46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-1234

DETECTION OF GROUND MOTION INDUCED PIPE DEFORMATION USING A SENSING TEXTILE

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ABSTRACT

Instrumenting deteriorated critical civil infrastructure such as underground pipes with distributed sensors provides continuous health-related information for early-warning of disasters and effective rehabilitation and repair. While the use of fiber optic sensors (FOS) for structural health monitoring (SHM) of underground pipes has been reported in many applications for decades, most of the applications are semi-distributed (e.g., using fiber Bragg grating) in the past. This study presents an application of a novel sensing textile for detecting ground motion induced pipe deformation (e.g., bending and rotation). Four-point bending tests were performed on a HDPE pipe before and after rotation. The feasibility of proposed sensing textile for detecting bending and rotation of the HDPE pipe was demonstrated.

Keywords: Optical fiber, BOTDR, sensing textile, pipe

1. INTRODUCTION

Underground pipes are extensively used to transport water, gas, petroleum products and sewage. Ground motions caused by earthquakes, tsunamis or landslides can induce excessive deformation to the underground pipes and lead to catastrophic failures such as gas pipe explosions or oil leakage. Monitoring of the underground pipes is crucial for detecting deformation/damage of underground pipes [1-3]. The use of fiber optic sensors (FOS) has been reported in many applications for nondestructive evaluation (NDE) of underground pipes due to their advantages such as compact size and long-term reliability [4-6]. However, traditional FOS are non-distributed or semi-distributed. In this study, a sensing textile is proposed for measuring ground motion induced pipe deformation such as bending and rotation.

The purpose of this study is to experimentally demonstrate the feasibility of proposed sensing textile for measuring ground motion induced pipe deformation through surface strain. A sensing textile prototype is installed on the bottom surface of a pipe. Four-point bending tests are performed to the rotated/unrotated pipe in order to simulate ground motion induced pipe deformation. Strain distributions on the pipe are then measured by the sensing textile. Setup of experiments is presented in the following section.

2. EXPERIMENT SETUP

A 304.8- centimeter long high-density polyethylene (HDPE) pipe was installed with a sensing textile prototype that covers the bottom surface of the HDPE pipe. Strain distributions of the HDPE pipe under three loading cases (i.e., normal condition, bent, and rotated) were measured by the sensing textile. Materials and experiment method are reported in the following.

2.1 HDPE pipe

Dimensions of the HDPE pipe are depicted in FIGURE 1. It has length of 304.8 centimeters, thickness of 1.7 centimeters, and diameter of 27.3 centimeters. Material properties of the HDPE pipe are listed in Table 1. Sensing textile is installed on the bottom half of the HDPE pipe using 3M Hi-Strength 90 adhesive.

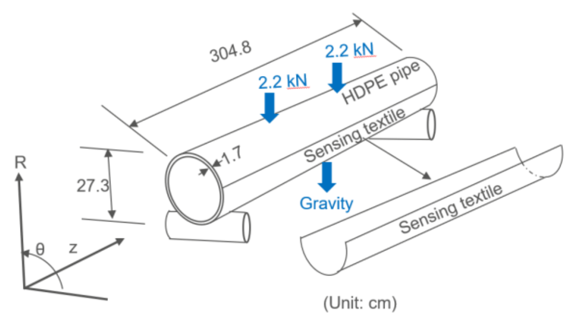

FIGURE 1: EXPERIMENT SETUP

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Table 1. Material properties of HDPE

Material	HDPE (PE4710)
Density (kg/m^3)	959
Young's Modulus (MPa)	724
Poisson's ratio	0.33

2.2 Sensing textile

Our sensing textile was manufactured by sewing a continuous optical fiber onto 52.6 centimeters - by - 284 centimeters rectangular textile, as shown in FIGURE 2. The pattern of the optical fiber was designed to capture both longitudinal strain and hoop strain. Precisely, sections 1 and 3 measure longitudinal strain on two sides of the HDPE pipe. Section 2 measures longitudinal strain at bottom of the HDPE pipe. Zig-zag sections measure hoop strain. The optical fiber was 12 meters long. It was connected to a Brillouin optical time domain reflectometer (BOTDR) that estimates the strain on the optical fiber based on proportionality between the strain and its Brillouin frequency shift. The spatial resolution of BOTDR was 1 meter and the sampling interval was 0.5 meters.

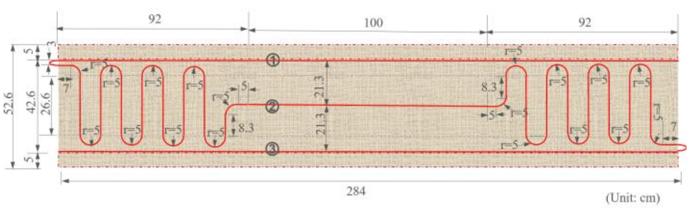

FIGURE 2: DESIGN OF SENSING TEXTILE

2.3 Loading cases

To simulate ground motion induced pipe deformation, such as bending and rotation, three loading cases were designed. These three loading cases were: 1) gravity loading while the HDPE pipe was sitting level on two supports; 2) four-point bending while the HDPE pipe was sitting level on two supports and; 3) four-point bending after the HDPE pipe was rotated 20 degrees about its longitudinal axis (z-axis), as shown in FIGURE 3. In cases 2 and 3, two concentrated forces (2.2 kN each) were applied at one-third span from each end of the HDPE pipe.

FIGURE 3: HDPE PIPE UNDER FOUR-POINT BENDING

Effects of bending and rotation of the HDPE pipe on its strain distributions were obtained by subtracting baseline strain measurements, as shown in FIGURE 4. For example, effect of bending was obtained by subtracting case 1 from case 2. Effect of rotation was achieved by subtracting case 2 from case 3. Strain measurements of HDPE pipe under three loading cases are reported in the following section.

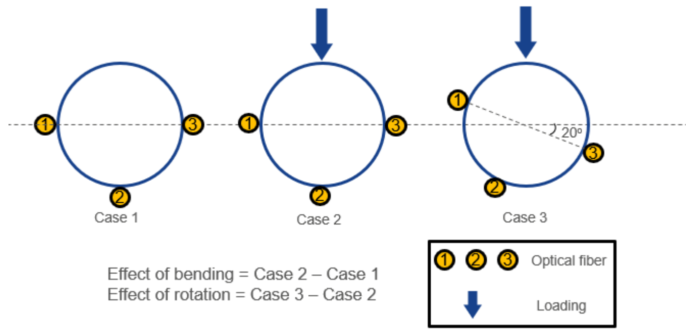

FIGURE 4: OPTICAL FIBER SECTION LOCATIONS IN THREE LOADING CASES

3. RESULTS AND DISCUSSION

Strain measurements along the optical fiber in three loading cases are shown in FIGURE 5. A distinguish peak was observed at 6 meters, which represents longitudinal strain at the bottom of the pipe. Another peak was found around 12 meters. This was caused by the pre-curved geometry of the HDPE pipe, which was formed during manufacturing and transportation process. As a result, the Brillouin frequency of the sensing textile at the pre-curved part shifted.

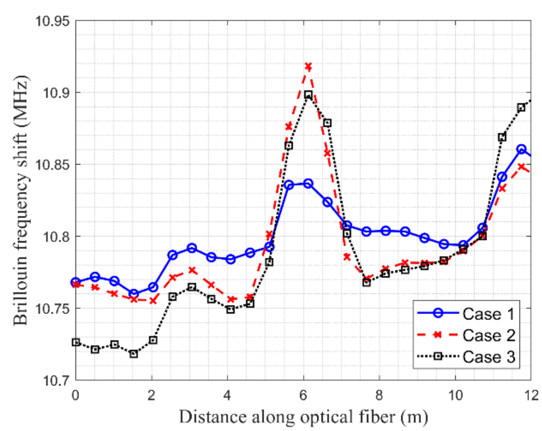

FIGURE 5: STRAIN MEASURES OF CONSIDERED CASES

To study the effect of the four-point bending, the measurement of case 1 was subtracted from that of case 2, as shown in FIGURE 6. Maximum strain (1634 με) was found at 6 meters along the optical fiber, which is section 2 in FIGURE 2.

From 5.0 to 6.9 meters along the optical fiber, positive strains were observed. This indicated that the longitudinal tensile strain at the bottom of the HDPE pipe. From 0 to 5 meters and 7 to 12 meters, strain values were found to be negative. This indicated that the deformation of the pipe due to the external loading results in compressive hoop strain at the bottom. In addition, the longitudinal strain at two sides of the pipe was also in compression.

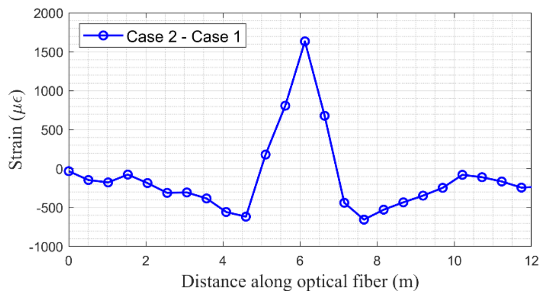

FIGURE 6: EFFECT OF FOUR-POINT BENDING

To study the effect of the rotation on the pipe, the measurement of case 2 was subtracted from that of case 3, as shown in FIGURE 7. After rotating the pipe 20 degrees, section 1 of the optical fiber (0 to 2.8 meters) was moved to compressive region and this led to negative differential strain. Similarly, tensile strain in section 3 of the optical fiber (9.2 meters to 12 meters) increased after rotation and this led to positive differential strain. At 6 meters along the optical fiber, since the optical fiber was moved away from the bottom center line, section 2 (5.5 to 6.5 meters) no longer measured the greatest longitudinal tensile strain. As a result, the strain value of section 2 reduced, which yielded a negative differential strain.

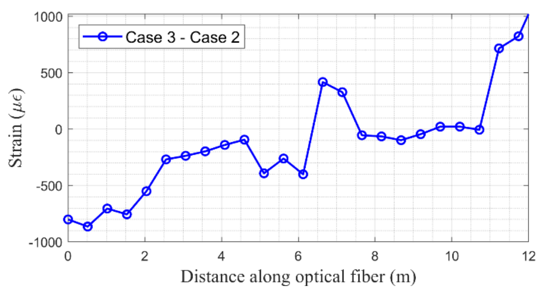

FIGURE 7: EFFECT OF PIPE ROTATION

In summary, the effects of the four-point bending on the strain distribution of the HDPE pipe are as follows: tensile strain was found around 5.0 to 6.9 meters along the optical fiber; the maximum tensile strain was found at 6 meters along the optical fiber and; the longitudinal strain at two sides of the pipe and hoop strains at the bottom were in compression. Rotation of pipe results in differential strains. A negative differential strain indicates an increase in compression or a decrease in tension. On the contrary, a positive differential strain indicates a reduction in compression or an increase in tension. Hence, the sign of differential strain can be used for determining the direction of rotation.

4. CONCLUSION

In conclusion, this study experimentally demonstrated the feasibility of the proposed sensing textile for monitoring ground induced pipe bending and rotation. It is believed that our proposed sensing textile can be used for other non-destructive evolving applications such as damage detection of underground pipes.

ACKNOWLEDGEMENTS

The authors wants to express their gratitude to the support from the Advanced Functional Fabrics of America (AFFOA) (PI: Prof. T. Yu, UMass Lowell).

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