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A test device used to measure the leakage dissolution characteristic of diaphragm wall

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Abstract. In this research paper, a test device that measures the leakage dissolution characteristic of diaphragm wall is introduced. The article mainly describes the thought of development, the basic principle, the structure, and the test result of the device that shows the test device is reliable using the testing examples of measuring the leakage dissolution characteristic of diaphragm wall.

1. Introduction
The diaphragm wall is widely used in the dam foundation of a water conservancy project and the embankment leakage-resistance reinforcement project, mainly including concrete diagram wall and plastic concrete diagram wall. In the late 1950s, China began to build concrete diagram walls. In the 1980s, flexible diagram walls such as plastic concrete and cement soil were used more and more widely in actual projects[1]. The diagram wall is located underground and subject to the leakage dissolution of the pressurized water in the environment for a long term, so its durability directly determines the safe operation and service life of the building, thus the test research on the leakage and dissolution of the diagram wall has been attached more importance. At present, there is neither uniform test method and evaluation indicators for the dissolution resistance test of diagram materials[2], nor special test device for indoor test. The development of a test device dedicated to the study of the leakage and dissolution resistance of diaphragm wall is of great significance for the accurate evaluation of the leakage resistance and durability of the diaphragm wall.

2. Principle of the test device that measures the leakage dissolution characteristic of diaphragm wall
With the test device that measures the leakage dissolution characteristic of diaphragm wall, it is possible to carry out the leakage coefficient test, dissolution test and limit leakage slope for the leakage-resistance building. The device can achieve the following three tests:
① To accurately solve the leakage coefficient using the Darcy's law with clear physical significance;
② To determine the CaO dissolution by simulating the actual project with the flow-through method, to evaluate the durability of the diaphragm wall;
③ To achieve indoor test of limit leakage slope under higher head pressure.

2.1. Development thought of the test device
① A pressure chamber is designed. This structure allows the application of leakage pressure to the height direction of the test specimen, and peripheral pressure to the side surface. In the test, the
leakage pressure can be flexibly adjusted depending on the actual condition of the test specimen to shorten the observation time of the leakage coefficient test.

② The bypass leakage problem is solved by applying a large peripheral pressure after the test specimen is applied with adhesive film to ensure the accuracy of the test results.

③ Two pressure water tanks are designed, one is the leakage pressure water tank and the other is the water make-up tank. Through the pressure regulating valve, the water make-up tank can continuously replenish the leakage pressure water tank, ensuring the leakage dissolution test and the limit leakage slope test being conducted without interruption.

④ Install a water collecting pipe at the leakage outlet to achieve the measurement of the water in the limit leakage slope and the leakage dissolution test.

2.2. Structure and working principle of the test device that measures the leakage dissolution characteristic of diaphragm wall

The test device that measures the leakage dissolution characteristic of diaphragm wall is composed of a pressure source, a pressure chamber, a leakage pressure water tank, a water make-up tank, a pressure regulating valve, a pressure gauge and a water collecting pipe. From the structure, it is divided into three parts:

① Pressure chamber. The pressure chamber includes a fixing structure for pressure chamber, a pressure outer cover, and a screw fastening ring with a handle.

② Pressure control part. It consists of three pressure regulating valves and three precision pressure gauges, which are installed on the panel of the control cabinet. The air pressure source provides pressure for the water make-up tank, the leakage pressure water tank and the pressure chamber (peripheral pressure) through a tee valve.

③ Pressure water tank. It includes the leakage pressure water tank and the water make-up tank. The water make-up tank is connected with the water source and the leakage pressure water tank, and applies pressure onto the water in the water make-up tank through the water make-up tank’s regulating valve, and makes the pressure is greater than the pressure in the leakage pressure water tank to form a water make-up flow, ensuring the leakage dissolution test and the limit leakage slope test are conducted without interruption.

The working principle of the test device that measures the leakage dissolution characteristic of diaphragm wall is: to apply the leakage pressure onto the test specimen in the pressure chamber by the pressure regulating device in the control cabinet, based on simulation of the operating condition of the diaphragm wall with pressure leakage in the actual project. The pressure water is forced to flow through the test specimen. After a stable leakage is formed, the leakage flow of the leakage water and the calcium ion content thereof are measured, and the leakage coefficient and the leakage slope are calculated by using the Darcy's law. Next, the dissolution relation curves are prepared, thus completing the leakage characteristic test. The leakage water pressure of the test device that measures the leakage dissolution characteristic of diaphragm wall is converted by the air pressure being applied into the leakage pressure water tank. The water enters the test specimen from the lower part and flows out from the upper part. After the leakage flow is stable, the water collector will measure the leakage amount, thus the stable leakage amount within a certain interval will be obtained. The leakage coefficient and leakage slope of the test specimen are calculated as per the Darcy's law, and the Ca^{2+} content of the leakage water is detected, the dissolution relations curves like the curves showing the relations between Ca^{2+} dissolution and leakage duration, and the relations between CaO cumulative dissolution and leakage duration are prepared.
3. Verification of application effect of leakage dissolution test device for diaphragm wall

In order to verify the application effect of the test device, the test specimen like the wall with different proportions of plastic concrete, cement soil and cement slurry from the actual project were tested check if the performance and test results of the device can meet the test requirements.

3.1. Test Results of Leakage Coefficient

The diaphragm wall of a plain reservoir of Liangshan County Drinking Water Safety Project is a multi-head small-diameter cement-soil deep mixing pile diaphragm wall with a cement incorporation of 15%. The results of the leakage coefficient of the cement-soil specimens are shown in Table 1.

Table 1 Leakage coefficient results of cement-soil mixing pile for diaphragm wall of a plain reservoir

| Parameter | Pile No. | Peripheral pressure (Mpa) | Leakage pressure (Mpa) | Pressure Difference (Mpa) | Leakage slope | Leakage coefficient (cm/s) | Average leakage coefficient (cm/s) |
|-----------|---------|---------------------------|------------------------|--------------------------|--------------|-----------------------------|-------------------------------------|
| 3+200     | 0.10    | 0.06                      | 0.04                   | 100                      | 1.70×10⁻⁷    |                            | 1.83×10⁻⁷                          |
| 3+200     | 0.12    | 0.06                      | 0.06                   | 100                      | 1.98×10⁻⁷    |                            |                                     |
| 4+170     | 0.10    | 0.06                      | 0.04                   | 100                      | 1.41×10⁻⁷    |                            |                                     |
| 4+170     | 0.15    | 0.09                      | 0.06                   | 150                      | 1.33×10⁻⁷    |                            | 1.40×10⁻⁷                          |
| 4+170     | 0.20    | 0.12                      | 0.08                   | 200                      | 1.46×10⁻⁷    |                            |                                     |

A seven-day leakage coefficient test was carried out on the test specimens with two proportions for the vibrating and shot impact diaphragm wall of a certain reservoir in Dongying City, Shandong Province by using the test device. The two proportions of diaphragm wall is:

① 1# mixing proportion: cement: bentonite: fine sand: water = 1: 0.5: 1: 2;
② 2# mixing proportion: cement: silty soil: water = 1: 1.5: 1

The test results are shown in Table 2.
Table 2 7d leakage coefficient results for the test specimens with two proportions for the vibrating and shot impact diaphragm wall of a certain reservoir

| Parameter No. | Test specimen type | Peripheral pressure (Mpa) | Leakage pressure (MPa) | Pressure Difference (MPa) | Leakage slope | Leakage coefficient (cm/s) | Average leakage coefficient (cm/s) |
|---------------|--------------------|------------------------|----------------------|--------------------------|--------------|------------------------|-------------------------------|
| 1-1           | 1# mixing proportion | 0.20                   | 0.06                 | 0.14                     | 100          | 5.66×10⁻⁶               | 5.66×10⁻⁶                     |
| 1-2           | 1# mixing proportion | 0.20                   | 0.09                 | 0.11                     | 150          | 5.93×10⁻⁶               |                               |
| 1-3           | 1# mixing proportion | 0.20                   | 0.12                 | 0.08                     | 200          | 5.38×10⁻⁶               |                               |
| 2-1           | 2# mixing proportion | 0.18                   | 0.12                 | 0.06                     | 200          | 1.22×10⁻⁶               | 1.15×10⁻⁶                     |
| 2-2           | 2# mixing proportion | 0.15                   | 0.09                 | 0.06                     | 150          | 1.10×10⁻⁶               |                               |
| 2-3           | 2# mixing proportion | 0.12                   | 0.06                 | 0.06                     | 100          | 1.13×10⁻⁶               |                               |

The test methods with constant peripheral pressure and variable leakage pressure, constant peripheral pressure and leakage pressure, constant leakage pressure and variable peripheral pressure as well as any combination of peripheral pressure and leakage pressure were applied in the process of the leakage test. According to the Darcy's law, the leakage coefficient $k$ is a stable value for the same leakage material. From the above test results, the measured leakage coefficients are very close, which proves that the quality of the test device that measures the leakage dissolution characteristic of diaphragm wall is stable and reliable.

3.2. Dissolution Test
The proportions of the dissolution test specimens are as shown in Table 3.

Table 3 Mixing Proportions in the Dissolution Test (kg/m³)

| No. | Material | Cement | Bentonite | Sand | Water |
|-----|----------|--------|-----------|------|-------|
|     | Place of origin | Shanshui | Weifang | Taian | Drinking water |
|     | Type | PO42.5 | Class I | Medium sand | Drinking water |
| 1# proportion | Weight proportion | 1 | 1.42 | 11.3 | 2.3 |
|     | Material consumption (kg/m³) | 120 | 170 | 1350 | 280 |
| 2# proportion | Weight proportion | 1 | 2.1 | 18.1 | 3.8 |
|     | Material consumption (kg/m³) | 80 | 170 | 1450 | 300 |

3.2.1. Dissolution Test Method
The plastic concrete mixture was molded into a standard test specimen with size of ø100 mm×60 mm, and the test specimen was maintained in the curing room to a predetermined age, and deionized water was used as the leakage medium. The dissolution test conditions of No. 1 proportioning test specimen are: leakage pressure 0.24MPa, peripheral pressure 0.35MPa, leakage slope 400, test duration: 79 days; The dissolution test conditions of No. 2 proportioning test specimen are: leakage pressure 0.30MPa, peripheral pressure 0.40MPa, leakage slope 500, test duration: 63 days. The test specimens with two proportions were subject to the dissolution test under the above conditions. The curves indicating that the dissolution amount of Ca²⁺ ions varies with the leakage duration were obtained through the
chemical analysis on the leakage water in the leakage test. The Ca\(^{2+}\) was determined by EDTA-2Na titration. In order to avoid the carbonatation of the leakage water due to CO\(_2\) in the air, the leakage water in the test was filled into bottles and sealed timely. In the stable leakage phase of the dissolution test, the leakage coefficient of the then current day of the test specimen was calculated by the measured amount of daily water leakage.

3.2.2. Dissolution Test Results

![Fig.2 Curves for relations between Ca\(^{2+}\) daily dissolution and leakage duration for No. 1 proportion specimen](image1)

- **Fig.3** Curves for relations between CaO Cumulative dissolution and leakage duration for No. 1 proportion specimen

![Fig.4 Curves for relations among leakage coefficient, cumulative water leakage and leakage duration for No. 1 proportion specimen](image2)
Fig. 5 Curves for relations between Ca$^{2+}$ daily dissolution and leakage duration for No. 2 proportion specimen

Fig. 6 Curves for relations between CaO Cumulative dissolution and leakage duration for No. 2 proportion specimen

Fig. 7 Curves for relations among leakage coefficient, cumulative water leakage and leakage duration for No. 2 proportion specimen
From Fig. 2 to Fig. 7, it can be seen that the dissolution rules of the plastic concrete specimens of two proportions are consistent. The early dissolution rate is fast, the amount of dissolution is large, and the dissolution rate is gradually slowed down with the increase of the leakage time, and the dissolution rate curve tends to be gentle. After a period of time, the test specimen began to have no or little dissolution. These rules are consistent with current domestic and international research conclusions. The results are consistent with the conclusion curves obtained from the leakage dissolution test on the 6 earth dams in Nuremberg conducted by H. Beyle and TH. Slarob of Germany, the test research on the plastic concrete dissolution of Xiaolangdi Reservoir of Yellow River and the test study on the dissolution durability of plastic concrete carried out by China Institute of Water Resources and Hydropower [3].

4. Conclusion

Through a large number of tests and practical engineering applications, it is verified that the test device that measures the leakage dissolution characteristic of diaphragm wall has the advantages of clear physical significance, stable performance and strong applicability, and can meet leakage test requirements of the anti-leakage materials such as concrete, plastic concrete, mortar material.

The pressure chamber technical scheme adopted by the test device can effectively shorten the observation time of the leakage test by adjusting the size of the leakage water head, improving the test efficiency. The pressure chamber adopts a screw fastening structure, which is characterized by good sealing performance, simple operation, and convenient assembly and disassembly of the test specimen. The key techniques adopted such as applying the adhesive film to the specimen and applying the peripheral pressure greater than the leakage pressure solved the problem of bypass leakage around the test specimen well. The water make-up system can ensure the continuous operation of the leakage test and meet the necessary conditions for the leakage dissolution test.

As a test research platform, the test device that measures the leakage dissolution characteristic of diaphragm wall will play an important role in the study of the leakage characteristics of diaphragm wall, the design and construction of the diaphragm wall and the quality inspection of the relevant project, as well as the evaluation of the safe operation period of the diaphragm wall.

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