SMART STRUCTURES. OPTICAL FIBER INSTRUMENTATION

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RESUMEN

Las estructuras presumen de su belleza a través del diseño y se quejan de sus problemas mediante sus daños. Cuando nos enfrentamos a una estructura "dolida" por algún daño concreto o "resentida" por las muchas actuaciones sobre ella, con distintos resultados, es importante hacer una buena diagnosis para luego acertar con la "medicina". La tecnología de "diagnosis médica" sobre las estructuras avanza a pasos agigantados, y una de las últimas herramientas con garantías para conocer el estado nervioso del "paciente" es la fibra óptica, que complementada con el control de otras variables, permite crear modelos estadísticos de comportamiento que nos acercan al conocimiento de su salud estructural.

Se presentan ejemplos de aplicación en estructuras singulares, que han servido para actuar sobre la misma cuando de acuerdo con un plan de contingencias y un seguimiento de la temperatura y las microdeformaciones con fibra óptica, se ha sobrepasado el umbral de daño.

ABSTRACT

Structures boast their beauty through their design and also they complain of their troubles through their damage. When we have a "painful" structure due to some specific damage, or it is "resentful" by a lots of actuations with many different results, it is important to do a good diagnosis in order to obtain a successful "medicine". The SHM "Structural Health Monitoring" technology on structures is continually in advance, and one of the last technique about the knowledge "patient" is the optical fiber sensor technology. It is complimented with control of others variables in order to know completely the structural health.

This research presents some examples in singular structures, where we are using this technique in cases in which, according to a specific contingencies plan, the threshold damage has been exceeded.

PALABRAS CLAVE: Fibra óptica, monitorización, salud estructural

1. STRUCTURAL HEALTH OF BUILDINGS

In order to manage the structural health of infrastructures and buildings, meanwhile the structure “is alive” or when by age has “some problems” and it needs a refurbishment, the pathologist has to know how to diagnose the cause of damage to act accordingly and cure, if necessary, the patient.

In construction there are a lot of devices for damage’s diagnose (potencimetric displacement transducers, laser, scanner, a lot of NDT, GPR…) to get the structure’s nervous system be able to transmit data about its health. In that line, a tool in relatively recent development is optical fiber, which begins to have direct applications for the quality and quantity of useful information on deformation and temperature.

The optical fiber OBR (Optical Backscatter Reflectometer) is a measurement sensor’s technology promising for monitoring structures, either on time (load testing, unload, change in uses…) or continuously over time to study the response of the structure and its deformation and temperature variations, managing according to the results this constructive element. You can also check the structure periodically when incorporates optical fiber.

Optical fiber instrumentation needs a structure’s previous knowledge, to put the “nervous system” in the right position in such a way that is possible to identify where are the new cracks, or deformations or temperature’s changes. Thus we control where there may be breakage without notice or thermal influence, which would be subject to a contingency plan to limit the maximum values that detects the optical fiber, acting accordingly.

In aeronautic industry (metal elements) we have experience of feasibility, but in a stony element (concrete, ceramic…) there are difficulties for their surfaces roughness and heterogeneity due to components of different morphology or size. Discontinuities created by the cracking of concrete, in reduced load levels, can cause breakage if no action is taken.

The Company has used this tool pioneer in stony elements and in combination with other devices, because it enhances the understanding of the structure, making it more communicative, expressing where may have problems and allowing validate their behavior over time, that is its health.

Now see various examples of “medical treatment” prompted by the optical fiber and based thereon.

2. MEDICAL TREATMENTS. OPTICAL FIBER

2.1 When the structure needs specific treatment

In these cases optical fiber can follow the evolution of strengthening during operation and impact on the rest of the structure. An example is the case of the substitution of columns in a modernist building, where columns support four vaults between ribbed arches. The masonry columns have vertical cracks in evolution after 100 years of service live, for what was recommended replacing them. The process of replacing this column is proposed by a metal one, that will then return to reposition the masonry this time without charge arises. Since the structure for the "replacement operation" will remain in use, the vault's structure is instrumented with optical fiber to verify that the tensions that occur before, during and after "surgery" are normal, although the patient available "anesthetized" (without column) nothing happens to the other important parts of the structure that have certain level of damage (see figure 1).
Optical fiber instrumentation enables the entire process, and if it's necessary to establish a contingency plan in case any fault occurs.

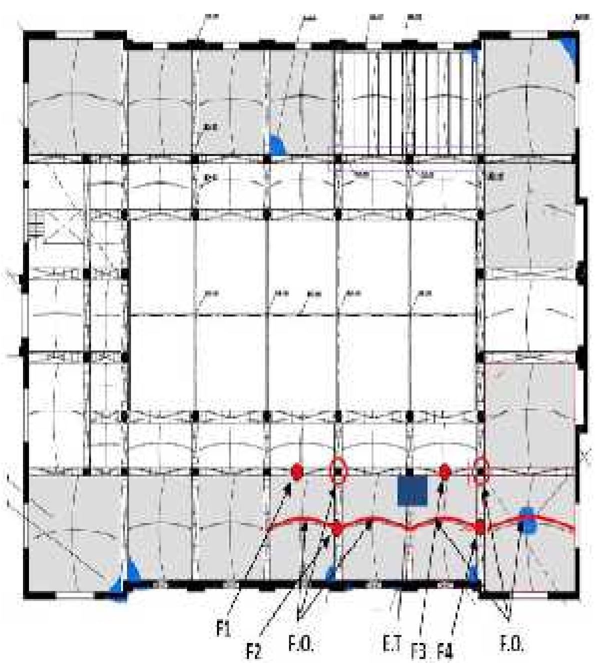


Figure 1. Scheme with the monitoring plan with optical fiber.
F.O. Optical Fiber
F_n. Potentiometric displacement transducers

Photo 1. Optical fiber in vault.

Photo 3. Column eliminated. Optical fiber in vault.

Photo 2. Instrumented vault.

In this particular case, the variations of arch movements before the substitution with the live loads were up to 0,4 mm. When cutting the column, the prestressed structure which support the vaults, reised the arch 0,3 mm and it produce little entity compression stresses improving performance of the structure in the section in which acted, and while maintaining the tension acting on the rest.

Completed the process, it has been able to corroborate that the vaults haven't suffered any affectation, it means they are in good health after the "operation".

2.2 When the structure is in ICU

To learn about the behavior of optical fiber and its answer in extreme cases, it has been done a load test to fatigue failure of a reinforced concrete slab in laboratory (ICU).
The fiber was located in the upper and lower part of the slab as indicated in Figure 2 and Photo 4, and it was recording the microdeformations with different loading processes to bread. Optical Fiber was able to accompany the patient to death following $2x10^6$ cycles of fatigue loading.

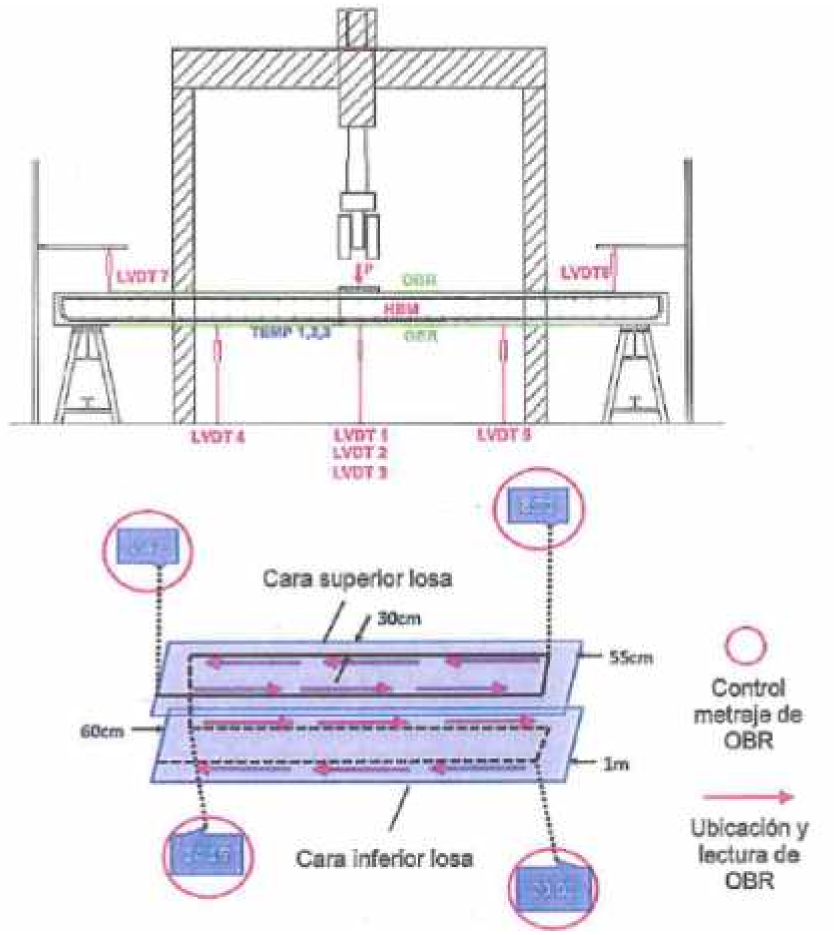


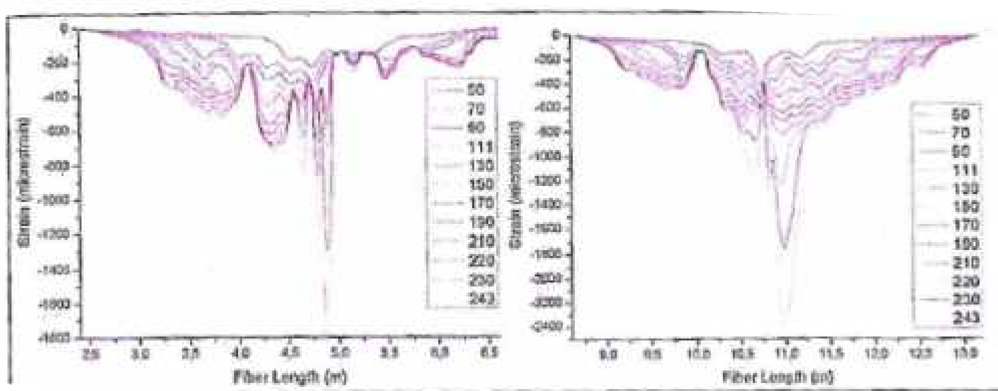
Figure 2. OBR position of the sensors and other instrumentation.

Photo 4. Pre-broken slab state.

Implement with the optical fiber to break allowed contrast and validate the results of monitoring for both the detection of premature appearance of cracks and to analyze the evolution at break.

Photo 5. OBR Sensor (upper face – First part)

Results (Graphics 1) show haw the OBR sensor is not only able to detect microcracks, but also to correctly measure the load levels that cause cracks in excess of 1 mm openings (up to 60% of the breaking load) acquiring frequency original signal properly and provide correct values deformation without fiber breaking occur.



Graphics 1. Lengths of fiber deformation (first and second part)

2.3 When the service live of the structure concerned

This is the case of this cooling tower, which is a 120 m high reinforced concrete shell, 14 cm thickness and 24.000 m^2 inner surface. There was a long crack for several concomitant causes (wind, durability, execution with incorrect geometry and with no proper disposal of reinforced…) has been implemented to check its behavior in time, before repairing the crack and once repaired. Monitoring before being repaired can calibrate the movement of the main crack and the appearance of microcracks in the shell in its behavior such as going to work with the damage area when it asked him.

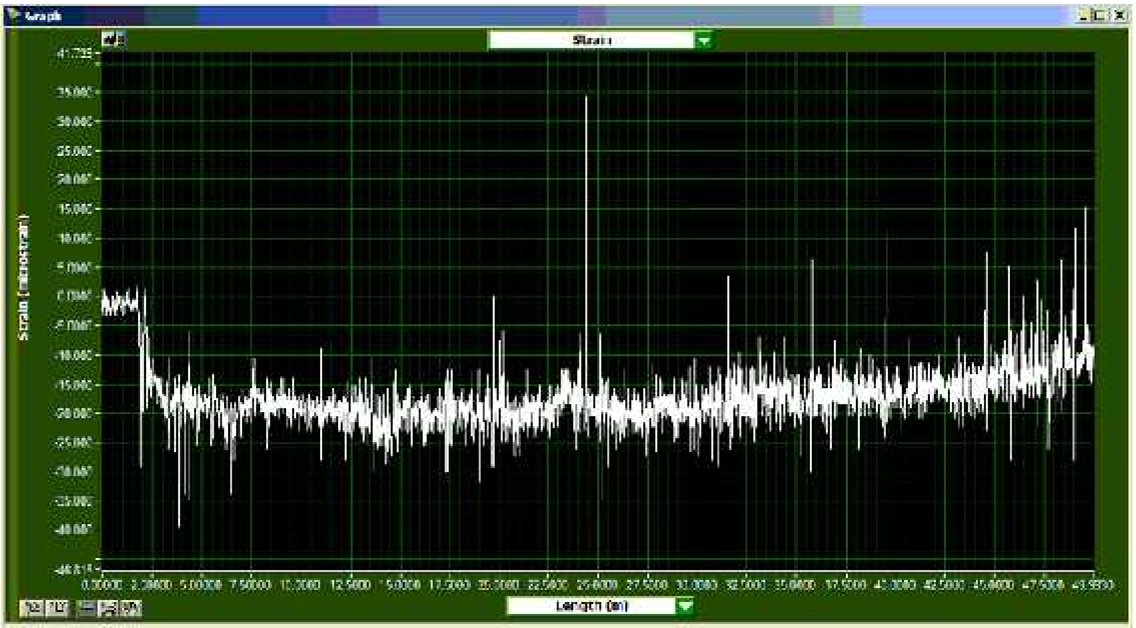


Figure 4. Optical fiber calibration.

Monitoring during the repair operation with optical fiber in other sensitive areas away from the main one reveals that no anomalies occur in the most sensitive areas of the tower.
La instrumentación durante la operación de reparación con la fibra óptica en otra zona sensible apartada de la grieta principal permitió constatar que no se producen anomalías en las zonas más sensibles de la torre (ver figuras 5 y 6).

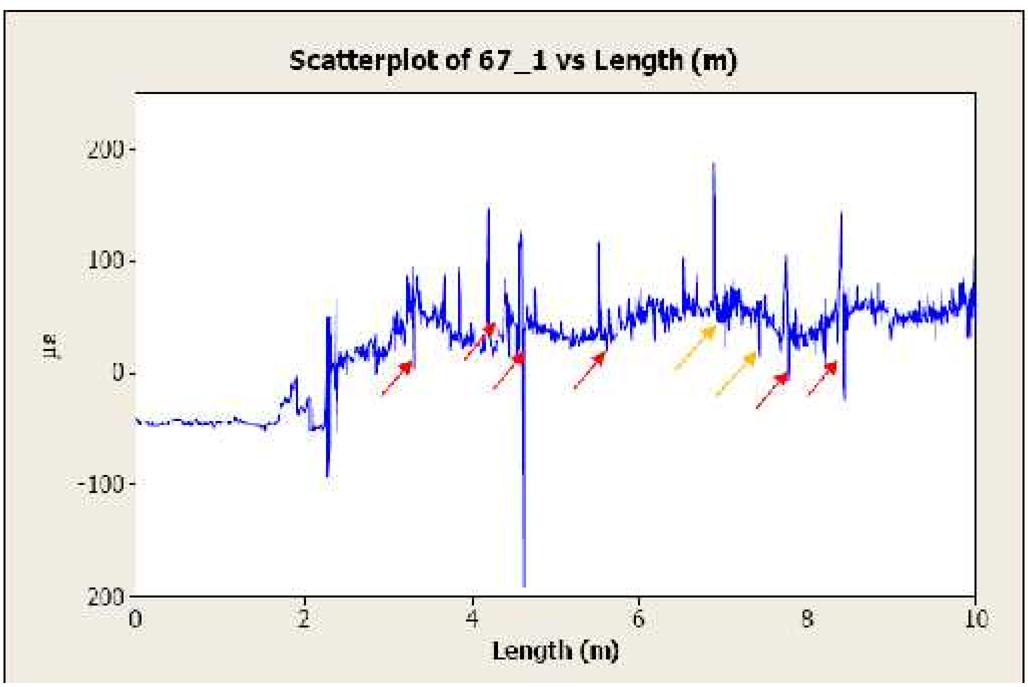


Figure 5. Optical fiber calibrations.

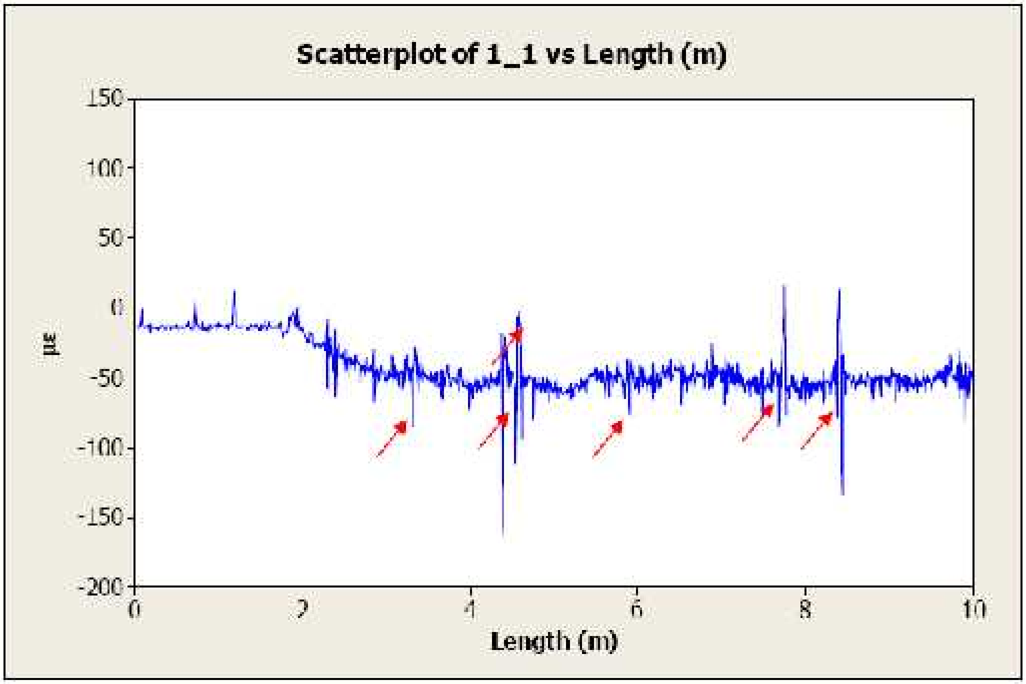


Figure 6. Optical fiber calibrations.

Monitoring after reparation allows watching the adquired load of the reinforcing elements.
In this case, the used fiber was an OSIDI-A50. The fiber is based on scanning of the wavelength of the interferometry, so that hundred of locations interrogates a single optical fiber simultaneously. It thus has a data adquisition continuously along de fiber. With 50 meters maximum length detection and submillimeter spatial resolution, constituting an essential tool for obtaining values of strain and temperature of the structure.

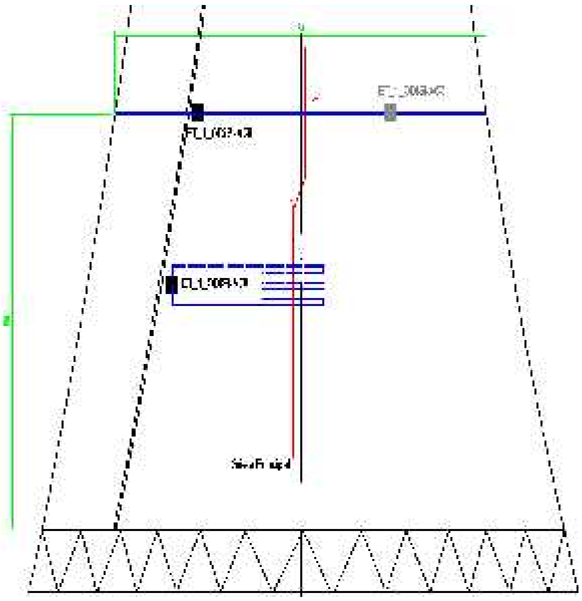


Figure 7. Optical fiber arrangement in cooling tower.

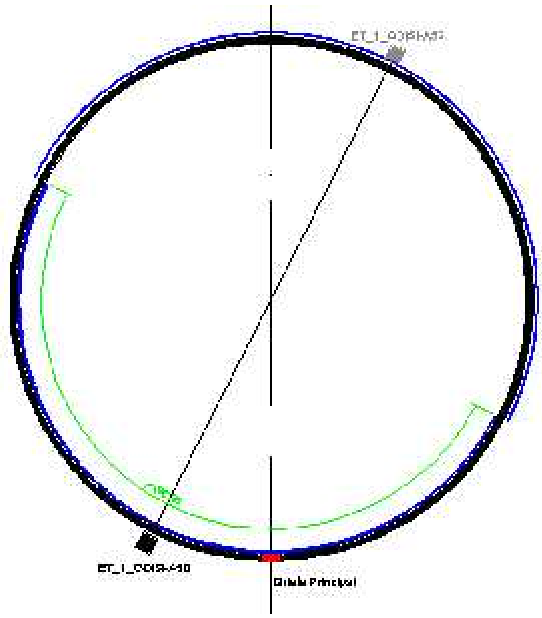


Figure 8. Position scheme shell and crack.

Correlating, in the future, the placement of the fiber with the modeling of the causes of the most significant damage, it may approximate a diagnosis of the weight of each of the causes which damage the structure, ie that part of the fault has wind, the geometry, the durability, etc.

The correct diagnosis allows proper maintenance plan and extend its service life.

3. CONCLUSION

Generally been treated with different cases demonstrate that the optical fiber is an excellent monitoring system for the knowledge and/or monitoring the health of a structure. It's to incorporate a nervous system to those elements that require it, and talk through the fiber about damages related with deformations, temperature, vibrations.

As a system of continuous monitorization is water and corrosion resistant, and ignore problems of electromagnetic interference and stray current caused to other equipment.

To control the patient when performing repair or replacement are made, or to control variables of elements in the ICU is also a suitable tool in combination with others that are needed to control other variables (hygrometer, thermography, geo-radar, endoscopy, scanners…) of the structure.

To diagnose structural diseases, giving weight to each of the causes that can cause damage, optical fiber conveniently located to capture the various actions in their more sensitive spots and a tool for validating statistical models based on knowledge from the previous response of the main variables that define the behavior of the structure, or infrastructure.

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