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35-Year Structural Monitoring of a Prestressed-Concrete Pressurized Wind Tunnel

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ABSTRACT

In this paper, we present a unique SHM feedback based on 35-year monitoring data of a prestressed concrete pressurized wind tunnel. 276 double coil vibrating wire extensometers have been embedded in the concrete structure during construction. Long term strain measurement performed during 35 years show elastic behavior during daily pressurizing tests and long-term shrinkage due to concrete creep and prestressing cable relaxation. In addition some mircocracks have been detected with the vibrating wire extensometers. Such microcracks have no structural effects whereas they affect concrete wall permeability therefore wind tunnel serviceability. Such a monitoring system may be integrated in a service life management plan as it represents a durable and economic tool for conditional maintenance (repair of prestress losses, microcrack repair). The presented durable SHM system will help to ensure that the wind tunnel will continue to meet its design requirements throughout its operational life.

INTRODUCTION

Ageing of prestressed concrete structures is a very sensitive issue for infrastructure asset management mainly due to their big size (bridges, reservoirs, high towers) and often their strategic function (nuclear powerplants, LNG reservoirs, oil platforms, military bases). As in every concrete structure, deteriorations may occur due to carbonatation, chloride, sulfate attacks or other concrete chemical expansive reactions such as Alkali-silica reaction or delayed ettringite formation. Furthermore, in presstressed concrete structures, decrease of compressive stress due to concrete creep, fatigue, or tensioning wire relaxation or corrosion may cause local tensile stress in concrete inducing major failures requiring repairs (cracks).

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A good way to assess and prevent such troubles is to monitor internal concrete strain within the structure during its service life. In the presented paper, we expose a case where durable double coil vibrating wire sensors are embedded in a concrete Wind Tunnel at construction. Such strain measurements are commonly achieved for French sensitive infrastructures such as Nuclear Power Plants, tunnels or dams. The Wind tunnel operated by ONERA (the French Aerospace Lab) has been extensively instrumented at construction by Double Coil Vibrating Wire Extensometers (VWE). ONERA regularly performed "manual" strain measurement of the tunnel wall for 35 years. In 2001, VWE as well as internal pressure measurement were remotely acquired through a data acquisition system. Cementys helped ONERA to interpret and use recorded measurement data for long term asset management.

STRUCTURE AND USE OF THE F1 WIND TUNNEL

The ONERA-F1-Wind-Tunnel was built in 1975 in Fauga, Toulouse. This wind tunnel is a low-speed continuous-flow, pressurized wind tunnel, with a test section size of 3.5 m high, 4.5 m wide, and 11 m long. It is used by aeronautic industry for landing and takeoff configurations as well as research activities. The tunnel operates at Mach numbers up to 0.36, and stagnation pressures up to 3.85 bars.

Figure 1. Construction (left: Wind-Tunnel overview, right: post-tension setup)

The aerodynamic circuit is made of prestressed concrete, which was a major innovation for a pressurized wind tunnel (1) in the 70's. Coyne and Bellier company designed the wind tunnel, based on its large experience within prestressed concrete structures (reservoirs, reactor vessels, etc.)

This type of construction offers a saving in both time and money, and in addition, this heavy structure behaves better than a metal structure under vibrations. On the other hand, concrete is submitted to creep, fatigue, and other strain due to material ageing. Because of stress cycles regularly applied to the prestressed-tunnel structure by pressurizing the circuit, fatigue process is enhanced.

Figure 2. Visible microcracks causing air leaks when pressurizing (left: resin repair).

After more than 25 years of operation, few microcracks occurred and became visible on the outside tunnel surface. As a consequence air leaks is hindering nominal pressure to be reached inside the wind-tunnel.

INSTRUMENTATION OF THE WIND TUNNEL

Sensor Locations

The used sensors are double coil vibrating wire extensometers with a large track record in France. Indeed, they have been widely deployed during construction works of dams, powerplants, and bridges since the 40's. Their high reliability (low percentage of failure), good strain resolution (less than 1µm/m) and very low drift make them the best solution to perform long term monitoring of concrete structures.

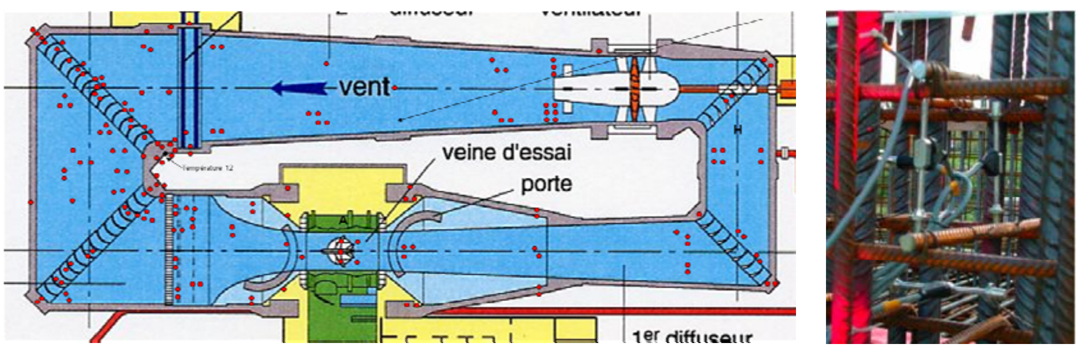

Figure 3. (left) Wind Tunnel instrumentation: red dots represent VW extensometers. (right) View of VW extensometers before concrete pouring (2).

Thus, as shows figure 3, the prestressed wind-tunnel structure has been extensively instrumented with 276 VW extensometers measuring strain, as well as temperature.

A measured total concrete strain regroups different contributions that can be partially estimated by measuring the free concrete strains through concrete samples stored in the same environmental conditions (2).

$$\varepsilon_{total} = \varepsilon_{free} + \varepsilon_{mechanical} + \varepsilon_{cracking}$$

$$\text{with : } \varepsilon_{free} = \varepsilon_{thermal} + \varepsilon_{shrinkage}$$

In the following, we measured that thermal expansion of concrete was:

$$\alpha = 11.10^{-6} {}^{\circ}C^{-1}$$

Thus, we can directly estimate a thermal expansion-free strain from measurement by applying the relationship:

$$\varepsilon_{comp.} = \varepsilon_{total} - \alpha.\Delta T = \varepsilon_{shrinkage} + \varepsilon_{mechanical} + \varepsilon_{cracking}$$

Data Acquisition

Measurement campaigns have been performed regularly since 1975 by ONERA operators. Data acquisition of strain, temperature and inner pressure has been automated from 2001 at frequency of 1 measurement each 8 hours. Periods without data are visible on figure 3, but measurement available clearly highlight main evolution of strain. 63% of installed sensors are still operational in 2010.

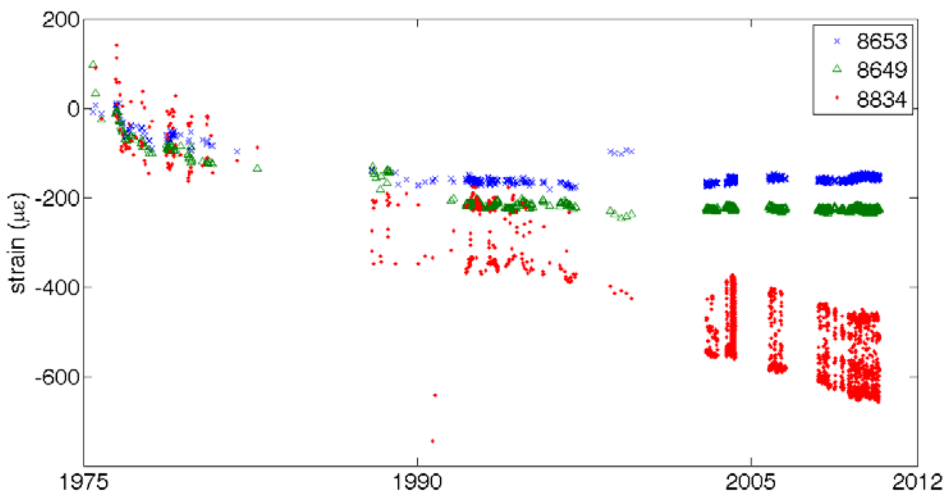

Figure 4. 35-year strain measurement performed by 3 different sensors.

Figure 4 shows 3 sensor charts. "Noisy" appearance of sensor 8834 strain measurement (red curve) is due to elastic stress applied to the structured by pressurizing (every wind tunnel working-day). On the contrary, Sensor 8653 (see legend) and 8649 strain values are not modified by any elastic strain. They are stabilized around -200µm/m whereas Sensor 8234 strain is about -650 µm/m. Thus a large part of strain is due to fatigue creep.

24 HOURS PRESSURIZING TEST

As it is typically done for dam monitoring (3), we proposed to isolate irreversible strain (cracking and shrinkage) by subtracting elastic reversible strain from measurements (see figure 4).

Assuming the unique cause of elastic strain is pressurizing, test we determined the current behavior of the structure by measuring strain on each sensor during a one-day pressurizing/depressurizing test. For these 24h acquisition frequency has been raised to 1 measurement each 30 minutes.

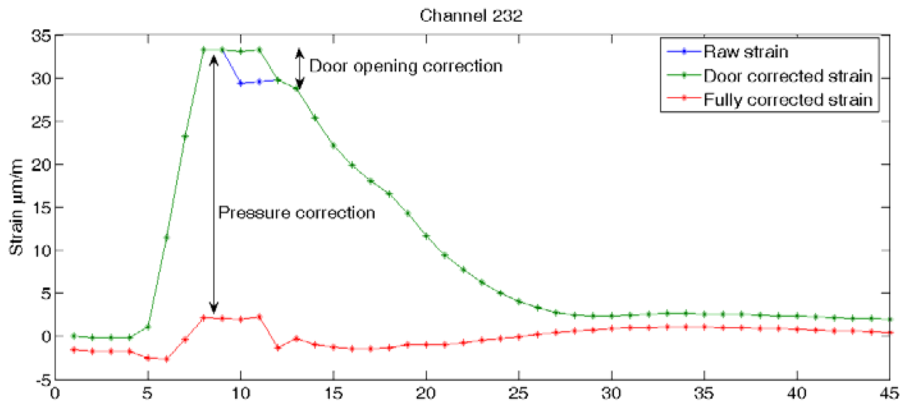

Figure 5. 24-hour test: rising pessure, opening door, stopping compressor, opening gate. Example of sensor strain compensation.

From the obtained results we were able to assign a linear dependence coefficient between elastic strain and pressure for all sensors. Subtracting the pressure induced strains and door opening induced strains on previous measurements, creep and fatigue strains are isolated and can be used for ageing diagnosis as shown on figure 6.

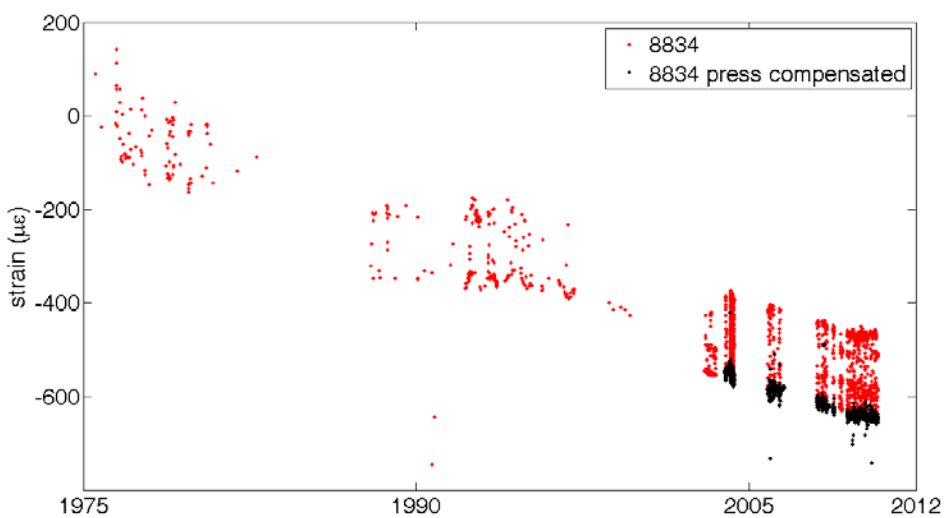

Figure 6. Pressure compensated strain.

LONG TERM MEASUREMENT RESULTS

With previously presented method, we numerically compensated strain on each sensor measurement. Thus, based on pressure-dependence we identify to main behaviors:

- ELASTIC ZONE: If absolute value of strain induced by the test doesn't rise above 1 m/m.
- CRACKED ZONE: If it does.

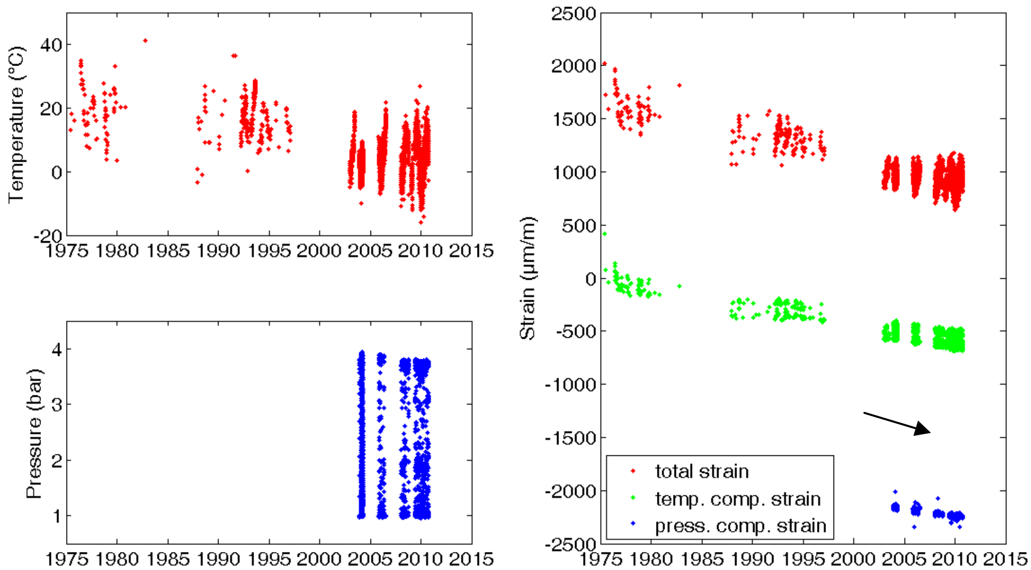

Figure 7: Strain measured on elastic zone.

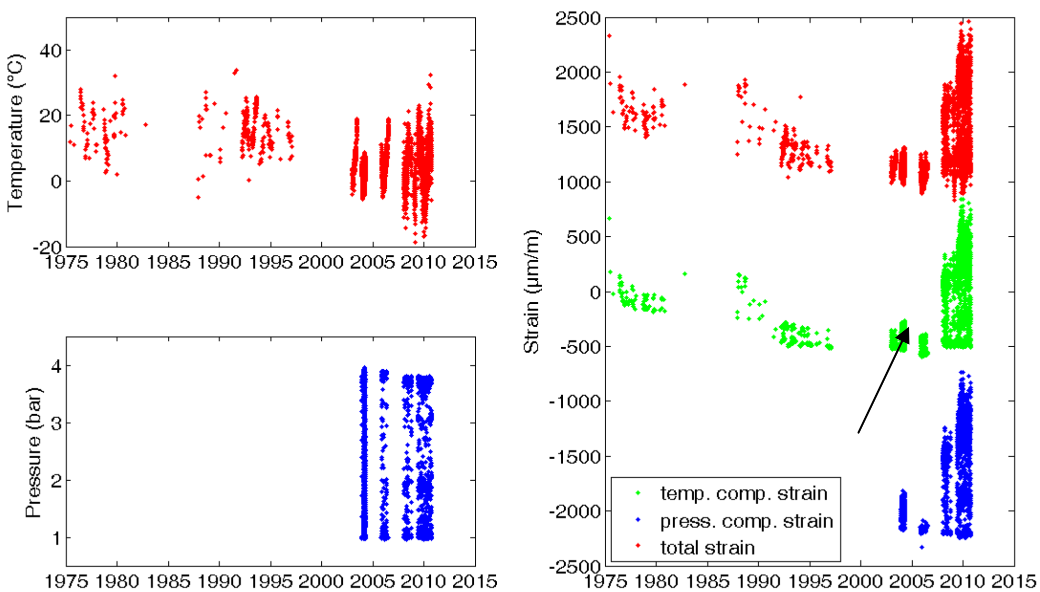

Figure 8. Strain measured on cracked zone.

Figure 7 and Figure 8 show respectively evolutions of strain measured by sensors located on elastic and cracked zones. On figure 7, the presented analysis enables to isolate long term strain evolution. In cracked zone, it enables to follow crack opening.

Table 1. Sensor classification.

Channel	S/N	Zone	Service	Door Strain	C_P	C_T	Mode
249	8835	ZONE T3	OK	-1.93	-451	7.15	Crack
250	8834	ZONE T3	OK	1.29	63.4	-0.24	Elastic
251	8662	ZONE U	OK	3.96	31.9	-0.63	Elastic
252	8659	ZONE U	OK	1.78	17.5	-1.39	Elastic
253	8666	ZONE U	OK	1.01	80.4	-0.20	Elastic
254	8660	ZONE U	OK	-1.28	67.9	0.05	Elastic
255	8719	ZONE U	OK	4.41	29.9	-0.35	Elastic
256	8683	ZONE U	KO				
257	8681	ZONE U	OK	-1.07	-5.70	0.069	Elastic

CONCLUSION AND PERSPECTIVES

We propose the basics of an automated monitoring method for ageing surveillance, based on strain deconvolution through embedded vibrating wire strain gage measurements within concrete structure. Mechanical and thermal strains are deduced from the coupled strain-pressure-temperature measurements such that cracking events and evolution are monitored over service life. This includes analysis on crack-free zone: creep evolution of low stress zones, fatigue evolution on high stress zones (typ. 200µm/m for 3 bars of overpressure). On indentified cracked zones, crack opening evolutions are monitored and individual alert thresholds can be defined for long term air leak control.

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