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Monitoring the Deformation of Pipelines During Soil Freeze-Thaw Cycle Using Distributed Fiber Sensor

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ABSTRACT

The soil freeze-thaw process can lead buckling or even leakage of the buried pipeline. This paper presents experimental methods and results to describe the deformation of oil and natural gas pipeline during the soil freeze-thaw process using distributed fiber sensor. The test box for simulating soil freeze-thaw cycle and test pipeline were produced. Two distributed fiber sensors were attached to the test pipeline. A FBG temperature sensor was fixed inside the test pipeline. The test pipeline was first placed in the box and then covered by saturated soil. A LUNA-A distributed fiber sensing system and a FBG demodulator were monitored deformation and temperature change of the pipeline during the soil freeze-thaw transition, respectively. The strain data collected at the LUNA-A are utilized to quantitatively describe the deformation of the pipeline. The alteration of the deformation of the pipeline during the soil freeze-thaw process has an important effect on the strain data. Potentially, distributed fiber sensor solves the problem that the quasi-distributed FBG sensor cannot monitor the whole deformation of the pipeline, which is a promising sensor in pipeline safety monitoring.

1. INTRODUCTION

With the rapid development of the industrial economy, the consumption needs of oil and natural gas, which are important resources for human development, are increasing. The pipelines, an important means to transport oil and gas through long distance, whose amount of usage is also increasing(Ren, Jiang et al. 2017). However, due to the geospatial differences in energy origin and consumption area，the pipelines are buried underground and inevitably cross the partially frozen soil or warm permafrost site. It is well known that frozen soil is a great threat to the safe operation of structures(Kong, Wang et al. 2014). Seasonal freezing causes significant change in the stiffness of the soil and bridge seismic behavior(Zhaohui, Dutta et al. 2007, Xiong and

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Yang 2008). During the freeze-thaw cycle, the soil is subjected to expansion and contraction, which may lead buckling or even leakage of the pipeline. Once the pipelines are subjected to leakage as large flow rates imply that even smallest leaks may cause serious pollution.

Thus, a number of pipeline detection technologies have been developed to ensure pipeline safety. Tavakoli, Marques et al. designed pole climbing robots that perform periodical inspections and detect welding defects(Tavakoli, Marques et al. 2010). An ultrasonic inspection robot with an electromagnetic acoustic transducer was developed for inspection of the circumferential pipe parts(Murayama, Makiyama et al. 2004). However, these monitoring technologies cannot provide real-time monitoring of the pipelines. And oil and natural gas has flammability, it is not suitable for inspection with electric sensors. Generally, oil and natural gas pipelines are buried underground and extend hundreds of kilometers. The frozen soil conditions mean that many traditional structural monitoring technologies are not applicable for pipeline structure. A fiber optic sensor is an ideal approach for pipeline safety monitoring because of its superior immunity to electromagnetic interference, long distance transmission, good embeddability and reliability(Li, Li et al. 2004). Jiang, Ren et al. have verified that the pipeline leakage and corrosion can be detected by FBG hoop strain sensor(Jiang, Ren et al. 2017). However, the widely applied fiber grating sensor has its own advantages and limitations. For example, cracks or corrosion can occur at any stage of the pipeline in service and any position of the pipeline. Therefore, it is virtually impossible to detect the local damage of the pipeline only by the FBG sensor at a specific position of the pipeline. To detect the whole deformation of the pipeline, a novel distributed sensor, employing metal coated polymer-clad fiber optic cables, was studied and developed theoretically by Alhandawi et al(Lynch, Alhandawi et al. 2016). According corresponding strain-pressure data, the locations of structural indentations were found(Zou, Sezerman et al. 2008). Consequently, the distributed fiber sensor can detect the whole deformation of the pipeline and make up for the limitation of FBG monitoring technology.

In this paper, a simulated experiment was conducted to detect the strain of the test pipeline. A LUNA-A distributed fiber sensing system and a FBG demodulator were monitored deformation and temperature change of the pipeline during the soil freeze-thaw transition, respectively. The experimental results were provided to describe the deformation as well as the spatiotemporal extent and development process of the pipeline during the soil freeze-thaw process using distributed fiber sensor.

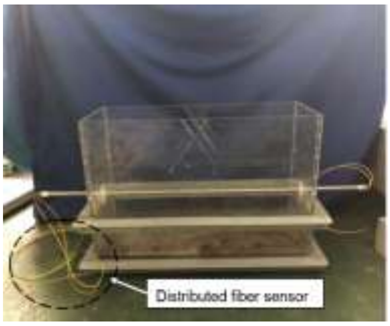
2. EXPERIMENTAL METHODS AND RESULTS

2.1 Experimental Methods

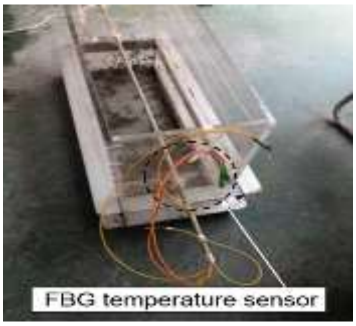
The test box was manufactured and the box model size is: 600x200x400 mm (shown in Fig. 1). The material is acrylic board with the wall thickness of 10mm in order to observe changes in the soil. On both sides of the short side of the test box, two round holes with a diameter of 12 mm were opened respectively at 180 mm away from the bottom of the test box. So that the test pipeline can penetrate the test box. The two movable angle steel play a reinforcing role to restrict the deformation around the test box.

Fig. 1 Picture of test box model

The pipeline deformation experiment during the soil freeze-thaw process was conducted on the test steel pipeline with a length of 1 m. The outer diameter and the wall thickness of the test pipeline are 10 mm and 0.5 mm, respectively. Two distributed fiber sensors were attached on the surface of the test pipeline with 502 and then coated with epoxy-resin adhesive: one was attached on the upper side and the other was attached on the lower side of the pipeline axis. A FBG temperature sensor was fixed inside the test pipeline. The test pipeline with the sensors installed was centered in the test box. Because the length of the test box is 600 mm, the length of the test pipeline actually put into the box is also 600mm. The position of the test pipeline in the test box is displayed in Fig. 2a. The distributed fiber sensors and the FBG temperature sensor are presented in Fig. 2a and 2b. The saturated soil was filled into the test box, and filled to 220 mm away from the bottom of the test box. The pipeline is 180 mm away from the bottom of the test box, hence the height of the soil covering the test pipeline is 40 mm. The saturated was vibrated and pounded evenly with a vibrator.



(a)



(b)

Fig. 2 Test pipeline installed sensors put into test box: (a) distributed fiber sensor; (b) FBG temperature sensor

An entire freeze-thaw process was simulated in a temperature-controllable freezer. The test box filled soil and installed the test pipeline was put into the freezer, as shown in Fig. 3. In the freezing process, the temperature of the freezer was -20℃. In the thawing process, the test box was kept in the laboratory at a room temperature of 10℃. The distributed fiber sensors were utilized to detect the strain of the test pipeline. The FBG temperature sensor was used to record the temperature of the test pipeline. A LUNA-A distributed fiber sensing system and a FBG demodulator (shown in Fig. 4a and 4b) monitored deformation and temperature change of the test pipeline during the soil freeze-thaw transition, respectively. During the experiment, one measurement was recorded every 30 min.

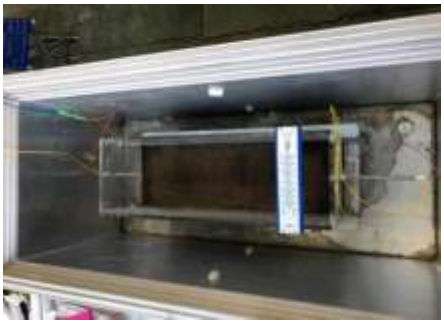
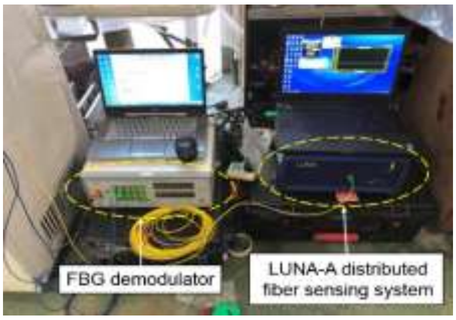


Fig. 3 Test box put into freezer



(a)

(b)

Fig. 4 Experimental equipment: (a) FBG demodulator and LUNA-A distributed fiber sensing system; (b) Picture of experimental equipment

2.2 Experimental Results

The experimental results were based on the measured data of the distributed fiber sensor attached on the upper side of the test pipeline axis. Fig. 5 presents the strain and temperature change of the test pipeline during the freezing process. Between 0 and 9 hours, the measured strain values were all negative, and showed a decreasing trend. The data indicated that the pipeline was compressed at this moment and was considered to be cold-contraction phenomena. The test pipeline did not deform under the influence of the freezing soil. Between 23 and 33 hours, the measured strain values appeared positive, indicating that the upper side of the test pipeline was pulled. The deformation around the test box was restricted, and hence soil would only produce upward deformation during the freeze process. Therefore, the test pipeline bended upwards causing the upper side of the pipeline to pull. The results measured in the experiment coincided with the actual conditions. After 44 hours, the deformation of the test pipeline was basically stable. The largest micro-strain of the pipeline occurred at 29 hours (displayed in Fig. 5). During the freeze process, the lowest temperature of the pipeline was -10℃.

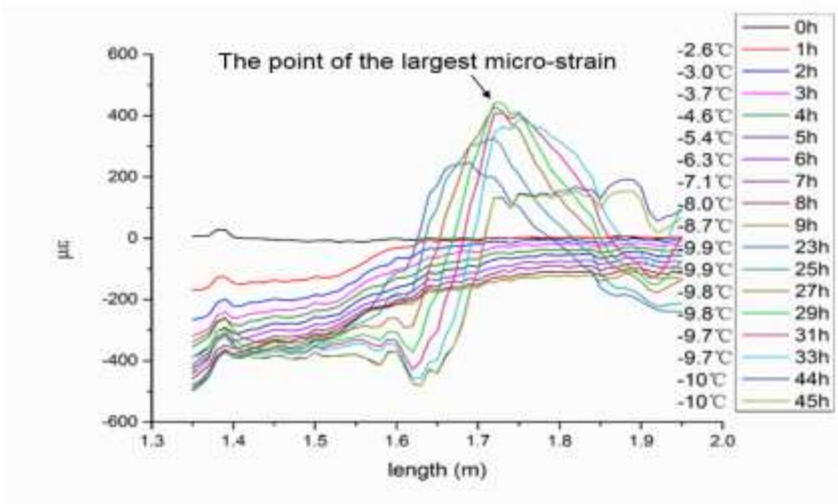


Fig. 5 Experimental results in freezing process

Fig. 6 presents the strain and temperature change of the test pipeline during the thawing process. Between 0 and 50 hours, the measured strain values were positive and showed an increasing trend. The data indicated that the pipeline was pulled and was considered to be thermal expansion phenomena. The test pipeline did not deform under the influence of the thawing soil. From 52 hours to 53 hours, the measured strain values were positive but showed a decreasing trend. The data indicated that the upper side of the pipeline was compressed, demonstrating the pipeline bended downwards. The deformation around the test box was restricted, and hence soil would only produce upward deformation during the thaw process. Therefore, with the increase of temperature, the test pipeline bended downwards due to the soil thawing. The results measured in the experiment coincided with the actual conditions.

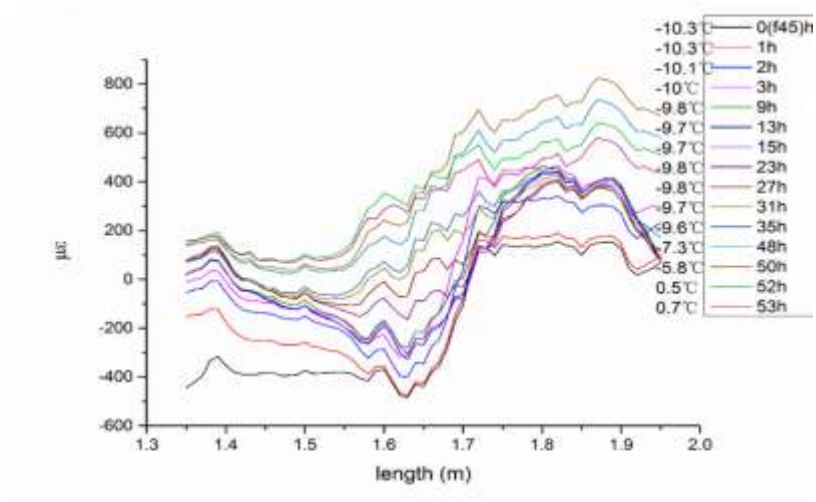


Fig. 6 Experimental results in thawing process

3. CONCLUSIONS

The distributed fiber sensor is used to successfully monitor the deformation of the test pipeline during the transition between the freeze and thaw states of the soil. The experimental results demonstrate that the test pipeline bend upwards with the soil freezing and bend downwards with the soil thawing. The deformation state and trend of the test pipeline under the influence of the soil freeze-thaw process are completely simulated. Potentially, it can be concluded from the experiment that the distributed fiber sensor is ideal for monitoring long distance pipelines. Further investigation will be conducted to study the reduction of pipeline shape and improve the sensitivity of the distributed fiber sensor.

REFERENCES

Jiang, T., et al. (2017). "Application of FBG Based Sensor in Pipeline Safety Monitoring." Applied Sciences 7(6): 540.

Kong, Q., et al. (2014). Monitoring the Soil Freeze-Thaw Process Using Piezoceramic-Based Smart Aggregate.

Li, H.-N., et al. (2004). "Recent applications of fiber optic sensors to health monitoring in civil engineering." Engineering Structures 26(11): 1647-1657.

Lynch, J. P., et al. (2016). "Corrosion monitoring along infrastructures using distributed fiber optic sensing." 9803: 980340.

Murayama, R., et al. (2004). "Development of an ultrasonic inspection robot using an electromagnetic acoustic transducer for a Lamb wave and an SH-plate wave." Ultrasonics 42(1-9): 825-829.

Ren, L., et al. (2017). "A method of pipeline corrosion detection based on hoop-strain monitoring technology." Structural Control and Health Monitoring 24(6): e1931.

Tavakoli, M., et al. (2010). "Development of an industrial pipeline inspection robot." Industrial Robot: An International Journal 37(3): 309-322.

Xiong, F. and Z. Yang (2008). "Effects of seasonally frozen soil on the seismic behavior of bridges." Cold Regions Science and Technology 54(1): 44-53.

Zhaohui, J., et al. (2007). Seasonal Frost Effects on the Soil–Foundation–Structure Interaction System.

Zou, L., et al. (2008). Pipeline Corrosion Monitoring by Fiber Optic Distributed Strain and Temperature Sensors.