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Model test to investigate waterproof-resistant slab minimum safety thickness for water inrush geohazards

Hai-ming Jiang [a], Lang Li [a,b,*], Xiao-li Rong [a], Ming-yang Wang [a], Yuan-pu Xia [a], Zhi-cheng Zhang [a]

[a] State Key Laboratory for Disaster Prevention & Mitigation of Explosion & Impact, PLA University of Science and Technology, Nanjing 210007, China
[b] Equipment Academy of the Rocket Force, Beijing 100085, China

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ABSTRACT

The study of waterproof-resistant slab minimum safety thickness for water inrush geohazards is of great significance during the design and construction phase of tunnel engineering. Firstly, to obtain minimum safety thickness of rock wall of tunnel face, a simplified model for simulating the whole process of water inrush disasters is established. Then a three-dimensional (3D) model test system which can be applied to simulate water inrush geohazards, is researched and manufactured. Based on Yuelongmen tunnel of Chengdu to Lanzhou railway line in China as the engineering background, a series of large-scale geomechanical model test have been carried out. The effect of strata pressure, hydraulic pressure and waterproof-resistant slab thickness of surrounding rock on water inrush disaster is studied. Model test results show that minimum safety thickness increases with the increase of strata pressure and decreases with the increase of hydraulic pressure. Besides, there are two main destruction characteristics on tunnel face for water inrush disaster. One is the shear failure occurred at the center of tunnel face which accounts for most of the destruction form. The other is osmotic instability occurred at the edge of tunnel face.

1. Introduction

Nearly 40,000 km of new railways and expressways will be built in China from 2008 to 2020. Water inrush accidents, one of the most severe disasters in underground engineerings, occur frequently both in civil construction and mining industry (Wang et al., 2004; Huang et al., 2012; Li et al., 2013). Due to the diversity of geological conditions, the causes of disasters and accidents process are extremely complicated. And it is difficult to grasp the adverse geological condition in construction course during the early stage. As a result, the construction of underground engineering always leads to sudden water inrush, which poses serious threat to the safety of construction workers and causes huge economic losses (Zhao et al., 2013; Hou et al., 2016). For instance, in the Yesanguan tunnel of Yichang-Wanzhou Railway, water inrush occurred in "DK124 + 602" karst tunnels on 5 August 2007. The peak flow rate reached 1.5×10^5 m^3/h, causing 10 workers died unfortunately and the equipment and machinery in the tunnel to be seriously damaged. In recent years, some theories and methods have been proposed all over the world to reveal the mechanism of water inrush and prevent the disasters in practical engineering cases (Shi and Singh, 2001; Tang et al., 2011; Wang et al., 2012; Li et al., 2013, 2016; Goel, 2014; Li and Li, 2014; Pang et al., 2014; Zhang et al., 2015). Meanwhile, there are more work to be done to understand water inrush disasters fully.

Generally, the collapse or breakdown of rock strata between the tunnel face and water-logged stratum is the main factor causing the dynamic damage phenomenon (Guo and Qiao, 2012). Here water-logged stratum contain these sources of water such as karst water, underground rivers and productive aquifer etc. Consequently, waterproof-resistant slab minimum safety thickness is an key parameter to formulate the prediction and prevention measures of water inrush disaster. Estimating the minimum safety thickness properly in advance, will be practical for adjusting the construction scheme to ensure the safety of construction. In recent years, some models and mathematical derivation on waterproof-resistant slab minimum thickness, which adopt the method of elastic theory, elastic-plastic theory, fracture mechanics, the perturbation method and so on, were developed (Yan et al., 2006; Zang, 2007; Li et al., 2015). However, in view of the complexity of geological environment, they need to be simplified to a certain degree but then fail to fully describe the complex field geological conditions.

* Corresponding author at: State Key Laboratory for Disaster Prevention & Mitigation of Explosion & Impact, PLA University of Science and Technology, Nanjing 210007, China.

E-mail address: lilang593@163.com (L. Li).

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Hence, model test has become an important means to study water inrush disasters. Some scholars studied water inrush under joint action of complex stress conditions, hydraulic pressure and external excavation disturbances by similarity model tests (Liu et al., 2009; Liang et al., 2016; Wang et al., 2016). The current situation is that there is little attention paid to the quantitative analysis about waterproof-resistant slab minimum safety thickness in above tests. Moreover, the model size of those test are usually too larger which have many disadvantages such as high costs, long test period and high strength. Thus it is not prone to carry out a series of tests under different conditions or model test with large sample.

Considering above mentioned, this paper attempts to present a series of experimental investigation to obtain waterproof-resistant slab minimum safety thickness of water inrush disasters in underground openings. The focus is not aiming at research the mechanism of water inrush disaster. The developed 3D model test system can prepare a large number of model samples in advance. Then to study minimum safety thickness under different strata pressure and hydraulic pressures, a series of large-scale model tests have been carried out. The influence of strata pressure and waterproof-resistant slab thickness on water inrush are analyzed. And the experimental results can provide data support and guidance for prediction of water inrush disaster.

2. Simplified model and the test system

2.1. A simplified model for water inrush geohazards

Waterproof-resistant slab minimum safety thickness is affected by the following factors such as the physical and mechanical properties of the surrounding rock, hydraulic pressure, the size and shape of water-logged stratum, external excavation disturbances as well as strata pressure (Zhao et al., 2013). In this paper, the surrounding rock, hydraulic pressure and strata pressure are three main factors selected as the research objects. The establishment of simplified model for water inrush geohazards based on the following assumptions: (1) The cross sections of tunnels in practical engineering is simplified as a circular chamber; (2) The focus is aiming at obtaining minimum safety thickness. And mechanism study of water inrush disaster is not the research emphasis; (3) Assuming that water-logged stratum is located in front of tunnel face, the minimum safety thickness is obtained by the method of model test under the action of excavation disturbances. And for water-logged stratum located in other direction such as tunnel vault, floor and sidewalls, this thickness is used as minimum safety thickness instead. To obtain this thickness, a simplified model shown in Fig. 1 is established. The model is cylindrical in shape. And it can simulate the process of water inrush disasters under different conditions of strata pressure, hydraulic pressure and surrounding rock induced by external excavation disturbances. In order to simulate strata pressure of rock mass, a load with pressure γH is applied at the boundary of the model. And hydraulic pressures P is applied at the front face of the model.

2.2. 3D model test system for water inrush geohazards

Based on the model established above, a 3D model test system which can be used for simulation of water inrush disasters in the construction progress of underground tunnels, is researched and manufactured (Li et al., 2016). It consists of 3D model test device for water inrush geohazards, sample molding device and device of simulation tunnel's excavation and unloading.

The overall design of 3D model test device is shown in Fig. 2. It consists of the axial loading system, confining pressure loading system, the hydraulic loading system, sample model components and measurement system, etc. The strata pressure of model is applied by the axial loading system and confining pressure loading system. The axial loads of model is loaded by a jack located in the bottom direction. The confining pressure is loaded by the method of compressed gas. And the air pressure is controlled by a high-precision pressure regulating valve. In order to simulate hydraulic pressure of underground water-logged stratum, a tank is designed to provide for hydraulic pressure through compressed water by air pressure. And a load sensor is arranged on the top of the tank to monitor the overall weight of the water. During the process of creating a new openings, it can accurately grasp the time water inrush disasters occurred because at the moment the water in the tank reduced sharply. In order to seal the model, a layer of latex film is parceled outside of the model. And the tightening strips is used to tighten the model at both ends. Many sealing rings are arranged on the key part of the test device to ensure the sealing performance and the independent application of the loads. The maximum confining pressure and axial pressure of test device are both designed as 1.2 MPa. And the maximum hydraulic pressure is 1 MPa. Sample molding device and device of simulation tunnel's excavation and unloading are introduced in the next chapter. The test system have many advantages such as shorter test periods, high reliability, high efficiency, low cost and convenient, etc.

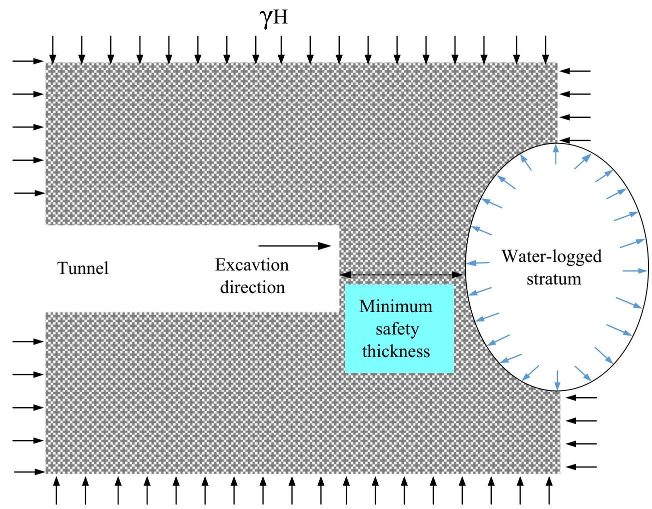

Fig. 1. Schematic diagram of waterproof-resistant slab minimum safety thickness.

3. Test design and procedures

3.1. Engineering background

Yuelongmen tunnel of Chengdu to Lanzhou railway line is selected as engineering prototype. The tunnel have a double line with the maximum line spacing of 60 m. And the minimum distance is 30 m. The tunnel origin destination mileage of left line is D2K91 + 020–D2K110 + 994.3 with the total length of 19,974 m. The tunnel origin destination mileage of right line is YD2K91 + 002–YD2K111 + 046 with the total length of 20,044 m. Approximately 2.64 km in length of the tunnel's buried depth are more than 800 m. The biggest buried depth of tunnel is as deep as 1445.5 m. The tunnel pass through the central fault zone. Faults and folds are highly developed in some place and the lithology is almost limestone. The karst phenomenon is obvious. The groundwater is rich and the amount of water is large. Water inrush disasters occurred in construction process of tunnel.