The Genoa San Giorgio Bridge Fiber-Optic Structural Monitoring System

Federica Piastra[1](✉), Giovanni Cusano[1], Giulio Ventura[2], Bruno Griffoni[3], Justin Stay[4], and Daniele Costantini[4]

[1] CETENA SpA, 16121 Genova, Italy
federica.piastra@cetena.it
[2] ARCOS Engineering Srl, 10129 Turin, Italy
[3] GHT Photonics Srl, 35135 Padova, Italy
[4] LUNA Innovations Inc, Blacksburg, VA 24060, USA

Abstract. A fiber-optic based structural monitoring system has been designed and deployed by CETENA of the Fincantieri Group on the new Genoa San Giorgio bridge, which replaced the collapsed Polcevera viaduct. A network of more than 240 sensors, most of them based on fiber-optic technology, has been installed to follow movements, vibrations and operating conditions of the bridge deck and piles in real-time. First of all, the monitoring solution aims to keep under control the loads and deformations of the structure, for verifying that its behavior lies within the boundaries of the project design. Both the bridge displacement and strain (due to the temperature changes and the passage of vehicles) and the piles' tilt are recorded and analyzed to relate the actual behavior of the structure. In addition, several accelerometers are distributed along the bridge deck to check the bridge vibrations with Operational Modal Analysis (OMA). OMA allows to reconstruct the real structural dynamic behavior in real-time and compare it to the project design one, depending on the boundary conditions. At the same time, a database on both the structure behavior and the surrounding conditions is being built for properly and efficiently planning maintenance activities in the medium and long term. In summary, the fiber-optic structural monitoring system is the solution chosen by the owner for both efficiently operate the infrastructure and assuring the safety of people over many decades.

Keywords: Fiber-optic · SHM · Sensors · Operational Modal Analysis · Safety

1 Introduction

Large scale civil engineering structures such as bridges, tunnels and large dams have significant need for long term structural health monitoring (SHM). Their service life is usually decades or even hundreds of years, over which they are inevitably affected by several types of environmental loads. Real-time health monitoring can be a powerful tool to improve both the operation performance and the safety of both existing and new structures [1].

P. Rizzo and A. Milazzo (Eds.): EWSHM 2022, LNCE 254, pp. 42–50, 2023.
https://doi.org/10.1007/978-3-031-07258-1_5

SHM uses embedded or surface mounted sensors as the nervous system to sense and predict defects and damage of the structure. In the case of large structures like bridges, fiber-optic sensing is a valuable alternative to the traditional electrical sensing techniques because of higher durability, reliability and simplified deployment [2].

A fiber-optic monitoring system was designed and deployed by CETENA of the Fincantieri Group for the new Genoa San Giorgio bridge. Such a fiber-optic structural monitoring system aims at keeping under control in real-time the loads and deformations of the structure, in order to verify the design assumptions. At the same time, it will allow to build a database of the bridge structure main vital parameters as a function of the surrounding conditions, that the operators can use to guide maintenance activities in the medium and long term. It is going to be an essential system to understand the loads caused by the wind, the temperature changes, the passage of vehicles or earthquakes while alerting in real-time on the actual behavior of the structure.

2 The Genoa San Giorgio Bridge

The Genoa San Giorgio Bridge is a motorway viaduct that crosses the Polcevera river and the districts of Sampierdarena and Cornigliano in the city of Genova (Italy). It replaces the Ponte Morandi which tragically collapsed on 14 August 2018 and was demolished in June 2019. The architect Renzo Piano designed the new bridge as a gift to his hometown.

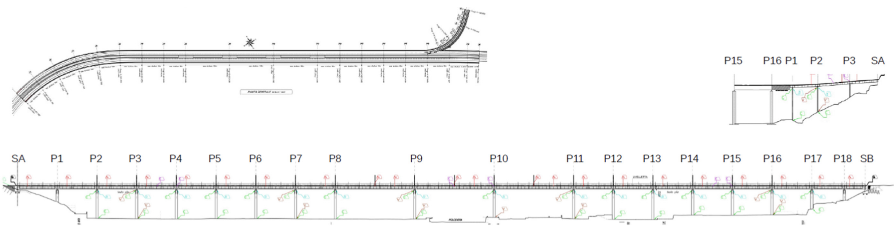

Fig. 1. The Genoa San Giorgio Bridge plan.

The new viaduct, with its associated junction (ramp) (Fig. 1), constitutes the initial section of the Italian A10 motorway which in turn is included in the European route E80: it has been built in a very short time, because of its huge economic value in the main traffic routes of northern Italy. Not only it connects Genoa and its main commercial and passengers' harbors to the North West of Italy, but it also connects Italy to France.

The new San Giorgio bridge was jointly built by Fincantieri Infrastructures and by WeBuild and inaugurated on 3 August 2020. Built as a mixed steel-concrete structure, it is 1,067 m long and consists of 19 spans supported by 18 elliptical section reinforced concrete pillars with constant cross section (Fig. 2). It has a ramp which connects the main bridge with the motorway coming from Milan (A7), with three smaller pillars like the main ones.

Fig. 2. The Genoa San Giorgio Bridge: a mixed steel-concrete structure with 18 concrete pillars and a 1km long steel deck made of 19 spans.

3 The Fiber-Optic Monitoring System

The bridge structural designer indicated both the type and positioning of the sensors on the bridge and their specifications. CETENA took care of both the executive project and the entire development, installation and implementation phase of the system. Thus, supported by commercial and technical consulting of GHT Photonics, they selected the sensors, the acquisition systems and the analysis algorithms and methodologies, with a close collaboration with the designer and under the approval of the construction supervisor. The monitoring system is made up of over 240 sensors of various types (most of them based on fiber-optic technology but not only) distributed across the concrete piers and along the steel deck.

3.1 Description of Sensors: Type, Positions, Purposes

Forty-one fiber optic accelerometers (Fig. 3) are installed on the deck to check the vibrational behavior of the bridge with OMA (Operational Modal Analysis) analysis. Eighteen plus twelve (six couples) of them are installed in the vertical direction at 1/3 and 2/3 of the span to evaluate the vertical bending and torsional modes. Then, eleven accelerometers are placed in the correspondence of the pillars to analyze the horizontal and longitudinal modes.

ARCOS Engineering developed and implemented the OMA analysis system which allows to determine the dynamic features of the bridge in real time, compare the real dynamic behavior of the deck with that estimated by the project designers and monitor its evolution in time.

In addition, the structural health of the bridge is evaluated from the point of view of the deformations and stresses. In particular, eight deck sections have been identified to be monitored with the aim to evaluate the stress state of the structure in the mid of the span and in correspondence to the pillar for four categories of spans (50 m curve span, 50 m

Fig. 3. The installation of the LUNA os7520 fiber-optic accelerometers.

straight span, 100 m straight span and ramp span). In each section, six positions (four for the ramp, respectively) have been identified by the designer to check the structurally most critical points of the metal deck with the sensors (Fig. 4).

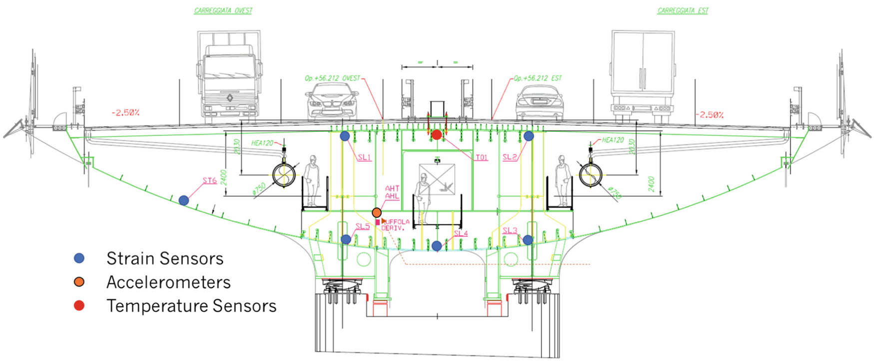

Fig. 4. Cross section of the bridge deck with the positions of the strain sensors (blue dots), temperature sensors (red dots) and accelerometers (orange dots).

Before the installation of the definitive monitoring system, which is characterized by forty-four fiber optic strain gauges, CETENA played an important role in the stress monitoring during the construction, launch and testing of the bridge. In the same positions identified for the in-operation stress monitoring, just as many temporary strain gauges have been installed with the aim to monitor the deformation of the structure from the initial assembling stages up to deck launch, and during the test trials (successfully performed in July 2020). In this way, not only the bridge deformation has been monitored during the transitional phases, but also the in-service monitoring system has been calibrated based on the specific evaluated strain status for each fiber optic strain gauge.

The strain gauges of the in-operation monitoring system have been installed near the ones previously placed for construction, launch and testing phases.

In the behavior along seasons and years, the thermal action has a large influence on bridge displacement which needs to be monitored. For this purpose, fifty-two displacement sensors based on radar technology are installed in transversal and longitudinal directions with the aim to measure the millimeter displacements of the deck with respect to the piles. The deck is welded from side to side without joints, constituting a single beam over a kilometer long, resting on eighteen piles. Following thermal variations or wind action, the metal structure undergoes expansion and deformation and glides over the supports. These relative displacement sensors have been therefore installed to verify that the behavior, according to the surrounding conditions (wind and temperature), complies with what was estimated in the design phase.

In addition to the wind (acquired with two anemometers and one climatic unit installed on the road level), thermal excursions are also of great importance, not only between night and day, but also between one side and the other: due to the location of the bridge in the Genoa area, the sea side of the steel deck faces south and it is greatly affected by solar radiation, while the one upstream to the north is characterized by lower temperatures.

As for the temperature, there are thirty-one fiber optic temperature sensors installed inside the deck (Fig. 4), dedicated or combined with the strain sensors. By knowing the temperature at the specific points of interest, the thermal effect is evaluated in various ways for the different types of measurements (strain, displacement, tilt).

As it concerns the pillars, seventy-two fiber optic tiltmeters and fourteen fiberoptic accelerometers used as velocimeters are installed both in the longitudinal and transversal directions and both at the base and at the top of each element (Fig. 5). They are placed in stainless steel boxes fixed with the structure to monitor the static and dynamic movements of the pillars respect to the design expectations. The accelerometers implemented as velocimeters allow to check possible seismic events in the area.

A dynamic weighing motion system completes the structural monitoring system of the bridge, detecting every vehicle in transit, in both directions, and determining their speed and weight. Such information complements the data measured by the field sensors and it is combined to be elaborated by the analysis algorithms.

Regarding the fiber optic instrumentation installed on the San Giorgio bridge, it represents the state of the art in this field: the high precision optical fiber sensors, specifically required and installed for the purpose, are inter-connected to and read out by two LUNA Innovations si255 Hyperion interrogators (one at 10 Hz for strain and temperature sensors and one at 1 kHz specifically dedicated to the accelerometers). These acquisition units are installed in the technological building near the bridge.

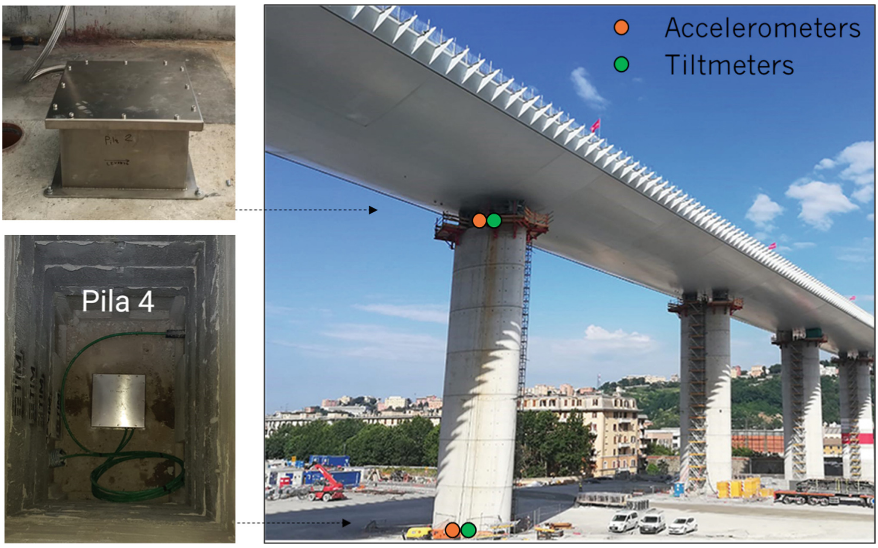

Fig. 5. The position of the fiber optic accelerometers and tiltmeters at the base and head of each pile.

4 Measurement Data

The operator has access to the system via the SCADA (Supervisory Control and Data Acquisition) user interface, which includes not only the structural monitoring system but collects all the systems installed on the bridge (lights, electrical distribution, robot inspection, etc.). The user interface has been specifically developed to give a simple and immediate representation of the bridge status from the structural point of view, with dedicated sections for each type of sensors and a tab dedicated to the diagnostics where alarms and warnings are displayed in real time. In the user interface, the elaborated data are reported while the raw data are saved in a dedicated database which is available for the post processing analysis.

A background interface, reserved to CETENA, allows to remotely check the status of the system during normal operation and in case of exceptional cases (for example, malfunctioning circonstances), in order to periodically perform all necessary activities to check and maintain the system in a good operating status.

Following the acquisition, specific algorithms continuously process the data to verify that the detected parameters are within the safety margins and the operating behavior envisaged by the designers. In particular, the identification of these safety margins is extremely important for the correct management of the monitoring information to take under control the structural conditions, assessing the design-compliant behavior of the bridge and to provide all data for driving maintenance issues. The values of these safety limits have been determined by designers after observing (and comparing with the design models) the behavior of the viaduct and the measurements acquired during one year (from December 2020 to December 2021). As a matter of fact, only after such a time of operation it is possible to have meanigful data set covering a complete season cycle, as it concerns weather conditions, temperature and traffic, as well as sensors responses.

The continuous monitoring over one year allowed to perform all the fine tuning activities (necessary for a such complex system on a big civil structure). Some small issues have been promplty evaluated and fixed, sensors measurements have been optimized in order to have them as much accurate as possible. In particular, signals coming from fiber optic sensors are observed through a specific tool to verify the absence of attenuation, ensuring the measurement accuracy. At the end of this first year, the safety limits which guide the alarm and warning communications towards SCADA have been updated to finalize commissioning.

In general, all the data acquired from the structural monitoring system are satisfactory, reflecting the bridge behavior which matches with the designer expectations. An example is reported in Fig. 6, where displacement measurements are reported (blue dots in the upper chart) together with the design expected behavior (red stripe in the upper chart). In the lower chart the displacement behavior (blue line) follows the temperatune one (red line) along 4 months of acquisition.

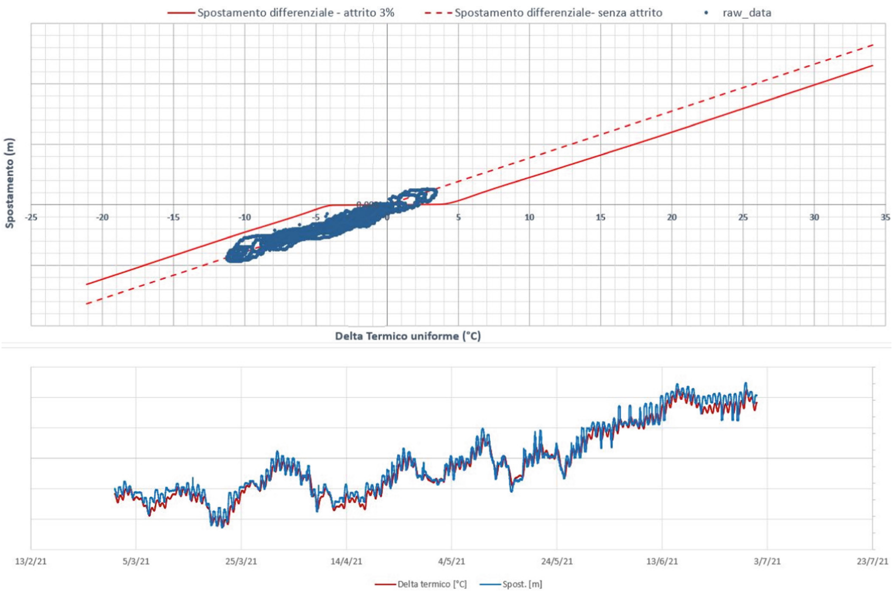

Fig. 6. Results of displacement measurements matching with the design expectations.

4.1 Data from Accelerometers and OMA

In order to meet the demanding requirements for microseismic monitoring and operational modal analysis (OMA), which allows engineers to capture the dynamics and health of the structure, LUNA worked closely with CETENA to provide best in class fiber-optic interrogators and instrument the entire bridge with an extensive network of

Luna's os7520 fiber optic accelerometers, the only optical solution today available on the market that fits the project's OMA requirements.

The accelerometers implemented as velocemeters and installed on the piles allow to instantaneously register anomalous behaviors due to seismic activity; typical data acquired from these sensors are reported in Fig. 7. The accelerometers can detect the micro vibrations at the top and at the base of the piles; via an integration of the acceleration data, velocity at the top and bottom of each pile is calculated.

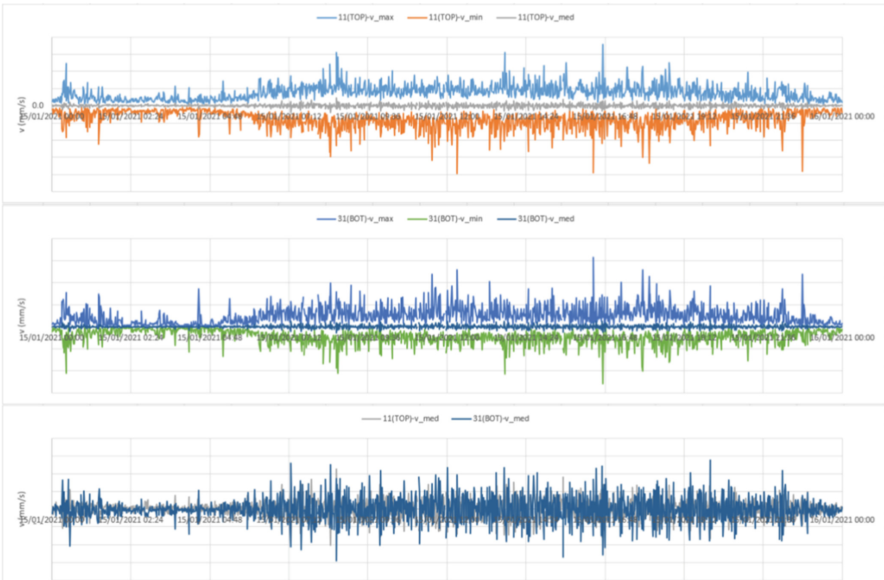

Fig. 7. Integration of the accelerometers data allows to measure the velocity at the base and top of each pile.

The forty-one accelerometers distributed along the main deck record the data used to perform the Operational Modal Analysis of the bridge. Although in general OMA cannot detect all structural features of interest for SHM, it should be noted that in the present case, as previously illustrated, the bridge is monitored through a moltitude of sensors that allow to follow the structural behavior in both the quasi-static and dynamic regimes through several physical quantities. In this sense, even if OMA is able to provide a large-scale view only of the dynamic behavior, a full structural view of the bridge is available.

The OMA system, designed and implemented by ARCOS Engineering, has a computational core based on SVIBS ARTeMIS Modal software [3]. On the top of the computational core, ARCOS Engineering has developed a specialized data preprocessing and filtering software algorithm that has been proven essential to exalt the fiber optic accelerometers features and accurately capture the dynamic properties of the bridge and their tracking in time. The specialized data preprocessing algorithms custom developed by ARCOS Engineering have allowed an extremely high repeatability of the OMA results. The OMA system receives the acquired data from LUNA's interrogators, applies the custom preprocessing algorithms, feeds the data to ARTeMIS Modal and recovers its results for insertion in the general monitoring database. The determined first flexural deck mode is reported in Fig. 8.

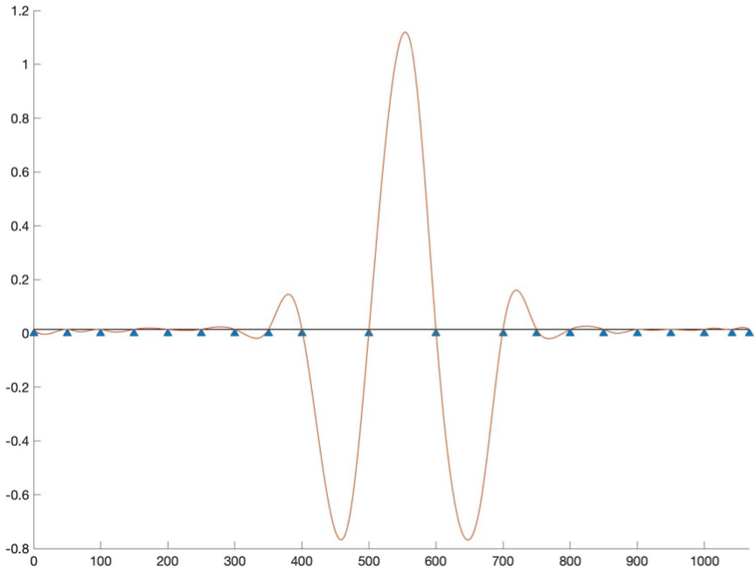

Fig. 8. First deck flexural mode determined by OMA analysis (1.118 Hz). Filled triangles represent the bridge pillars.

5 Summary

The fiber optic-based technology and the information it provides represents an effective engineering tool to enhance the safety and the security of people, to protect the environment and to minimize the costs of operation. Acquiring, processing and properly analyzing data from sensors in an automated real time way will allow the Genoa Sang Giorgio infrastructure owner to take under control the bridge behavior over the years, ensuring the safety of all people daily driving on it.

References

1. Wenzel, H.: Health Monitoring of Bridges. Wiley (2009)
2. Glisic, B., Inaudi, D.: Fibre Optic Methods for Structural Health Monitoring. Wiley (2019)
3. ARTeMIS Modal Software for Operational Modal Analysis and Experimental Modal Analysis, Structural Vibration Solutions. https://svibs.com/