Non Destructive Evaluation of the durability and damages of concrete in nuclear power plants.


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ABSTRACT

The “Non Destructive Evaluation of containment nuclear plant structures” project (ENDE) is a French project developed with 8 partners. Its aims are to control the containment of structures by Non Destructive Testing with ultrasonic, electromagnetic and electric techniques. The results are than combined together to consolidate the final evaluation. Two different objectives are proposed, the first is to estimate concrete properties and the second to follow concrete damages and cracks. The 4 years project was carried out in two steps (in laboratory and on site).

The first step consists in realizing two sets of tests on concrete specimens in the laboratory. Objectives of the first set are to characterize the material and to quantify the sensitivity of the Non Destructive Evaluation (NDE) to durability indicators (elasticity modulus, strength, porosity, water content) of the concrete. Two new indicators (thermal damage and stress applied) are tested in order to take into account a possibility of an accident (LLCA). Such accident induces relatively very severe conditions (pressure=4.2 bar and temperature T=180°C) inside the containment. The second set was developed to evaluate damaged zones and cracks. The data fusion of measured NDE parameters is applied and developed for each result with two specific processes. It allows to select most sensitive and efficient approaches.

The second step consists in an investigation of selected non destructives parameters on a real structures that is containment structures under varying pressure. The presented results were obtained on a mock-up of a containment wall realized in a 1/3 scale and constructed by EDF (Electricity of France) within the VeRCoRs program. These tests are realized in 2017 and simulate the ten-year nuclear power plants control in which the two functions regularly tested are: the concrete mechanical properties and the containment walls leakage.

This paper presents the ENDE project and some of in site obtained results.

PROJECT DESCRIPTION

The project is divided in 4 work packages (WP) that correspond to the experimental plan which includes the concrete characterization in laboratory, the defects detection in laboratory and the on-site application.

WP1 has defined the experimental plans that have been further realized during the WP2 and WP3. It has described the tests, the non-destructive techniques used and the conditioning of the specimen representative to different steps of the containment life, the observables (that are output NDE parameters) which are to be measured. The methodology used to select the best observables them is based on four statistic criterions used in data fusion.

WP2 consists in realizing the testing under different conditions of the saturation rate (30, 60, 100%), of the thermal damage (the specimen are conditioned at 20°C, 80° C, 150° C or 200°C) and under conditions of stress (from 0 to 12 MPa). The NDE allows us to establish the conversion model from observables to indicators.

WP3 leads to follow-up the diffuse damage and its transition to continuous damage as well as the crack propagation. These tests are carried out on 50x25x12 cm³ concrete specimens. Testing of crack opening and closure are realized under compressive loading on 250x25x12 cm³ specimens.

WP4 consists to transfer the NDE technics achieved in laboratory to on site measurement. The in situ involved constraints are for exemple the proximity of reinforcement bars and the properties gradients in the concrete. The testing are implemented on the VeRCoRs mock up that is a double-walled enclosure.

The NDE methods applied for the WP2 and WP3 include various techniques like ultrasonic methods (linear, diffused, nonlinear), the use of electromagnetic waves (GPR, capacity) and of the electric techniques (resistivity).
RESULTS

The laboratory tests results were already presented in 2016 QNDE (Atlanta) and 2016 SFEN (Paris) congresses. Here, we focuses on the in situ measurements only. The mock up (Fig.1 a, b) is a \( \phi \) 15 x h 20 m cylinder, with 40 cm thick walls. It was constructed by EDF in order to enable the experimental simulation of the behavior of a containment building under the pressure 4.2 bar. The tests have been conducted on areas selected previously. They were manual or monitored (Figure 1 c, d) A real measurement constraint is the high density of steel reinforcement with a 10 x 8 cm mesh size. That can induce a bias in NDE measurements.

**FIGURE 1.** a) VeRCoRs containment mock-up developed by EDF, b) ultrasonic surface wave non-contact scanner, c) resistivity measurement, b) diffused ultrasonic waves monitoring

The presented results correspond to tests carried out during two periods (June 2016, March 2017). During the first period, the NDE procedures was tested and validated. During the second, the containment follows a cycle of internal pressure (Figure 2.a) which the pressure increase up to 4.2 bar. Figure 2.b. shows the evolutions of the ultrasonic shear waves within different periods. We can observe that the velocity follows the concrete water saturation rate. This rate decreases with the time between June and March what corresponds to the natural drying of concrete. During the March test, the internal pressure increased up to 4.2 bar from time T0 to T1. The velocity decrease corresponds thus to the decrease of the concrete pre-stress. Finally, in the last step (T2), the pressure decreases, and the ultrasonic velocity increases.

**FIGURE 2 a) Internal pressure cycle, b) Follow-up of shear waves velocity for different of testing,**

Concerning the follow of cracks, an automated scanner (Figure 1.b) using ultrasonic surface waves allowed to detect cracks and to follow their openings. This device analyses the evolution of the local surface wave attenuation \( \Delta \alpha \) as a function of the pressure evolution. Figure 3 plots this evolution during the pressure increase from 0 to 4.2 bar. The lines A correspond to the tendons ducts identified by the knowledge of their positions. The line B corresponds to a visible crack position identified during a previous pressure test in 2016. We can observe that the \( \Delta \alpha \) increases regularly with time what can be linked with the cracks openings, thus with leakages. The lines C correspond to two events increasing with the time that cannot be linked to any known cause. So we conclude that these lines C just indicate non-emergent cracks.

**FIGURE 3: Evolution of the surface wave attenuation variations \( \Delta \alpha \) measured along the horizontal profile as an increasing pressure function.**

CONCLUSION

The presented examples cover the only small part of results obtained by the ENDE project. We have shown that NDE methods can be successfully used on a mockup of a nuclear power plant. Two techniques were presented. First, the evolution of the ultrasonic velocity that can be linked to the concrete saturation rate and the internal pressure. Second the cracks monitoring by means of the automated surface wave scanner which allows the detection of invisible cracks and its evolution. So it allows to follow the leakage or cracks openings.