Advanced Condition Assessment & Pipe Failure Prediction

Optimal management of water infrastructure

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Progress on Activity 1

Distributed Strain Sensing with Optical Fiber Sensors

Objectives

In Activity 1, we try to answer the question how, where and when pipes fail in a network. As part of this activity, smart monitoring techniques using optical fiber sensors as applicable to above ground or new buried pipelines are investigated.

Corrosion is one factor that significantly affects the performance of a pipeline. However corrosion is hard to monitor on a pipeline because corrosion can take place anywhere along the length of the pipeline and usually at multiple sites at one time. Distributed optical fiber strain sensors may provide a solution to this due to their ability to detect strains at multiple points on the entire length of the sensor. The question that follows then is how to instrument the pipe with these sensors in such a way that it can detect and monitor the growth of corrosion while still being economically viable. In this study, an experiment was carried out to demonstrate the ability of the fiber optic strain sensors to measure strain. Finite element simulations were then employed to model corrosion growth on the surface of a pipe and how different configurations of corrosion were detected by a distributed optical fiber strain sensor bonded to the surface of the pipe at a helical angle of 45°.

Fiber Optic Sensor System

The Distributed Brillouin Fiber Optic Strain Sensor was purchased from Oz Optics Ltd. Based on the manual the spatial resolution or gauge length of the sensor can be adjusted from 0.1 m up to 50 m. Depending on the spatial resolution used the sensor has a sensing range from 1 km to 100 km. The sensor could also be configured to read out strains at intervals of 0.05 m up to 50 m along the length of the fiber. The strain resolution and temperature resolution of the sensor according to the manual was 0.1 με and 0.005 °C respectively. The fiber used as the sensor is acrylate coated SMF 28 e fibers which are common.

Experimental Setup

A 2.8m long steel beam with a 24.5 mm by 8 mm cross section was loaded in a 4 point bend configuration. A single strand of SMF 28 e fiber was bonded along the bottom of the beam with araldite. Two weights, one weighing 2.26 kg and the other 2.3 kg were used to load the beam. Strain gauges were instrumented at the middle of the beam to provide a comparison for the fiber optic sensor.

Experimental Results

The results shown in Figure 1 are for when each weight was loaded 1.2 m from each end. The series labeled "theoretical" are strains derived from Euler-Bernoulli's beam theory. The series labeled "prediction" is our attempt to predict the strains that would be measured by a fiber optic sensor based on Euler-Bernoulli's beam theory and taking the spatial resolution of the fiber sensor into account which was 1 m in this experiment. From the results we see that the experimental and predicted results are in good agreement with theory.

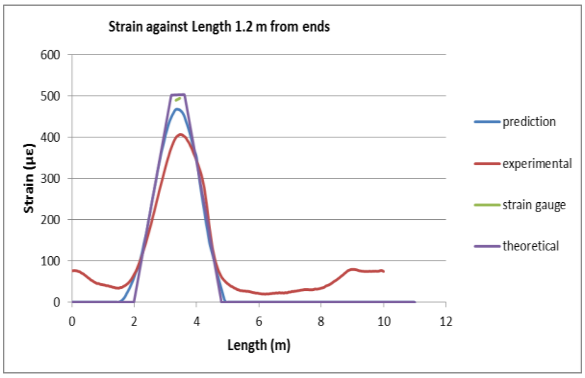

Figure 1 Strain along a steel beam under four point bend plotted as a function of length.

Computational Work

A pipe was loaded with an internal pressure of 400 kPa and had an outer diameter of 660 mm and a wall thickness of 20 mm. The material of the pipe was assumed to be grey cast iron. A fiber optic sensor was assumed to be bonded to the surface of the pipe at 45°. Different forms of highly idealized corrosion damage were then inflicted on the surface of the pipe and, using the "prediction" algorithm from the experimental section, theoretical strains measured by the fiber sensor were obtained.

Damage scenario

Damage along a pipeline is unlikely to occur in isolation. Whilst there are copious amount of research devoted to the monitoring and detection of single damage on a given test specimen, we need to develop the scientific basis to develop a robust monitoring system for multiple damage in a pipeline. Figure 2 shows two elliptical damages used to represent corrosion moving further and further away from the fiber sensors untill they start to interact with one another. The strains that would be theoretically detected by the fiber sensors are shown in Figure 3. From the graph we see that the closer the damage is to the fiber sensor the better the chances of detecting it. Even though the damage in the 0.4m and 0.3m cases is arguably more severe than its predecessors it goes undetected by the sensor.

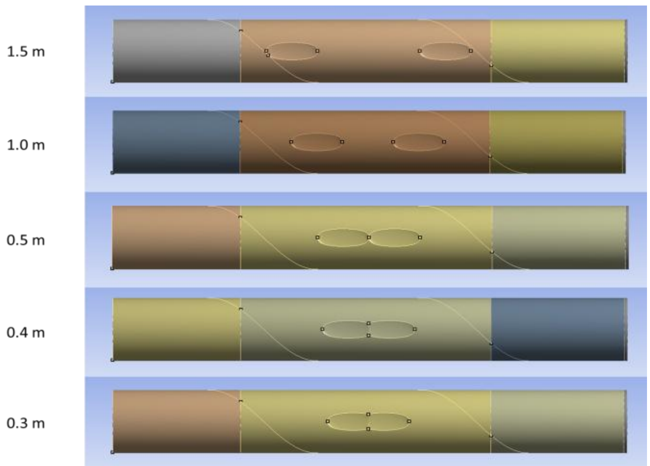

Figure 2 Two elliptical damages on the surface of a pipe as they move closer to each other.

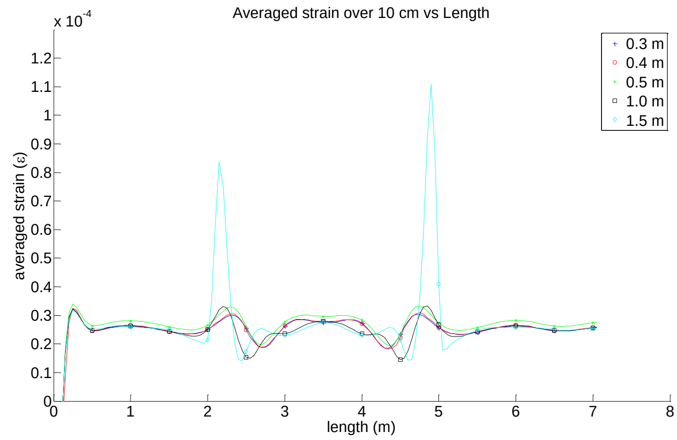

Figure 3 Theoretical strains measured by a distributed optical fiber strain sensor bonded helically to the surface of a pipe along its length.

The above results highlight the significance of the work performed which is;

- The development of the necessary scientific basis to develop a robust monitoring system to minimize the incidence of false negatives/positives,
- The findings will also be useful in establishing the protocols for fibre placement and how they can be related to the critical damage size expected along a given length of pipe.

Concluding Remarks

From the computational results we see that more than one strand of fiber sensor may be needed in order to fully detect and quantify damage on the surface of the pipe. The pitch between the helical angle of the fibers is also limited by the size of the damage considered critical. Experimental work will be carried out on pipes in order to validate our computational studies but thus far using distributed fiber optic strain sensors to detect corrosion on pipes has shown to be promising.

Partners

The partners in this research project include Sydney Water Corporation, UK Water Industry Research Ltd, Water Research Foundation of the USA, Water Corporation (WA), City West Water, Melbourne Water, South Australia Water Corporation, South East Water Ltd and Hunter Water Corporation. Monash University leads the research supported by University of Technology Sydney and the University of Newcastle. Other collaborators include Dr Balvant Rajani from Canada.

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