Introduction

A concrete structure can be subject to several factors that may damage it during its service life. These factors are either climatic, chemical or accidental. The security requirements are more and more specific and severe. To ensure the safety of a structure, it is important to know its state and the properties of the materials that make it up. For this purpose, many tests have been developed. Most of them consist of applying mechanical or chemical tests on specimens of a structure. These tests are called Destructive Tests. The use of this kind of tests to determine properties from a structure in service should be avoided as often as possible.

The first and the most simple test is the visual inspection of the structure, but this can only identify macroscopic damage at accessible locations. As an alternative, many Non-Destructive Tests have been developed during the last thirty years with applications either in civil engineering structures or in aeronautics. Most of them also require an inspector and, in addition to the high costs, the number of tests and the location of these tests are strongly restricted. The current trend in research is the development of embedded structural health monitoring methods. The main goal is to reduce inspection costs and risks of unexpected failure using real-time online monitoring systems. For this purpose, sensors and inspection devices are miniaturized and some of them are embedded in the structure. The automation of the measurement improve the efficiency, the repeatability of the tests but also has the advantage of a better integration in the overall design of the structure.

In the field of damage detection in concrete, tests using piezoelectric transducers are very common. The principle is very basic, it consists of sending acoustic waves from a transducer and measuring the response on another transducer. Acoustic waves are produced by the mechanical vibration of the medium. For instance, this method allows of computing the velocity of the propagated waves, which is an important property to evaluate the state of the concrete. Integrate this kind of sensors in the structure improve the efficiency of these tests and add more flexibility in the choice of the location. Within this framework, the concept of Smart Aggregates has been developed by researchers at the University of Houston, Texas.

Experiment

The main goal of the Master Thesis was to be able to detect the appearance of cracks in a reinforced concrete beam using Smart Aggregates as shown on Figure 1.

![Figure 1: Test principle. The beam is loaded, cracks appear on the center of the beam, acoustic waves are sent from the transmitter to the receiver, the signal response change with appearance of damages](image1)

With the increase of the load, damages appear on bottom of the center of the beam due to the weak tensile resistance of the concrete. Two piezoelectric transducers are cast in the structure, one is a emitter and one is a receiver. They are located on each side...
of the center of the beam, where the first crack is supposed to appear. These piezoelectric transducers are called Smart Aggregates.

As shown on Figure 2, the smart aggregates are first composed of a piezoelectric material that is deformed by a difference of potential on its faces and conversely. This kind of material can therefore be used for sending and recording acoustic waves. The waterproof coating avoids any electrical link between the different Smart Aggregates in presence of water. The electrical coating is a shielding that aims to reduce the noise due to the electromagnetic environment. The mortar is used both for a better mechanical strength of the transducers and to improve the efficiency of the transducer.

The test consists in sending short pulses at high voltage and recording the transmitted waves on the receiver during the loading of the beam. Cracks or microcracks in the structure appear with the load increasing. This modifies the internal structure of the beam and the paths of waves and therefore the received signals.

From the observations, a damage index is defined. It is based on a simple principle: the first part of the received signal corresponds to the shortest path of the propagating waves. If a crack appear, the path followed by the waves is modified and then the signal is modified. This index is constructed from the received signal at a certain load by comparison with the received signal before any load and therefore without any damage. A high-quality picture corresponds to each signal, it is then possible to compare modifications in the signal with the appearance of cracks.

Results

Figure 3 summarises the results of the test. The damage index starts to evolve slightly before the first observation of appearance of some micro-cracks on the center of the beam. The value of the damage index continue to increase until the crack is totally opened. After that, the cracks width grows but the damage index does not evolve. These results show a good correlation with the observation during the experiment. Much of the increasing of the indices is located before the formatting of cracks. This demonstrates that this method is able to detect the exact moment of appearance of crack in the structure.

Conclusions and future applications

It is exposed that using embedded piezoelectric transducers is suitable for evaluating the health state of a structure. MS$^3$ (Material and System for Safety and Security) is a company specialized in the study of specific safety barrier and associated to this Master Thesis. This company shows a great interest in integrating smart aggregates in the concrete slabs where the security barriers are founded. In this case, smart aggregates could help to evaluate the health state of the concrete, after a crash for instance. Previous works has also demonstrated that Smart aggregates can also be used for following the concrete curing in the first hours after the pouring and during its service life.

http://www.ms3.be