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Fatigue Damage Monitoring of a Cast Iron Pipeline Using Distributed Optical Fibre Sensors

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Abstract

Corrosion induced failures are common in cast iron (CI) pipes used in water supply networks. Over times, cracks may initiate from the corroded pits and grow when subjected to fatigue internal loading. When the particular region of the pipe loses its structural capacity, it will eventually lead to leakage or even pipe burst. Thus, it is important to use non-destructive techniques to perform permanent and real-time integrity monitoring on these pipelines. Distributed optical fibre sensors (DOFS) have been proposed to monitor the structural health of water pipelines for past decades. Most of the previous studies show that DOFS is effective in monitoring the condition of a pipeline and to assess the damage. This paper aims to experimentally demonstrate the ability of distributed optical fibre strain sensor to monitor the fatigue crack growth along the cast iron pipeline. The fatigue test was carried out using a large scale cyclic internal pressure loading facility. The distributed optical fibre sensor was instrumented on the pipe to monitor the condition of the pipe when subjected to internal pressure loading which vicinity to typical water pressure loading (operating pressure and pressure transient) experienced in the field. The measured response will show the potential application of distributed optical fibre sensor for crack detection, as well as monitoring the fatigue crack growth along the pipe. The results confirmed that DOFS is able to enhance the detection of cracks along the monitored pipe.

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1. Introduction

Cast iron (CI) pipes are commonly served to transport water, gas and sewage in most urban centres around

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the world including all major cities in Australia. The in-service CI pipes are very likely to expose to aggressive environmental conditions (i.e. the combinations of biological, chemical, electrical reactions with moisture and air). After exposure to these conditions for a long period of time, pitting and patch corrosion with different severity can happen and hence degrade the structural capacity of these cast iron pipes [1, 2]. Cracks will most probably initiate and propagate from the weakest point along the pits and patches. This can eventually lead to leaks and even burst along the in-service CI pipelines. A pipe failure in a critical water main could lead to significant economic, social and environmental loss. Thus, it is important to have a non-destructive technique to perform permanent and real-time integrity monitoring on these pipelines prior to any pipe failure.

Recent advancements of the technology associated distributed optical fibre sensors (DOFS) allows DOFS to perform continuous and *in-situ* monitoring of pipeline integrity. The distributed optical sensing has been implemented to monitor the pipe response due to ground movement [3], leak detection [4] and pipe buckling [5]. Vectorial dislocations of pipes induced by bending can also be detected using three distributed optical fibre sensors installed 120^o apart along the axial length of the pipes. Distributed optical sensing can be used to detect the presence of cracks along the pipe [6] as well as for detecting changes due to operating internal pressure with varied pipe thickness [7]. Moreover, distributed optical fibre sensors are capable of detecting cracks, and localised stiffness change of pressurised out-of-roundness pipeline [8]. It is also important to highlight that distributed optical fibre sensors has the ability to detect and monitor fatigue crack growth along the monitored complex composite structure [9].

The aim of this paper is to experimentally demonstrate the ability of a distributed optical fibre strain sensor to monitor the fatigue crack growth along the cast iron pipeline. In this paper, an off-service cast iron pipeline with a diameter of 660 mm and 18 mm remaining wall thickness was used for the fatigue testing. An artificial patch was introduced on the pipeline to simulate as a severely corroded patch (with a minimum of 3.5 mm remaining pipe wall thickness at the centre of the patch). The crack is expected to initiate and propagate from the centre of the damage patch. The fatigue test is carried out using a newly developed large scale cyclic pressure loading facility in Civil Engineering laboratory, Monash University [10, 11]. The pipe was subjected to internal pressure loading which vicinity to typical water pressure loading (operating pressure and pressure transient) experienced in the field. A swept-wavelength interrogator (SWI) based distributed optical fibre is exploited along the pipe to perform a continuous and real-time distributed strain measurement. With a specific frequency response bandwidth, DOFS manage to detect and monitor the growth of the crack.

2 Fatigue Test Monitoring

2.1 Distributed Optical Fibre Technique

A LUNA Technologies' Optical Distributed Sensor Interrogator (ODiSI-B series) is used for the experiment presented in this paper. The ODiSI sensor is a distributed optical fibre sensor (DOFS) functions on Rayleigh optical frequency domain reflectometry (OFDR) principle coupled with Swept-Wave Interferometry (SWI) technique [12, 13]. Light from a tuneable continuous wave (CW) laser source is split and propagated through the testing fibre and static reference arms of a fibre optic Mach-Zehnder interferometer [14, 15] and the signals are recombined at an optical detector. The interference patterns are generated as the laser frequency is tuned. The patterns are detected and related to the optical amplitude and phase response of the fibre under test. The patterns (in spectral domain) of the fibre under test is processed using the inverse Fourier transform to time domain. A map of the reflections as a function of distance of the fibre under test can then be constructed. Thus, OFDR can be used for both spectral and time domain reflectometry. This sensor has a spatial resolution of 5 mm, a maximum measuring length of 10 m and a temporal resolution of 0.01s (data acquisition rate of 100Hz).

2.2 Pipeline Specification

A decommissioned CI pipe was sourced from Strathfield, Sydney for the test. A detail information of the