Thermal seepage measurement in rock and soil

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Abstract. In the measurement of seepage in rock and soil, the osmotic pressure meter is mainly used to measure the infiltration water pressure inside rock and soil, and then the seepage monitoring is performed. The measurement is scalar, and there is a poor dynamic response, small range, non- Direct measurement and other defects are difficult to meet the needs of monitoring and development of seepage in rock and soil; in view of this, a remote online flow meter based on the principle of thermal diffusion is designed; it consists of power module, temperature detection module, constant power heating module, and display module. Three-wire platinum resistance constant current source temperature measurement circuit detects the temperature difference between the two ends of the influent water, the test results are returned to the display to the stm32 and passed through RS485 to the host for data analysis; experimental results show that the flow meter can be implemented on-line monitoring The seepage in rock and soil can effectively detect the velocity of seepage in rock and soil, with a resolution of 0.05ml/s.Thermal percolation meter has good sensitivity, accuracy and repeatability, and is suitable for the seepage measurement of most types of rock and soil.

1 Introduction

Because of the special physical properties of rock and soil, the groundwater moving in the space of rock and soil is also the measurement of seepage flow, which is difficult to detect by traditional means such as sound, light and electricity. The seepage in rock and soil has low velocity and low flow rate. The constituent is complex and so on. Porous water pressure gauge is widely used for measuring seepage of rock and soil. Its measuring principle is to measure the hydraulic gradient between two points with different height in rock and soil. By using Darcy's law, the magnitude of seepage flow is obtained and the seepage velocity is obtained by flow [1].In addition, it has the disadvantages of small range, low resolution and difficult construction. There is no sensor to measure the percolation velocity directly at present.

In view of the shortcomings and defects of the current measurement method, a new measurement method is proposed in this paper. A liquid flowmeter is designed for measuring tiny flow in rock and soil. Based on the principle of heat diffusion, a micro ceramic heating rod is heated and the micro platinum resistance is measured. The platinum resistance is placed at each end of the pipe and the heating rod is placed in the center of the tube. When the water flow is out of date in the pipe, the water first passes through the platinum resistance at one end. At this time the platinum resistor transforms the temperature value into the electrical signal, then the water flows over the heating rod and then flows through the platinum resistance at the other end and measure its temperature and convert it to the electrical signal. The heating rod is heated by constant power, and the platinum resistance at both ends is collected. The temperature difference will vary with the velocity of flow. RS485 serial port communication method is used to upload the collected electrical signals to the experimental host in real time. The mathematical model of electrical signals and time collected by platinum resistance is established by the host computer to find out the corresponding relationship between the changes of electrical signals and the speed of seepage.

2 Monitoring method and Scheme Design of seepage in Rock and soil

Two PT100 platinum resistors with a diameter of 3mm and a ceramic heating rod with a diameter of 3.3mm are used in the design. The platinum resistance and the heating rod are fixed in a polycarbonate tube with a diameter of 6mm and a diameter of 200mm by glue. The heating rod is fixed at the center length of the tube, and the platinum resistance is fixed at both ends of the tube. The thin pipe and the funnel with a diameter of 55mm are glued together, the permeable stone with a diameter of 50mm and 5mm is placed in the funnel with glue, and The device is placed in a 60mm diameter tube fixed with glue. The design of seepage sensor is shown in Figure 1.

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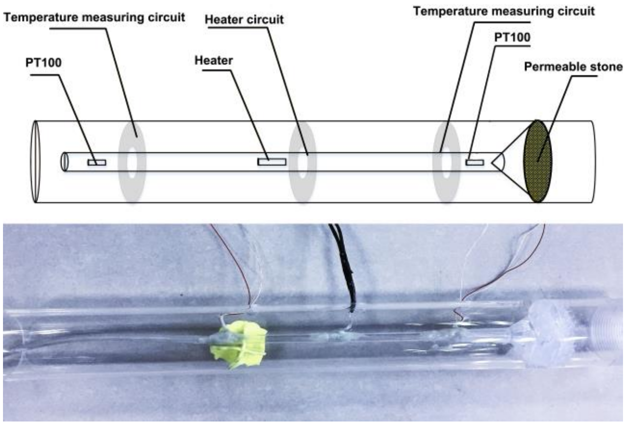

Figure 1. Seepage sensor design

2.1 Simulation of velocity and temperature fields of water in tube

The Ansys Fluent software was used to model and simulate the flow state and temperature of the fluid in the thin tube. Figure 2 shows the temperature field of the fluid in the thin tube. Figure 3 shows the velocity field of the fluid in the thin tube. The heating rod has a constant power of 4w and the water flows from right to left at a rate of 0.05mL/s.

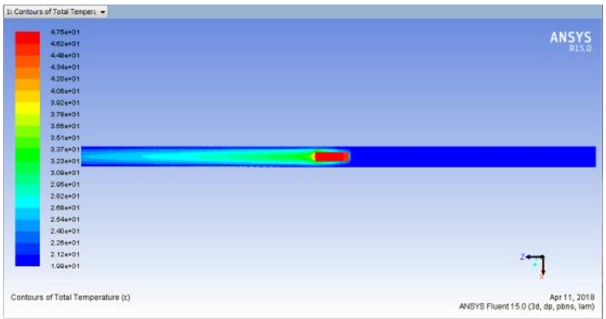

Figure 2. Temperature field simulation

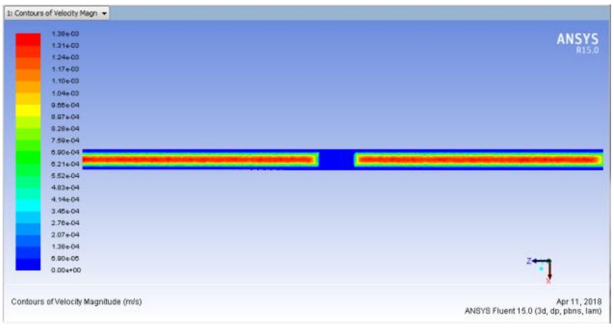

Figure 3. Velocity field simulation

As can be seen from Figure 3, the relationship between velocity and radius is parabolic, that is, the velocity at the center of the capillary is the largest, and the slower the flow toward the wall, the velocity is almost zero at the wall.

From the simulation diagram of the temperature field in Figure 2, it can be concluded that the temperature difference between the upstream and downstream ends is about 6.8℃ in the case of a constant power of the heater 4w and a water flow rate of 0.05mL/s (a drop of water). Author names should be typed in 9-point Arial. The style for the names is First Names then Last Name, with a comma after all but the last two names, which are separated by “and”. Do not use academic titles.

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2.2 Hardware circuit design

2.2.1 Platinum resistance temperature measuring circuit

The temperature measurement circuit mainly collects and amplifies the voltage signal on the PT100 platinum resistance. The voltage signal outputted by the temperature measuring circuit is sampled and displayed on the screen through the internal A/D sampling port of the stm32, and the data is uploaded to the host for processing by using the RS-485. Figure 4 is a block diagram of the design of the temperature measurement circuit.

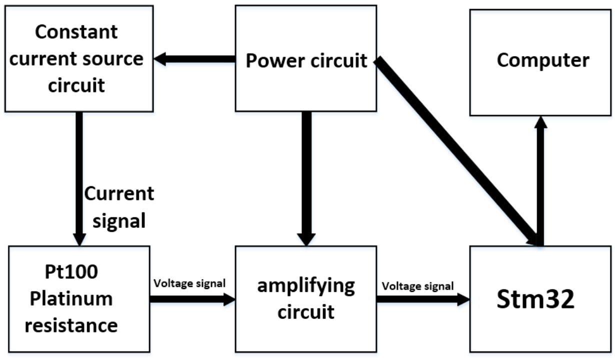

Figure 4. Temperature measurement circuit block diagram

The temperature measurement circuit mainly includes PT100 platinum resistance,signal amplification circuit, filter circuit, stm32 controller and power supply circuit and so on. Finally realizes real-time collection and upload of platinum resistance voltage signal.

The 1mA constant current source generation circuit uses the Howland op amp current source, and uses a three-wire PT100 platinum resistor to reduce the additional error caused by the lead resistance. The op07c voltage operational amplifier is used to collect the voltage signal on the platinum resistor and perform 100-fold amplification.

2.2.2 Temperature measurement circuit calibration

Four 109.73 Ω, 120 Ω, 125 Ω, 140 Ω RX70 type high precision wire wound resistors are used to replace the platinum resistance in the circuit to calibrate the temperature measurement circuit. The calibration result magnification is about 99.93. The average error is 0.1655 mV, which corresponds to the PT100 platinum resistance indexing table. The temperature measurement accuracy is about 0.1 ℃, which satisfies the demand for seepage monitoring in rock and soil.

2.3 Experimental device design

2.3.1. Experiment on the relationship between flow rate and temperature

In order to verify the relationship between the flow rate and the temperature change, we designed the experimental device shown in Figure 5 . It was divided into a current limiting device, a temperature signal detecting and amplifying circuit, a heater circuit, and the water bag was suspended by a bracket.The water bag, seepage meter, tube and restrictor valve are connected by hose.The thin tube of the seepage meter is fixed and maintained horizontal by the iron frame. We can rotary the flow restrictor knob to obtain different flow rates, and the heating rod is heated at a constant power. The flow rate can be calculated by the temperature difference between the ends of the seepage meter collected by the PT100.

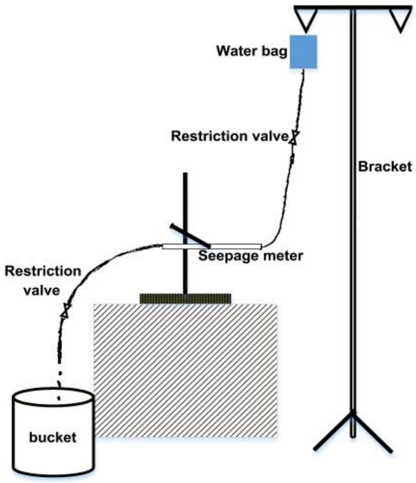

Figure 5. The relationship between flow rate change and temperature

2.3.2 Seepage meter calibration experiment device

In order to obtain the true situation of seepage in rock and soil and better simulate the condition and environment of seepage in rock and soil, we designed a calibration experimental device , which is shown in Fig. 6. The transparent tube with the diameter of 110 cm and 6cm in diameter is connected with the elbow of DN50 diameter and the transparent tube with the horizontal length of 40cm and 6cm in diameter, and the arc bracket is used to hold the stability on the bottom plate. There is a combination of percolation pipe and funnel and permeable stone in the transparent pipe, which is connected and filled with waterproof glue. Add a certain amount of soil to the vertical transparent tube, then add water, which seeps through the soil by gravity and flows through the bend The head then flows through the permeable stone to gather in the funnel, and when the water in the funnel is half full, the water level and the percolation pipe are flat, and the water begins to fill the pipe. Flow through the pipe PT100, heating rod PT100, the whole set of device joints are sealed with waterproof glue.

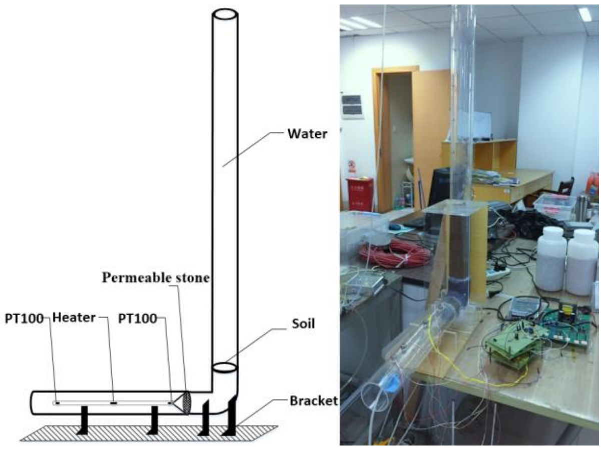

Figure 6. Seepage meter calibration experiment device

2.4 Experimental data processing and results

In order to simulate the seepage velocity in the soil, we used a flow restrictor to limit the flow rate. The permeability coefficients of various soils are shown in Table 1:

Table 1. Empirical value of rock penetration coefficient.

Stratigraphic lithology	Permeability coefficient (m/d)
Clay	0.005
Silt sand	0.5~1.0
Fine sand	1.0~5.0
Sand	5.0~20.0
Coarse sand	20~50
Slightly cracked rock	20~60

The seepage measurement in rock and soil is to monitor a series of disasters such as barrage, landslide and foundation pit collapse. Most of the rock and soil are coarse sand or loose deposits with large particle diameter. Therefore, fine sand (particle diameter of about 0.05 mm) and permeability coefficient of 0.6m/d were selected as the simulated rock soil. The conversion to the long tube section is 0.18 ml/s, and the water flow rate is about 0.05 mL per drop, the flow rate is approximately 3~4 drops/s. The flow rate was limited to 1 drop/s, 2 drop/s, 3 drop/s, 4 drop/s by using a flow limiting valve. The experiments were carried out at the same time on the same day, with the same water level in the long pipe and constant heating rod power of 4W. For the convenience of comparison, the experimental results are shown in Figure 7.The abscissa represents time, the unit is second, the ordinate is the voltage value of the downstream PT100 temperature measurement, the unit is volt. The larger the voltage, the higher the temperature.

It can be seen that at different flow rates, the stable time is reached, and the slopes are significantly different. Among them, 0.05 mL/s (1 drop of water) needs about 4,500s to reach stability, and 0.1 mL/s (2 drops of water) needs about 3,300s to reach stability, 0.15 mL/s (3 drops) is approximately 2100s, and 0.2 ml/s (4 drops) is approximately 390 s.

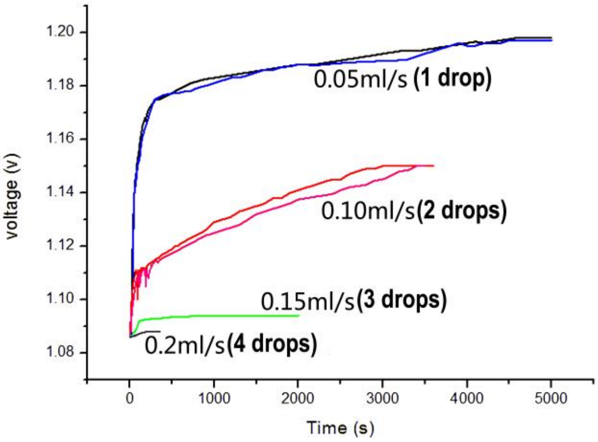

Figure 7. Comparison of voltage changes at different flow rates

The voltage signal collected on both ends of PT100 corresponds to the standard PT100 thermal resistance distribution table.The voltage value on PT100 is converted to a temperature value. When the heating rod is kept at constant power for 4W, the maximum temperature on the downstream PT100 is 51.1 ℃at a flow rate of 0.05 mL/s (one drop of water). At this time, the temperature at the upstream PT100, that is, the initial temperature of the inlet is 22.1 ℃, after 4600 s, the temperature difference is approximately 29 ℃ and remains unchanged. At a flow rate of 0.1 ml/s (two drops of water), the maximum temperature of the downstream PT100 is 38.6 ℃, and the inlet temperature is 22.1 ℃. After 3000 s, the temperature difference is about 16.5 ℃and remains unchanged. At a flow rate of 0.15 mL/s (three drops of water), the differences of upstream and downstream temperature are approximately 2 ℃ and remain unchanged. The temperature difference is measured at 0.2 mL/s or above is too small to be detected. Therefore, 4W heating rod is used for constant power heating,when the PT100 is 10 cm away from the heating rod in the thin tube, it is suitable for the percolation velocity of 0.05~0.15 mL/s. At this time, the measurement accuracy is the highest.

3 Conclusion

In this paper, a liquid micro-flowmeter based on thermal diffusion principle is designed for seepage measurement in rock and soil. This method uses two PT100s and a heating rod to be fixed in the thin tube. The temperature difference collected by the two ends PT100 is used to judge the flow rate, and the serial port method is used to send the data to the host for processing in real time. The experimental results show that this detection method can measure very small seepage velocity, good repeatability, high precision, and can realize multi-point measurement, thus realizing on-line monitoring of seepage in rock and soil, which is a new measurement of seepage in rock and soil solution.

Acknowledgements

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