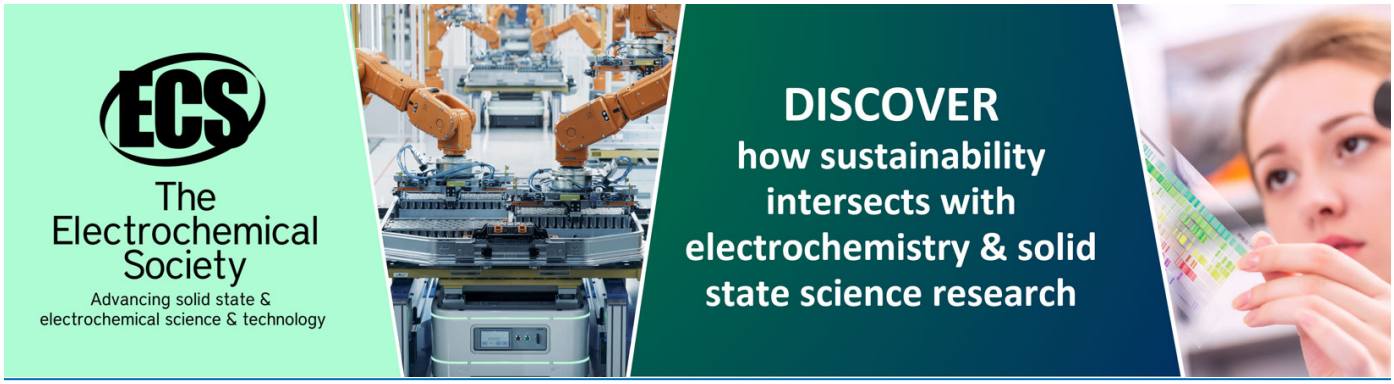
Semi-automatic apparatus of the permeability coefficient for cutoff walls in expansive soil areas



Semi-automatic apparatus of the permeability coefficient for cutoff walls in expansive soil areas

Min Zhang[1,2,a], Xizhong Shen[1,2,b*], Yan Lan[1,c], Chenghui Dong[1,d]

[1]Yellow River Institute of Hydraulic Research, Yellow River Conservancy Commission, Zhengzhou 450003, China

[2]Research Center on Levee Safety and Disaster Prevention, Ministry of Water Resources, Zhengzhou 450003, China

[a]email: 344970103@qq.com

*Corresponding Author: [b]email: shenxz@126.com

[c]email: 18091025@qq.com, [d]email: dong510@foxmail.com

Abstract: The permeability coefficient of most cutoff walls with plastic materials is less than 10^{-6} cm/s, it exceeds the measurement range of the existed devices. For the permeability coefficient testing for cutoff walls with low permeability, there are complex in the automatic system of pressure control, difficult in the keeping stability of hydraulic pressure, high in the measurement precision, leaky in the contact surface between the fixing apparatus and the measured specimen. Firstly, based on the characteristic analysis of cutoff walls, the hydraulic pressure was accurately controlled when the valve of atmospheric pressure control with high precision worked in with the electromagnetic valve, the hydraulic pressure was controlled. Secondly, the shape of inner space for the fixing apparatus of the specimen is developed, the leakage of the contact surface between the fixing apparatus and the specimen was greatly decreased. The test showed that the semi-automatic apparatus could realize automatic control of the hydraulic pressure accurately with the combined action of an electromagnetic valve and a pressure reducing valve, the leakage of the contact surface could be basically avoided. The testing apparatus can be used in penetrability tests and detection of project quality for cutoff walls with low permeability.

1. Introduction

Expansive soil is mainly composed of strong hydrophilic minerals with significant expansive shrinkage [1]. It has the nature of water absorption expansion, water loss shrinkage, and reciprocating deformation, affecting engineering safety. Expansion soil is widely distributed in China, such as Guangxi, Yunnan, Henan, Hubei, etc. There are many cutoff projects in expansive soil areas, and the quality testing of cutoff walls is the premise and foundation to ensure the effectiveness of cutoff bodies [2]. Because of lots of advantages such as high bearing of hydraulic pressure, reliable anti-permeability capability, adaptability of various strata and so on, the cutoff walls is widely adopted in projects of water resources and hydropower, environmental protection and so on, and the permeability coefficient is one of the most important indices [2]. The permeability coefficient of cutoff walls with new-type materials is smaller, the measurement requirement of an automatic system of pressure control is difficult in keeping the stability of hydraulic pressure, high in the precision requirement, there is a leakage problem of the contact surface

between the fixing apparatus and the measured specimen, thus the permeability coefficient of cutoff walls with low permeability is difficult to measure.

Outdoor testing methods of permeability for cutoff walls are geophysical methods, soil test methods. Geophysical methods are still in an exploratory stage, mainly including high-density resistivity method, geological radar method, surface wave method, CT method and so on [3, 4]. These are applied in the detection of cutoff walls of embankment, dam, tunnel; these are mainly used for qualitative evaluation. Soil test methods involve in field and indoor methods of the soil test, field tests are main methods of water injection, hydraulic pressure, confining well and so on [5,6], these are used for quantitative evaluation. Normal indoor devices of permeability coefficient are type 70, type Nan 55 and so on, the measurement range of permeability coefficient is larger than 10^{-6} cm/s [4]. An apparatus of permeability test of type HM-4160A for a flexible wall made by American HUMBOLDT company is used [7], indoor measurement and prediction of anti-permeability capability about the modified loess soil liner with bentonites are carried. A device of permeability test for cutoff walls of concrete is developed, but it is limited to measure the permeability coefficient of plastic cutoff walls for concrete materials [8]. With the rapid development of projects of water resources and others, there are kinds of engineering materials suitable for cutoff walls, the permeability coefficient of them is less than 10^{-6} cm/s, and the permeability testing is higher requirements for pressure control, anti-permeability of the contact surface, testing accuracy and so on. When testing the permeability coefficient, it needs to test the permeability pressure and its corresponding permeability flux, and the automatic application and measurement of permeability pressure with low-permeability materials are difficult. With the wide application of most plastic cutoff walls with new materials, it is very necessary to develop a semi-automatic testing apparatus of permeability coefficient for cutoff walls with kinds of plastic materials.

Based on the engineering characteristics, material properties of cutoff walls with low permeability and permeability theory [3, 9], a fixing apparatus of the specimen was developed, a system of hydraulic pressure control was allocated rationally, a semi-automatic testing apparatus of permeability coefficient for cutoff walls was carried out with automatic application and measurement of permeability pressure, and the corresponding testing method was carried out, it can provide technical support for engineering testing and quality control of projects with cutoff walls.

2. Apparatus and Methods

2.1 Calculation method of permeability coefficient

The permeability coefficient of cutoff walls can be shown according to the following formula [3].

$$k_T = \frac{W_t \cdot H \cdot \rho_w}{10 \cdot A \cdot \Delta t \cdot P} \tag{1}$$

Where t is the time (unit: s); T is the temperature of a specimen (unit: degree); k_T is the permeability coefficient of the specimen when the temperature of water is T degrees (unit: cm/s). W_t is the permeability flux during the unit time (unit: cm^3/s); H is the height of the specimen (unit: cm); ρ_w is the density of the water when the water temperature is T degrees (unit: g/cm^3); $\triangle t$ is the time of the permeability process (unit: s); A is the area of the cross-section along the direction of water flow at the top of the specimen (unit: cm^2); P is the hydraulic pressure of the specimen (unit: kPa).

2.2 Apparatus

Based on analysis of permeability characteristics for cutoff walls, the technique of water pressure control with high precision was adopted, the fixing method of the specimen was advanced, a semi-automatic testing apparatus of permeability coefficient for cutoff walls with low-permeability materials was developed, including a loading apparatus of the specimen, an automatic system of pressure control, a measurement system and so on (shown in Fig. 1 and Fig. 2).

2.2.1 Loading apparatus of specimen

A loading apparatus of specimen involves a top cover, a fixing apparatus of specimen, and a base. The shape of the inner space of the fixing apparatus of the specimen is a circular truncated cone, a specimen

is placed in the circular truncated cone. The bottom diameter of the circular truncated cone is more than that of the top for 4mm-6mm. The upper and the nether ends of the fixing apparatus are fixedly connected with the top cover and the base through bolts respectively, there are lots of upper exhaust holes and nozzles of water outlet communicated with the fixing apparatus of the specimen at the top cover, the top exhaust holes are used for water outlet and exhaust of air, a volume change tube for measurement the water output is connected with the nozzle of water outlet through a rubber tube. There are nozzles of water inlet and nether exhaust holes at the base, nether exhaust holes are used for water outlet and exhaust of air, a water inlet is connected with an automatic system of pressure control through a volume change tube of the end of the water inlet. There are valves at holes of the upper and nether exhaust and nozzles of the water inlet and the water outlet.

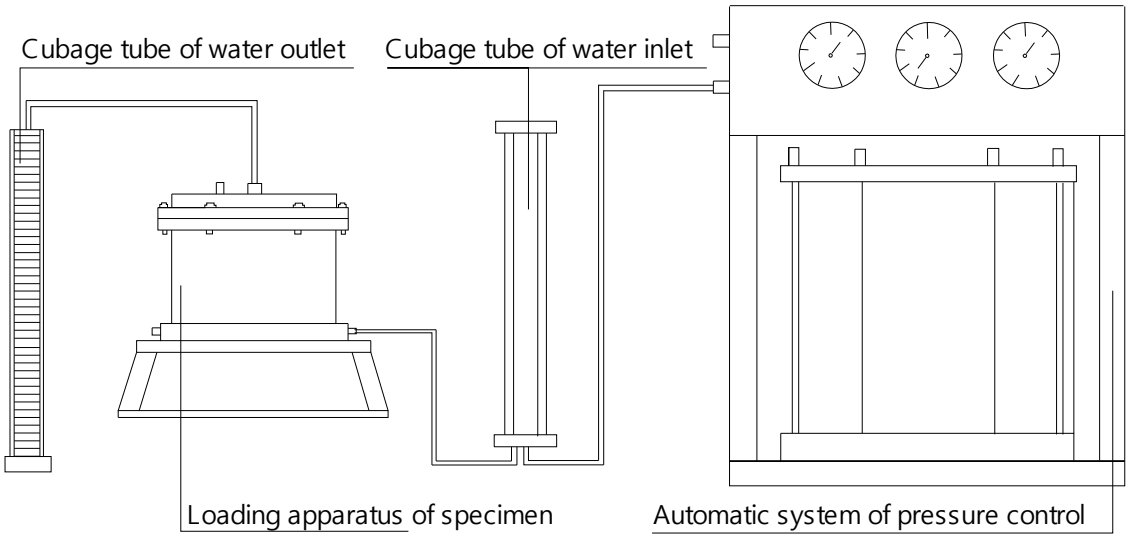


Fig. 1. Schematic diagram of a semi-automatic testing apparatus of permeability coefficient for cutoff walls

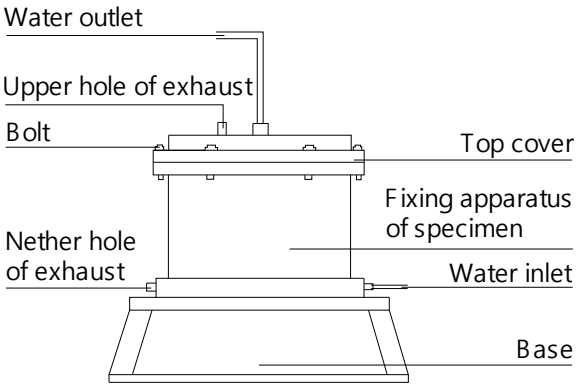


Fig. 2 Schematic diagram of a loading apparatus of specimen

2.2.2 Automatic system of pressure control

An automatic system of pressure control is connected with the nozzles of the water inlet through the volume change tube of the end of the water inlet. The valve of atmospheric pressure control with high precision works in with the electromagnetic valve, the hydraulic pressure is controlled. With the combined action of electromagnetic valve and pressure reducing valve, the pressurized liquid is transported into the specimen from the water inlet, thus the automatic application and control of hydraulic pressure come true accurately.

2.2.3 System of measurement

A measurement system involves volume change tubes at the ends of the water inlet and the water outlet. The volume change tube of the water output is connected with the nozzle of water outlet through a rubber tube; the permeability flux out of the specimen is measured. The nozzle of the water inlet is connected with the automatic system of pressure control through the volume change tube of the end of the water inlet; the permeability flux into the specimen is measured.

2.3 Measurement method

2.3.1 Preparation of specimen

Production of a disturbed specimen. Materials of plastic cutoff walls are made into a slurry, a clean, no-greasy sampling mold is placed on a flat plate in advance, a layer of sealing grease is coated around the outside of the sampling mold so that the gap between the mold and the flat plate is sealed. Then the slurry is filled into the sampling mold, the slurry is stirred for 20-30 times by a stir bar. The surface is scraped into a flat state, the specimen is covered on the sampling mold, then the sampling mold is placed into the warm water for maintenance, the water temperature is 22-25 degrees. Arrived at the test requirement of the specimen, the sampling mold is taken out, and placed in cold water, then the specimen is taken from the sampling mold, it is gently scraped into a flat state, the surface impurities are removed under the action of water flow. The shape of the specimen should be matched with the shape of the internal space of the fixing apparatus. Before measurement of permeability coefficient, the specimen should have been always soaked in water.

Production of an undisturbed specimen. After the construction of cutoff walls is completed, the core is drilled by the core drilling with diamond, the specimen is sawed into the required length for the test, The specimen is made into the shape of a circular truncated cone, its shape is matched with the inside space of the fixing apparatus of the specimen. After the production of the specimen finished, it is placed into the warm water for maintenance; the temperature of the water is 22-25 degrees.

2.3.2 Process of measurement

A semi-automatic testing apparatus of permeability coefficient for cutoff walls is ready, the prepared specimen is placed in the fixing apparatus of the specimen, the end of the larger diameter of the fixing apparatus is the end of water inlet, and the end of the smaller diameter is the end of water outlet, the specimen can be pressed tighter during the measurement process. The gap between the specimen and the fixing apparatus of the specimen is filled by the slurry mixed with cement slurry and expansive soil. The gap between the specimen and the fixing apparatus of the specimen is completely filled after slurry dried so that the water doesn't flow through the gaps, the leakage between the contact surface of the specimen and the fixing apparatus can be effectively avoided. The top cover and the base are fixed between the upper end of the fixing apparatus of the specimen and the nether end.

The nozzle of the water inlet is connected with the end of the volume change tube of the water inlet through a rubber tube; the other end of the volume change tube of the water inlet is connected with the automatic system of pressure control. The nozzle of the water outlet of the top cover is connected with the volume change tube of the water output through the rubber tube.

The water is filtered into the specimen in the circle truncated cone of the fixing apparatus with the automatic system of pressure control, when the water is flown out of the upper and the nether holes of exhaust at the same time, the automatic system is turned off, and the valves of the upper and the nether holes of the exhaust are closed.

The hydraulic pressure (P) is loaded through the automatic system of pressure control, the permeability test is carried out, the flux of the volume change tube at the end of the water inlet (W_1), and the flux of the volume change tube at the end of the water outlet (W_2) during the unit time are got. When W_1 is equal to W_2, the permeability state is steady. the flux (W_t) for successive 3-4 unit time ($\triangle T$) is got. When the flux (W_t) for successive several unit time ($\triangle T$) keeps stable, the test is over.

3. Results & Discussion

Minquan County of Henan Province covered a total area of 1,222 km^2 with a population of 720,700 in China. It was located in the central and south of the North China Plain and the south of the large alluvial fan of the Yellow River in China. Due to the double impact of the Yellow River scouring for years and the river has not been systematically treated in the urban area for many years, part of the river was siltation, and the flood problems were very prominent. In order to control the water system environment and improve the ecological environment quality of Minquan County, Minquan County has carried out the ecological city construction of Minquan County and the comprehensive water system management project construction. The construction content included a river ecological comprehensive improvement project, an ecological lake construction project, a water quality comprehensive improvement project, a road landscape greening project; the projects were divided into three phases of construction, each construction period of two years, undertaken by the Minquan Branch Office of Beijing Oriental Landscape Environment Co., Ltd in China. The first phase of the project construction was completed in 2019. Among them, the Anlan Lake Wetland, transformed from the upper reaches of Dasha River, the largest river in the "Nine Rivers", played an important role in building the pattern of "nine rivers, five rivers, and three wetlands", laying a good ecological foundation for Minquan County to build a water ecological civilized county, sponge city, and ecological garden city. Cutoff walls were carried out on both sides of Dasha River.

In order to evaluate the anti-permeability effect of cutoff walls of Dasha River, the semi-automatic testing apparatus of permeability coefficient for cutoff walls was used, permeability tests were carried out, and a result of the cutoff wall was shown in Table 1. From Table 1 we can see, for the cutoff wall of Dasha River, the permeability coefficient can lead to the design requirement of construction.

Table 1 Result of the permeability coefficient of cutoff wall

Testing time (month-day-year)	Result of measurement (cm/s)	Index of design (cm/s)	Whether or not arriving to the requirement of design
10-15-2018	1.03×10^{-7}	$\leq1.00\times10^{-6}$	Yes

The semi-automatic testing apparatus could be used for permeability coefficient of measurement for cutoff walls of new-type materials with low permeability, it overcome the problem of test devices was only applicable to larger permeability coefficient, and it was wider in adaptation.

The automatic system of pressure control was connected with the nozzle of the water inlet through the volume change tube of the end of the water inlet. The valve of atmospheric pressure control with high precision kept in coordination with the electromagnetic valve, the hydraulic pressure was controlled. With the combined action of the electromagnetic valve and the pressure reducing valve, the automatic applying, and control of hydraulic pressure come true accurately.

The shape of the inner space of the fixing apparatus of the specimen was a circular truncated cone, the diameter of the bottom of the circular truncated cone was more than that of the top for 4mm-6mm. During the experiment, the gap between the specimen and the fixing apparatus of the specimen was filled by the cement slurry, and the expansive soil was mixed into the slurry. The gap between the specimen and the fixing apparatus of the specimen was completely filled after the slurry dried so that water did not flow through the gaps, the leakage between the contact surface of the specimen and the fixing apparatus could be effectively avoided.

4. Conclusions

There was not appropriate measurement device for cutoff walls of materials with low permeability. Based on the characteristic analysis of cutoff walls, a semi-automatic testing apparatus of the permeability coefficient for cutoff walls was carried out with the automatic application and measurement of permeability pressure. It could be used to test cutoff walls with the permeability coefficient of less than 10^{-6} cm/s, and the corresponding testing method was carried out, thus it can be used in penetrability tests and detection of project quality for cutoff walls with low-permeability materials.

The shape of the inner space of the fixing apparatus for the specimen was a circular truncated cone, the diameter of the bottom of circular truncated cone was more than that of the top, the leakage of the contact surface between the fixing apparatus and the specimen could be basically avoided; the device could bring about the automatic infliction and control of pressure accurately with combined the action of the electromagnetic valve and the pressure reducing valve.

The permeability coefficient testing of the cutoff wall of the Dasha River Project showed that the measurement device of cutoff walls with low permeability was simple in structure, automatic in control of hydraulic pressure, convenient in operation, high in the precision of test, the permeability coefficient and permeability gradient of cutoff walls with low permeability could be measured quickly, thus it can provide technical support for engineering construction.

Acknowledgements
This work was supported by National key R&D program on monitoring, early warming and prevention of major natural disasters of China (No. 2017YFC1501202).

References
[1] Liu Q.B., Xiang W. Wu Y.G., Zhang W.F. (2015) Study on Engineering Characteristics and Modification Theory of Expansive Soil, China University of Geosciences Press, Wuhan, China.
[2] Wang Q.Y., Sun W.G., Xiong H. (2008) Plastic concrete cutoff wall, 1-20, China Water Power Press Beijing, China.
[3] Nanjing Hydraulic Research Institute. (2002) Test code for hydraulic concrete (DL/T 5150-2001), 10-20, Chinese Power Press, Beijing, China.
[4] Yang X.X., Ergun, K., Murray G., Simon I. (2019) CT-CFD integrated investigation into porosity and permeability of neat early-age well cement at downhole condition. Constr. Build. Mater., 205: 73–86.
[5] Yi H., Zhou H.; Wang R., Liu, D.. Ding J. (2018) On the Relationship between Creep Strain and Permeability of Granite: Experiment and Model Investigation. Energies, 11: 2859.
[6] Xiaohu L.I., Lei L.I. (2019) Experimental Study on Impermeability of Waste Fiber Recycled Concrete. IOP Conf. Ser. Earth Environ. Sci., 340: 052010.
[7] Zhang H.Y., Zhao T.Y., Wu J.R., Yan G.S., Feng L. (2012) Laboratory measurement and prediction to the permeability of bentonite-modified loess as a landfill liner. Rock and Soil Mechanics, 2011, 32: 1963-1969.
[8] Li J.J., Shao S.J., Yang F.Y., Yang F.Y., Yang C.M. (2012) Experimental research on impermeable characteristics of slurry cake in cutoff wall hole of coarse-grained soil. Rock and Soil Mechanics, 33: 1087-1093.
[9] Kong X.Y. (1999) Advanced Mechanics of Fluid in Porous Media. University of Science and Technology of China Press, Hefei, China. pp. 8-51.