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IN-SITU TEST EXPERIMENTAL RESEARCH ON LEAKAGE OF LARGE DIAMETER PRE-STRESSED CONCRETE CYLINDER PIPE (PCCP)

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ABSTRACT

In recent years, a big number of large diameter pre-stressed concrete cylinder pipe (PCCP) lines have been applied to the Mid-route of the South-to-North Water Transfer Project. However, the leakage problem of PCCP causes annually heavy economic losses to our country. In such a context of situation, how to detect leaks rapidly and precisely after pipes appear cracks in water supply system has great significance. Based on the study and analysis of the characteristic structure of large diameter PCCP, a new leak detection system using fiber Bragg grating sensors, which can capture signals of water pressure change, is proposed. The feasibility, reliability and practicability of the system could be acceptable according to data achieved from in–situ tests. Moreover, the leak detection system can monitor in real-time of dynamic change of water pressure. The equations of the leakage quantity and water pressure have been presented in this paper, which can provide technical guidelines for large diameter PCCP lines maintenance.

KEYWORDS

Large diameter pre-stressed concrete cylinder pipe; Leakage; In-situ Test; Fiber Bragg Grating

INTRODUCTION

PCCP, as a new kind of composite pipe which fully utilizes tensile characteristic of steel and compression performance of concrete, is widely used at home and abroad for its long service life, good seismic performance, easy installation, low operating cost, etc. Lots of large diameter PCCP lines have been adopted in the Mid-route of the South-to-North Water Transfer Project for its advantages. However, PCCP could leak water for some reasons, such as differential settlement or deformation of pipes and seal rubber grommet of pipes aging or losing effectiveness. It is not hard to understand that leakage problem brings great property damage to China. Experimental researches on leakage of PCCP lines heve been still rare until now, not mentioning large diameter PCCP in-situ tests. Mature automatic leak detection techniques of large diameter PCCP have not been applied widely in China. Furthermore, there are no formal codes for leak detection for reference. The common technologies for leak detection include Acoustic Emissions, Fiber Optic Sensing, Liquid Sensing and Vapor Sensing. The Acoustic Emissions is the only technology applied in the long pipelines. Acoustic Emissions has faults, for instance, its incapable of in-time monitoring. Considering this, the paper introduces a new leak detection system for large diameter PCCP pipelines based on fiber Bragg grating sensing technology. Sensitivity and reliability of the system are evaluated by in-situ tests. Meanwhile, the relationship between leakage and pressure is also presented and it will provide effective guidelines for PCCP pipelines.

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METHODS

Materials for this research: Optical fibre; sensor; large diameter PCCP pipeline; signal modulation mediation instrument.

Method used: Field experiments.

1. A BRIEF INTRODUCTION TO THE PRINCIPLE FOR IN-SITU TESTS OF PCCP PIPELINES

1.1. The principle for real-time leak detection monitoring of PCCP pipelines

The layout of pipes and equipment for the field test are shown in Figure 1-1. Water pressure in the circular cavity formed by rubber ring 1 and rubber ring 2 will change if the bell and spigot faucet for PCCP is broken. The change of water pressure will help realize real-time monitoring for leak detection. And following will be how the system works.

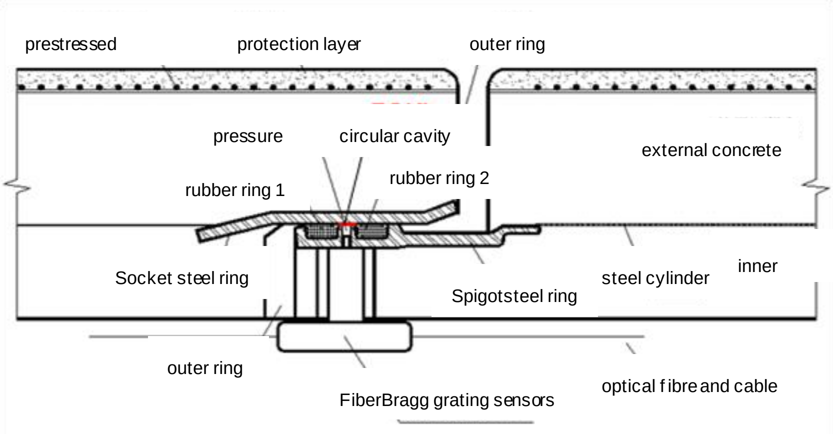


Fig.1-1 - The layout of pipes and equipment for the field test

Fiber Bragg grating sensors are placed on the pressure hole through the nipple, meanwhile, the other pressure hole is blocked by a bolt. Water will not flow into the circular cavity in a normal circumstance, water pressure is zero now. However, water pressure will not be zero if there is something wrong with rubber ring 1 or rubber ring 2 leading water flowing into the circular cavity through one of the twin rubber rings. The pressure change will be sensed in real-time by the fiber Bragg grating sensor placed on the pressure hole. The fiber Bragg grating will transform water pressure signals to the fiber Bragg grating demodulator and the computer can transform, paralyze and process signals. These signals will eventually be transformed into the data of water pressure change used to judge whether a pipe leaks or not, and also seepage discharge could be calculated. The installation position of the fiber Bragg Grating is fixed. So, pipe leaks can be located precisely based on the position.

1.2. In situ-test

The main indigenous equipment for the field test includes two PCCP pipelines, fiber Bragg grating demodulator, fiber Bragg grating, computer for the test, pressure hole pump and water injection equipment. The detailed procedure is described below. First, form pressure holes using the pressure hole pump. Second, correct the leak detection system. Finally, detect the pipes.

2. EXPERIMENT RESULTS AND ANALYSIS OF IN-SITU TESTS

2.1. Pre -pump for pressure hole test

In order to ensure the tightness of rubber rings at the sealing of pipes and fiber Bragg grating in normal conditions, pre-pump for pressure hole test is proceeded. The test is done on the cylindrical container where are placed with fiber Bragg grating sensors using pressure pump artificially. The pressure is controlled to about 0.8 MPa. Three pump tests and unpump tests together.

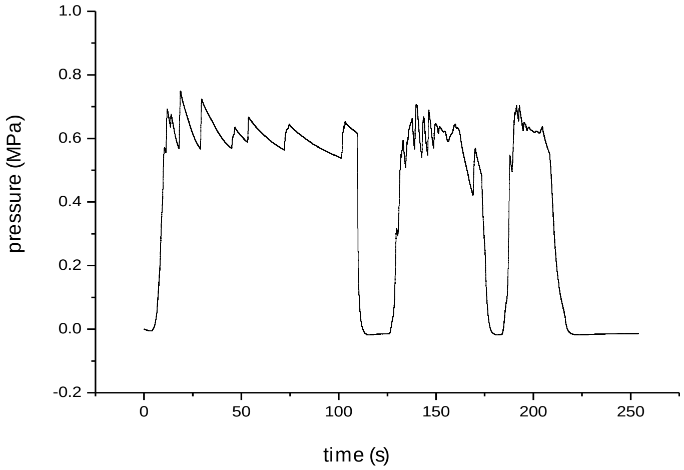


Fig.2-1 - The curve of pressure in pump hole

There are no water leakage points in process of pressure exerting. It indicates that the rubber rings are in their good sealing performances. The water pressure change sensed by the fiber Bragg grating is almost the same as the water pressure change displayed at pressure pump. It shows that the fiber Bragg grating sensors are reliable in measuring water pressure change. The test confirms the system's reliability.

2.2. Leak detection system correction test

The rubber ring 1 and rubber ring 2 are destroyed wilfully before the test. During the test, exert pressure on water in the pipe to needed value using the electric pump

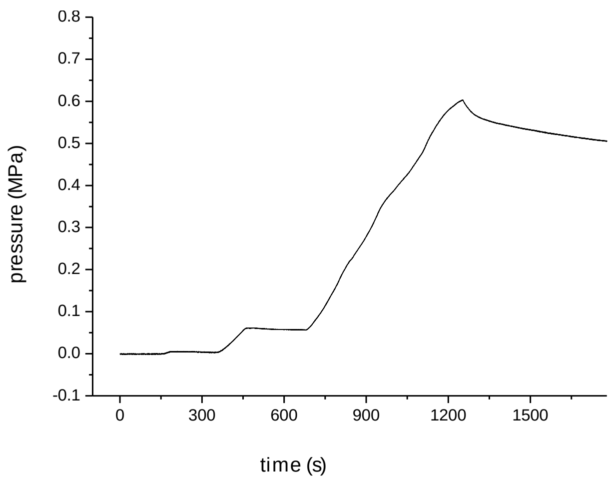


Fig.2-2 The change of water pressure measured by the fiber Bragg grating sensors

The leakage phenomenon at the bell and spigot faucet for PCCP could be found outside the pipe in the process of exerting pressure. When the water pressure elevates to about 0.6 MPa, the electric pump stops working. In the next stage, the water pressure decreases slowly all the time. It indicates that the water flows through twin rubber rings to outside. The whole change of water pressure is captured by the fiber Bragg grating sensors (See Figure 2-2), and this process is almost the same as that of the pipe. Thus, it is concluded that the system is valid.

2.3. Leak detection test

Based on the two tests above confirming the reliability and validity of the system, the test is adjusted in order to get the relationship between the leakage quantity and the water pressure. The test mainly focuses on the cylindrical container. The layout of the fiber Bragg grating and several function holes are shown in Figure 2-3. There are two blastholes, an adjust hole and three weep holes, and all holes are new formed in the cylindrical container.

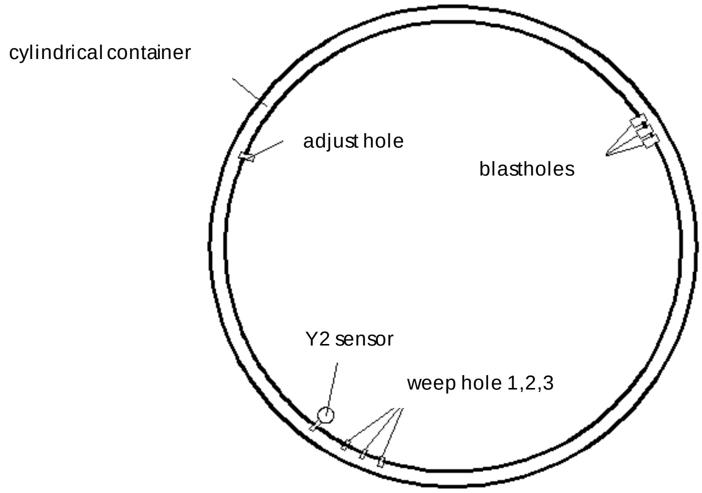


Fig.2-3 Schematic location diagram of the sensor and the functional holes

As the electric pump works, water will flow from the blasthole into the cylindrical container, as Figure 2-4 shows. The water coming from a blasthole will drain out of the weep hole through the adjust hole and Y2 sensor. There is a screw, the depth can be controlled to change and adjust the pressure in the adjust hole, as Figure 2-5 shows. The Y2 sensor is placed in the pressure hole above weep holes to measure water pressure of water of the weep hole, as Figure 2-6 shows. The Y3 sensor is placed on a tee union which is connected with a pressure hole neighbouring with a blasthole to measure water pressure of water of the blasthole, as Figure 2-7 shows.

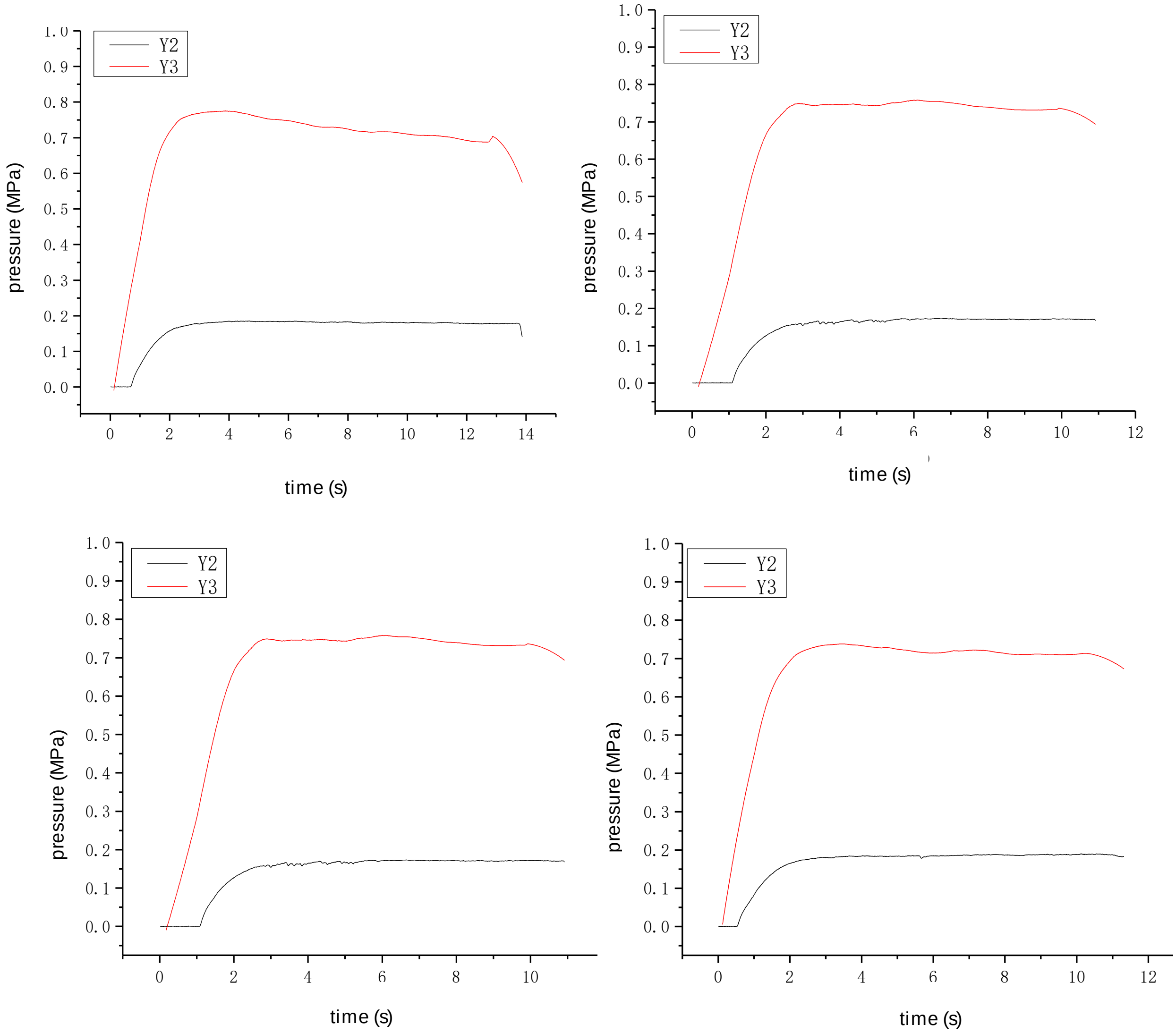
Fig.2-4 blasthole

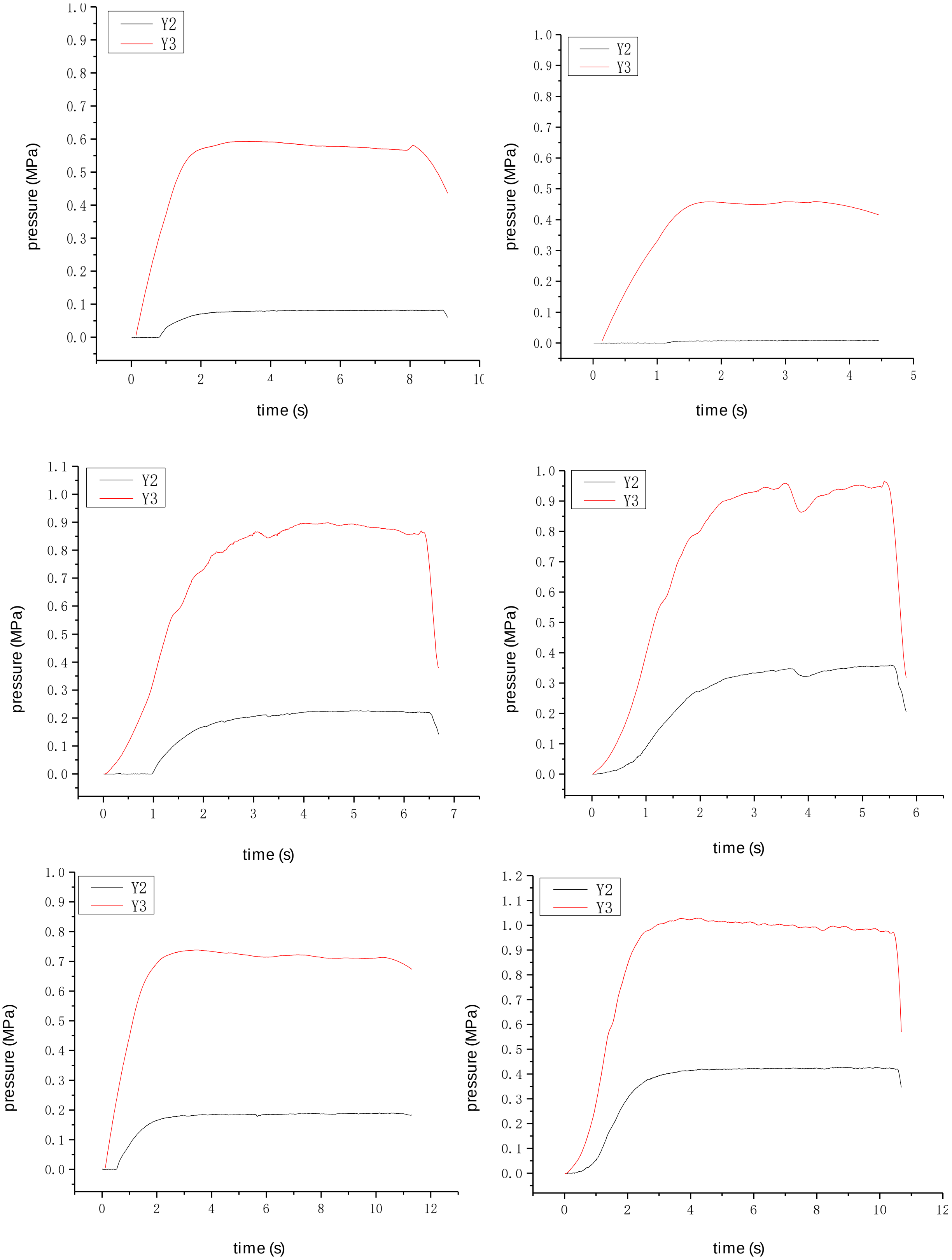
Fig.2-5 adjust hole

Fig.2-6 Y2 sensor

Fig.2-7 Y3 sensor

Adjust water pressure of blastholes to measure water leakage and flow rate in the pipe at the blastholes and the weep holes, and 11 groups of experimental data are got, as Figure 2-8 show.




Y2
Y3
pressure (MPa)
time (s)

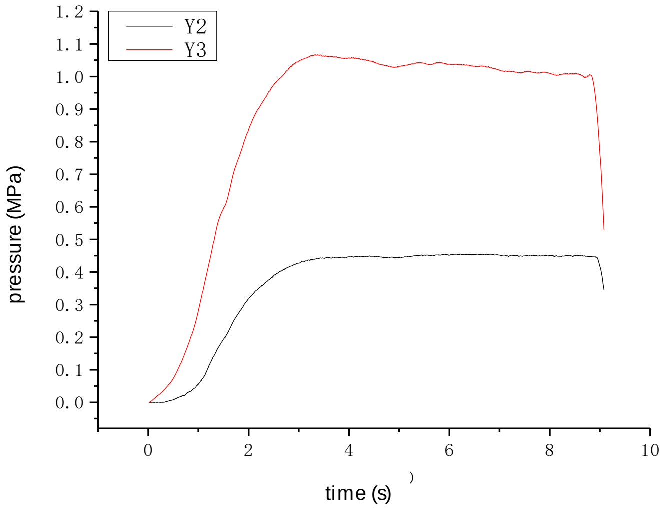


Fig.2-8 water pressure in the pipe varying with time

The water pressure got at the blastholes and weep holes, time, leakage and leakage rate are shown in Table 1.

Tab. 1 - Relationship of inlet pressure, outlet pressure, time, leakage and leakage rate

Name of experiment	inlet pressure [MPa]	outlet pressure [MPa]	Time[s]	Leakage[ml]	leakage rate [ml·s-1]
1.Screw in 10 buttons nut	0.75	0.18	13.96	1500	112
2.Screw in 8 buttons nut	0.74	0.17	10.72	1125	108
3.Screw in 6 buttons nut	0.79	0.13	11.84	1300	113
4.Screw in 4 buttons nut	0.73	0.15	9.37	1020	110
5.Screw in 2 buttons nut	0.58	0.08	9.03	900	100
6.Don't screw in the nut	0.46	0.007	4.42	500	98
7.Tighten the nut	0.9	0.22	6.94	875	126
8.Screw in 2 buttons nut in the weep hole 1	0.95	0.35	5.74	1350	235
9.Screw in 4 buttons nut in the weep hole 1	0.98	0.21	9.55	900	103
10.Tighten the nut in the weep hole 1	0.99	0.42	10.64	1400	132
11.Insert the screwdriver in the weep hole 1	1	0.45	8.88	1600	180

After an analysis of data of Table 1, the relationship between the water pressure at the blastholes in the pipe and the leakage quantity can be described into a curve (1) shown as Figure 2-9, the equation between two variables is described as following:

$$Q=112.93-81.10\,p+102.98\,p^2 \qquad (1)$$

Where Q represents leakage rate in a unit of ml/s; p represents water pressure at the blastholes in a unit of MPa.

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In the same way, we could get another curve describing the water pressure at the weep holes in the pipe and leakage quantity (2) shown as Figure 2-10, the equation between two variables is described as following:

$$Q=96.20+37.01\ p+334.22\ p^2 \tag{2}$$

Where Q represents leakage rate in a unit of ml/s; p represents water pressure at the weep holes in a unit of MPa.

Through the two equations above, we can calculate leakage rate based on the water pressure sensed by the fiber Bragg grating sensors.

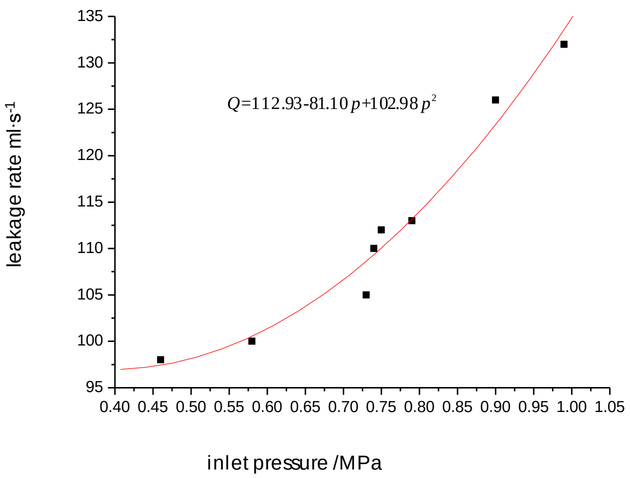

Fig.2-9 the diagram for pipeline leakage rate and inlet pressure

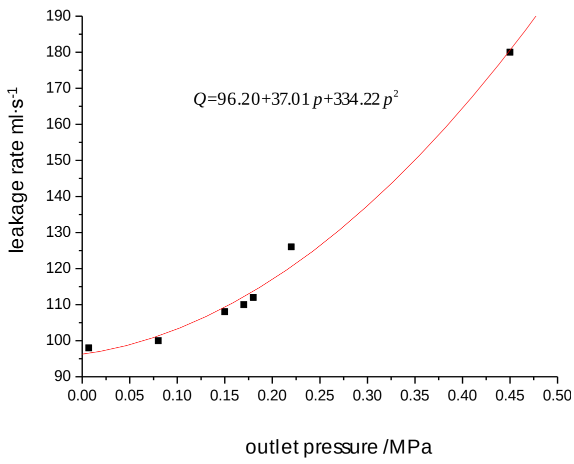

Fig.2-10 the diagram for pipeline leakage rate and outlet pressure

3. MONITOR CONTROL STANDARD FOR REAL-MONITOR OF LEAKS OF PCCP PIPES

There are two aspects for the control standards. One aspect is detecting water leaks of Pipe lines. The other is standard for how to judge water leak state.

1) Finding out water leaks

As the spot in which the sensors are placed is totally fixed, it's convenient to find out where water leaks precisely based on the places and where the sensors are fixed. Water will leak out of the pipes when the pressure sensed by the sensors is over zero.

2) Based on the principle of the system, three cases for judging leaks are listed below:

a. As water pressure sensed by the sensors is over zero and increases gradually to the pressure value of the pipe, we can make a conclusion that rubber ring 1 fails, rubber ring 2 is still at work, the pipe is in order, and no water leaks out.

b. As water pressure sensed by the sensors is over zero and increases gradually to the pressure value of the pipe, however, decreases gradually and final reduces to a certain value, we can judge that the rubber ring 1 and the rubber ring 2 are both out of order. At the same time, the tube leaks and is out of work. Water leak flow rate and leak quantity can be calculated through the relationships between the pressure in the pipe and the water leak quantity since the water pressure is easily sensed by the Grating Sensors.

c. As water pressure sensed by the sensors is over zero and increases gradually to a certain value which is much less than the water pressure in the pipe and there is no pressure reducing trend, the rubber ring 2 is out of work and the rubber ring 1 is still okay. The pipe is at work and no water leak takes place.

CONCLUSION

Based on the study on the analysis of large diameter PCCP itself characteristic structure, the authors propose a new leak detection system using fiber Bragg grating sensors which can capture signals of water pressure change. The feasibility, reliability and practicability of the system could be accepted according to the data achieved from in–situ tests. The creativity will provide some experience for operations of PCCP pipelines, meanwhile, provide reference for monitor regulations of leak detection.

1) A new real-time monitoring leak detection system and technolog is presented, whose reliability and feasibility is tested through in-situ tests.

2) Leak equipment, detectors and software system for in-time leak detection are invented. The reliability and feasibility is tested through in-situ tests.

3) The paper establishes the way and the system to locate possible leaks fast and accurately.

4) The paper establishes codes and procedures for leak detection of large diameter of PCCP lines.

5) The relationship between the water pressure in PCCP and the leak quantity is first presented by in-situ tests. Leak quantity can be calculated through data achieved from leak detection system.

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