Design and Evaluation of Optical Fibre Sensors in Civil Engineering Applications for Structural Health Monitoring

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Abstract
A number of studies on the use of optical fibre sensor techniques for structural monitoring are discussed and results obtained, both in the laboratory and in the field, are reported.

Introduction
Much of our current infrastructure, built of modern materials such as concrete, or more traditional materials such as brick or stone, has or will require extensive repair and usually when still in service. This can occur, for example, in the case of concrete after even a relatively short period of its design life and it may be necessary to extend that life and reduce the costs on 'new build'. Even stone buildings of many hundreds of years antiquity are subject to the deleterious effects of the modern envronment and require monitoring and repair to protect them for future generations. Currently an estimated ~US$1 billion per year is spent annually on the repair and maintenance of concrete infrastructure in the UK alone, a figure that is multiplied many times over across the developed nations and amplified by the enormous spend in recent years on infrastructure by the developing nations worldwide. This is indeed a global issue, one that will undoubtedly increase in relevance and in the costs involved in maintaining a satisfactory and safe infrastructural environment to underpin the world's economic system.

Serviceability and thus enhanced whole life performance are critical to effective use and the long-term monitoring of such structure. There is a clear future for the concrete infrastructure that dominates our modern building environment through the advancement of lightweight materials with a long service life – seen as essential to sustainable development, for example using highly durable lightweight, low energy concrete which can be used in a novel and pre-cast products and incorporating within it advanced monitoring systems. In addition to this approach for future building, critical to achieving the maximum value from our current infrastructure, is to understand more fully the needs and challenges of allowing for better assessment of *existing* structures during their service lifetime as well as creating better structures for the future, often using new materials. In both cases effective monitoring systems, installed or retrofitted and used to give reliable and informative data, having the confidence of the user community and industry, need to be developed, evaluated and used.

Structural Degradation and Monitoring Strategies
Structural Health Monitoring (SHM) is defined as the use of metrology techniques and sensors to provide a continuous assessment of the state of engineering structures. Structural degradation tends to be statistical in nature, rather than deterministic, and there is particular value to be gained from reliable *in situ* integrity monitoring, that can be achieved through the design and the implementation of suitable instrumentation to yield data at all stages during the lifetime of a structure, including prior to and post repair. To do so effective instrumentation is needed to give the requisite data: devices installed for such assessment should be capable of providing the means to implement ongoing condition maintenance and overall lifetime prediction, including post-repair lifetime and design verification for new structures. Addressing this is the use of new, calibrated monitoring devices applied both during the damage phases and additionally during repair procedures, to allow the effects of degradation and of repair on a range of structures to be evaluated .

Sensor Systems Development and Evaluation
New solutions to recognized problems in the built environment are proposed, to be able to obtain information on performance for critical or high value structures. This work tackles the needs for creating dedicated sensors and thus begins to address the associated socio-economic issues directly through developments involving creating enhanced monitoring ***systems,*** designed to make better and longer term use of *current* infrastructure and resources and thus to extend their working life.

Both conventional electrical techniques and fibre optic sensors (the focus of this work) for a range of sensor uses are widely available: for example fibre optic strain gauges, pressure or temperature sensors have been discussed extensively by some of the authors in previous publications for a number of industrial applications.

Fibre optic sensors have enormous potential for structural monitoring: they offer advantages over the electrical systems in a number of ways, namely they are small and lightweight, non-electrical in operation and are immune to electromagnetic interference: the fibres are inert to degradation and there is considerable potential for multiplexing.

Progress on the development of fibre optic sensors particularly for structural monitoring, emphasizing success in physical sensor development (particularly both strain and temperature monitoring), has been reported by some of the authors and others [1-3] and forms a backdrop to this research.

Fibre Optic Sensors and SHM

A number of sensor types and systems are often considered, including strain and temperature sensors, chemical sensors for pH (to detect carbonation), chloride attack and water (moisture) ingress, as prime examples. Two specific examples of the innovations in these areas are given below. Whilst considerable work has been undertaken to monitor strain in bridges under normal usage, few ’tests to destruction’ have been carried out. Figure 1 shows the results on one such test on a disused road bridge load progressively to 9MN in ~1 hour.

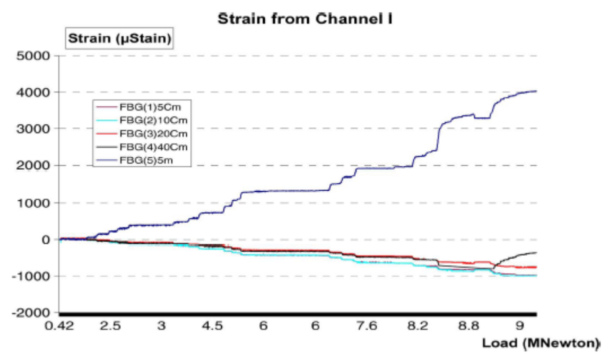

Figure 1: Strain monitoring on a test to destruction from 5 FBG-based sensors placed on the bridge with loading

The Fibre Bragg Grating (FBG) strain sensors used have been incorporated into carbon fibre reinforcement rods inserted into the structure to provide an intimate contact and, in addition to monitoring, in some cases to facilitate strengthening and repair. This is illustrated in Figure 2.

In a second example, sol-gel based sensors for pH monitoring are considered. Following prior research by the authors and others a major issue not adequately addressed previously was the long term cracking of the sol-gel during the fabrication stages and overcoming ths problem has been a focus of this work to create a durable, yet operational sensor. Further was the durability of a probe *specifically designed for applications to longer term monitoring in structural concrete* and able to deal with the very high pH, as another key issue to tolerate the harsh conditions of the concrete environment but yet be sufficiently absorbent to chemicals from the localized environment.

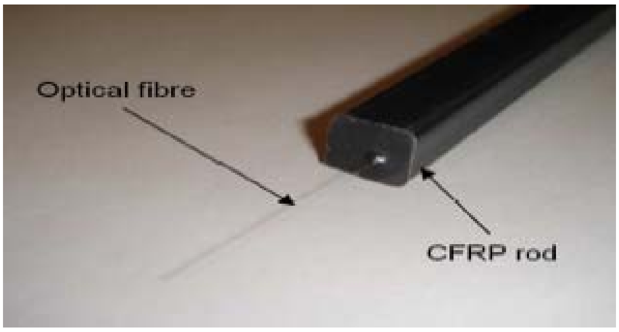

Figure 2: Optical Fibre installed in a CFRP rod

Figure 3 shows the results of tests using specially developed high range indicators containing sol-gel based sensors on the change of pH with accelerated carbonation of a concrete sample using a sepcially developed sol-gel sensor (Sensor A), comparing with the results of laboratory tests requiring sampling and using a conventional glass electrode (Sensor D), over 6 weeks.

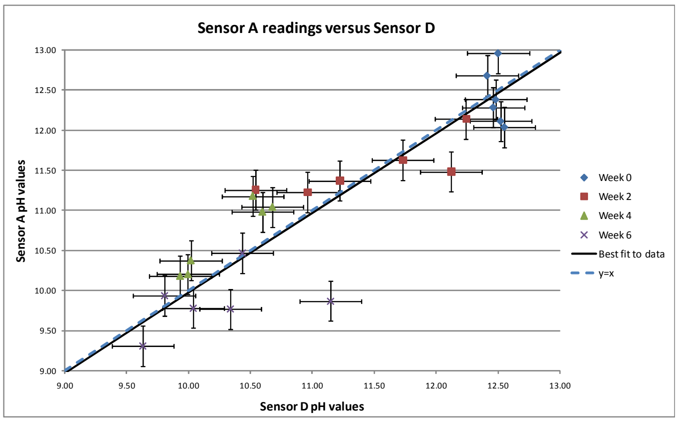

Figure 3: Results on pH monitoring in concrete samples using sol gel based sensor (Sensor A) v results from samples using a glass electrode sensor (Sensor D)

This work is a first step in the measurement ’grand challenge’ of creating a SHM system that is simple and effective for use by civil engineering contractors. The overall aim is better information to predict the likely potential for failure, the need for repair, the efficacy of the repair and thus the likely lifetime of a structure.

References

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