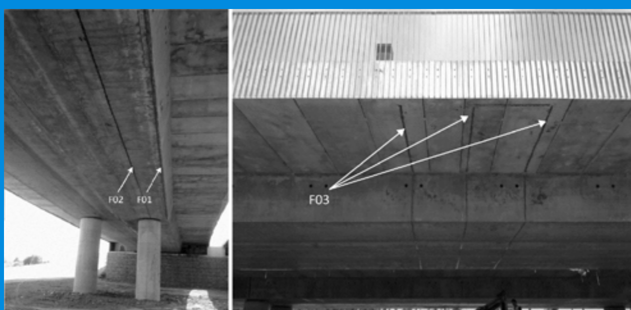
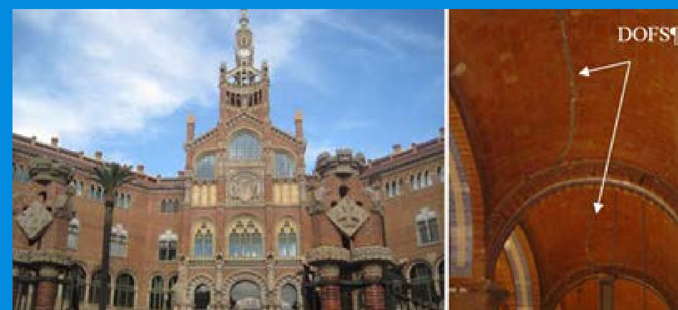
COST TU1402: Quantifying the Value of Structural Health Monitoring

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

CONCRETE STRUCTURES MONITORING WITH OBR BASED DISTRIBUTED OPTICAL FIBER SENSORS (DOFS)

WG 2-2





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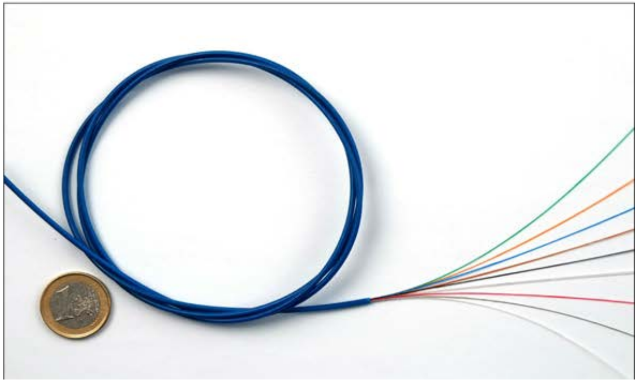
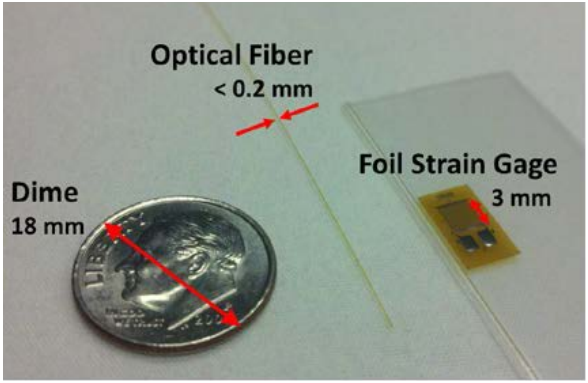
Copenhagen, 24th August 2016

Overview

- Introduction
- Distributed Optical Fiber Sensors (DOFS)
- Optical Backscatter Reflectometer Based Sensors Applications
- Conclusions

Fiber Optic Sensors

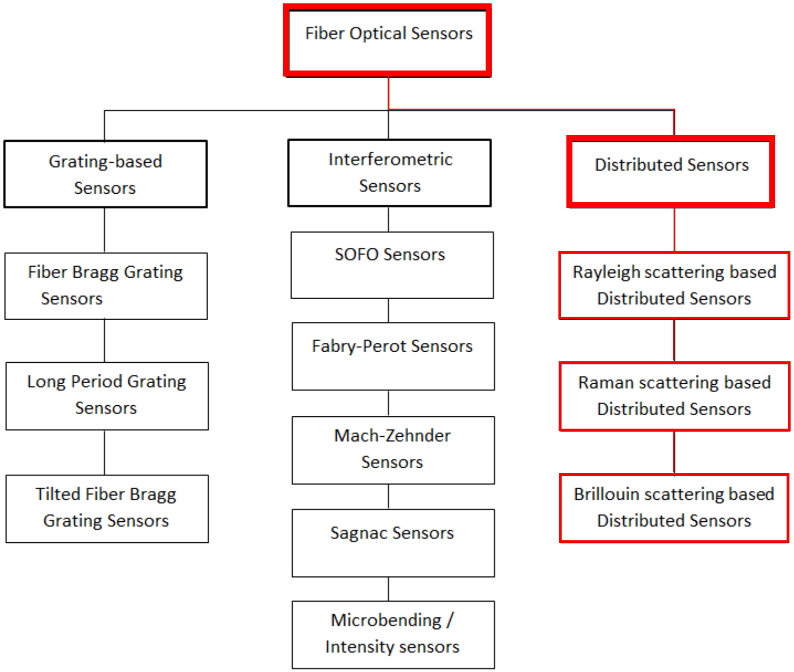


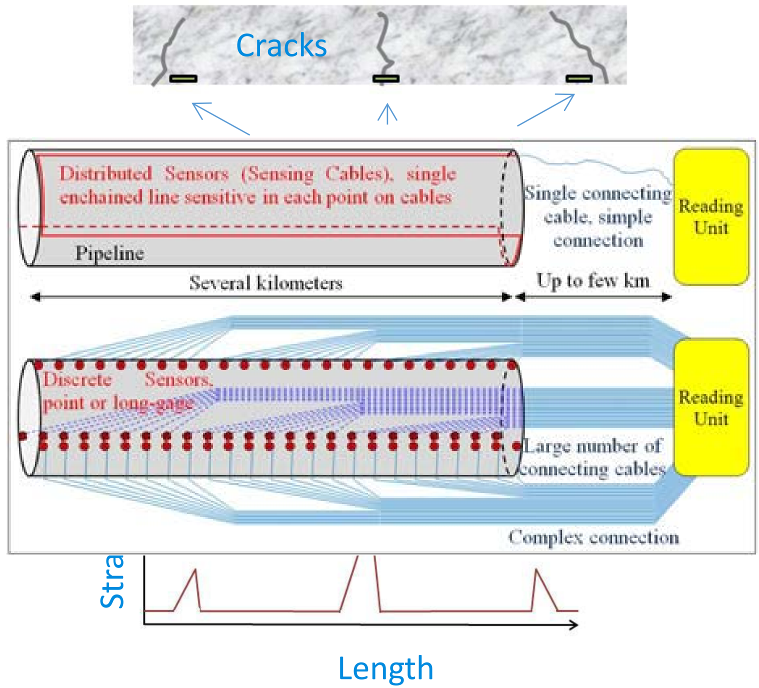


Advantages:

- Immunity from electromagnetic interferences
- Chemically inert – free from corrosion
- Withstand high temperatures
- Small and lightweight

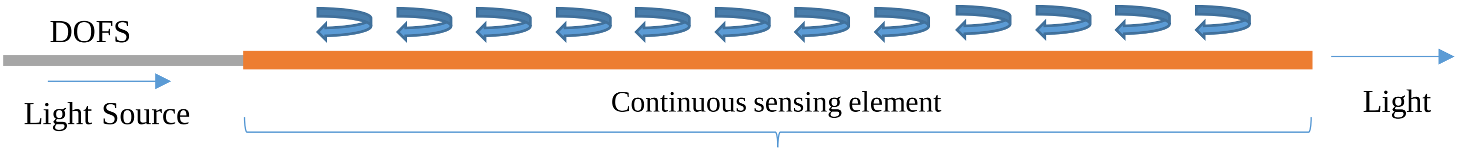
Fiber Optic Sensors



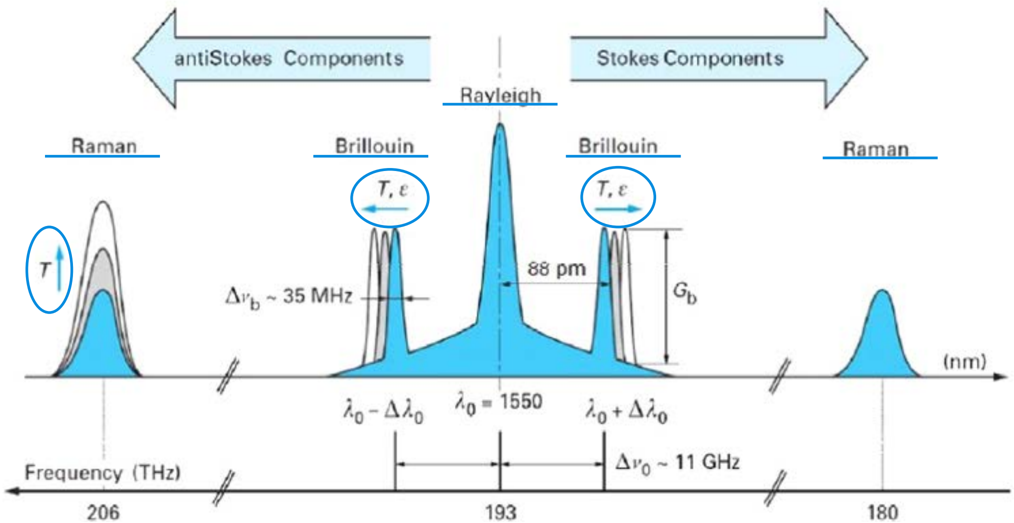


All possible crack openings are covered by the extension of the sensor

Scattering in Optical Fibers



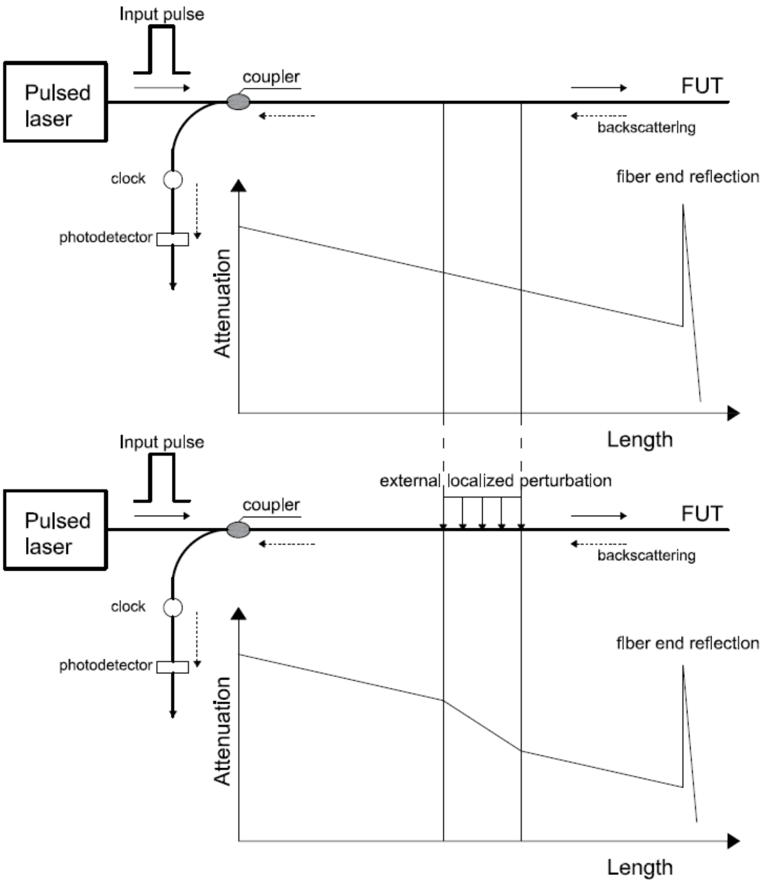
Light backscatter provides three different components



Time Domain Reflectometry - OTDR

Most used/successful:

- Brillouin Optical Time Domain Reflectometer (BOTDR)
- Brillouin Optical Time Domain Analysis (BOTDA)



- Long range (≈ km’s)
- Small spatial resolution (1 m) (insufficient for crack detection)

Frequency Domain Reflectometry - OBR

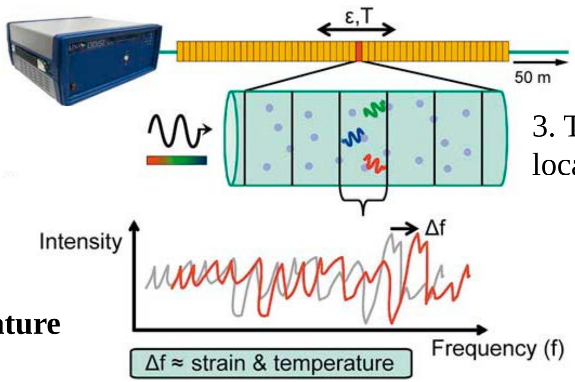
Most used/successful:

- Rayleigh based OFDR, also know as **Optical Backscatter Reflectometer (OBR)**

1. OBR system measures the **Rayleigh backscatter** as a function of length in an optical fiber with high spatial resolution **(1mm)**

Swept wavelength interferometry (fiber is divided in small windows)

2. External stimulus

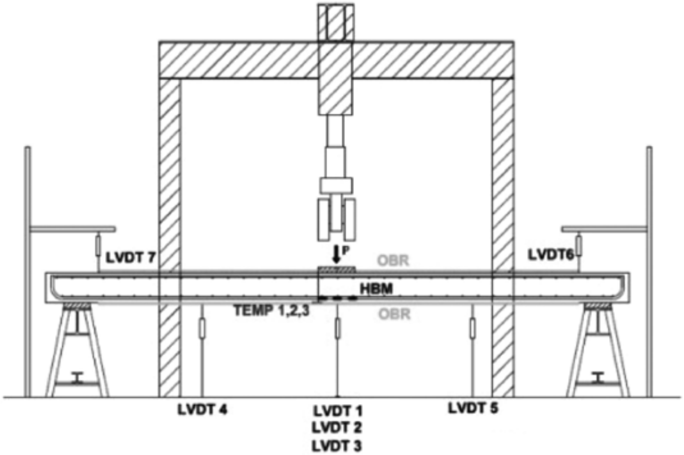


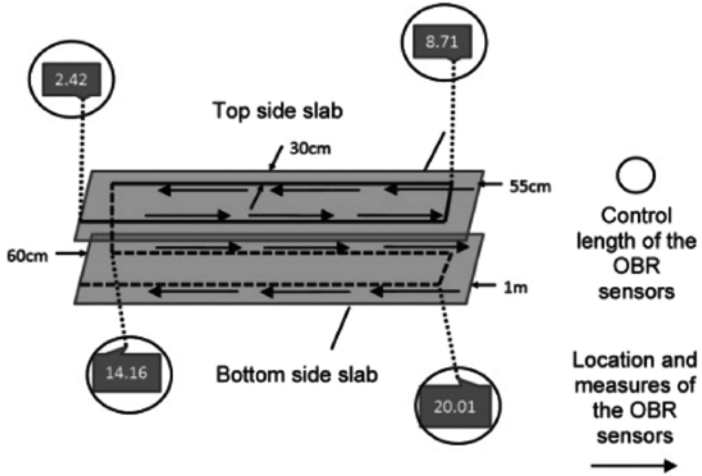
3. Temporal and spectral shifts in the local backscattered pattern

4. Shifts can be measured and scaled to give distributed **strain** or **temperature** measurements

- Short range (50-70 m)
- High spatial resolution (1 mm)

Laboratory test in a reinforced concrete slab

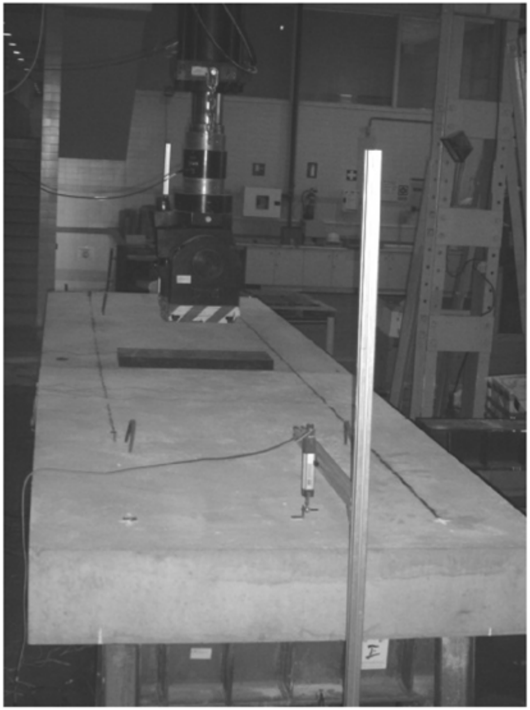




Main objective:

Assess the performance of the fiber when attached to a concrete surface and the **accuracy in detection and localization of cracks.**

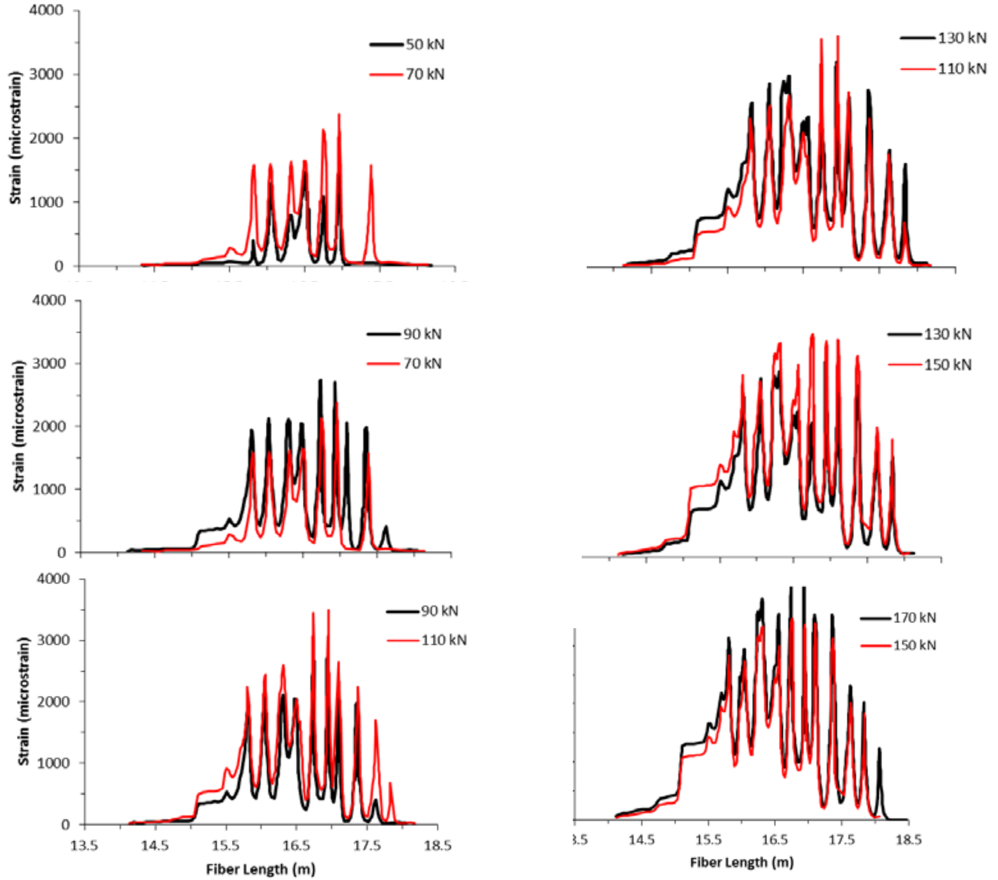
Laboratory test in a reinforced concrete slab



Dimensions: 5.60x1.60x0.285 [m]

OBR based sensors applications

Laboratory test in a reinforced concrete slab



Ultimate load of the slab was **255.15 kN**

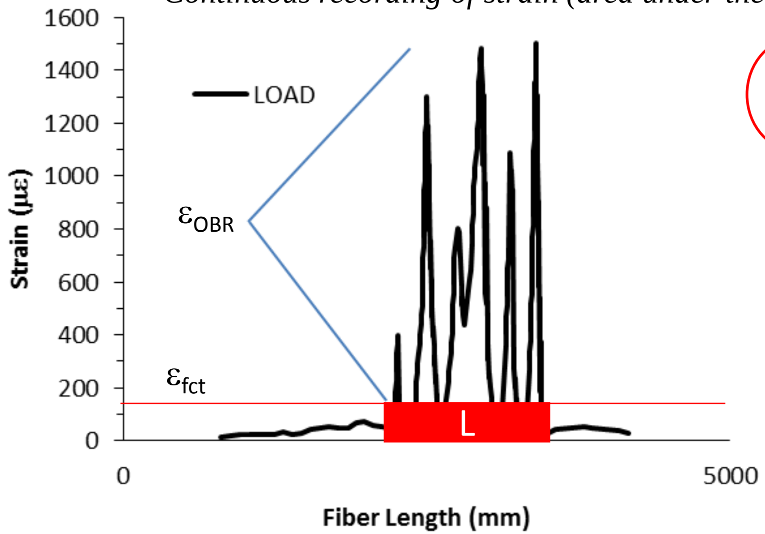
Continuous records at different loads levels.

It is possible to identify very clearly the location of the cracks (**Identification and Localization**)

Laboratory test in a reinforced concrete slab

Calculation of crack width at mid-span

Continuous recording of strain (area under the curve)



$$\varepsilon c = \varepsilon mean = \int_0^L \frac{\varepsilon OBR}{L} dL \quad (1)$$

$$\varepsilon mean = \varepsilon fct + \frac{\sum w}{L} \quad (2)$$

$$Wmean = \frac{\sum w}{N}$$

N = number of cracks

$Wmean$ = average crack width

ε_{fct} = *Tensile strain of the concrete*

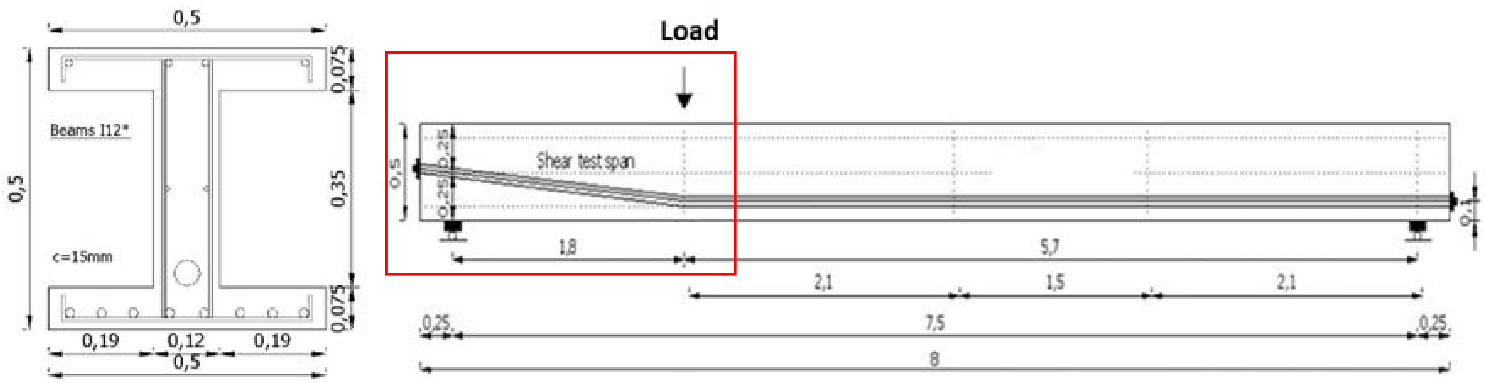
L = *Cracking length*

(Quantification)

Laboratory test in a reinforced concrete slab

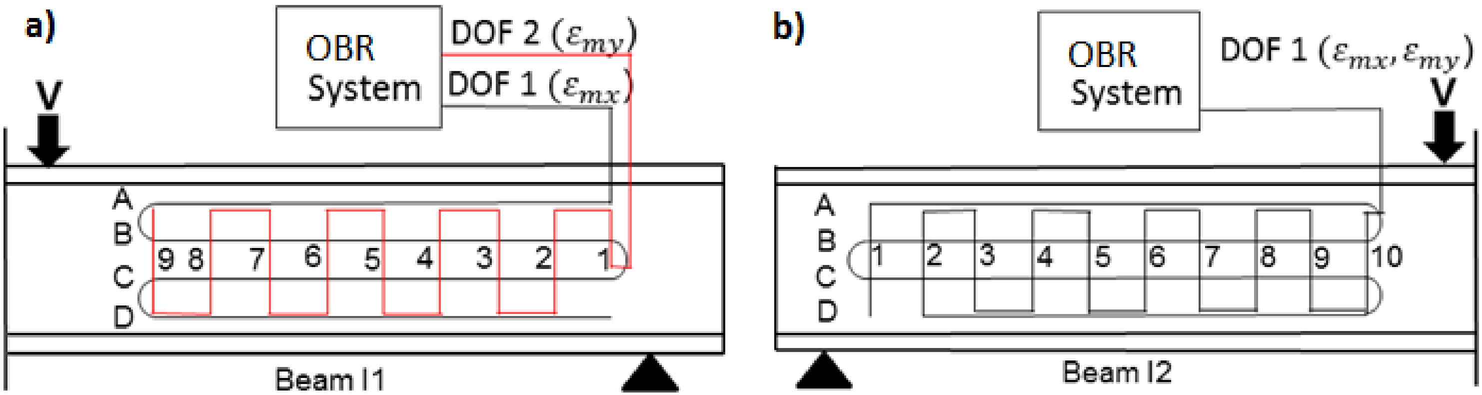
Load	*magnetictrans1crack*	*magnetictrans2crack*	*ARITHMETIC MEAN*	*OBRstretch 3*	*OBRstretch 4*
kN	*mm*	*mm*	*mm*	*mm*	*mm*
50	0.058	0.099	**0.079**	**0.062**	**0.065**
70	0.077	0.154	**0.116**	**0.112**	**0.101**
90	0.105	0.125	**0.115**	**0.149**	**0.127**
111	0.166	0.147	**0.157**	**0.190**	**0.163**
130	0.296	0.200	**0.248**	**0.237**	**0.209**
150	0.370	0.267	**0.319**	**0.298**	**0.246**
170	0.439	0.337	**0.388**	**0.354**	**0.213**

Laboratory test in a Partially Prestressed Concrete (PPC) Beam



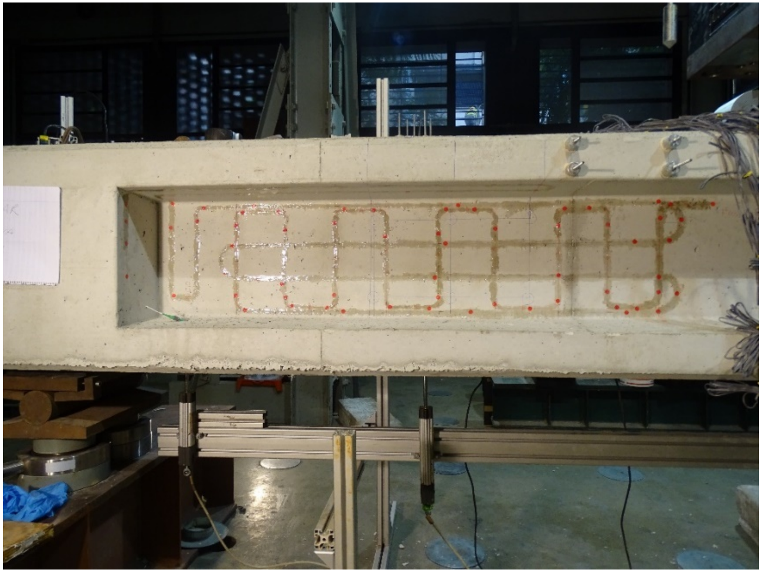
- Study the feasibility of the use of these sensors in **shear crack pattern detection**
- In this experiment, the beam was divided into shear and bending test span, but here only the shear span was instrumented and tested.

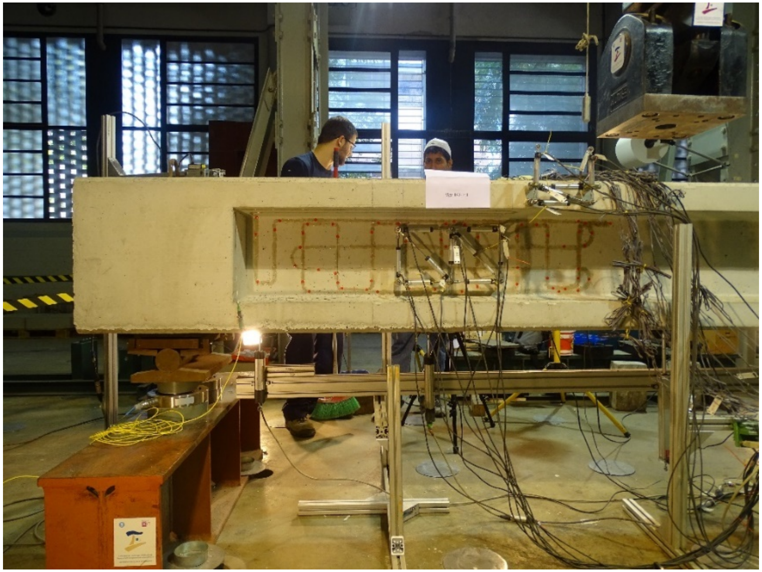
Laboratory test in a Partially Prestressed Concrete (PPC) Beam



Two dimensional DOFS grid is proposed in order to detect shear induced crack openings

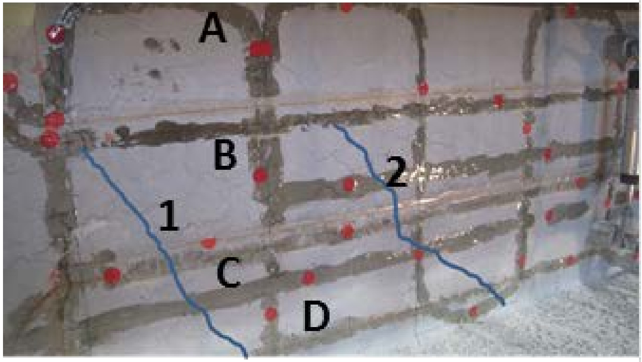
Laboratory test in a Partially Prestressed Concrete (PPC) Beam

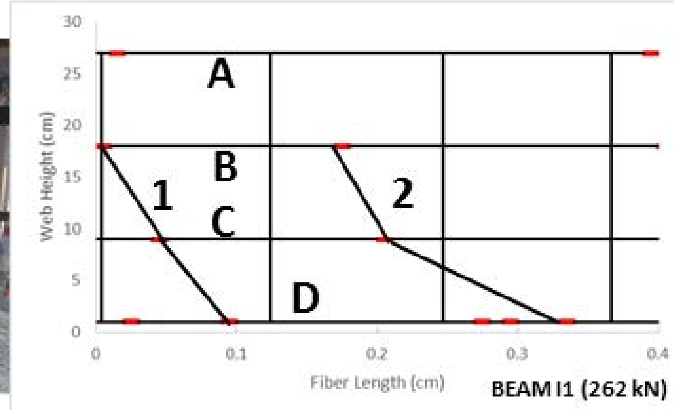


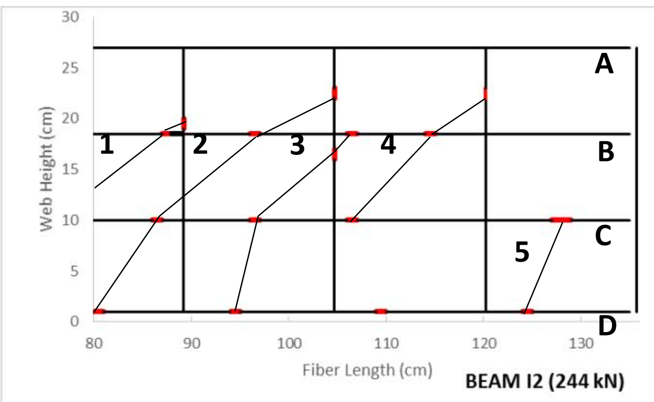


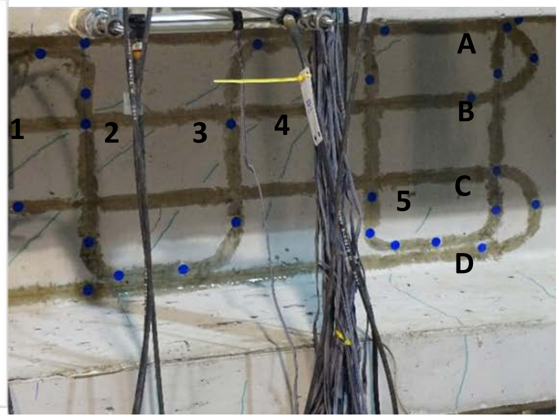
Use of conventional electrical sensors for comparison (potentiometers to conform a strain rosette)

Laboratory test in a Partially Prestressed Concrete (PPC) Beam

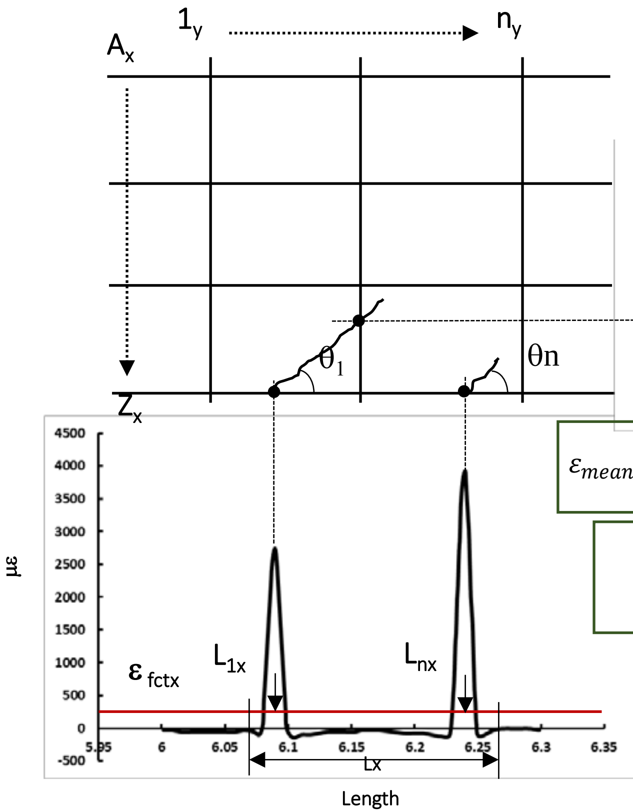




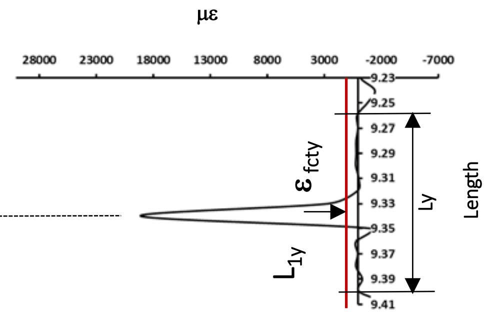




Laboratory test in a Partially Prestressed Concrete (PPC) Beam



Calculation of Shear Crack Width



Where N is the total number of cracks

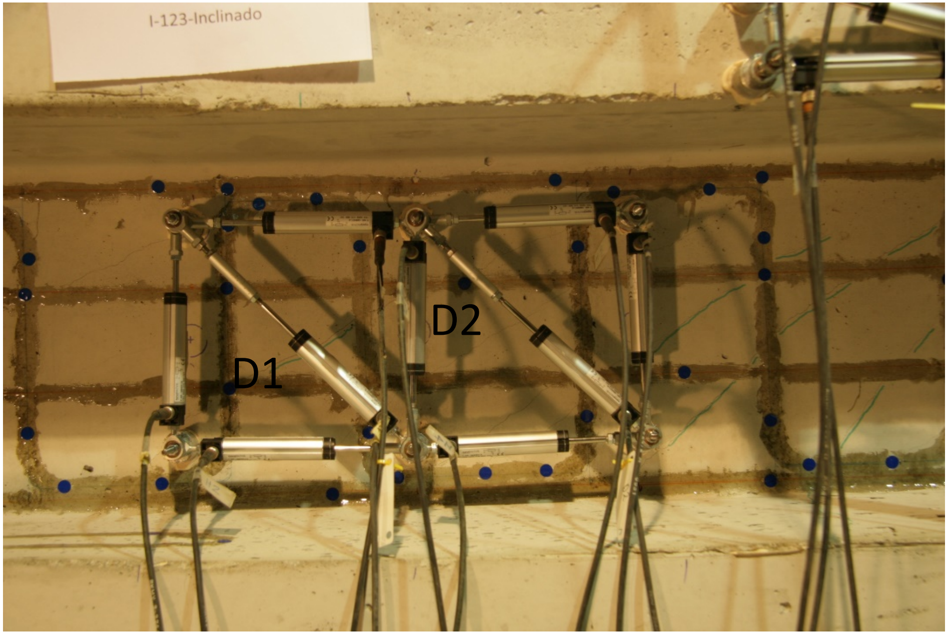
$$\varepsilon_{mean\ x,y} = \frac{1}{Leffective\ x,y}\int_0^{Leffective\ x,y} \varepsilon_{OBR}\ dLeffective\ x,y$$

$$Leffective\ x,y = \sum_{i=1}^{n} L_{n\ x},y$$

$$\varepsilon_{mean\ x,y} = \varepsilon_{fctx,y} + \frac{\Sigma wx,y}{Leffective\ x,y}$$

$$w_{meanx\ ,y} = \frac{\sum wx,y}{N}$$

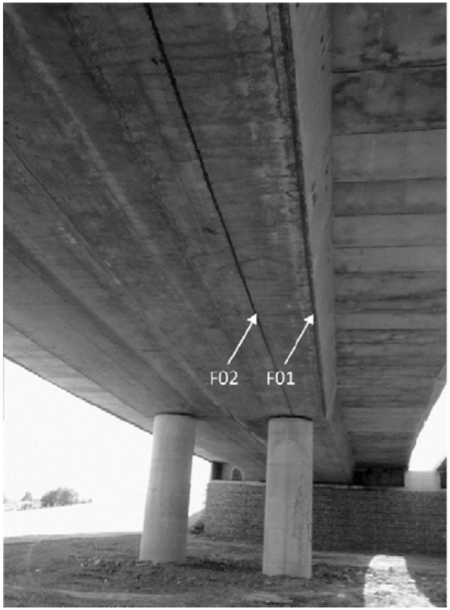
Laboratory test in a Partially Prestressed Concrete (PPC) Beam

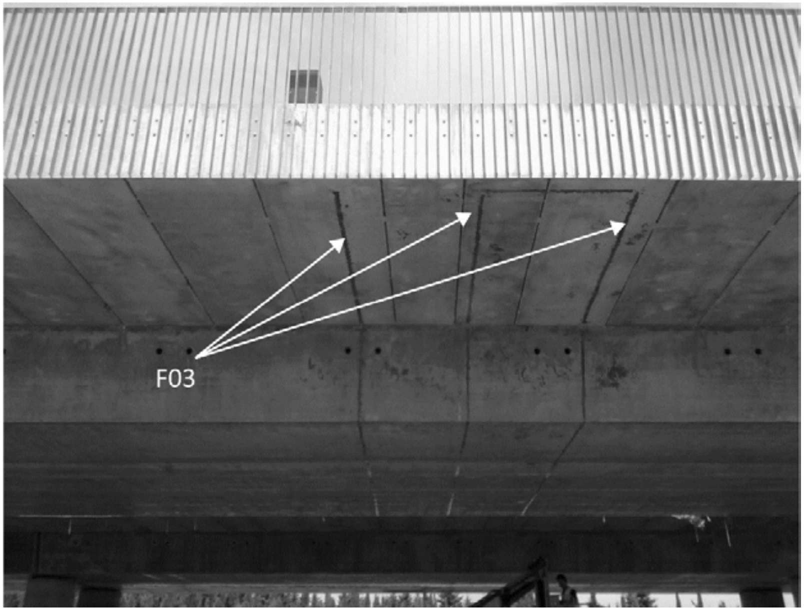


Comparison of the obtained average crack widths

Load (kN)	Crack Width (mm)	
	Strain rosette	OBR
203	0.24	0.20
213	0.27	0.21

Bridges – Can Fatjó Viaduct on the BP-1413





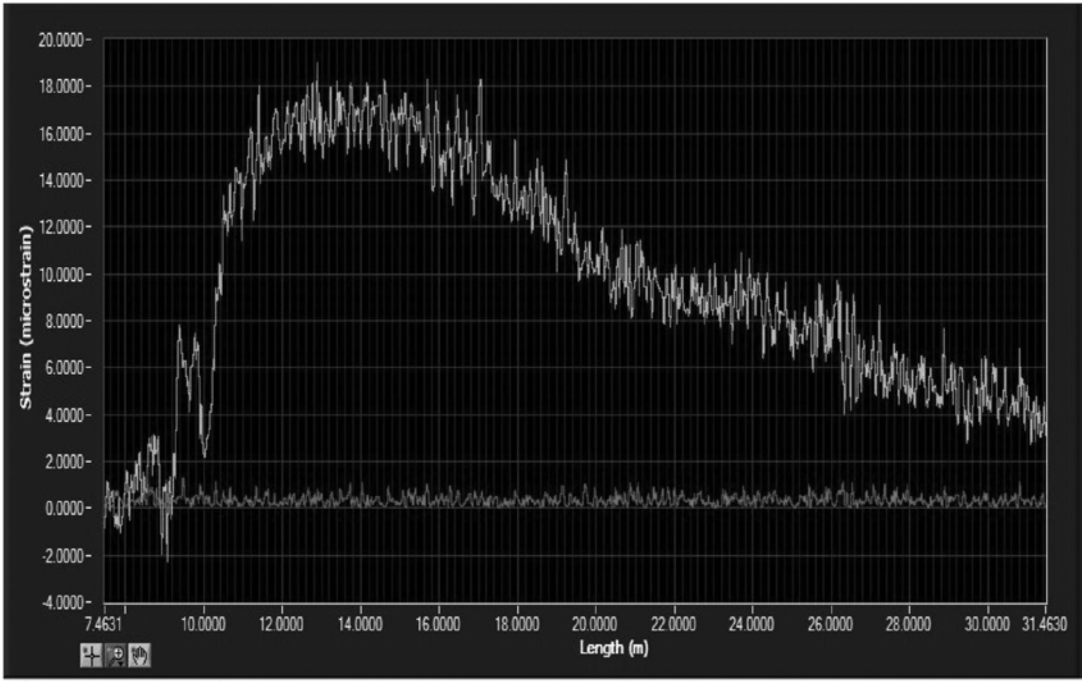
- 125 m long bridge over five spans.
- The deck is 14 m wide and is formed by prestressed precast box beams simply supported on intermediary double piles.

In this case, the experimental campaign had two main objectives:

- To check the feasibility and assess the system operation in concrete monitoring for a real bridge.
- To compare the resulting data with theoretical and experimental values obtained by flexmeters installed during initial load tests.

Bridges – Can Fatjó Viaduct on the BP-1413

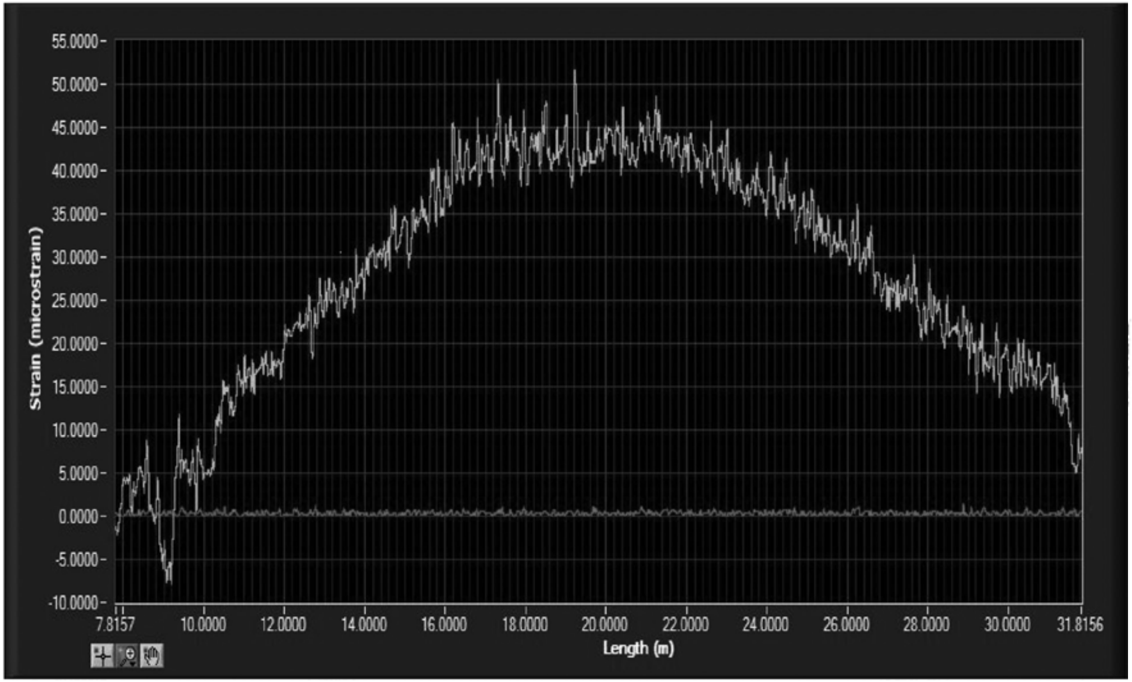
Reading strains under 400 kN moving truck



Strains obtained from the F02 when the truck is located at 1/4 of the span

Bridges – Can Fatjó Viaduct on the BP-1413

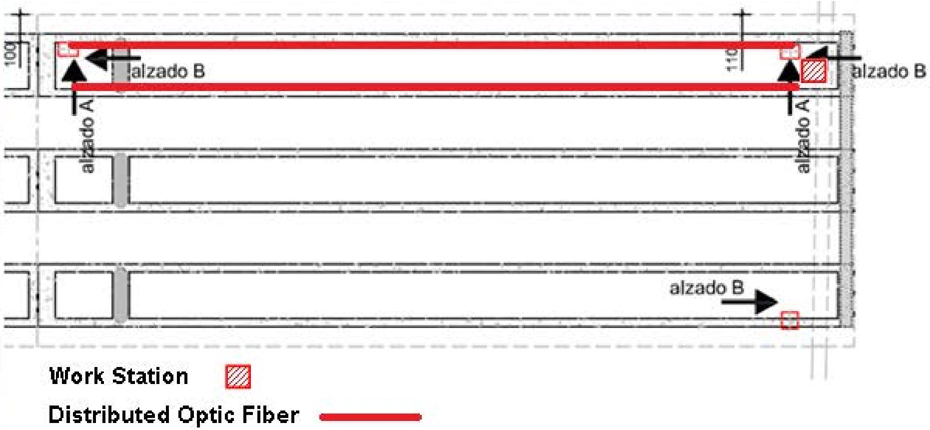
Reading strains under normal traffic and 400 kN static load

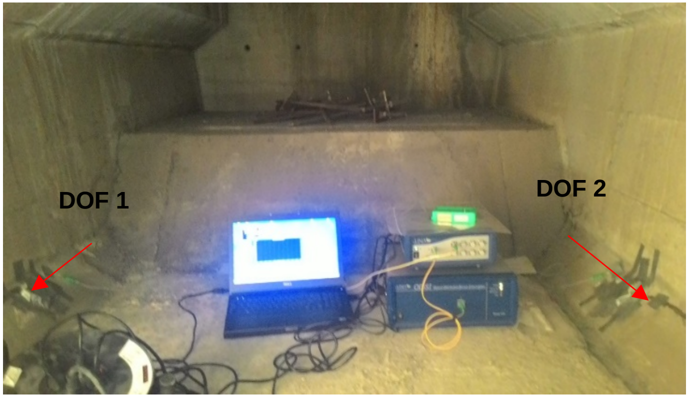


Applying double integration to the obtained strain data it was possible to calculate a **3.45 mm** deflection at mid/span, agreeing with one obtained experimentally by the fleximeters that were around **3.71 mm**.

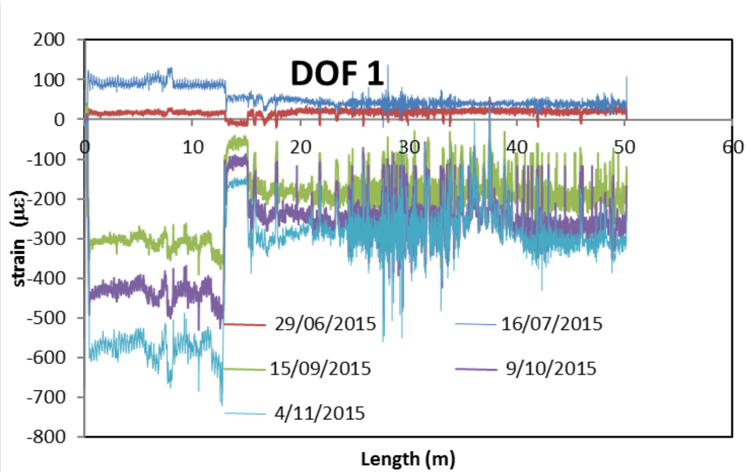
Strain increase recorded in the F02 after 10 minutes

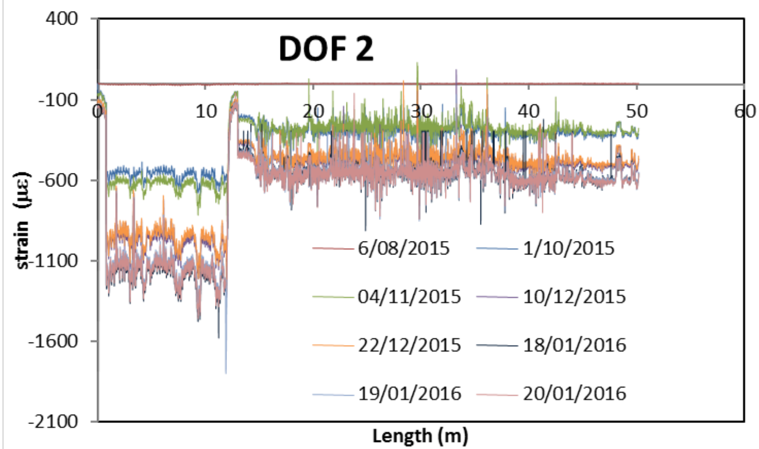
Bridges – Sarajevo viaduct (Barcelona)





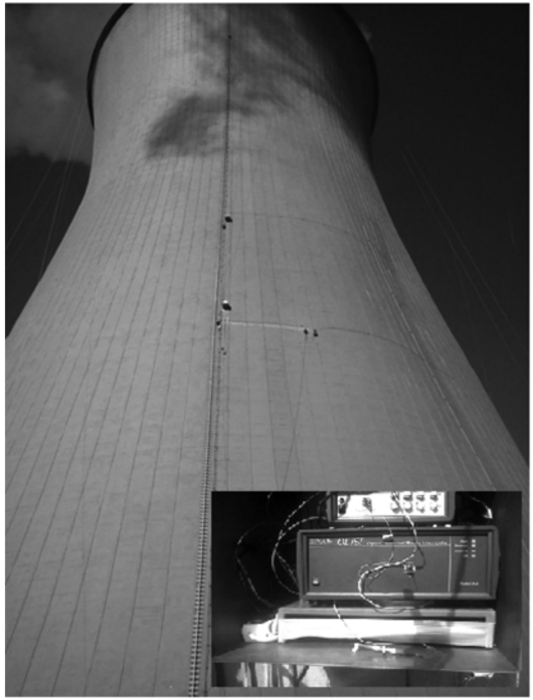
Bridges – Sarajevo viaduct (Barcelona)

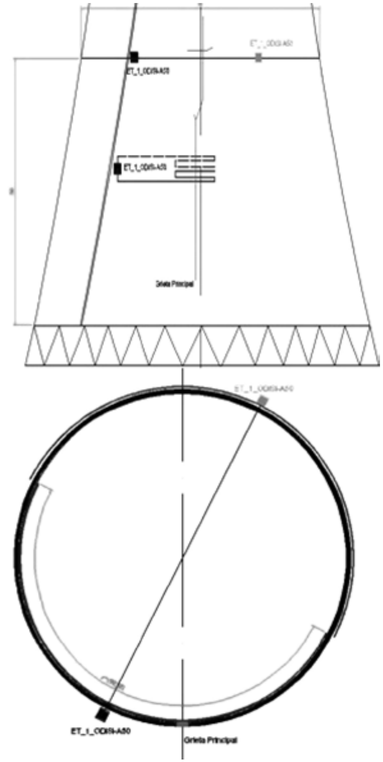




- From DOF 1 the biggest strain variation was observed for -304 με that correspond to a stress change of 11.42 MPa.
- Regarding the measurements of DOF2, the biggest variation was detected in January for -563 με that is equivalent to a stress increase of 21.16 Mpa.
- It was possible to conclude that **these stress variations did not induced changes in the bridge structural behaviour** since they are permissible and acceptable for these type of structures.

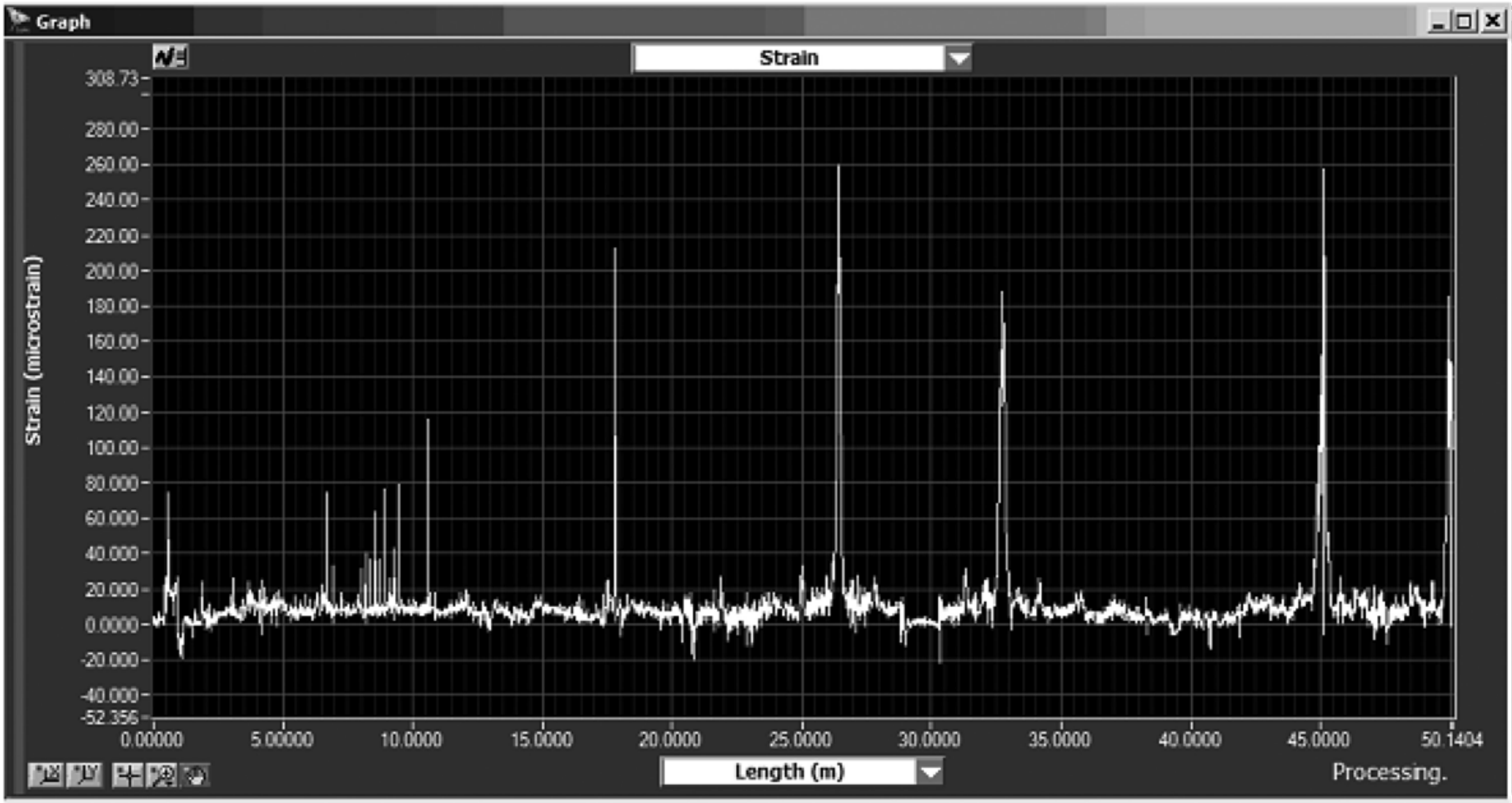
Concrete Cooling tower





During the structure's lifetime **two main vertical cracks had appeared** around the cooling tower due to different causes. For this reason the structure was monitored in order to **observe the behaviour before and after crack repair**.

Concrete Cooling tower



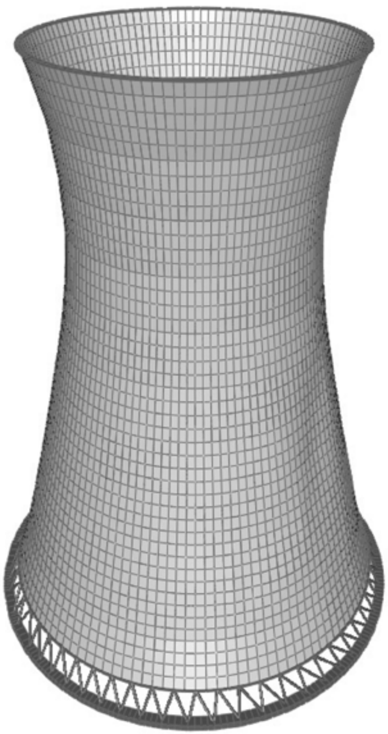
Strain-Fiber Length (Outside surface tower).

Strain-Fiber Length (Inside surface tower).

Concrete Cooling tower

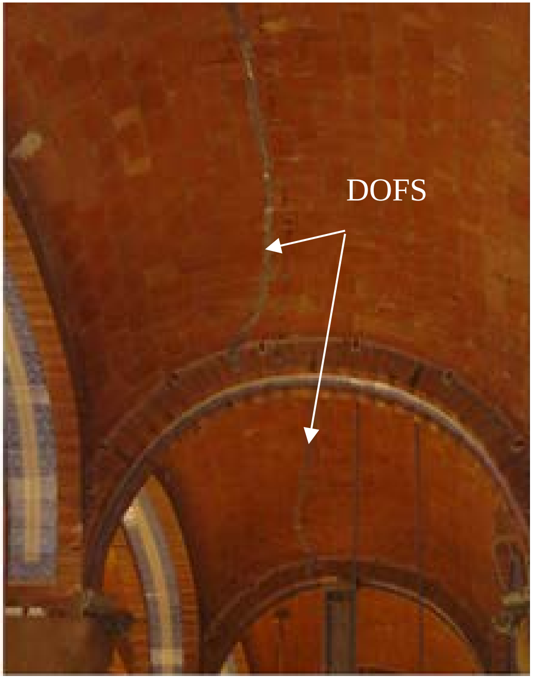
F. Optic F02	F. Optic F01	Structural model	LVDT
3.45	3.62	3.42	3.71

Deflection results at L/2 (mm)



From the results obtained, the structural behaviour is correct on shell surface without appearance of new damages during the repair procedure. **Optical fiber monitoring has allowed increasing the life time of the cooling tower**, showing the origin of the main cracks and allowing for the design of the appropriate repair.

Hospital de Sant Pau – Barcelona

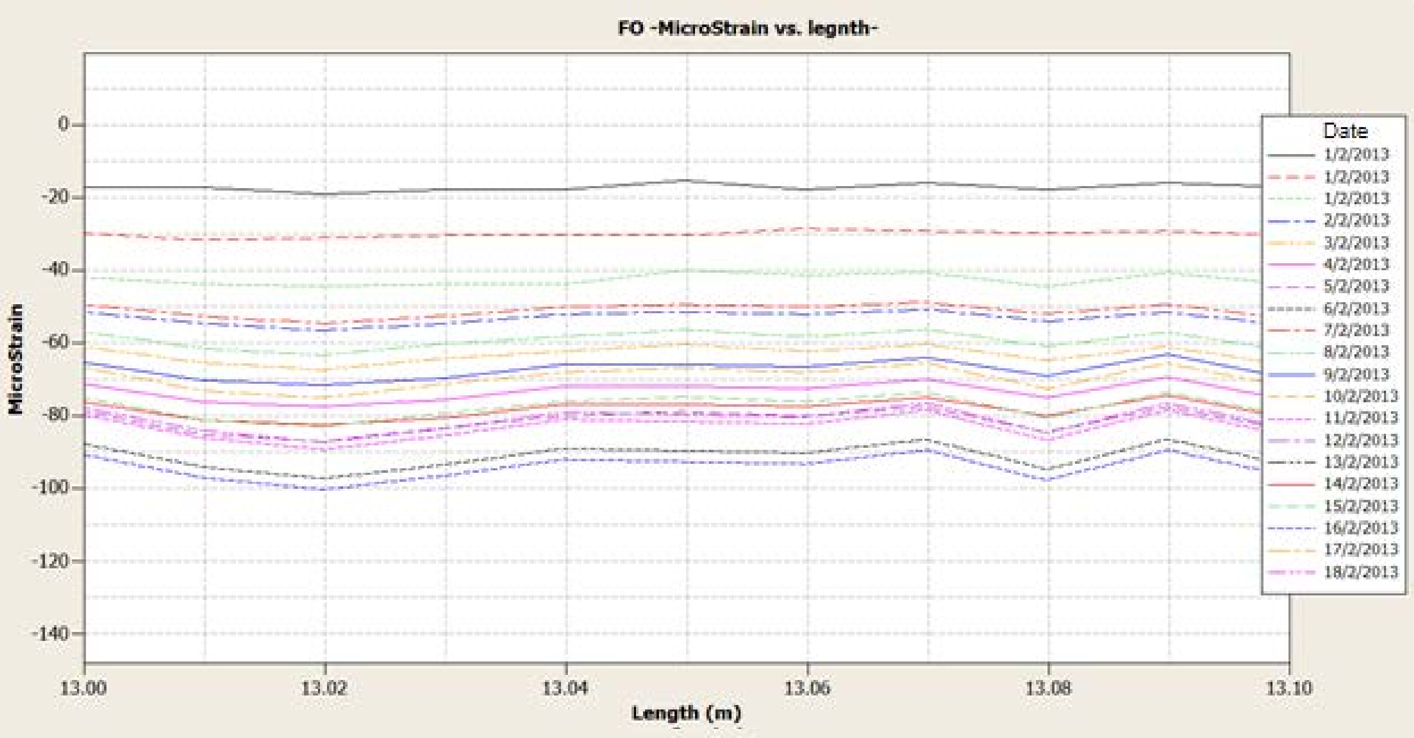


UNESCO World heritage site instrumented with OBR sensors

Hospital de Sant Pau – Barcelona

1- Work station
2- Non adherent DOFS
3- Adherent DOFS

Hospital de Sant Pau – Barcelona



DOFS measurements for a 10 cm stretch

Actions applied: strain increment of 80 με

Conclusions

- The use of Optical Backscatter Reflectometer (OBR) sensors is a **promising** measurement technology for **Structural Health Monitoring (SHM)** as it allows the possibility of **continuous** monitoring in **time and space of strain and temperature along the fiber.**

- The objectives were to **examine the performance** of these sensors when applied in concrete structures both subjected to **laboratory** and to **real world conditions**, weighing their advantages and disadvantages to derive general conclusions about their application.

- In these applications a **good performance** of the technique with optical fibers bonded in the surface of concrete structures was demonstrated with a **good correlation** of results when comparing **with conventional sensors**.

Conclusions

- The adoption of the **correct bonding agent** and the **smoothing of the concrete surface** is assumed as an **essential factor** in these type of applications.
- The OBR sensors record accurate values of strain, **either at low level** or at values **close to the failure** of concrete.
- Regarding **economic impact**, despite that the employment of OBR monitoring system requires an **initial high investment,** especially **on the acquisition system**, an important **economical saving is achieved when comparing with other monitoring techniques** used to obtain a similar number of monitored points and the same type of information, making this technique **optimal in a maintenance policy within a life-cycle cost analysis framework.**

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THANK YOU!

QUESTIONS?

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Copenhagen, 24th August 2016