects, obtains the disaster-causing evolution law and internal mechanism of water-inrush from floor by monitoring the multiple-field information during the evolution of floor water-inrush channels.

(2) Roof water and sand inrush of mining simulation system realizes the research on the catastrophe characteristics of the water and sand inrush on the mining roof under the water-rock coupling effects, through the testing machine, it clearly displays the structural configurations formed in the overlying strata space and the distributional patterns of the water and sand inrush channels after mining the coal.

(3) The true triaxial rock test system of coupled stress-seepage provides the deep loading environment of high stress and high water pressure as well as the 3D stress controlled by the independent servo for the rock test, it realizes the fully-digitized process of data acquisition and obtains the expansion and evolution law of rock fractures as well as the acoustic emissions in the failure process.

Acknowledgments

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