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CONSIDERATION OF THE USE OF OPTICAL SENSORS IN EMERGENCY PREVENTION AND METHODS FOR USE IN WATER

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ABSTRACT

The use of fibre optic sensors is becoming a valuable practice in sensory systems for the health monitoring of structures. The paper presents a few significant case studies in which fibre optic sensors have proven their effectiveness. Implementation of the sensory system as well as data analysis and interpretation are discussed. The definition of the objective of the instrumentation program usually follows the realisation that something about the structure is not known well enough and that measurements of a number of quantities at a certain location would be desirable for the sake of economy or safety. The first step is to reflect on all possible ways the construction might behave and to chose which quantities to measure, where to measure them, and to select adequate instruments to do so. This requires an estimation of the magnitudes of changes in the quantities to be measured, which allows the definition of the range, resolution, accuracy, and sensitivity of the instruments selected to measure them. In much the same way, the temporal behaviour of the observed phenomena might be a criterion for the dynamic requirements for both the instruments and the readout units. As next the instrument positions and the number of instrumented sections have to be determined. After testing, the taking of the readings and their processing and analysis must be carried out in a systematic, organised way [2].

In the last decade, an increasing shift from investments in the construction of new infrastructures to the maintenance and lifetime extension of the existing ones has taken place. For example republic, most of the transportation network, such as highways and railways, is completed and in service. A similar situation is encountered in ports and maritime infrastructure, where most of the facilities have been built

5 to 10 years ago. By the other hand, the establishment of a common economical and political in the territory of the republic larger than ever is pushing the demand for free circulation of people and freights, but the concern for the impact created by the construction of new facilities in delicate natural and architectural environments is also increasing. Therefore, the authorities managing civil infrastructure face the challenge of maintaining the transportation network in a satisfactory state, using a limited budget and with little perturbation to its normal use. This task is far more complex than that of building new structures and requires new management instruments.

Due to the loads, ageing of materials and environmental action, the performance of many in-service structures ha s decayed and the inherent level of safety can be shown inadequate relative to current design standards. Structural health monitoring is certainly one of the most powerful tools for infrastructure management, as witnessed by the recent technical and scientific literature [1]. In what we call the information age, structural health monitoring seems to close the gap between the traditional world of structural engineering and the frenetic one of information technology.

Monitoring includes the observatio n of deformations as well as environmentally induced processes. Climatic variables like temperature, humidity and wind loads shall be considered as well. A central point consists in the observation of the chemical parameters in the form of electrochemical potentials, resistivity, and penetration processes. However, an almost complete instrumentation of all imaginable physical phenomena would exceed the reasonable amount of financial efforts. Additionally, a larger number of collected data might not necessarily improve the quality of the drawn conclusions. Therefore, the identification and observation of the decisive parameters is fundamental for the development and calibration of consistent engineering models describing the deterioration mechanisms threatening ultimate limit state, serviceability, and durability [2].

2.Long-base fibre optic sensors for strain measurements

Recent advances in fibre optic sensing has led several technologies to become an alternative to classical electrical, mecha nical or vibrating wire strain gages [3]. Among them, Bragg grating and Fabry-Perot sensors are available to provide local strain measurements, but SOFO sensors can provide a very accurate and reliable measurement of the relative displacement of any two points chosen in a structure at distances from 20 cm to 30 metres.

The SOFO sensor, originally developed by Inaudi et Al. [4], consists of a pair of single-mode fibres installed in the structure to be monitored. One of the fibres, called measurement fibre, is in mechanical contact with the host structure itself, while the other, the reference fibre, is placed loose in a neighbouring pipe. All deformations of the structure will then result in a change of the length difference between these two fibres.

To make an absolute measurement of this path unbalance, a low-coherence double interferometer in tandem configuration is used. The first interferometer is made of the measurement and reference fibres, while the second is contained in a portable reading unit. This second interferometer can introduce, by means of a scanning mirror, a well-known path unbalance between its two arms. Because of the reduced coherence of the source used (the 1.3 micron radiation of a LED), interference fringes are detectable only when the reading interferometer compensates the length difference between the fibres in the structure.

The precision and stability obtained by this set- up have been quantified to 2 micron and a precision of 0.2%, independently from the sensor length and over more than five years. Even a change in the fibre transmission properties does not affect the precision, since the displacement information is encoded in the coherence of the light and not in its intensity.

3.Distributed strain and temperature fibre optic sensors

Brillouin scattering sensors show an interesting potential for distributed strain and temperature monitoring [5]. Systems able to measure strain or temperature variations of fibers with length up to 50 km with spatial resolution down in the meter range are now demonstrating their potential in the first field trials. Brillouin scattering is the result of the interaction between optical and sound waves in optical fibres. Thermally excited acoustic waves produce a periodic modulation of the refractive index. Acoustic waves can also be generated by injecting in the fibre two counter-propagating light waves.

It consists in generating the two scattering waves from a single laser source using an integrated optics modulator. This arrangement offers the advantage of eliminating the need for two lasers and intrinsically insures that the frequency difference remains stable independently from the laser drift.

4.Monitoring of Massive Concrete Structures

Massive concrete structures present characteristic behavioural parameters very difficult to observe by means of conventional sensors. Moreover, they undergo phenomena that are only detectable by long-term observation.

First of all, local strain fields are not very meaningful in deriving state conditions in massive structures. As a consequence, the use of long-base strain sensors with very high precision and stability over long periods of time is required. Secondly, thermal phenomena may be very important for structural integrity and develop very complex transient fields.

Massive structures are not easily modelled through conventional structural mechanics approaches. Consequently, interpretation of monitoring data seldom takes advantage of known analytical models only, and it shall also be based upon statistical system identification procedures. Two case studies are presented in the following.

5.Distributed temperature monitoring in a dam abutment

As noted, distributed temperature measurements are highly interesting for structural monitoring of large structures. In the presented application, the several construction companies used the DITEST system to monitor the temperature development of the concrete used to build a dam [8]. The Luzzone dam in Switzerland was recently raised by 17 meters to increase the capacity of the reservoir. The raising was realised by successively concreting 3m thick blocks. The tests concentrated on the largest block to be poured, the one resting against the rock foundation on one end of the dam. An armoured telecom cable installed in serpentine during concrete pouring constituted the Brillouin sensor. The temperature measurements started immediately after pouring and extended over 6 months. The measurement system proved reliable even in the demanding environment present at the dam (dust, snow, and temperature excursions). The temperature distributions after 15 and 55 days from concrete pouring are shown in Fig. 1. Comparative measurements obtained locally with conventional thermocouples showed agreement within the error of both systems. This example shows how it is possible to obtain a large number of measurement points with relatively simple sensors. The distributed nature of Brillouin sensing make it particularly adapted to the monitoring of large structures were the use of more conventional sensors would require extensive cabling.

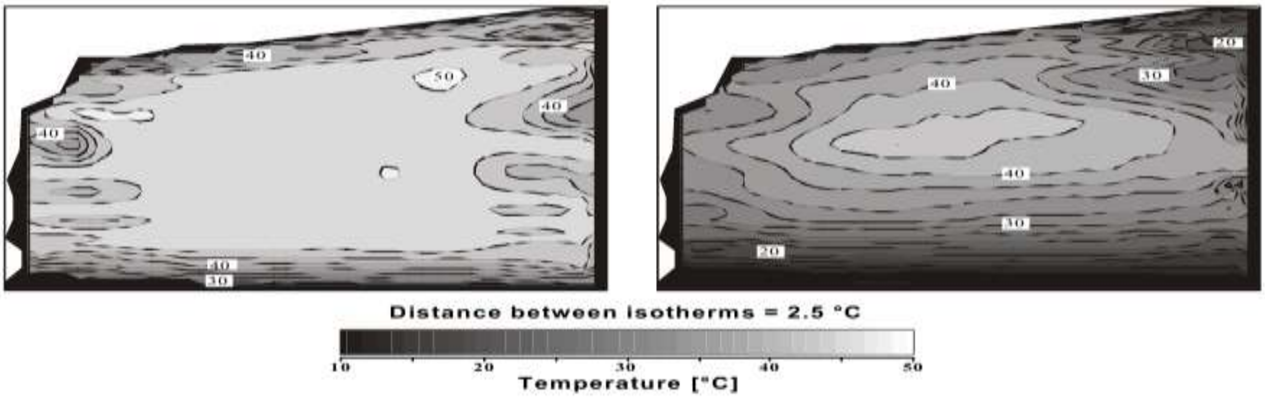

Fig. 1. In the dam temperature distribution measured with the DITEST system 15 and 55 days after concrete pouring.

It is interesting to observe how interpretation of the measurements in terms of the state or condition assessment of the structure is an open problem. Indeed, although temperature fields induced in massive structures by the chemical process taking place in the concrete and by the thermal exchange with the environment is a well-known concern for structural engineers, detailed experimental measurements in real structures were never performed. This example allow to underline that the possibilities offered by new sensing technologies can provide a breakthrough in structural health monitoring.

6.Monitoring of Beam Structures

Long-term monitoring of beam structures is usually conducted to infer information on the damage state suffered by the structure. To this purpose, it is better to reason in terms of the deformed shape (either static or dynamic) under known loads, as damaging may more easily influence the overall geometric conditions than the local state of deformation. The use of SOFO fibre optic sensors, besides providing accuracy and stability over very long periods of time, is also very effective in producing an average deformation measurement over the base length (that eventually will include structural cracks), and in giving rise to analytical processing of the data able to reconstruct the deformed shape of the beam.

A special purpose algo rithm named SPADS [9] is available to process SOFO sensors readings in order to produce the evolution of curvatures with time.

Conclusions. Monitoring of new and existing structures is one of the essential tools for a modern and efficient management of the infrastructure network. Sensors are the first building block in the monitoring chain and are responsible for the accuracy and reliability of the data. In the recent years, fibre optic sensors have moved the first steps in structural monitoring and in particular in civil engineering. Different sensing technologies have emerged and quite a few have evolved into commercial products. The applications of fibre optic sensors shown by the case studies presented in the paper demonstrate that this technology is now sufficiently mature for a routine use, especially in a severe environment, and that it can compete as a peer with conventional instrumentation.

Recent advances in sensing technologies and material/structure damage characterisation combined with current developments in computations and communications have also resulted in significant developments in diagnostic technologies for monitoring the integrity of and for the detection of damages of structures.

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