Scale Model Study on Water Seepage from Cracked Lining Structure

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Abstract: The calculation of water pressure behind a cracked lining structure requires determination of the crack width, amount of water seepage and the value of water pressure. Regarding the relationship among lining structure crack, water seepage and water pressure, self-made concrete splitting specimens and Chongqing University developed cavitation acoustic shock test system are used to study water seepage in the specimens. The test results show: water pressure and crack width are main factors influencing water seepage; at a given crack width, excessive water pressure imposes local load on the lining structure, aggravating its cracking; when the crack is excessively wide, water pressure changes slightly but flow rate increases considerably affecting traffic in the tunnel. Meanwhile, increased pressure from surrounding rock compresses the crack in the lining structure and reduces flow rate. The study results can provide reference to treatment of defects in tunnels at different depths in different areas.

1. Introduction
The amount of water seepage from a cracked lining structure is dependent on section roughness, section area, curvature, water pressure, etc. Cracks may occur on the surface of the lining structure after the tunnel structure is completed due to shrinkage of concrete material, unbalanced confining pressure and water pressure behind the lining. Geographic conditions are complex in China where the north and the south have distinct climates. In the south where rainfall is heavy, blind drains and drain ditches are prone to clogging and increased water pressure due to design and construction factors, thus aggravating crack creation and development. It is therefore important to study the relationship among crack conditions, water seepage state, surrounding rock and groundwater environment [1-3].

Changes of water seepage in a cracked lining structure is a key factor as the basis for study on reasonable lining thickness, calculation of lining structure thickness and water pressure, defect analysis and structure repair. Gao Chenglu et al. (2019) used an independently developed 3D geomechanical model loading system to simulate the mechanism of water seepage in tunnels at different depths, reveal the evolution of water seepage in lining and demonstrate drainage is an effective means of mitigating lining cracking and reduce water seepage [4]. Wang Zhijie et al. (2019) used a self-made even water pressure loading device to simulate the lining structure performance under different water pressure effects at varying depths and through comparison of finite element simulation results, concluded that as water pressure increases the negative bending moment at arch foot increases leading to reduced structural capacity and a safety factor of less than 1.5 [5].

In this paper, a small scale model test is performed on concrete specimens using the Chongqing
University developed cavitation acoustic shock test system and Isoc water pressure loading system to simulate the amount of water seepage from the concrete specimens under different water pressure, confining pressure and crack width conditions [7-9]. The analysis results show: the amount of water seepage is significantly affected by crack width and water pressure; as water pressure drops, the water seepage rate and amount decrease markedly; meanwhile, confining pressure can reduce the amount of water seepage.

2. Project Background
With an increasing number of tunnels in progress and completed, tunnel defects experience an explosive growth. In China the tunnel model test platforms for water pressure related defects are not mature yet, with a lack of study on the mechanism of water pressure caused disasters with cracked lining structure, lining structure performance characteristics, deformation patterns and appropriate treatment measures. Most existing researches rely on numerical modeling or water pressure equivalent substitution to very lining structure performance characteristics. Consequently, selection of maintenance parameters for defective tunnels and design parameters for tunnels under construction in areas with abundant water often rely on experience lacking relevant test basis and data support. This may result in a waste of human and material resources due to excessively high parameters or ineffective reinforcement and evolving defects due to excessively low parameters.

In the context of Topic 10 study on "complete technology and equipment for quick location of damage and post-disaster diagnosis for urban tunnels", this test is divided into three stages: small scale specimen test in Stage 1; full scale specimen test in Stage 2; and model test in Stage 3. This paper focuses on small scale specimen test in Stage 1.

3. Test Equipment
3.1 Comparison and selection of instruments
Table 1 lists different test instruments. On the basis of early survey of manufacturers and labs, it is found that using the cavitation acoustic shock test system at the national key lab for coal mine disaster dynamics and control at Chongqing University could meet the requirements of small scale test, with a relatively short queuing time, a wide range of adjustable instrument parameters and specimen parameters, low cost and high feasibility.

| Item for comparison | Concrete seepage resistance instrument | Rock permeameter | Cavitation acoustic shock test system |
|---------------------|----------------------------------------|------------------|---------------------------------------|
| Model shape         | Cylinder                               | Cylinder         | Cube                                  |
| Model size(mm)      | Ø175~185×153                           | Ø50×100          | Ø100×100~200                          |
| Instrument function | Water pressure                          | Water pressure and environment | Water pressure and axial pressure       |
| Measurement content | Water seepage state                    | Water seepage pressure and rate | Water seepage pressure, rate and acoustic emission |
| Ultimate water pressure (MPa) | <1MPa                                 | 4.0MPa           | 35MPa                                 |
| Ultimate confining pressure (MPa) | None                                  | 3.5MPa           | 30MPa                                 |
| Water seepage flow (L/min) | 0.16L/min                             | \               | 0~50L/min                             |
### 3.2 Test conditions

There are 160 data sets under different combinations of crack width, water pressure and confining pressure, as shown in Table 2.

| Name of test | Scale model for water seepage changes in lining structure |
|--------------|----------------------------------------------------------|
| Confining pressure (MPa) | 0.5 | 1 | 1.5 | 2 |
| Water pressure (kPa) | 100800 |
| Crack width (mm) | 0.2 | 0.4 | 0.6 | 0.8 | 1 |

### 4. Test Implementation Process

1) Silicone rubber is uniformly applied to side walls of the specimen and small voids in side walls of the concrete specimen; after the rubber is hardened, irregular silicone rubber is corrected so that the overall surface is flat.

2) The heat-shrink tube is unfolded and inserted through the upper piston rod base; the specimen is placed on the piston rod base which is adjusted to compress the specimen; the location of the heat-shrink tube is adjusted so that it is fully wrapped around the specimen and upper and lower piston rods; the heat-shrink tube is blown by a heat gun to ensure the specimen is completely tight.

3) The lifting platform is adjusted and fixing bolt tightened.

4) The axial pressure loading system is started to make axial pressure reach preset value. Confining pressure is applied to make it reach minimum preset value. Initial axial pressure is 12KN; initial confining pressure is 0.5MPa; loading rate is 0.05MP/s.

5) Air in the vacuum pump is discharged; the vacuum pump is connected to the test system and filled with ultrapure water making it reach the initial water pressure of 100Kpa. After axial and confining pressures have stabilized, water pressure is applied and data recorded. Water pressure values of 100 Kpa -800 Kpa are measured as one set at the same confining pressure, and then surrounding rock is adjusted to measure the next set of flow values at the same water pressure.

### 5. Data Analysis

From the above process it is known that there are 160 data sets under different combinations of crack width, water pressure and confining pressure. Therefore, the relationships among water injection pressure, confining pressure and crack width are compared under crack width of 0.2mm, confining pressure of 1MPa and water pressure of 200kpa respectively.

As shown in Fig. 1, when the crack width is 0.2mm the maximum stable water pressure is about 700KPa at different confining pressures; with increasing confining pressure, the water injection pressure is inversely proportional to flow rate; when the confining pressure is 1MPa, flow rate can...
reach maximum value of 107ml/min.

As shown in Fig. 2, when confining pressure is 1 MPa the stable water pressures can reach 200 KPa with different crack widths; when crack width is ≤0.4 mm and set water pressure ≤400 KPa, stable water pressures can all meet setting requirements; as crack widths increase, stable water pressures decrease. With wider cracks, the flow rate increases with water pressure until it reaches the design flow rate of the machine.

As shown in Fig. 3, stable water pressure with different crack widths can meet the 200 kPa requirement at a constant water pressure of 200 kPa and confining pressures of 1.0 MPa, 1.5 MPa, 2.0 MPa and 2.5 MPa; and the confining pressure is inversely proportional to water pressure possibly because the small specimen is wrapped by confining pressure and subject to annular compression during the test, leading to reduced crack in the specimen.
The above analysis results show: water pressure and crack width are main factors influencing water seepage; at a given crack width, excessive water pressure imposes local load on the lining structure, aggravating its cracking; when the crack is excessively wide, water pressure changes slightly but flow rate increases considerably affecting traffic in the tunnel. Meanwhile, increased pressure from surrounding rock compresses the crack in the lining structure and reduces flow rate. The study results can provide reference to treatment of defects in tunnels at different depths in different areas.

6. Conclusions
In the context of Topic 10 study on "complete technology and equipment for quick location of damage and post-disaster diagnosis for urban tunnels", study on water seepage changes was performed using scale model to analyze the amount of water seepage and flow rate for the reduced scale specimen with different crack width at different water pressures and confining pressures. The following conclusions can be drawn:

(1) According to the scale model test for water seepage changes, the water pressure is proportional to the amount of water seepage and flow rate at a constant confining pressure and crack width.

(2) At a constant confining pressure, a wider crack results in lower water pressure but higher flow rate; the confining pressure would squeeze the concrete specimen, leading to increased water pressure and flow rate under the same circumstances.

Acknowledgements
This work is financially supported by National Key Research and Development Program of China (2017YFC08060010, 2017YFC08060003), National Natural Science Foundation of China (41601574), Special Project of Scientific and Technological Innovation for Social Undertakings and People's Livelihood Guarantee of Chongqing, China (cstc2017shmsA30010).

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