Journal of Physics:
Conference Series

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To cite this article: Xiaodong Deng *et al* 2024 *J. Phys.: Conf. Ser.* **2897** 012026

Research on calibration method for flange-type apparatus to Measure Water Permeability of Concrete

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Abstract. The water permeability of concrete is a crucial indicator to evaluate its ability to resist the infiltration of water or other liquids under pressure, which is vital for ensuring the stability and durability of building structures. The flange-type apparatuses are commonly used for detecting concrete's impermeability and determining its impermeability rating. This article proposes a novel calibration method specifically designed for the flange-type apparatus to measure the water permeability of concrete, according to which the standard pressure measuring device is connected to the calibrated apparatus by a connection device designed and presented in this article in order to ensure sealing performance and operational safety during the experiment. Additionally, a host computer software is presented in this article for data recording and analysis to realize real-time recording and saving of experimental data, as well as generating pressure curves. The flange-type apparatus is calibrated mainly through the measurement of two metrological parameters, which are indication error and set pressure retention error. Experimental verification has confirmed that this method can simultaneously calibrate both parameters, which can significantly improve the accuracy and efficiency of on-site calibration of flange-type apparatus to measure the water permeability of concrete.

1. Introduction

Concrete is a mixture primarily composed of cement, sand, gravel, and other materials commonly used in construction and infrastructure projects. The water permeability of concrete is a crucial indicator to evaluate its ability to resist the infiltration of water or other liquids under pressure, which is vital for ensuring the stability and durability of building structures. Flange-type apparatus to measure water permeability of concrete (hereinafter referred to as flange-type apparatus) is specifically designed to evaluate the water permeability of concrete. By simulating the penetration effect of water pressure on concrete in actual environments, these apparatuses assess the concrete's resistance to infiltration. The flange-type apparatuses are commonly used for detecting concrete's impermeability and determining its impermeability rating. Therefore, they are widely employed in construction and transportation engineering inspections and testing laboratories. The flange-type apparatus adopts a flange disk format, which facilitates the installation and disassembly of the test mold so that the sealing process is simplified while the accuracy of test results is guaranteed.

The flange-type apparatus is calibrated mainly through the measurement of two metrological parameters which are pressure indication error and set pressure retention error. The determination of calibration items is based on the national calibration specification JJF 1812-2020 *Calibration Specification for Apparatus to Measure Water Permeability of Concrete* [1] and JG/T 249-2009 *Apparatus to Measure Water Permeability of Concrete* [2]. If the pressure indication error of the flange-type apparatus is out of range, there will be errors in its measurement results, which will lead to misjudgment of the impermeability of concrete, which may affect the durability and safety of building structures. Therefore, it is necessary to calibrate the flange-type apparatus regularly to ensure the accuracy and reliability of its test results. In the meantime, the pressure retention error is also an important index. It reflects the ability of the flange-type apparatus to maintain pressure stability under the set pressure, which can ensure that the flange-type apparatus can continuously and stably provide the required pressure during the whole working process, so as to ensure the reliability of the test results.

However, JJF 1812-2020 only set the requirement of pressure indication error, while pressure indication error hasn't been mentioned. Both JJF 1812-2020 and JG/T 249-2009 adopt a manual reading method, which is not only time-consuming and labor-intensive, but also difficult to accurately and promptly record all experimental data during the retention error detection. Meanwhile, due to the special structure of flange-type apparatuses, it is crucial to guarantee precise alignment between the calibrated apparatus and the standard device (digital pressure gauge), but neither JJF 1812-2020 nor JG/T 249-2009 specifies any means to ensure the sealing performance during the experimental process. Furthermore, in traditional testing methods for the impermeability tester, pressure values displayed on the tester and the standard device were manually recorded and compared to detect its metrological characteristics. However, this manual reading method is not only time-consuming and labor-intensive, but also difficult to accurately and promptly record all experimental data during the retention error detection. Meanwhile, at present, during the calibration process of flange-type apparatus, no special connection device is used, which will lead to calibration error, poor sealing, difficulty in operation, risk of equipment damage, and human safety. Therefore, a connection device is designed and presented in this article in order to ensure sealing performance and operational safety during the experiment. In the meantime, a host computer software is presented in this article for data recording and analysis to realize real-time recording and saving of experimental data and generating pressure curves.

2. The working principle of the calibration method

The standard pressure gauge is directly connected to the outlet of the calibrated apparatus's mold base, and the built-in water pump of the apparatus is used to pressurize the system until it reaches the target pressure value. According to Pascal's Law, in a closed container filled with static liquid or gas, when pressure is applied to one point, it will be transmitted to every point in the container with equal intensity and in the same direction. Based on this principle, once the pressure indication of the impermeability tester stabilizes, the displayed pressure reading can be compared with the measurement from the standard digital pressure gauge to detect the indication error. During the detection of the pressure indication error, the detection of pressure retention error can also be conducted simultaneously. When the water pressure of the calibrated apparatus rises to the predetermined pressure point, it is maintained at that level for 30 minutes. During this period, the pressure reading of the standard device is continuously monitored and recorded using the upper computer software. Analysis of these data determines the maximum deviation between the displayed value of the standard device and the predetermined pressure value, which represents the pressure retention error of the impermeability tester at that specific pressure point. The overall design diagram of the proposed calibration method is demonstrated in Figure 1.

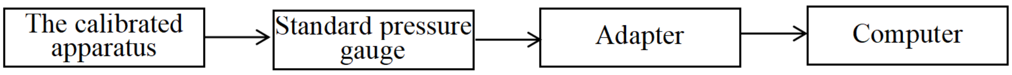

Figure 1. The overall design diagram of the proposed calibration method.

2.1. Design of the host computer software

The software is designed using the C# programming language and possesses functions such as automatic reading, real-time display, recording, saving, and analyzing experimental data. The time interval for data reading and recording is set to 1 second, enabling the generation of corresponding pressure curves based on the collected experimental data. Communication between the host computer and the standard device is established through a serial interface, facilitating the transmission of control instructions and the real-time collection of data. During the detection of pressure indication error, the built-in water pump of the calibrated apparatus is used for pressurization. When the displayed pressure value of the apparatus reaches the preset detection point and remains stable, clicking the read button allows for the collection and recording of the current measured pressure value. This value is then compared with the current pressure indication for analysis, calculating the indication error and determining whether it falls within the specified error range. Similarly, during the detection of pressure retention error, the built-in water pump of the calibrated apparatus is used for pressurization, maintaining the pressure for 30 minutes after reaching the preset detection point. During this process, the host computer software automatically records and analyzes the measured pressure data, generating corresponding pressure curves based on the collected experimental data, as demonstrated in Figure 2. This allows for the determination of whether the retention error falls within the specified range, completing the detection of retention error. Once the detection process is completed, the system automatically performs data processing tasks, calculating the maximum deviation between the actual measured pressure value and the preset pressure value. This establishes the peak value of error fluctuations, and the system automatically assesses whether this deviation falls within acceptable error limits, verifying whether the measurement accuracy of the calibrated apparatus meets the established standard requirements.

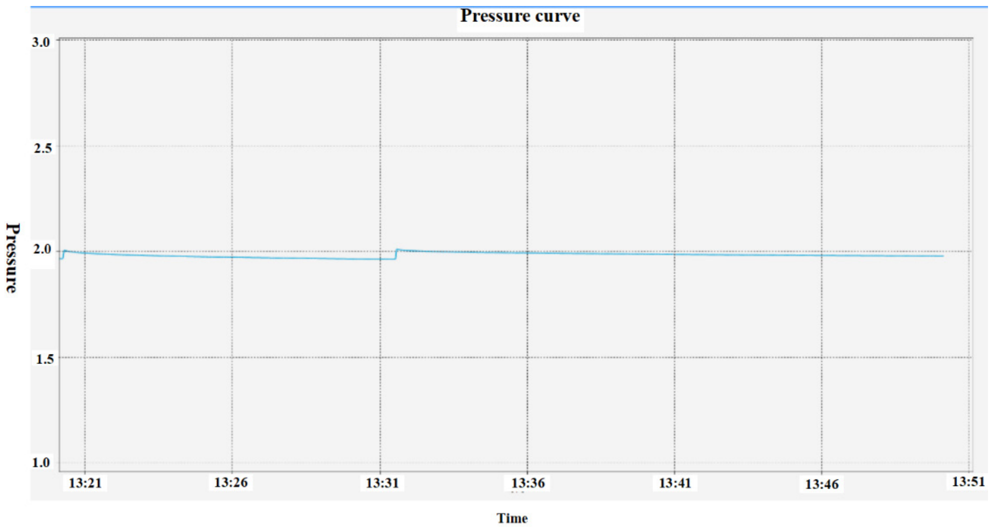

Figure 2. The generated pressure curve.

2.2. Design of the connection device

During the testing process, ensuring the precise alignment between the impermeability tester and the standard device is crucial. This step directly affects the accuracy of subsequent experimental results. Therefore, it is necessary to ensure the matching degree and sealing performance of all interfaces during the connection process to avoid any factors that may lead to deviations in experimental data. The rated working pressure of the calibrated apparatus is (0-4) MPa. Considering the maximum working pressure of the calibrated apparatus, the design of the connecting device must ensure that it can firmly withstand at least 4 MPa of pressure. Based on the structural characteristics of the flange-type apparatus, the flange design concept is adopted to manufacture a pressure-sealing disc as the connecting device. The sealing disc is made of high-quality stainless steel with a thickness of 10 mm. To ensure that it can stably withstand high-intensity water pressure exceeding 4 MPa, the entire disc needs to be milled and processed from a solid stainless steel material with a thickness of over 20 mm, without the use of welding or other splicing processes, which may affect the overall strength of the connecting device. Furthermore, the surface of the sealing disc has undergone an advanced chromium plating process, which not only significantly improves its hardness but also enhances its corrosion and wear resistance, enhancing the overall aesthetics and service life [3]. Based on the size and structural characteristics of the test mold base of the flange-type apparatus, the sealing disc is designed with a diameter of 270 mm and has six circular screw holes with a diameter of 15 mm evenly distributed around its circumference. The center-to-center distance between two adjacent holes is 236 mm, ensuring a perfect fit between the sealing disc and the test mold base of the flange-type apparatus. The sealing disc is securely fixed to the test mold base using bolts, and a rubber ring is used as the sealing medium, ensuring sealing performance and operational safety during the experiment [4]. The connection between the calibrated apparatus and the standard pressure gauge is achieved through a threaded port with M20×1.5 specifications on the sealing disc. Additionally, a circular hole with a diameter of 3 mm is specially machined at the center of the lower surface of the disc, allowing the water pressure inside the calibrated apparatus to be uniformly transmitted to the standard pressure gauge, thus ensuring the accuracy and reliability of the experimental process and data. The design of the connection device is demonstrated in Figure 3.

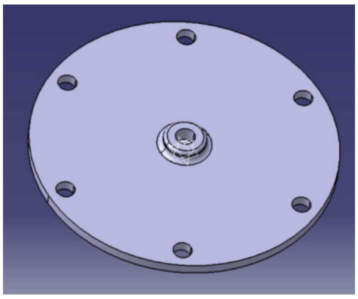

Figure 3. The design of the connection device.

3. Calibration process

The comparison method is used to calibrate flange-type apparatus, which is to determine the errors by comparing the pressure value displayed by the calibrated apparatus with the pressure measured by the standard pressure gauge. This method is based on the similarity principle, that is, under the same conditions, the measurement results of two measurement systems for the same physical quantity should be consistent. By calibrating the flange-type apparatus with the comparison method, the measurement accuracy of the flange-type apparatus can be accurately evaluated. In practical application, it is necessary to pay attention to the selection of an appropriate standard pressure gauge and connection system and take effective measures to reduce the error, so as to improve the reliability of measurement.

3.1. Calibration of pressure indication error

Before calibration, the pressure sealing disc is accurately installed on the test mold base at the top of the calibrated apparatus and securely fixed with bolts to ensure sealing effectiveness. The standard digital pressure gauge is mounted on the pressure disc and connected to the host computer through a serial data cable. The host computer software is then started, and preset indication error detection points are set at 20%, 40%, 60%, 80%, and 100% of the calibrated apparatus’s nominal pressure. Afterward, the pipeline valve of the base with the sealing disc installed is opened, ensuring that all other valves are closed. The calibrated apparatus is operated to increase the pressure to 20% of the apparatus’s nominal pressure. Once the pressure reaches the preset value and stabilizes, the “read” button is clicked, and the indication error value displayed by the software is recorded. This value represents the pressure indication error of the apparatus at that detection point. Using the same method, the preset points of 40%, 60%, 80%, and 100% of the apparatus’s nominal pressure are operated in sequence, and the indication errors at each point are recorded. Once all indication error detections are completed, the entire process is completed.

3.2. Calibration of pressure retention error

After detecting the indication error at the first point according to the above steps, maintain the status of the standard pressure gauge and the calibrated apparatus unchanged. Click the “Retention Error Detection” button on the host computer software. After 30 minutes, the host computer software will automatically provide the maximum pressure holding error value at that point, along with a pressure curve graph. Using the same method, it is possible to operate on the preset points of 40%, 60%, 80%, and 100% of the calibrated apparatus’s nominal pressure in sequence and record the retention error value at each point.

4. Experimental verification results and analysis

To verify the accuracy of the calibration method presented in this article, a control experiment is conducted. The aim of this experiment is to confirm the precision and reliability of the results derived from the proposed calibration method by comparing them with the data obtained by traditional means, which directly calibrate the pressure sensor of the calibrated apparatus.

4.1. Design of control experiment

The pressure sensor of the calibrated apparatus is installed outside the water tank and securely connected to the tank via M20×1.5 threaded screws. Based on the principle of static hydraulic balance, the sensor is capable of accurately measuring the water pressure within all pipelines and channel ports of the apparatus. The experiment will be conducted under conditions protected from rain, water immersion, and strong vibrations. The environmental temperature will be maintained at 20 °C, and the humidity at 60%RH. A digital pressure gauge with a precision grade of 0.05 and a measuring range of (0-6) MPa will be used as the pressure standard. Firstly, the experiment is conducted by traditional means: the pressure sensor on the calibrated apparatus is removed and installed on one end of a desktop air pump, while the standard digital pressure gauge is installed on the other end [5-6]. The desktop air pump will then be used to pressurize the system to the following pressure indications on the calibrated apparatus: 0.8MPa, 1.6MPa, 2.4MPa, 3.2MPa, and 4.0MPa. The pressure indications on the standard gauge will be recorded as the actual measured values of the pressure sensor.

4.2. Experimental verification of pressure indication error calibration

The experiment is conducted using the calibration method and the control experiment method introduced in this article. Five calibration points are evenly selected: 0.8MPa, 1.6MPa, 2.4MPa, 3.2MPa, and 4.0MPa. The calibration results of the control experiment for pressure indication error are presented in Table 1.

Table 1. The calibration results of the control experiment for pressure indication error.

Calibration point	Results obtained by traditional method	Results obtained by the method presented in this article
0.80MPa	0.801MPa	0.801MPa
1.60MPa	1.601MPa	1.602MPa
2.40MPa	2.412MPa	2.412MPa
3.20MPa	3.212MPa	3.212MPa
4.00MPa	4.013MPa	4.013MPa

As can be seen from Table 1, the maximum difference between the pressure values measured using the two methods is ±0.001 MPa, which is only 1/10 of the minimum resolution of the calibrated apparatus. Therefore, the method presented in this article to calibrate the pressure indication error is not only simple and feasible to operate but also ensures the accuracy and reliability of the calibration results.

4.3. Experimental verification of pressure retention error calibration

Five calibration points are evenly selected: 0.8MPa, 1.6MPa, 2.4MPa, 3.2MPa, and 4.0MPa. The pressure retention error calibration is conducted according to the method described in this article. Simultaneously, manual readings of the standard pressure gauge's indications are taken, and the maximum difference between the standard pressure gauge's indications and the set pressure values of the calibrated apparatus are recorded over a period of 30 minutes. The calibration results of the control experiment for pressure retention error are presented in Table 2.

Table 2. The calibration results of the control experiment for pressure retention error.

Calibration point	Results obtained by traditional method	Results obtained by the method presented in this article
0.80MPa	-0.012MPa	-0.012MPa
1.60MPa	-0.010MPa	-0.011MPa
2.40MPa	-0.011MPa	-0.011MPa
3.20MPa	-0.017MPa	-0.017MPa
4.00MPa	-0.018MPa	-0.018MPa

As can be seen from Table 2, the maximum difference between the pressure retention errors measured using the two methods is ±0.001 MPa, which is only 1/10 of the minimum resolution of the calibrated apparatus. Therefore, the method presented in this article not only ensures measurement accuracy but also significantly improves work efficiency, overcoming the time-consuming and labor-intensive issues associated with traditional manual inspection processes.

5. Conclusion

This study aims to address the challenges in calibrating flange-type apparatus to measure the water permeability of concrete and proposes a comprehensive method for the apparatus. Based on the structural characteristics of the flange-type apparatus, a sealing technique is innovatively designed that allows a direct connection between the apparatus under calibration and the standard pressure gauge. By developing specialized upper computer software, automatic comparison of pressure readings between the calibrated apparatus and the standard pressure gauge is achieved. This method has demonstrated its effectiveness in comparative experiments with the traditional method of directly calibrating the built-in pressure sensor of the calibrated apparatus. By comparing the calibration results obtained by the method presented in this article with those obtained by the traditional method, the accuracy and reliability of the presented in this article are further validated. The feasibility of the method is verified, providing a new means for the calibration of flange-type apparatus to measure the water permeability of concrete, which will not only provide a strong technical basis for metrological calibration of flange-type apparatus but also meet the needs of enterprises and research institutions that use flange-type apparatuses. The follow-up study will concentrate on the optimization of the calibration software in order to improve calibration efficiency and operability.

Acknowledgments

Our work is supported by a Research Project of Chongqing Academy of Metrology and Quality Inspection: Calibration Device for the Flange-type Apparatus to Measure Water Permeability of Concrete (Grant No. 2023 (Research) - 09).

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