# Application of new tools for the monitoring of Nuclear containments

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ABSTRACT: The nuclear containments designed with Pressurized Water Reactor have several safety barriers in case of leakage of their primary coolant circuit. The global structural barrier is made of a concrete containment prestressed by large post tensioned tendon to guarantee the absence of leakage in case of accident.

During the life of the containment the designer integrate several monitoring device that allows to follow the comportment of the structure and confirm the adequacy of the containment to its purpose.

The Nuclear industry has been using such containment since the 60's and there is an important feedback on the monitoring of these structures. The authors have been working on a project where they have been invited to combine the use of standard monitoring equipment validated by years of use with more recently developed tools that allow a more precise and reliable follow-up of the structures. A minimum redundancy between old and new equipments have been kept to allow comparison of the different system in the future.

This article will describe the various options taken and the expected characteristics of these solutions.

## 1 INTRODUCTION

"The objective of nuclear safety is to protect, under every circumstance, mankind and the environment by preventing leakage of dangerous quantities of radioactive materials". SFEN (French Society for Nuclear Energy)

For different types of nuclear power plants (EPR, VVER, KSNP…etc.), the containment building is the last barrier against the leakage of radionuclide to the environment. For containment that is designed with a pressure of over 0.3 Mpa, the prestressed concrete is widely used. The ageing of the concrete and post-tensioning system will conditioned the correct operation of the power plant. During the lifespan of the building, it is required that the mechanical features of the structure are constrained within acceptable levels of stress regarding the normal and abnormal operating conditions. Monitoring, with periodic inspections and continuous data acquisition, is currently the most efficient tool to assess the deterioration of a structure.

Figure 1. Double wall containment – cutaway

Since the 60's the containment buildings have often been equipped with sensors, installed usually from construction. The objective of this paper is to outline the use of monitoring equipments validated by extensive operational years as compared to the use of more recently developed tools. This combination allows a more precise and reliable record of the structures.

## 2 SENSOR OVERVIEW

### *2.1 Stresses in the concrete - The strain gages*

Generally, local stresses are monitored in various locations of the containment. This can either be some common parts such as raft, wall, and dome or in specific parts such as around hatches. For each location, different kinds of mountings, namely; doublet and triplet are used. The choice of a mounting depends on the direction of the expected stress. Moreover, the sensors are distributed within the thickness (for instance of the wall) in order to precisely record the mechanical behaviours. The vibrating wire, as shown in figure 2 is one of the preferred sensors used for data acquisition within walls by embedding. The choice of a vibrating wire is attributed to its simplicity, stability and robustness. Some of these sensors are inclined to display some notable drift and losses after operating for a number of decades. This compromises the accuracy and reliability of the measurements.


Figure 2. View of a vibrating wire extensometer

To improve on the reliability, considering that an embedded sensor cannot be replaced, the proposed solution in this instance is to install additional external sensors on the surface of the wall in question from the beginning of the construction. These external sensors will all have the same frequency as the embedded sensors and will be distributed along the lifespan of the structure. Installing external sensors will enable, with a sufficient operating period, acquisition of a transfer curve between the embedded sensors and the external sensors. In case of sensor failure inside the concrete information will remain available enabling continous monitoring of structures.

The proposed external sensors are based on the Fibre Bragg Grating (FBG) technology. Briefly, the FBG extensometer is made of an optic fibre tightened between two points connected to the concrete. A grating is “inscribed” on the optic fibre. This grating acts as a selective mirror for a laser injected inside the core of the optic fibre. The frequency mirrored by the grating depends on the tension applied to the optic fibre. By measuring the frequency shift between two times as shown in figure 4, it is possible to compute the strain. Figure 3 demonstrates the principle of operation of FBG sensors.

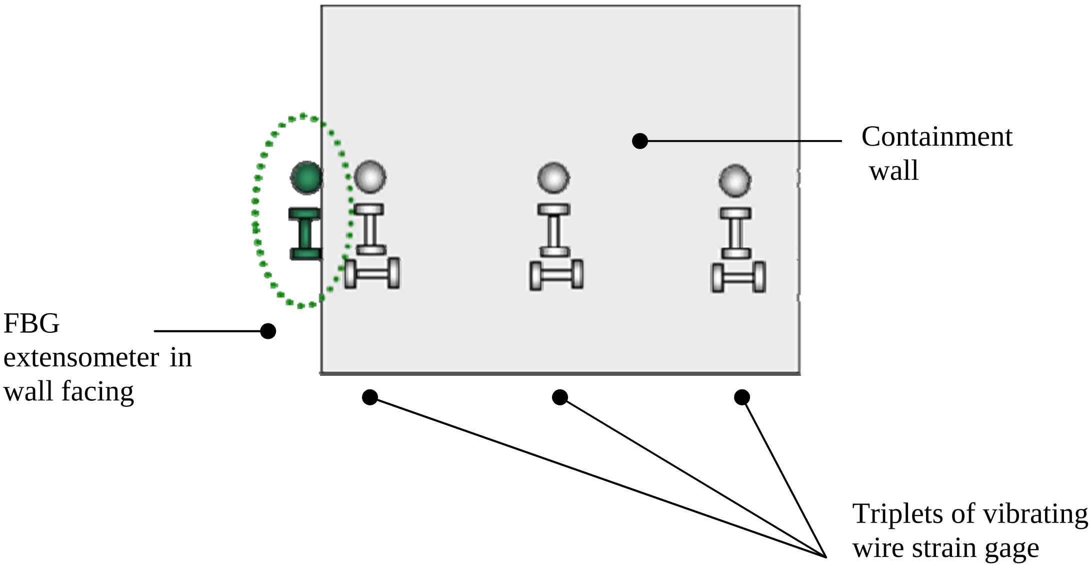


Figure 3. Principle of FBG sensor completing vibrating wire sensors

This technology has been chosen for this application for three main advantages. Firstly by inscribing several gratings with different natural frequencies, it is possible to get several sensors on a single fibre (up to 16) and thus, reducing a significant amount of cabling. The second advantage is attributed to the material as it shows no sensitivity to the corrosion. The third advantage is the inherent immunity to electromagnetic interference due to a measurements principle based on light (optical fibre).

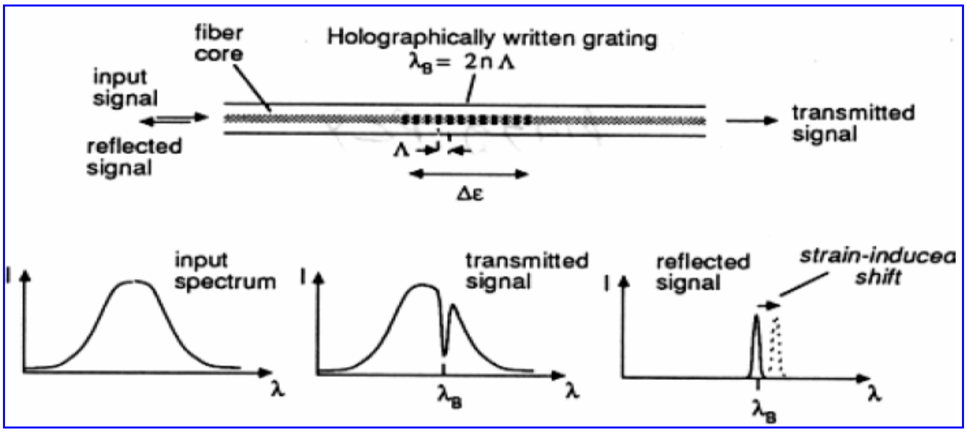


Figure 4. Bragg grating sensor principle

### 2.2 *Temperature and water content sensing*

The temperature is a main physical quantity impacting not only on behaviour of the structure but also the reliability of measurements. In order to compensate for temperature, a temperature probe (i.e. PT 100) is systematically coupled to a sensor or group of sensors. The temperature sensor can be embedded in one of the sensors or located near a group of sensors.

The feedbacks on the previous containment buildings tests have also shown that the water content inside the concrete is also an important physical quantity that could adversely affect the measurement. For this purpose 14 sensors will be distributed in different locations and at different thicknesses to measure the moisture content.

### 2.3 *The tendon monitoring*

The post-tensioning system is a centrepiece for the structure behaviour, and as such, meticulous monitoring is required. A common way of monitoring is to equip several unbonded tendons with load cells. The load cells are inserted between the anchorage and the bearing plate on the concrete. These load cells are able to provide a continuous measurement of tension at the anchorage. While the measured value matches with the total tension of the tendon, it does not however provide information on the force distribution along the cable. Following this, it is proposed that the system be improved by spreading 32 additional sensors along the length. This will allow for a precise representation of the force distributions to be obtained during the tendon stressing stage as well as the life of the structure respectively.

The sensors used have been specially developed and qualified for this application. The sensor technology, shape and robustness have been greatly enhanced. One of the main tasks was to define the methods to ensure effortless installation of the sensor at the construction site. For the qualification stage, some test blocks as shown in figure 5 were used.

Figure 5. View of a test block

These tests blocks are made of reinforced concrete, with a prestressed bar simulating the tendons. The new sensors are installed in conjugation with some reference sensors. The tests involved application of a post-tensioning force to the concrete with a hydraulic jack in several increasing steps. The stress was later decreased and the behaviour observed. Figure 6 shows the results throughout the tests.

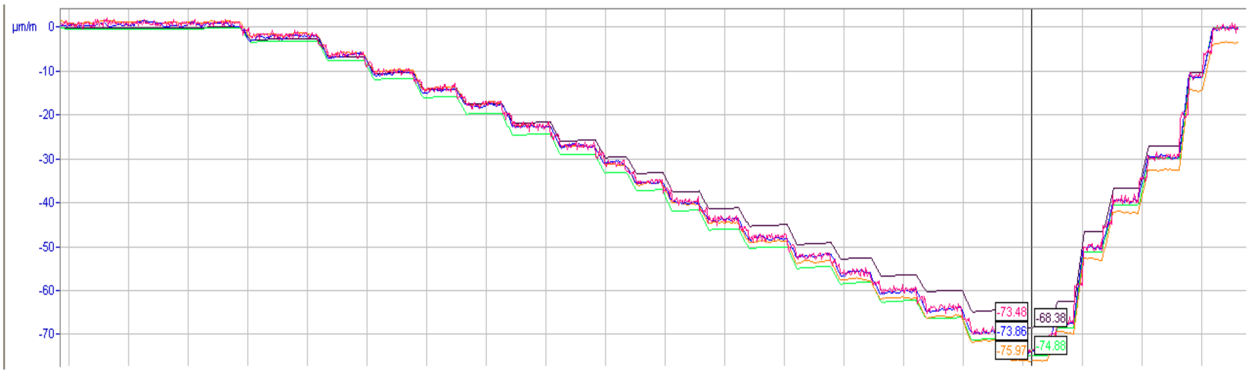


Figure 6. Graphic of the stressing – de-stressing test

These curves are plotted with the raw data, the thermal compensated data and the reference data. In this case, the results founded are in accordance with the values expected. The sensitivity is good, the behaviour is elastic (return to 0) and hysteresis is minimal.

### *2.4 Global deflections: pendulum & invar wire*

The global deflection instrumentation allows for monitoring the behaviour of the foundation on the long term and the elastic response of the walls during the life of the containment and during the pressure test.

Two kind of global deflection are monitored. The first one is the containment tilt using pendulums, the second correspond to the vertical deformation of the walls. In some case these measurements are completed by the levelling of the base slab and the post-tensioning gallery.

This containment tilt measurement corresponds to XY displacement of a defined level of the containment related to the lowest level. Practically, a metallic wire is anchored in a current part of the wall (for instance + 38 m above the ground) and is plumbed at the base of the wall. At this level, a manual or automatic coordinatometer is also anchored in the wall, enabling to read the free horizontal displacement.

A typical installation scheme is to anchor three pendulums at three different heights of the wall. All the coordinatometers are concentrated at a single low level. The main drawback is these equipments require a lot of place in a wall already widely encumbered. The proposed solution outlined in this regard works with only one plumb line and several last generation optoelectronics sensors spread along this line. This system is more accurate (<0.01 mm) and faster. It is noticeable that maintaining one plumb line instead of several is immediately cost-effective.

If the pendulum provides the XY components of the global deflections, this is the very long base displacement sensor who gives the Z component. Traditionally, the "invar wire system" is used on numerous containments. Practically, an Invar wire of tens meters is tightened between the top and the bottom of the wall. To measure the vertical deflection, a linear sensor measures in fact the displacement of one end of the Invar wire. Considering that the invar material has a very low thermal dilatation coefficient (usually < 1x 10-6 m/°K), the system is considered almost insensitive to the ambient temperature. In this case, replacing these systems by long base optic fibre sensors, based on the Michelson interferometer principle is a viable solution. Briefly, these sensors are composed of 2 optic fibres anchored between two points of the wall. The distance between these points can reach up to 10 meters. The sensor is shown in figure 7.

Figure 7. View of a long base optic fibre sensor

One of the two fibres is tighten between the anchorages whereas the second one is lightly slackened. If the first one is sensitive to the temperature and the displacement of the wall, the other is only sensitive to the temperature. Both are connected to the interferometer where the sensors act as some arms. The advantage is to obtain a completely temperature compensated measurement. One other advantage is a very high accuracy, reaching 2 µm over 10 meters.

Figure 8. View of the pendulum (left) and Michelson optic fibre sensor (right)

The system is completely immune to the electromagnetic perturbation, just as the FBG systems. In reality, each vertical line is equipped with several sensors, each of them giving an intermediate deflection and the sum providing the total deflection.

## 3 DATA ACQUISITION

All the sensors are connected to a data acquisition unit which measures the values following a predefined schedule. The data acquisition unit is usually installed inside a room distant from the containment building. Often, the connections between the sensors and the monitoring room are analogic. In these cases, there is a significant amount of cabling required, because all the connections are point to point. The proposed solution to the problem is to replace, all the wires by a numeric connection (based on RS-485), which radically reduces the cabling requirements. Some industrial protocols and redundancy on the RS-485 to reach much higher reliability than standard point to point wired systems are applied.

The SIMON.E software manages the system. This is a web application which can be accessed over the intranet through a VPN-SSL encrypted link.

SIMON.E offers also a friendly-user interface. The user, depending on its level of access, can set the acquisition parameter (calendar, frequencies), the thresholds (the limit values not be exceeded), view and export the data.

Figure 9. Example of software graphic interface

## 4 MONITORING SYSTEM USE

The life of a containment building is punctuated with several main events which are the post-stressing, the pre-commissioning containment tests and the periodical containment tests. During the post-stressing operation, the sensors are monitored with a close data acquisition frequencies (for instance 1 measurement per hour). The values recorded are real-time compared to the values expected using calculations.

The containment test consists in injecting pressure inside the containment building. Usually it can reach 5 bars. Like during the post-stressing operation, the values recorded are compared to the values expected using calculations.

## 5 CONCLUSION

The instrumentation of the containment is clearly indicated in the regulation like the ETC-C or the NRC regulation. The ETC-C require the complete instrumentation of the containment (displacement, temperature, stresses in the concrete) for instrumentation during the periodic full scale pressure test and in between to monitor the ageing of the concrete. The NRC regulation requires periodic monitoring of the greased tendons when available and the completion, if necessary, by monitoring of deformation under pressure.

Beside this regulatory requisition, and following experience in other field of structural monitoring, it appears very important to initiate the monitoring of the containment at the earliest stage to have a reference that can be used in the future and to acknowledge the status of the structure. This early monitoring can be done during the concreting of specific area like the large concrete volume of the base slab or at the start of the life of the structure like during the post-tensioning operation, during the first pressure test or at the delivery of the cooling towers. In the absence of these initial status the interpretation of further periodic surveillance may be compromised.

This paper describes the benefit of the monitoring technologies applied to the containment building. Some difficulties where expressed in the past regarding the durability of the sensors, this paper attempts to highlight the new measurement methods and tools that can provide long term confidence in the measurement quality and availability.

This tool helps the employer to check that its structure has reached and keeps the mechanical features expected to satisfy the safety principle. As all the equipments of a nuclear power plant, a monitoring system is subjected to strong quality check. All the components have to be carefully selected. The methods and procedures used must be proven as efficient and reliable. The traceability has to be total, and most importantly: the employees working on the system must be qualified with relevant experience.