Automatic and Remote Deformation Monitoring of the Genoa San Giorgio Pier using SOFO sensors

Daniele Inaudi
SMARTEC SA
Via al Molino 6,CH-6916 GRANCIA, Switzerland
Tel: +41 91 993 09 24, Fax: +41 91 993 09 40
email: inaudi@smartec.ch, Web: www.smartec.ch

Andrea Del Grosso, Fancesca Lanata
Università degli Studi di Genova
Istituto di Scienza delle Costruzioni
Via Montallegro, I-16145 Genova, Italy

Giorgio Brunetti
TECNITER s.r.l.
Via Majorana 4, I-20060 Cassina de'Pecchi (MI), Italy

Mario Fedolino
Autorità Portuale di Genova
I-16125 Genova, Italy

ABSTRACT

SOFO is a structural monitoring system using fiber optic deformation sensors. It is able to measure deformations between two points in a structure, which can be from 20 cm up to 10 meters (or more) apart with a resolution of two microns (2/1000 mm) even over years of measurements. The system is composed of optical deformation sensors adapted to direct concrete embedding or surface mounting, the cable network, the reading unit and the data acquisition and analysis software. The system is particularly adapted to precise short and long-term deformation monitoring of large structures.

An array of more than 60 sensors have been installed on the pier of San Giorgio Levante in the Genoa harbor. These sensors allow the measurement of the pier displacements during the dredging works, ship docking and in the long term. The sensors measure the curvature changes in the horizontal and vertical planes and allow a localization of settlements with a spatial resolution of 10 m over a total length of 400 m. The sensors can be measured automatically and remotely. This paper presents the sensor installation and the results from the first monitoring period..

1. SAN GIORGIO LEVANTE PIER MONITORING

The San Giorgio Levante pier (Figure 1) is part of the Genova harbor and is operated under the responsibility of the Genova harbor authority.

This pier is mainly used for loading and unloading of coal and other bulk goods. Its has a length of approximately 400m and a width of 40m. In order to increase the water depth from the current 11m to 14m, it has been decided to reinforce the pier foundations with jetting columns and anchorages.

Figure 1 The San Giorgio Levante Pier

The aim of the instrumentation is to monitor the pier longitudinal and transverse deformation in the short and long term. The sensors will be used to measure both the local and global pier deformations during pier dredging, during ship docking and in the long term.

2. SENSOR NETWORK

The instrumentations is based on the use of SOFO® fiber optic sensors. These sensors allow the measurement of deformation of the order of a few micron over measurement bases up to 10m with excellent long-term stability and no temperature cross-sensitivity.
In the case of the San Giorgio Levante pier it was decided to install 10m long sensor in the cable gallery inside the pier itself. The sensors are placed parallel to the pier length and are reunited in 24 groups of 3 sensors (see Figure 2). Some of the sensor near the end of the pier are also installed in grooves machined in the pier concrete (see Figure 3). A total of about 70 sensors was installed.

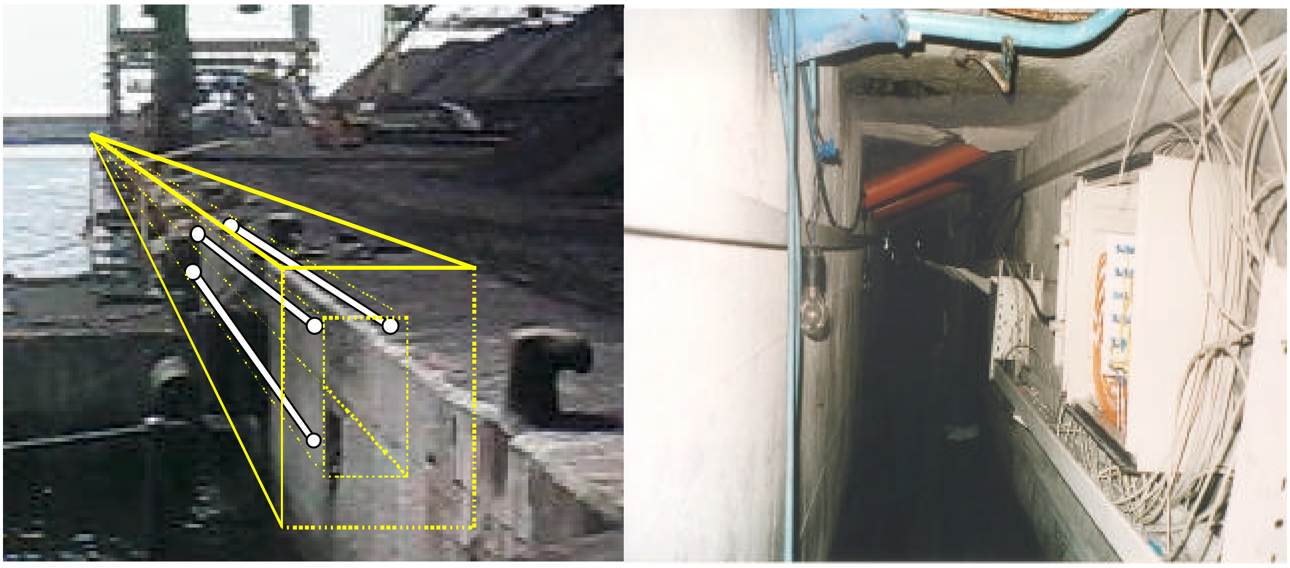

Figure 2 Sensor installation in the pier gallery

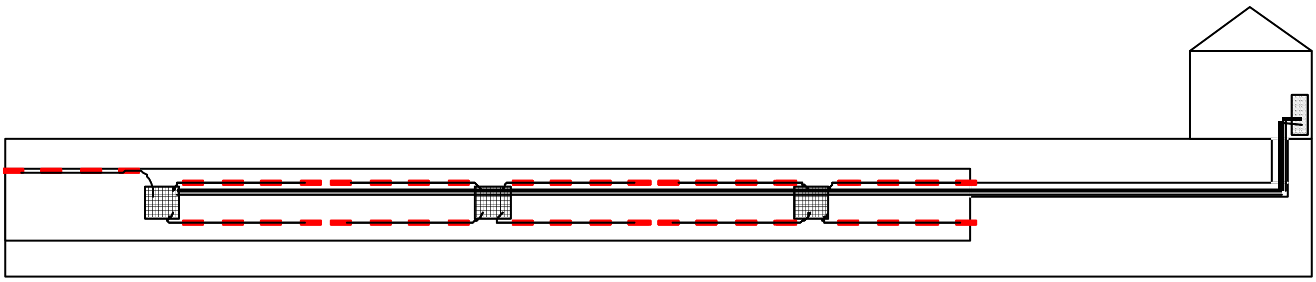

Figure 3 Sensor installation along the pier

Figure 4 Sensor installation with L-brackets. One end of the 10m long sensoris shown

Figure 5 SOFO reading unit , optical switch, control PC and cable connections

The sensors are installed in standard cable ducts and are attached to concrete using L-bracket adapters (see Figure 4).The cable from the sensors is than routed to 3 connection boxes. From there, three multi-fiber cables connect to the measurement system located in a container and easily accessible without interfering with the pier operation.
The readout is based on the SOFO system and is located in an easily accessible location with connection to the Genova harbour data network. The sensors are measured fully automatically thanks to an optical switch that sequentially connects the sensors to the reading unit (see Figure 5). The system is programmed to measure at pre-defined intervals or on request. The measurements are stored into a relational database that can be read remotely through the harbour fiber-optic data network.

3. DATA ACQUISITION AND ANALYSIS

In the case of the San Giorgio Levante pier we have to deal with a non homogeneous structure which does not necessary deform like a continuous beam. Several joints are placed along the pier and the pier itself was constructed in phases over long periods of time. This means that the cross-section is not uniform. The analysis of the measurements therefore requires particular attention. In this first phase, we are observing the pier in its initial state and learn its behavior under changing conditions like temperature, coal load, ship docking and crane position. When the dredging will start, we will than compare the measured deformations with the ones recorded in this training phase. This should allow the detection of the onset of abnormal deformations and avoid damage to the structure.

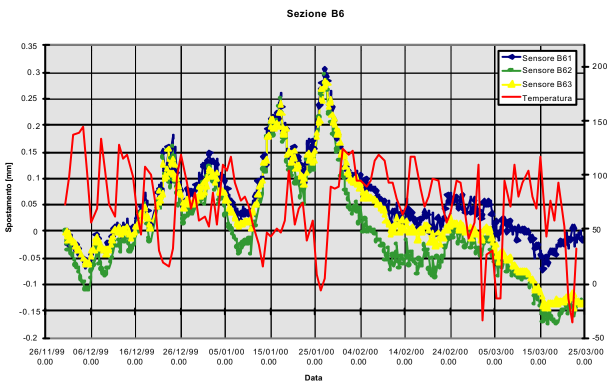

Figure 6 Deformations and temperature changes in cell B6. Deformatins are in counter-phase with the temperature.

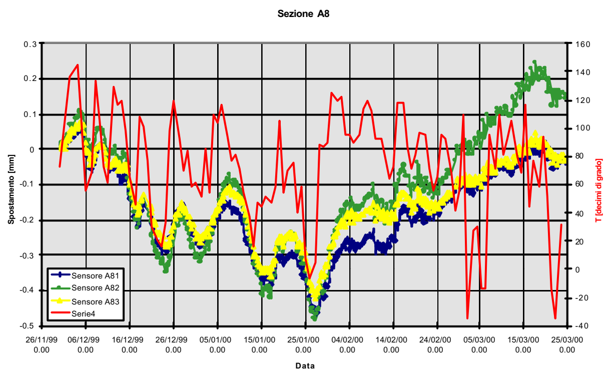

Figure 7 Deformations and temperature changes in cell A8. Deformatins are in phase with the temperature.

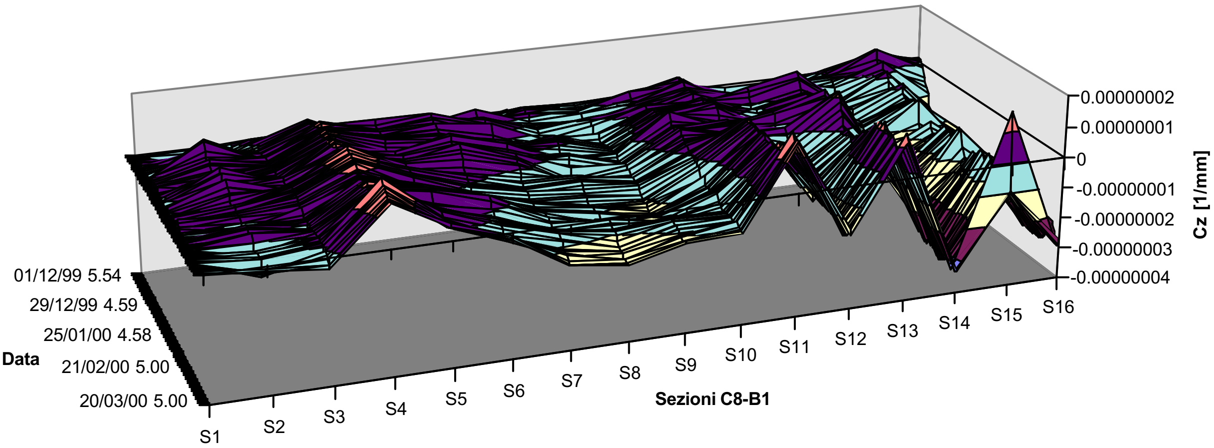

Figure 8 Recorded Curvature as a function of the position in the Pier and of the temperautre

Figure 6 and Figure 7 show the recorded deformations over a period of 4 months. Each graph shows three sensors installed in the same cell (B6 and A8 respectively). It can be noticed that the measurement in each cell are well correlated, indicating that the main deformation is a uniform elongating or shortening. The recorded deformations follow the temperature changes with a response time of a few days, indicating the large thermal inertia of the structure. It is interesting to notice that some cells, e.g. A8, follow the temperature changes in phase, while others, follow it in counter-phase. This is due to the presence of dilatation joints in the structure. For a falling temperature, the sensors spanning the joints will measure an increased joint opening , while those mounted on a continuous block will measure a shortening.

Figure 8 shows the measured curvature as a function of the position in the pier and of the date. It can be noticed that the sections near the beginning of pier show smaller curvatures than those at the end. This behavior still needs to be fully explained, however it seems that the sensors installed in grooves on the surface are more reactive than the ones installed in the gallery.

This data is now used to train a phenomenological model that will than detect deviations from the "normal" behavior during dredging works. We also plan co carry out additional measurements to correlate the deformations with the presence of ships and coal on the pier.

4. CONCLUSIONS

This application shows how long-gage fiber optic sensors can be conveniently used to monitor a large structure with a reasonable number of sensors. This global monitoring system allows the detection of any degradation that has an effect on the structural performance of the system. When irregularities are found at that level it is usually necessary to proceed to a deeper investigation and possibly additional local instrumentation. The described sensor network can be seen as an equivalent to our nervous system that signals any problem in its functions with the apparition of pain and urges us to call the doctor for further investigation.

This instrumented pier is only the first step to the realization of an "intelligent harbour" capable of self-diagnosis and able to provide information on its state to increase its security and, most of all, to give quantitative data useful for the management of the structure maintenance.

REFERENCES

D. Inaudi, N. Casanova, P. Kronenberg, S. Vurpillot "Embedded and surface mounted sensors for civil structural monitoring", Smart Structures and Materials, San Diego Mars 1997, SPIE Vol. 3044-23.

S. Vurpillot, D. Inaudi, A. Scano, "Mathematical model for the determination of the vertical displacement from internal horizontal measurement of a bridge" smart structures and materials, San Diego February 1996, SPIE Volume 2719-05.

N. Perregaux, S. Vurpillot, J.-S. Tosco, D. Inaudi, O. Burdet, "Vertical Displacement of Bridges using the SOFO System: a Fiber Optic Monitoring Method for Structures", 12th ASCE Engineering Mechanics. San Diego, La Jolla. May 1998.D. Inaudi, N. Casanova, B. Glisic, P. Kronenberg, S. Lloret, L. Pflug, S. Vurpillot, "SOFO: Structural Monitoring with Optical Fiber Deformation Sensors".

S. Vurpillot, D. Inaudi, "Object-Oriented Concept Classification of Large Measurement Data Sets in Civil Structures", 12th ASCE Engineering Mechanics. San Diego, La Jolla. May 1998.

D. Inaudi, N. Casanova, G. Martinola, S. Vurpillot, P. Kronenberg "SOFO: Monitoring of Concrete Structures with Fiber Optic Sensors", 5th International Workshop on Material Properties and Design, Weimar, October 1998, Aedificatio Publishers, pp. 495-514.