ABSTRACT

The use of Optical Backscaterr Reflectometer (OBR) sensors is a promising measurement technology for SHM as it offers the possibility of continuous monitoring of strain and temperature along the fibre. Several applications to materials used in the aeronautical construction have demonstrated the feasibility of such technique. These materials (composites, steel, aluminium) apart from having a smooth surface where the bonding of the sensor is easily carried out, they also have a continuous strain field when subject to external loading and therefore the bonding of the OBR on the material surface is not in danger for high levels of loading as the OBR can easily follow the strain in the material. The application of such type of sensor to concrete structures may present some difficulties due to: 1) the roughness of the concrete surface and the heterogeneity due to the presence of aggregates of several sizes, 2) The fact that reinforced concrete cracks at very low level of load, appearing a discontinuity in the surface and the strain field that may provoke a break or debonding of the optical fiber. However the feasibility of using OBR in the SHM of civil engineering constructions made of concrete is also of great interest, mainly because in this type of structures it is impossible to know where the crack may appear and therefore severe cracking (dangerous for the structure operation) can appear without warning of the monitoring if sensors are not placed in the particular location where the crack appears. In order to explore the potentiality of detecting cracks as they appear without failure or debonding, as well as the compatibility of the OBR bonding to the concrete surfaces, a test was carried out in the loading up to failure of a concrete slab.

Sergi Villalba[1], Antonio Fernández[2], Joan R. Casas[1] and Alfredo Güemes[2]

[1]Universitat Politècnica de Catalunya, Civil Engineering Department, Barcelona
[2] Universidad Politécnica de Madrid, Aeronautical Engineering, Madrid

EXPERIMENTAL SET-UP

Test specimen, fabrication procedure, loading and measurement locations

The use of optical Backscaterr Reflectometer (OBR) sensors was carried out in a slab of an experimental campaign conducted in the Structural Technology Laboratory of the Technical University of Catalonia (U.P.C.)

Dimensions of the slab of reinforced concrete were 5.60 x 1.60 meters long and 0.285 meters thick. This was implemented in two phases of concrete with a lag of 48 hours between concreting. Existed a concrete joint at a distance of 2.9 meters respect one extrem of the slab (see Photograph 1). The substantiation for this mode of operation was to follow up rigorously with the actual construction and implementation stages. The loading was applied using an actuator "MTS" of 1MN capacity externig loads P at 1 point localed at the middle of slab (see Figure 1).

Photograph1. Fabrication procedure

The slab was monitored with OBR sensors at their top and bottom faces, exactly in the four stretches of this (see Photography 2). The slab was monitored in the interior steel bars, so discreet in its middle, with dynamics extensometers gauges, too. Deflection was measured at the center and extreme of the slab using an LVDT and crack widths were measured from the initiation of cracks using magnetic transducer "Temposonics" (see Figure 1).

The concrete used in this study is a concrete with design strength of 50 MPa. The reinforcement used for the specimen is a deformed bar with yield strength of 500 MPa with diameters of 20 mm (see Table I).

Photograph2. Specimen slab

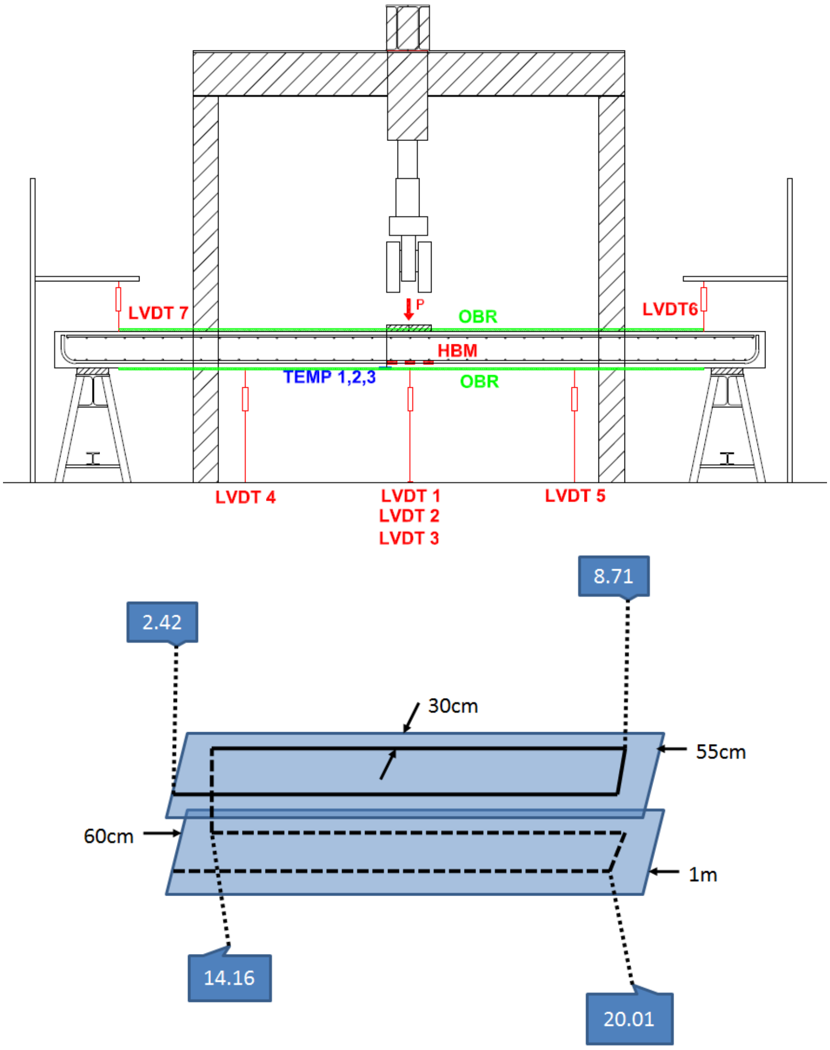

Figure1. Monitoring set-up and positioning of OBR sensor

TABLE I. MATERIAL PROPERTIES AND CHARACTERISTICS

Yield bar (N/mm^2)	**Concrete (N/mm^2)**	**Additive**	**Cement**	**fckm (N/mm^2)**	**E (N/mm^2)**	**M_crack (kNm)**	**P_crack (kN)**
500 SD	HA-50	Glenium C-355	I 52,5R	51.31	33147.63	89.721	43.30

TEST RESULTS AND ANALYSIS

Using O.B.R. sensors

Firstly, the ultimate load capacity of the slab tested was 255.15 kN. This load was 1.123 (12.30%) times the design theoretical load of 227.20 kN.

The figure 3 and figure 4 present lectures of Strain-Fiber Length (third and fourth stretches) curves of specimen measured under different loading until failure.

By superimposing several load levels, is observed as the lengths (location) where the peaks are due to cracking remain stable. In some cases, a single initial peak degenerates into a double because to the nearness of two cracks coming, surely.

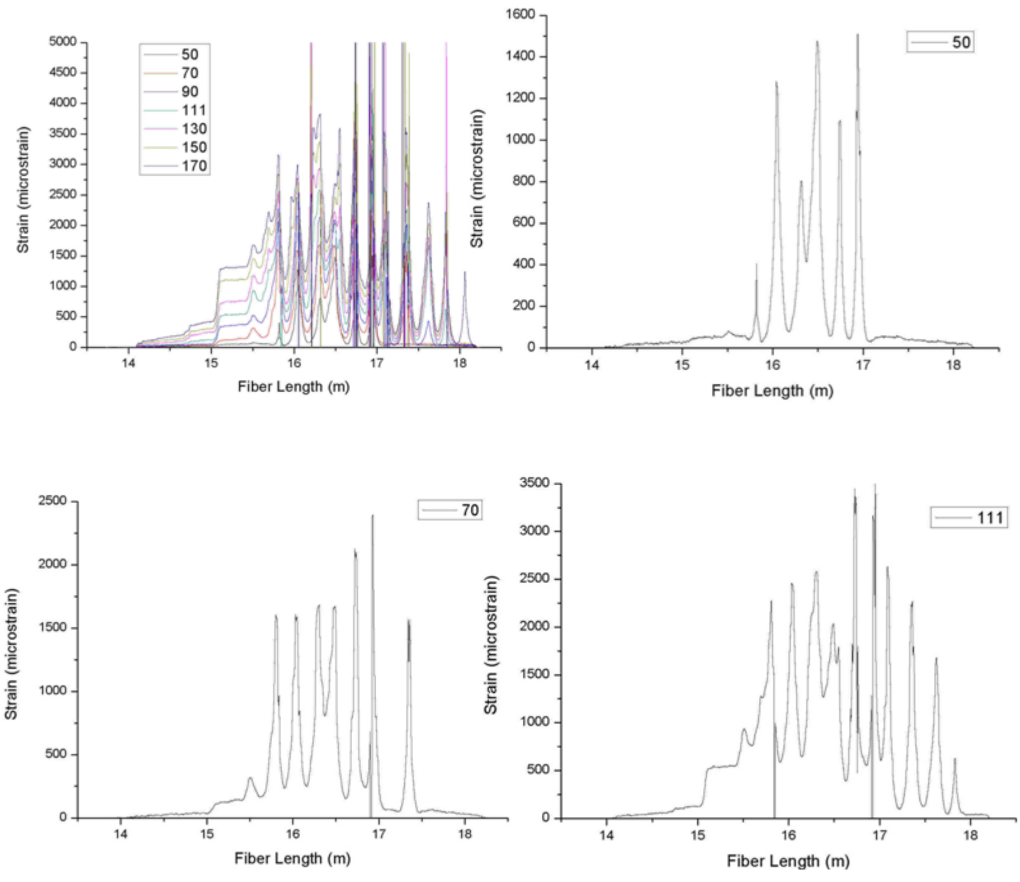

Figure2. Strain-Fiber Length (third stretch)

Specifically, it was tested the behavior of the specimen slab for the load levels 50, 70 and 110kN. The location of the peaks obtained from the use of OBR sensors, are shown in Table II and III for third and fourth stretches (for 50 and 110 kN load levels). These are coincident with the measurement of the slab test. Peaks strain obtained by frequency signal indicating the strain change (increase strain) produced by the generation of cracks. In the center of the slab is where most of them are concentrated.

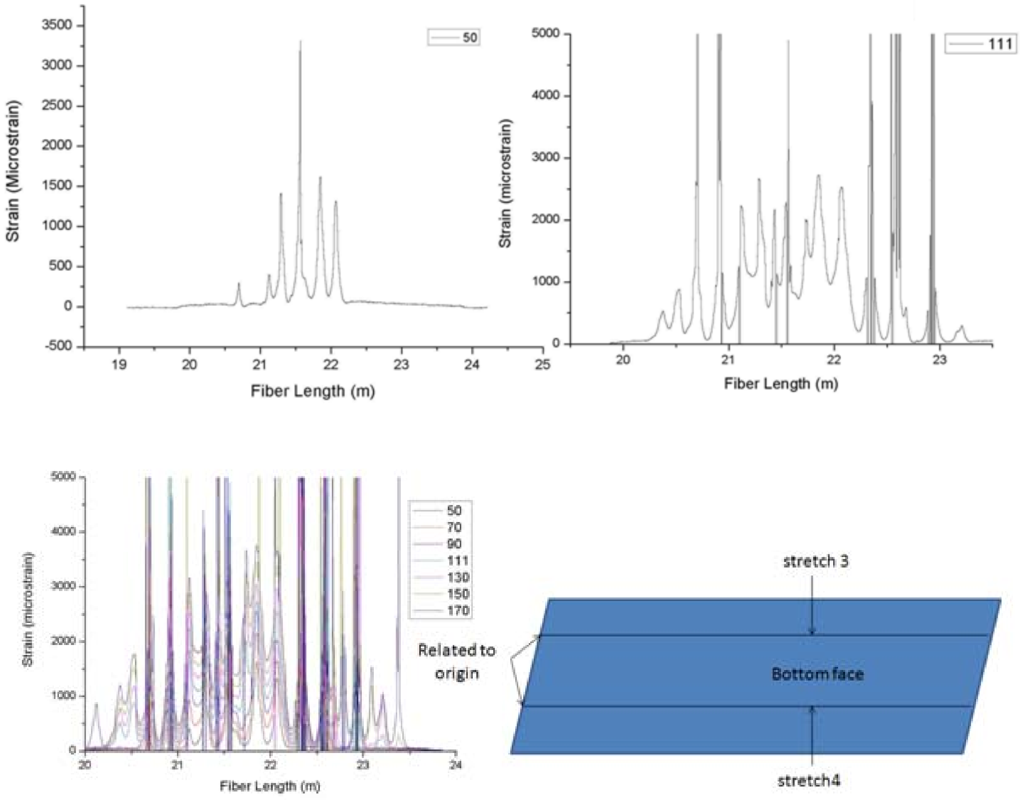

Figure3. Strain-Fiber Length (fourth stretch)

TABLE II. PICK LOCATION OPTICAL FIBER LENGTH (THIRD STRETCH)

Stretch "Length"	**Peak Location in optical fiber Length (m)**	**Peak Location related to origin of stretch (m)**	**Micro strain (μE) (50kN load level)**	**Micro strain (μE) (110kN load level)**
3	15.513	1.953	-	800
3	15.818	2.258	400	2250
3	16.046	2.486	1300	2450
3	16.318	2.758	800	2590
3	16.492	2.932	1480	2040
3	16.551	2.991	-	1550
3	16.745	3.185	1090	3450
3	16.942	3.382	1500	3500
3	17.085	3.525	-	2650
3	17.355	3.795	-	2240
3	17.626	4.066	-	1700
3	17.830	4.270	-	675

TABLE III. PICK LOCATION OPTICAL FIBER LENGTH (FOURTH STRETCH)

Stretch "Length"	**Peak Location in optical fiber Length (m)**	**Peak Location related to origin of stretch (m)**	**Micro strain (μE) (50kN load level)**	**Micro strain (μE) (110kN load level)**
4	20.374	3.736	-	510
4	20.522	3.588	-	800
4	20.694	3.416	270	4400
4	20.909	2.931	-	4460

4	21.123	2.987	400	2250
4	21.288	2.822	1450	2600
4	21.436	2.674	-	2150
4	21.562	2.548	3260	4910
4	21.735	2.375	-	2000
4	21.851	2.259	1650	2700
4	22.064	2.046	1270	2500
4	22.357	1.735	-	4500
4	22.575	1.535	-	4450
4	22.940	1.170	-	350

Photographs 3 and 4 show some of the trigger cracks. These peaks correspond to the points located 2.931 (concrete joints), 2.822, 2.674 and 2.548 for the fourth stretch; and the point located 2.932 for the third stretch. In these can be seen as a high-level loads (170 kN), the OBR sensors have continued to acquire information correctly and also to perform correctly for hight-load levels without breaking the fiber, too.

Photograph3. Cracking Location (Fourth stretch)

Photograph4. Cracking Location (Third stretch)

Figure 4 shows the strains of top face for the first and second stretches. In this case, the signal doesn’t provide noise perturbations, and, for different load levels under fracture, the microstrains values obtained have been low. Only, when test arrives at load values next to the breaking load (compression failure in top face), the OBR sensor detects peaks strain values, that indicate the slab is cracked and test has finished (see photograph 5).

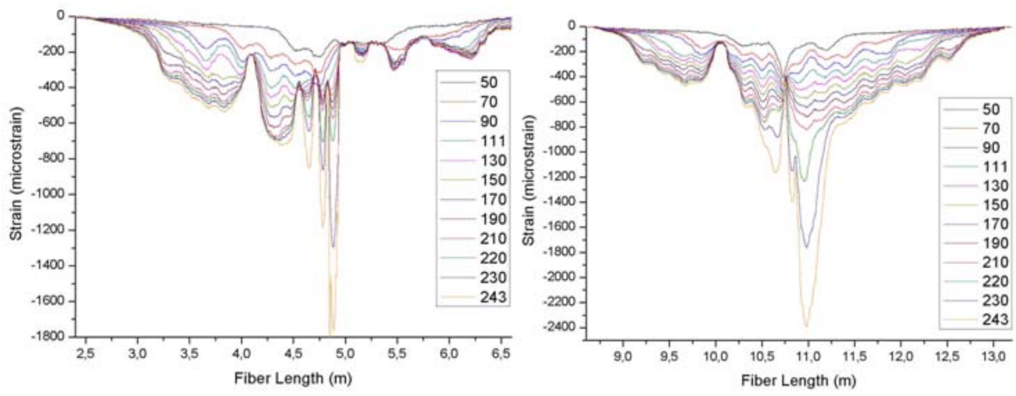

Figure4. Strain-Fiber Length (first and second stretch)

Photograph5. OBR sensor (Top face – First stretch)

Using extensometers gauges

The use of monitoring extensometers gauges is usual for testing discrete reinforcing bars in concrete structures. However its use in concrete material doesn’t provide satisfactory results.

Figure 5 present the Load - Microstrain curves of the specimen for the various bars tested. The cracks began to develop near an applied load of 41 kN, instant at which the gauges measured for each bar a sudden change (increase) of stress (tension) which involved a microstrain of it. In Table IV are shown microstrain of the bars for 50 and 110 kN load levels. The locations of the gauges are approximately similar to the detection of peaks between the lengths of 2.991 and 2.987 meters of the third and fourth stretches.

Obviously, the values obtained don’t match exactly. The OBR measures the deformation of the extreme fiber of the section, so be applied deformations’ compatibility for the exact value for the bars. However, the range of values obtained show a satisfactory and successful strain obtained from the use of sensors OBR

TABLE IV. LOAD vs. MICROSTRAIN SPECIMEN SLAB

Reinforcing bars tested	Micro strain "Average" (μE) (50kN load level)	Micro strain "Average" (μE) (110kN load level)
B6-B5-B3-B2	400	1810

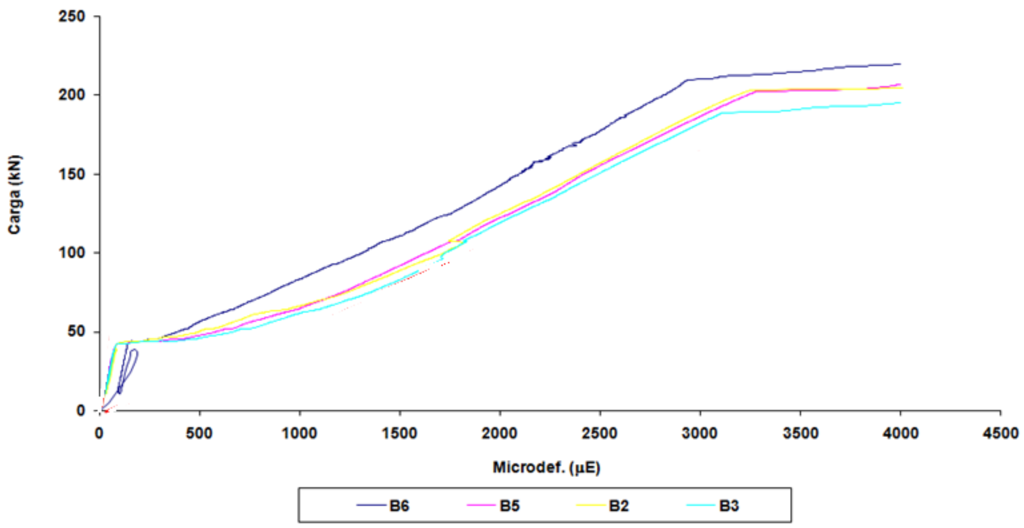

Figure5. Load vs. Microstrain.

SUMARY AND CONCLUSIONS

The behavior of slab has been experimentally examined in this study. Test results make it possible to draw the following conclusions.

The experimental results through OBR sensors have been compared with those obtained from extensometers gauges. The accuracy of the results obtained validates the use of this technique to know where the cracks may appear, their premature evolution and behavior.

The results obtained show how the OBR sensor is not only capable to detect appearing cracks hardly visible, but also to perform correctly up to load levels producing a crack width higher than 1 mm.

ACKNOWLEDGEMENTS

This study is a part of the projects, BIA2006-15471-C02-01 and BIA2007-28685-E. The authors would like to thank the Spanish Ministry of Education and Science.

REFERENCES

1. Villalba, Sergi. 2008. "Design, development and experimental verification of loop joints in incrementally cast concrete bridges. Optimization of constructive process". Thesis project, Civil Engineering Department, Technical University of Catalonia, Barcelona (Spain).