Bridge spatial displacement monitoring with 100 fiber optic sensors deformations: sensors network and preliminary results

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ABSTRACT

In 1996, our laboratory fitted an highway bridge near Geneva (Switzerland) with more than 100 low-coherence fiber optic deformation sensors. The Versoix Bridge is a classical concrete bridge consisting in two parallel pre-stressed concrete beams supporting a 30 cm concrete deck and two overhangs. To enlarge the bridge, the beams were widened and the overhang extended. In order to increase the knowledge on the behaviour between the old and the new concrete, we choose low-coherence fiber optic sensors to measure the displacements of the fresh concrete during the setting phase and to monitor its long term deformations. The aim is to retrieve the spatial displacements of the bridge in an earth-bound coordinate system by monitoring its internal deformations. The curvature of the bridge is measured locally at multiple locations along the bridge span by installing sensors at different distances from the neutral axis. By taking the double integral of the curvature and respecting the boundary conditions, it is than possible to retrieve the deformation of the bridge. The choice of the optimal emplacement of the sensors and the sensor network are also presented.

Keywords: Bridge monitoring, Deformation sensor, Fiber Optic Sensor.

1. INTRODUCTION:

The civil engineering community is becoming increasingly interested in the monitoring of the structural behavior and in new tools allowing the assessment of structural integrity and performances. Concrete structures are especially interesting because of their prevalence in the ground transportation infrastructure and because of the increasing attention accorded to the behavior of aging structures.

In 1996, our laboratory fitted a highway bridge near Geneva (Switzerland) with low-coherence fiber optic deformation sensors. The engineers, who had studied the enlarging of this concrete bridge were interested, besides the long-term monitoring, by the spatial displacement of the bridge and the effects of concrete shrinkage between the old part and the new part of the bridge. To obtain reliable measurements, special attention was given to the design, the emplacement and the definition of the multiplexing network of the deformation sensors.

Figure 1: The north Versoix bridge during its widening

2. THE VERSOIX BRIDGE: DESIGN AND WIDENING

The North and South Versoix bridge are two parallel twin bridges (see figure 1). Each one supported two lanes of the Swiss national highway RN9 between Geneva and Lausanne. The bridges are classical bridges consisting in two parallel pre-stressed concrete beams supporting a 30 cm concrete dec k and two overhangs. In order to support a third traffic lane and a new emergence lane, the exterior beams were widened and the overhangs extended (see figure 2). The construction progressed in two phases: the interior and the exterior overhang extension. The first one began by the demolition of the existing overhang followed by the reconstruction of a bigger one. The second phase consisted to demolish the old overhang, to widen the exterior web and to rebuild a bigger overhang supported by metallic beams. Both phases were built by 14 m stages. The differential shrinkage between the old and the new concrete influences the bridge security. In order to increase the knowledge on the bridge behavior, the engineer choose to monitor the long term deformation of the north bridge.

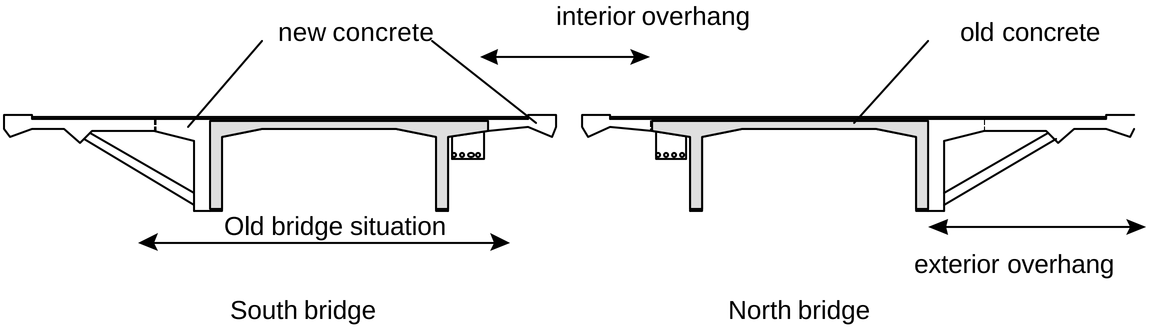


Figure 2: The north and south Versoix bridge: widening principle

3. THE MONITORING SETUP

3.1 Choice of the monitoring method

To measure the differential shrinkage during the construction, a monitoring method including both a reading unit and a stand-alone sensor (to be installed in the concrete) has been chosen. This system had to be robust, usable in the harsh building site conditions, quick to install and very accurate (about 10 µm/m). For this application, the SOFO system (French short for Monitoring of Structures by Optical Fibers) was chosen. It was already used with success on more than five bridges[1]. It is based on low coherence interferometry and the reading unit measures the difference of length between two fibers, one is called the measurement fiber and follows the displacement of the structure while the other one (the reference fiber) is free (see figure 3). The system is composed by a portable, waterproof and battery powered reading unit and a sensor. The resolution of this monitoring method is about 2 µm (independent of the measurement length) with a linearity of 1% and a dynamic range of 50 mm. The sensor were pre-tensioned at 0,5 % allowing to place it in the structure very rapidly. All these component were furnished by the SMARTEC SA company.

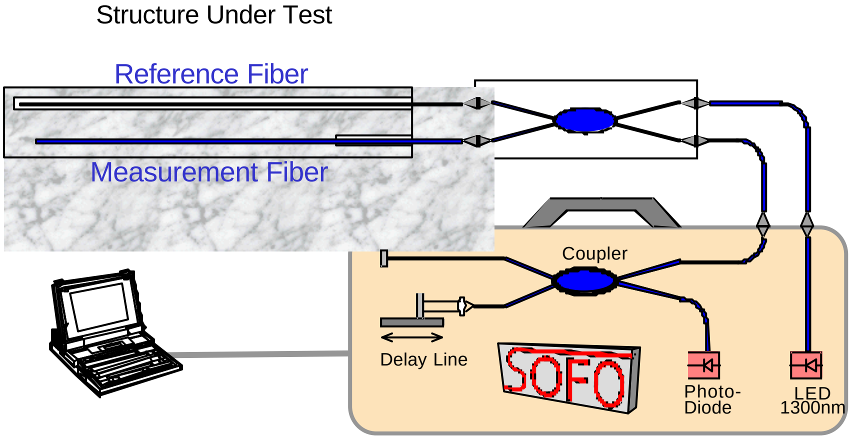


Figure 3: Optical setup of the SOFO system. The portable reading unit is waterproof and battery powered. The Sensor is made up of a reference fiber which is free and a measurement fiber which is attached to the structure.

3.2 Number and emplacement of the sensors

To measure the spatial displacements of the bridge, we apply an algorithm calculating them from the curvature measurement[2]. In order to get redundancy and to follow the building stage of 14 m, 1 section of sensor has been placed each 7 m. Because of budget limitations, only 2 of the 6 spans were fitted by optical fiber sensors. A preliminary study by finite element showed that the deformations of the two spans could be approached by two 5th degree polynomial functions. At least 4 curvatures measurements for each span are therefore necessary to obtain the bridge spatial displacements. Five sensors (Sensor 1, Sensor 2, Sensor 3, Sensor 4, Sensor 6) have been placed inside the new concrete and to give a good representation of the curvature section. One additional sensor (Sensor 8) has been installed on the surface of the old concrete (see figure 4). To obtain a ggod representation of the mean curvature, sensors with four meter active length have been chosen. Two additional sensors were been installed (Sensor 3 and Sensor 5) to give information about the differential shrinkage between the old and the new concrete. Curvature measurement will be retrieved by 8 sensors for each section and the spatial displacement will be calculated by 5 and 7 sections on the first and the second span (see figure 5).

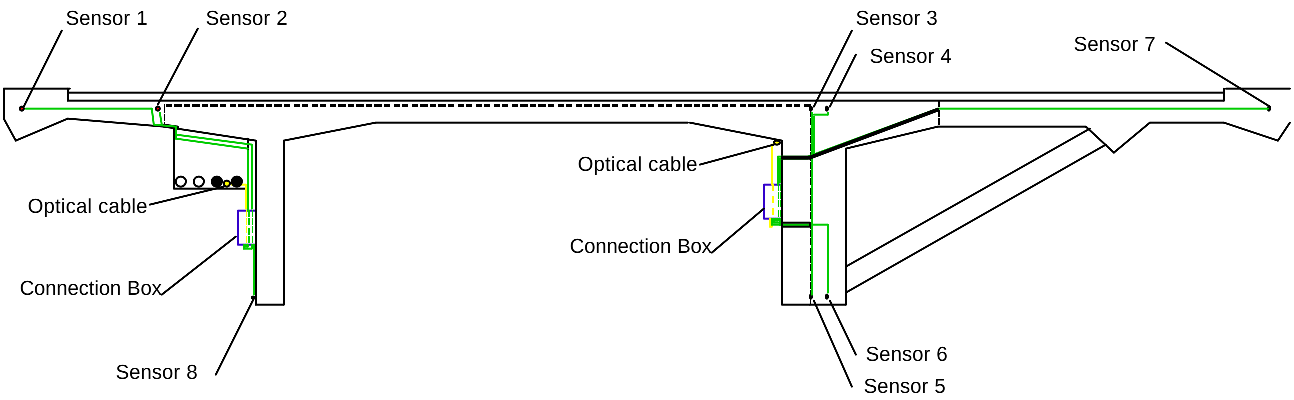


Figure 4: Sensor situation.

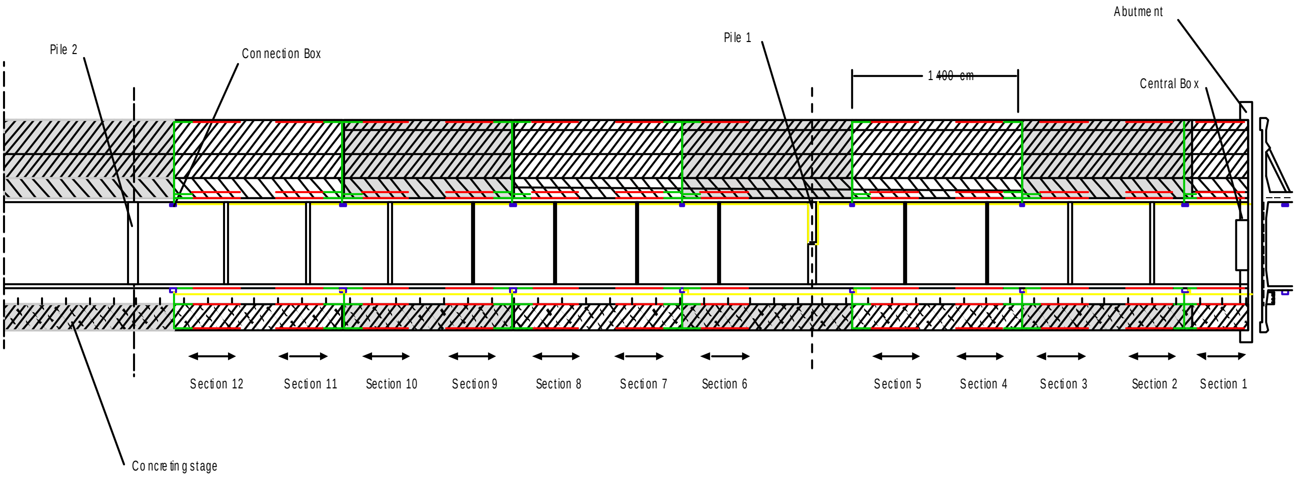


Figure 5: Top view of the Sections situation.

3.3 Sensor network

To facilitate the future implantation of automatic and remote surveillance, the sensor network has to be measured in one single and easily accessible location: the abutment. To rapidly install the sensors in the structure, their size has been optimized and each one reaches a connection box linked by an optical cable to the central box. The network is composed by 104 fibers optics deformations sensors of 4 m active length and 2-10 m passive length, 14 optical cables 10-100 m length, 14 connections boxes (see figure 6) and one central box. The central box will allow to place the reading unit, optical switches, portable PC and mobile phone to measure the bridge through the Internet.

4. SENSOR INSTALLATION

The sensor installation follows the bridge widening schedule. The installation was very rapid, 2 hours were enough to place 4 sensors in each concrete stage (for the interior overhang widening). Sensors were placed in the framework just after its completion and the building yard schedule was not delayed. Sensors were only held with plastic strings (and not fixed) to the re-bars (see figure 7). Connection boxes were placed at the same time than the sensors in order to protect the optical connector, to control and to measure each one during the installation and the bridge construction. Finally, the connections boxes were linked to the central box to measure all the sensors from the same place. The 13 exterior sensors (sensor A8) were fixed to the surface of the interior web using metallic squares.

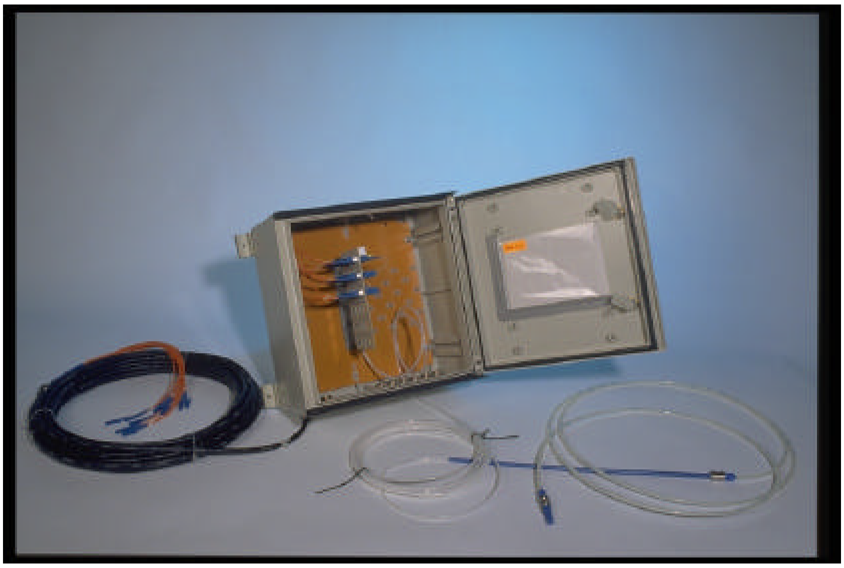


Figure 6: From left to right: a optical cable, a connection box and a sensor (active length 4 m)

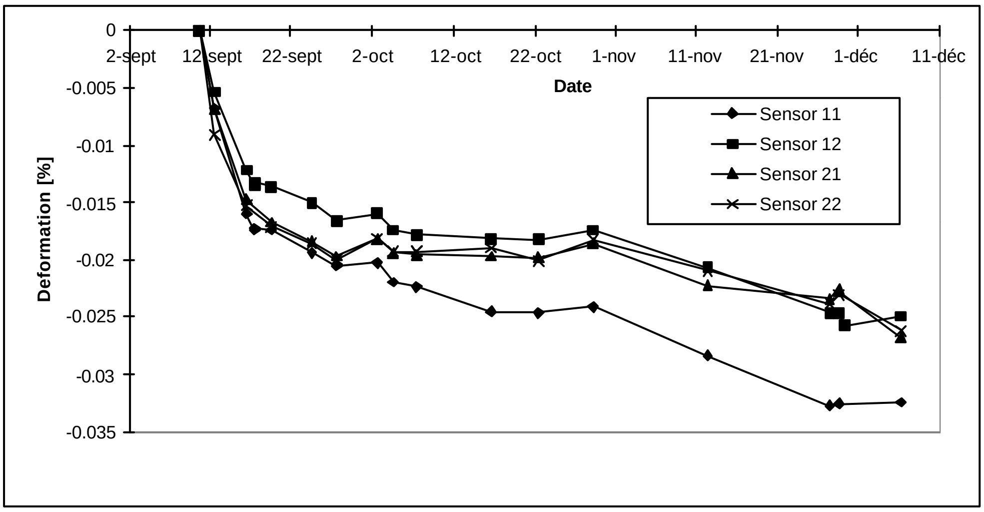
Figure 7: Fixation of the sensor to the the framework. Sensor are held but not fixed to the re bars with plastic ring

During the concreting phases the workers did not know that optic sensors were present in the framework and worked like every day, pouring the concrete directly on the sensors (see figure 8).

Figure 8: The concrete was poured on the sensors without any precaution

5. PRELIMINARY RESULTS

Only the interior extended overhang were instrumented at the time of writing, therefore the curvature measurements can not to be analyzed yet. The realized measures concern essentially the drying shrinkage of concrete. Figure 9a) and 9b) show the concrete deformation of stages 1 and 2. All the optical fiber sensors of a same stage indicate a same behavior. The sensors show however a different behavior between stages 1 and 2. Stage 1 has a shrinkage of .02 % while the other one has a shrinkage of 0.005%. This difference is e xplained by the use of a different concrete mix between the 2 stages and the different climatic conditions. On the 2 graphs, three phases are distinguishable: the first is the drying shrinkage, the second is a stabilization phase The last one is due to the decrease of the bridge temperature during the month of November 1996. These variations are consistent with a temperature reduction of about 10°C that was actually observed.



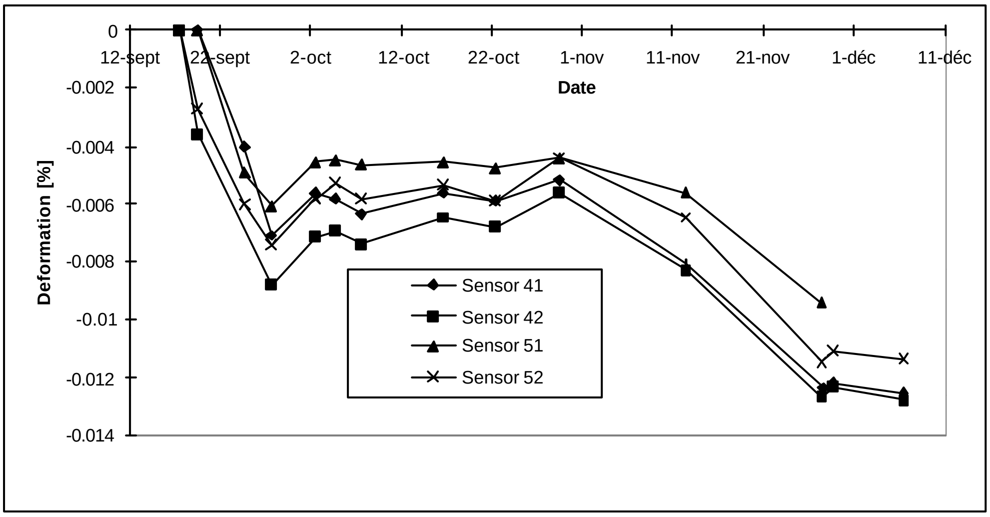


Figure 9a) et 9b): Sensor measurement of the first and the second concr ete stage.

6. CONCLUSION

The possibility to install more than 100 sensors in a bridge without delayed the building yard schedule was been showed. It is necessary to rely on a well proven monitoring system including both a reading unit adapted to the harsh building site conditions and a stand-alone sensor (to be installed in the concrete). The measures of the different building stage show that it is possible to appreciate very rapidly the different quality of concrete and explain, for example, the crack's appa rition. Fiber optic sensors based on low-coherence interferometry proved ideal to implement this concept in the case of concrete structures. The presented application shows the power of the technique, the great amount of information and the precision that can be obtained. The Versoix bridge will be measured regularly and the curvature measurement will certainly allow to better understanding of the real bridge behavior allowing and increased security.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

For further information on the SOFO project look at the following WWW home page: **http://imacwww.epfl.ch**

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