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Advances in acoustic emission, fiber optic sensing, and global optical methods for civil structures

F. BOURQUIN, J-M. CAUSSIGNAC, S. DELEPINE-LESOILLE, V. LE CAM, F. TAILLADE

Public Works Laboratory (LCPC), 58 bld Lefèbvre, 75015 Paris, France

Abstract

Enabling technologies for structural health monitoring such as acoustic emission sensors, fibre optical sensors and shearography have been developed at, or transferred to, the Public Works Laboratory. This paper reviews a few technical aspects and field implementations.

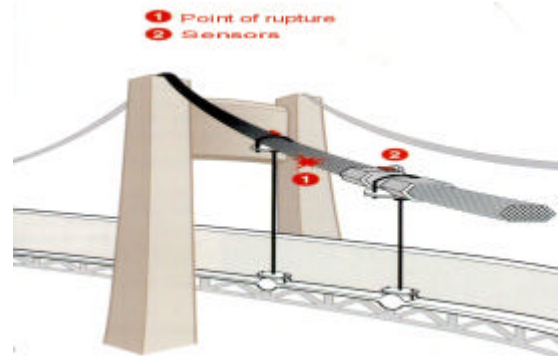
Introduction

Permanently installed acoustic emission sensors are currently operated on bridges in service. They will be replaced with intelligent wireless sensors relying on a standard communication protocol. Moreover, several physical principles such as birefringence or light attenuation due to curvatures underly the conditioning of fibre optical sensors (FOS) in view of weigh in motion (WIM) or bridge bearing monitoring. Finally, shearography emerges as a global optical method for crack detection at the surface of concrete structures.

Research

1) Acoustic emission

Cable health determines the serviceability and the safety of cable-stayed and suspended bridges. Health diagnostics thus plays a crucial role in the maintenance and impacts on the global cost of the bridge management. Acoustic emission emerged as a favorite avenue towards mechanical health monitoring of individual cables, which are often bundles of multilayer single strand cables. When a wire breaks, its two ends re-anchor close to the crack location, and give rise to an acoustic wave in two opposite directions. The point of rupture is located by means of three sensors.



Several bridges, such as Tancarville or Iseron bridge are equipped with this system.



Tancarville Bridge



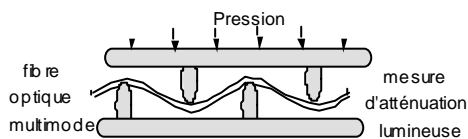
Iseron Bridge

In view of flexibility, cost efficiency and increased reliability, intelligent **wireless sensors** have been designed. Each sensor is provided with a signal processing capability. The wireless capability is based on a smart sensor network architecture using the wireless TCP/IP protocol, originally dedicated to office applications, and therefore widely widespread. Supervisor and each sensor have an Internet Protocol address and a logical core. The supervisor consists in a "wireless Access point" connected to a PC. A user-friendly interface is provided. Each sensor includes two fully independent modules : A wireless Ubicom IP2022 module containing the TCP/IP stack for communication tasks only, and a Digital Signal Processing (ADSP-2991) unit that

receives and processes signals from cables. The independence of the communication module from the DSP makes the system completely versatile and able to host heterogeneous sensors such as strain gauges, accelerometers, or pressure cells at no extra charge. Since accurate time is of paramount importance to locate cracks in cables, a cheap synchronization strategy based on a periodic broadcast of an absolute time throughout the network is proposed. The method works whenever the distance between the supervisor and the wireless sensors is not greater than about 1km, which is suitable to large bridges.

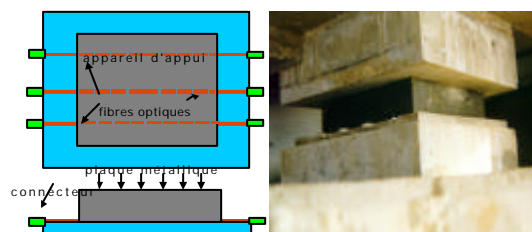
2)Fiber optical sensors (FOS) for civil engineering structures

Several types of measurements can be carried out by means of an optical fibre [1][2][3]. External loads or strains in the surrounding material impact on the wave propagation through the guide. Conditioning aims at making the optical fibre sensitive to a given load or strain.

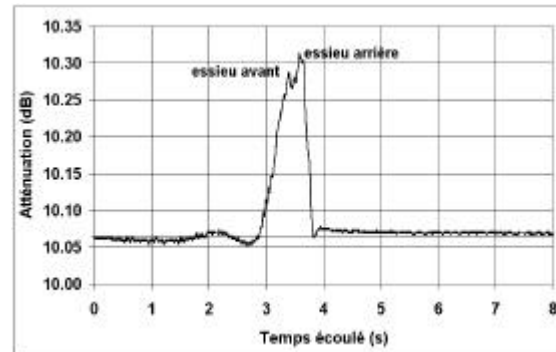


Structure peigne

Microbending conditioning consists in laying out the fibre between two shifted combs of a half period, whose step corresponds roughly to the space period of the propagation modes, about 1.3mm for standard multimode fibres. Any pressure applied to such a system results in microbending [4] in the vicinity of the contact points modifies the attenuation of the light in the guide. A bridge bearing has

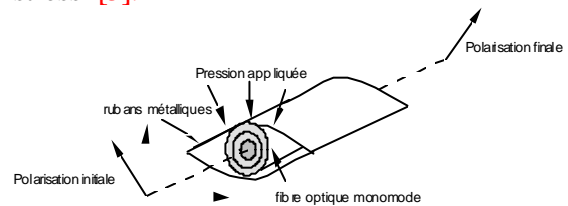


been equipped with three such optical fibres after a laboratory calibration. The sensors yield the actual load of the bridge deck, the dynamic overload due to a heavy truck, or a decrease of prestressing.



Light attenuation of the middle FOS in the bearing, when a truck crosses the bridge at 30km/h

Polarization conditioning primarily applies to single-mode fibres. One principle consists in inserting the fibre between two ribbons crimped on the edges, in order to make the guide sensitive to a single axial stress [5].



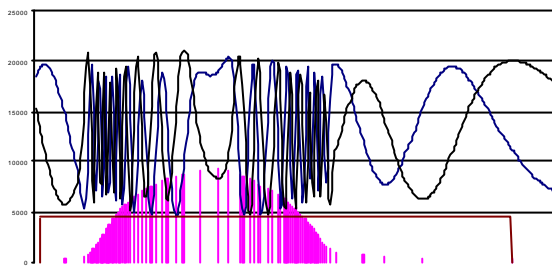
Principle of Polarization conditioning

The applied pressure induces a birefringence in the fibre and hence modifies the polarization of an initially polarized light wave. Measurement is therefore based on the comparison between input and output polarization directions. The light intensity exhibits polarimetric fringes due to multiple phase rotations. The load applied to the sensor results from counting the fringes. Weigh-in-motion based on this principle was put to work on an experimental site.



sensor installation on NR 10 (France)

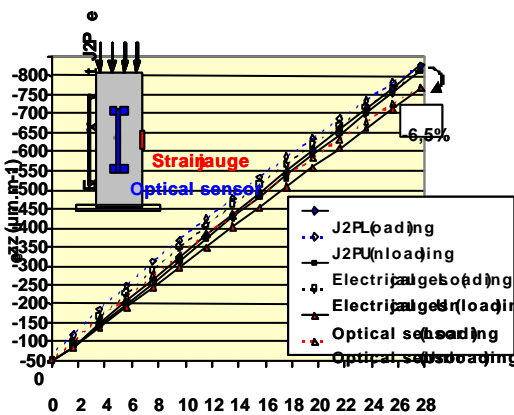
The slanted configuration of the sensors yields the weight of each wheel of an axle separately, and thus the total load. Vehicle speed is also determined that way.



vehicle signature with profile reconstruction of load versus time

Inclusion effect on the behavior of fiber optical sensors embedded into concrete.

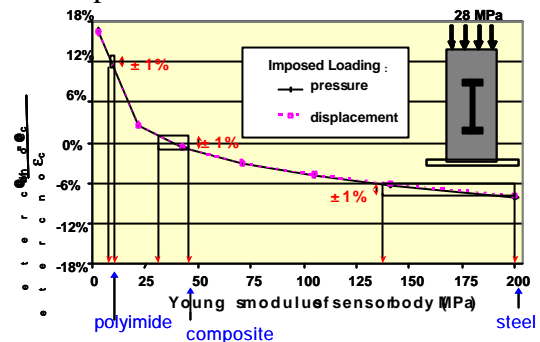
Commercially available optical fiber sensors, once embedded into cylindrical concrete structures (16cm diameter 32cm height) instrumented with conventional sensors and tested under press, underestimate the axial strain by more than 6%.



Measured strain versus imposed pressure for strain gauges and optical sensors

Finite element analysis with CESAR-LCPC predicts a -7.5% error, quite close to the measured (-6%), assuming linearized elasticity, perfect bonding between materials and taking into account friction of the loading plates.

This error is due to the shape and materials of the sensor body. Indeed, Young's modulus of the sensor body strongly influences the difference between the strains in the optical fiber and in the concrete.



Computed measurement error vs Young's modulus of sensor body

A theoretical calibration factor has to be taken into account because effect of inclusion can strongly affect the response of embedded sensors.

A french partnership with Fogale Nanotech and IDILE investigates the opportunity of using composites instead of steel for embedding optical fibers into concrete.

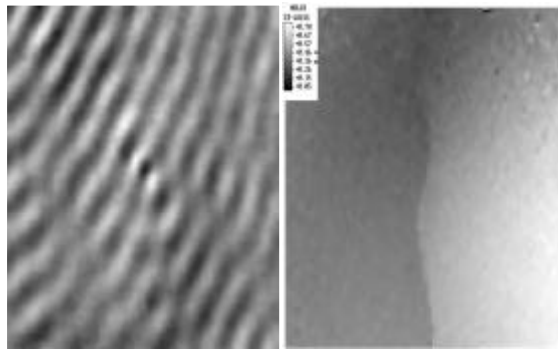
3) Shearography, a global optical method for NDE

Shearography is a recent common-path speckle interferometry method that outperforms holography in several respects. As a matter of fact, the evaluated structure may experience slow rigid-body motions, which is not really the case for holography. Moreover, shearography imposes less stringent conditions regarding LASER coherence length. It leads to compact instrumentations of tunable sensitivity. This contact free global method enables one to measure in quasireal-time displacements of

the order of a few nanometers between two successive positions of a body.

When combined with a mean of excitation such as actuation, ambient vibrations, or flash heating, shearography reveals damages inside the body of material, and assess its mechanical properties. Note that external excitation can be static, harmonic or even impulsive.

Various NDE applications can take advantage of this technique. To quote a few, shearography can increase the basic knowledge of wave propagation and interaction with potential damages inside a complex structure. It can also be used to detect cracks in a concrete wall, or to assess the quality of the glue between concrete and composite materials like FRP.



Lamb wave interacting with a multi-delamination in a quasi isotropic carbon-epoxy plate

Deformation of the surface around a crack in a concrete wall after a shock with a hammer

Conclusions

Acoustic emission wireless intelligent sensors, fiber optical sensors and shearography emerge as mature or promising enabling technologies for the health monitoring of civil structures. The relevance of several principles is substantiated by field or laboratory experiments. Current research directions include sensor lay-out optimization for embedded applications, band-limited sensors and sensor placement.

Acknowledgments

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The work on shearography combined with Lamb waves for delamination assessment was completed at ONERA.

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