Study on Frictional Force between Lining Concrete and Rubber Blocks

Zhiyong Zhou¹,²⁺, Sen Gao³, Xiaolu Chen⁴ and Chengying Guan⁴

¹ Wuda Jucheng Structure Co., Ltd. Research Institute, Wuhan, Hubei, 430223, China
² Engineering Research Center of Building Inspection and Reinforcement, Ministry of Education, Wuhan University, Wuhan, Hubei 430072, China
³ Central Route Construction Management Bureau of South to North Water Transfer Project, Beijing, 100053, China
⁴ School of Civil Engineering, Wuhan University, Wuhan, Hubei, 430072, China
⁺ Corresponding author’s e-mail: zp@wudajucheng.com

Abstract. This paper mainly studies the friction coefficient between lined concrete and rubber blocks, designs the Friction resistance test device, puts forward two different Shaw hardness rubber blocks in different environments, and carries out the experimental research, obtains the corresponding coefficient of friction results, and provides the parameters and basis for the development of the special enclosure for the research of the subject.

1. Introduction

The first phase of the South-North Water Transfer Central Line is 1432 km long and has a wide variety of building types, including 1100 km of aqueducts. The operation of the project is facing safety issues, especially the soil channel slope instability, lining structure damage and other dangerous situations are difficult to avoid.

Since the main canal of the central line is put into operation, it is responsible for the task of supplying water to the residents and industrial production of large and medium-sized cities such as Beijing and Tianjin. Once the water delivery is interrupted, the impact will be wide and the social impact will be large. It is necessary to repair the main canal lining board without interrupting the channel water delivery.

According to the characteristics of the South-North Water Transfer Project, the National Key Research and Development Plan puts forward the project of "Research on Emergency Rescue and Rapid Repair of Key Technologies and Equipment of the South-North Water Transfer Project", and this paper and one of the research contents of the special topic of the siege in the project under the topic 2017YFC0405001. When the enclosure system is working, it is subject to the impact of upstream water flow and the pressure of the side static water, and it is necessary to verify whether the friction between the perimeter equipment and the lining plate under this operating condition can offset the force of the water flow on the surrounding equipment, so that the enclosure does not slip.

Therefore, the friction coefficient between the rubber pressure block at the bottom of the enclosure and the lining plate is studied experimentally. The friction coefficient between the two is obtained, which provides calculation parameters for the development of special cofferdams.
2. Pre-research
The research on the frictional properties between hard rubber and concrete has carried out literature review and research. The literature "The effect of rubber pad on the contact characteristics of tunnel lining tube sheet"[1] is analyzed by straight shear test, and the influence of rubber pad on the contact characteristics of tunnel lining pipe sheet can be used as a qualitative reference in determining the coefficient of friction between concrete and rubber. The paper "Rubber resistance skateboard in China's water transportation engineering for the first time"[2] in the paper introduced the concrete structure bottom surface set rubber resistance skateboard and stone-throwing machine tool friction coefficient test and related results, analysis of the friction coefficient of each test process - block displacement relationship curve, the determination of the machine machine under different pressures(40kPa,60kPa and 80kPa)coefficient of friction - horizontal slide relationship curve, the study of this paper (pressure in 90kPa) is of reference value. The paper "Experimental study of many friction interfaces and coefficients of friction under water"[3] gives the conclusion that the mean coefficient of friction between concrete and rubber plate in underwater environment is 0.56. JTG 3362-2018"Road reinforced concrete and prestressed concrete bridge culvert design specification"[4] shows that the friction coefficient between rubber bearing and concrete is 0.3. "Mechanical Design Manual"[5] gives the conclusion that the friction coefficient of concrete and rubber is 0.4 ~ 0.75 under wet conditions. It is shown that the coefficient of friction between concrete and rubber is greatly affected by wetting conditions, and this research project is also in the underwater environment, while the channel lining plate may actually have some silt accumulation, so this study should design different test conditions for these influencing factors when conducting a test study on the frictional force between concrete and rubber plate.

3. Friction test

3.1. Pilot scheme
Based on the research situation, the Shore hardness of rubber suitable for underwater concrete is generally 60±5. Therefore, two rubbers are selected in this test, and the Shore hardness is 65 and 55 respectively. Corresponding test conditions are designed for different needle environments, as shown in Table 1.

Working conditions 1 and 2 are friction tests in a conventional dry environment.
Working conditions 3 and 4 are to soak the concrete slab in water for 15 days, then take it out and conduct a friction test on the surface of the concrete without clear water.
Working conditions 5 and 6 are to soak the concrete slab in water for 15 days, then take it out and place it in a test tank for friction test, which is to simulate a clean water environment.
Working conditions 7 and 8 are to soak the concrete slab in water for 15 days, then smear the silt from the bottom of the pond and place it in a test tank for friction test, which is a simulated silt environment.

| Conditions | Concrete Slab Environment | Rubber Shore Hardness |
|------------|--------------------------|-----------------------|
| One        | Regular dry environment  | 65                    |
| Two        |                          | 55                    |
| Three      | Remove after 15 days of soaking in water. | 65 |
| Four       | There is no clear water on the surface | 55 |
| Five       | Remove after 15 days of immersion, | 65 |
| Six        | Water environment resistance test | 55 |
| Seven      | After 15 days of soaking in water, the silt at the bottom of the pond is applied and the water environment is tested | 65 |
| Eight      |                          | 55                    |

The coefficient of friction can usually be determined by the method of friction angle. The method is generally to place one of the two objects to be measured as a slope, and the other is placed on the slope and slides down along it, gradually reducing the slope angle $\theta$. It can be found that when $\theta$ reaches a certain value $\theta_0$, the object will slide down at a constant speed. As shown in Figure 1. then from $mg\sin\theta_0 = \mu mg\cos\theta_0$, we get: $\mu = \tan \theta_0$, where $\theta_0$ is the angle of friction, that is, the value of $\mu$ between two objects is obtained by measuring the angle of friction.

![Figure 1. Uses friction angles to determine the coefficient diagram](image)

Because the above-mentioned method of measuring friction angle is difficult to control the friction angle $\theta_0$ accurately in practice, the device as shown in Figure 2 is designed for friction testing. The basic principle of the device is: the rubber block and concrete block are pressurized vertically by the universal material tester, the rubber block is placed on one piece of concrete each, and the concrete horizontal direction is limited, and the rubber block is placed in the carrier. Connect the carrier to the pull load structure with a traction rope and install the pull sensor. The vertically loaded part of the structure is placed in the sink, and the rubber and concrete blocks can be added to the underwater environment.

![Figure 2. Frictional force test device](image)

### 3.2. Test conclusions

Tests are conducted according to design test conditions, and the test analysis data are shown in Table 2. Figure 3 is the test state of the test device under the universal material test machine, and Figure 4 is a photo of the mud at the bottom of the reservoir being smeared after 15 days of concrete immersion and placed in a water environment for a drag test.

| Serial Number | Test Conditions | Shore Hardness | The Measured Value | Average Value |
|---------------|----------------|----------------|--------------------|---------------|
| 1             | Regular dry environment | 65             | 1.88               | 1.72          |
| 2             |                 | 55             | 1.55               | 1.53          |

Table 2. Results table for the coefficient of friction test
3. Remove after 15 days of soaking in water, There is no clear water on the surface
4. Remove after 15 days of immersion, Water environment resistance test
5. After 15 days of soaking in water, the silt at the bottom of the pond is applied and the water environment is tested

|    | 65  | 1.12 | 1.24 | 1.21 | 1.19 |
|----|-----|------|------|------|------|
| 3  | 55  | 1.09 | 1.13 | 0.88 | 1.03 |
| 4  | 65  | 0.88 | 0.83 | 0.84 | 0.85 |
| 5  | 55  | 0.84 | 0.76 | 0.74 | 0.78 |
| 6  | 65  | 0.57 | 0.59 | 0.6  | 0.59 |
| 7  | 55  | 0.42 | 0.43 | 0.47 | 0.44 |
| 8  |     |      |      |      |      |

The test found that the test value of the number of Friction systems of rubber and concrete slabs with a hardness of 65 under different operating conditions was between 0.57 and 1.88, of which the underwater Friction coefficient was between 0.57 and 0.88. The test value of the molybdo coefficient of rubber and concrete slab with a hardness of 55 is between 0.42 and 1.62 under different operating conditions, of which the coefficient of underwater Friction is between 0.42 and 0.84.

In the dry environment, the Friction coefficient is the largest, the water environment with pond mud situation is the smallest, for this project, you can refer to the water environment with pond mud Friction coefficient test value. The rubber with a Shore hardness of 65 has a greater resistance factor to concrete slabs than the rubber with a Shaw Hardness of 55, which is more conducive to anti-slip during operation of the perimeter system.

Due to the relative softness of the rubber of Shaw's hardness 55, it can be more adapted to the uneven condition of the bottom of the lining plate, and can better disperse the pressure and avoid the disadvantage of excessive local stress to the lining plate, but the rubber block is applied to the pond mud after the average Friction coefficient in the water environment 0.44, the measured minimum value is 0.42, the hardness rubber is used as a pressure block, under the conditions allow, the lining plate can be properly desilted first, so as to improve the anti-slip capacity of the enclosure.

4. Conclusion
This paper introduces the study of frictional force tests of two types of Shore hardness (65 and 55) rubber and concrete slabs under different environmental conditions. The friction coefficient between the rubber and the concrete slab under different working conditions is obtained. The friction coefficient of the two materials is the largest in a dry environment, and the humid environment has a greater impact on the friction between the two materials. In addition, when there is silt, the two are not completely in direct contact. Under this working condition, the friction coefficient is the smallest, which is the most unfavorable for the cofferdam to resist overturning. Through the experimental research, the resistance parameters between the rubber pressure block and the lining plate, which are used with the special fence of the south-north water-north midline channel lining plate, are obtained, which provides the calculation parameters for the development and application of the special fence.

Acknowledgments
This work was financially supported by the National Key R&D Program of China (project No. 2017YFC0405001).

References
[1] Zhang ZY, Jia CH, Li HJ, Feng JL. Experimental study on the influence of rubber pads on the contact characteristics of tunnel lining segments. J. Railway Construction, 2017.07.18:1003-1995.
[2] Xie SW, Li YB. The first application of rubber anti-sliding plate in my country's water transportation project. J. Water Transport Engineering, 2006, B12:53-57.

[3] Zhang JX, Zang B, Liu JK. Experimental Research on Underwater Multi-friction Interface and Friction Coefficient. J. China Harbour Construction, 2017, 2(37):65-67.

[4] JTG 3362. (2018) Road reinforced concrete and pre-stressed concrete bridge culvert design specifications. People's Transportation Press. Beijing.

[5] Wen BJ. (2018) Mechanical Design Manual. Machinery Industry Press. Beijing.