THE STRUCTURAL HEALTH MONITORING SYSTEM OF RION ANTIRION BRIDGE "CHARILAOS TRIKOUPIS"

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ABSTRACT: Structural monitoring is a relatively newly developed tool particularly useful in structural assessment. "Charilaos Trikoupis" bridge incorporates it as an integral part of inspection, maintenance and management plant. The architecture of system and the operation principles are presented as well as the required maintenance and ongoing enhancements.

KEY WORDS: Rion Antirion Bridge; Structural Monitoring System.

1 INTRODUCTION

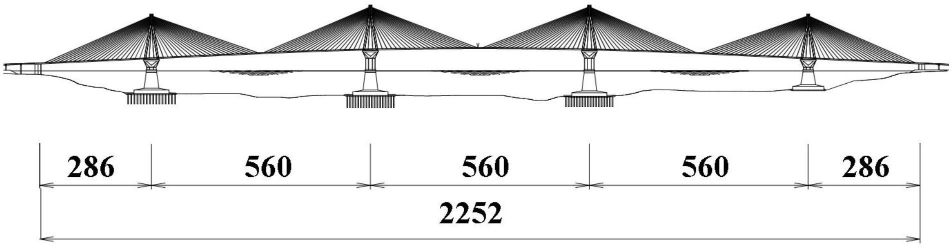

Figure 1. Rion Antirion Bridge elevation

Rion Antirion Bridge "Charilaos Trikoupis" is a 5 span cable-stayed bridge joining Continental Greece with Peloponnesus. The continuous composite deck has total length of 2252 m, with 3 main spans of 560 m and side spans of 286 m, and is suspended by 4 concrete pylons, with total height of 189 up to 227 m, through 368 cables with total length from 79 up to 295 m. At each far end of the deck, a steel rotating frame (RF) supports the structure allowing longitudinal movement that is accommodated by special designed expansion joint. Furthermore, at pylon and RF locations, the deck is transversally restrained through a fusing steel element that releases the deck when the transverse load, on each element, exceeds ±10.500/±3.400 kN (pylon/RF). Their capacity is based on wind ultimate design loads. In case of moderate/strong earthquakes, the deck is released and the induced energy is dissipated through viscous dampers located close to fuse elements.

The size and the importance of the structure, combined with the particularly harsh environmental conditions on site (maximum wind speed up to 266 km/h, design earthquake with p.g.a 0.48 g and tectonic movements up to 2 m between each pylon) required a permanent monitoring system that would provide valuable structural information.
The design, implementation and operation of the system are answering to the selected objectives such as the maximum expected structural response range, measurement accuracy and system robustness.
Through out the operation years (2004-2011) the structural health monitoring system provided invaluable information regarding the actual structure response for very different excitation cases (strong wind/earthquake/accidental events) that were used for both verification of structural integrity and optimization of structural equipment design. Also it should be mentioned the contribution to user safety through real time information regarding weather and road condition (i.e. ice on road/fog)

2 DESCRIPTION OF STRUCTURAL MONITORING SYSTEM

The structural monitoring system of Rion Antirion Bridge was designed according to the structural risk analysis regarding accidental, frequent and permanent load conditions. The selection of the most appropriate sensors and their respective location was done in order to be able to provide all the necessary data, for every possible loading, by minimizing the required number of sensors.

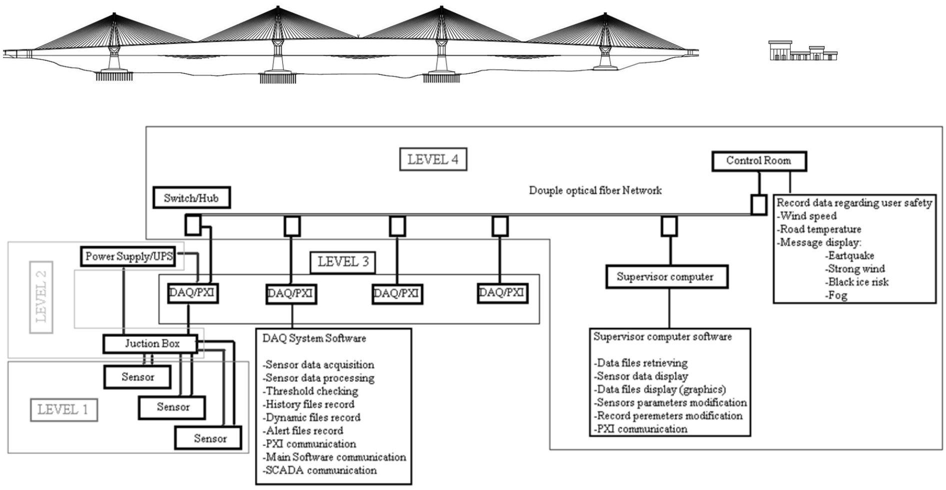

Figure 2. Overview of structural monitoring system

The current architecture of the monitoring system, *Fig.2*, can be divided into 4 different levels:

- Sensors
- Power supply and signal transferring
- Digitalization, acquisition and signal processing
- Communication network and data management.

Each level is equally important for the proper operation of the monitoring system, and the basic features are presented hereunder.

2.1 Sensors

A large variety of sensors are incorporated to the monitoring system in order to record the response of various structural elements under different loading conditions.

Table 1. Sensors description

Sensor	Quantity	Expected range of values	Actual sensor range	Monitored phenomenon
3D anemometers	2	0-50 m/sec	0-60 m/sec	Wind intensity
Temperature and Humidity sensor	2	50º C/0-100%RH	-50ºC, up to 50ºC/ 0-100% RH	Thermal loading
3D Pylon accelerometers	12	±1.9g (top) ±1.0g(base)	±20g(top) ±3g(base)	Pylon vibration (Earthquake/wind)
1D/3D Deck accelerometers	3/12	±2.7g	±3g	Deck vibration (Earthquake/wind)
3D Ground accelerometers	2	±0.48g	±3g	Earthquake
3D Cable accelerometers	13	-	±3g	Cable vibration Wind
Monostrand load of cables	16	0 up to 75% F_{GUTS} (199 kN)	0-320 kN	Cable load variation (Wind/Earthquake/Balance)
Magnetic distance meter	2	+1260/-1150 mm	3 m	Expansion joint opening (Earthquake/Balance/Thermal)
Strain gauges (full bridge)	4	±10500 kN	±1500$\mu\varepsilon$ ±17000 kN	Wind induced lateral load
Road temperature sensors	4	-	-50ºC, up to 50ºC	User safety (black ice risk)
Deck temperature sensors	5	-	-10ºC, up to 80ºC	Thermal loading

The total number of channels exceeds 300. A significant portion is dedicated to the monitoring of the system itself (power supply voltage, surge protection status) in order to be used for proper troubleshooting and maintenance.

In *Fig.3* the position of the sensors that are related with Wind and Earthquake loads is presented.

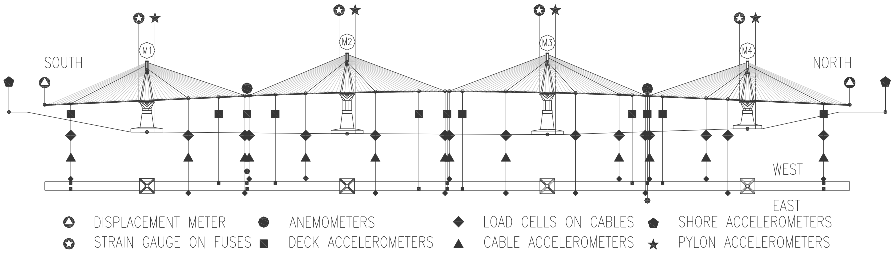

Figure 3. Overview of structural monitoring system

2.2 Power supply and signal transferring

The power supply of the sensors that are up to 400 meters away from acquisition unit, is achieved through the installation of junction boxes (JBs) that contain AC/DC (~230 to 24 VDC) convertors close to the location of sensors. Inside JBs the signal returned from each sensor is amplified (not for all sensors) and transmitted through shielded wires to data acquisition unit. An important design parameter is the surge protection system that should prevent overloads (i.e. lightning) from spreading inside the wiring network and causing damage to sensors. Additionally, it should be noted that even when major power outage occurs, the system remains active, powered by UPS devices and local power generator.

2.3 Digitalization, acquisition and signal processing

Due to the size of the monitored structure (more than 2500 m between extreme sensors), 4 different digitalization and acquisition units (DAQs) are installed, each on one pylon. The DAQs are located in controlled temperature shelters and are specially designed to be operable in harsh environments. The following operations are performed in each DAQ:

- Low pass hardware filtering at 10 kHz
- Digitalization at 500 Hz
- Conversion of signal to engineering units
- Continuous threshold checking
- Data file creation and real time transmission of selected values

A significant aspect, necessary for any further analysis of the recorded signals, is synchronization. In current architecture all the DAQs are synchronized with a server through SNTP protocol.

2.4 Communication network and data management

The communication of each DAQ with the supervisor computer (SE) and with the Control Room of the Bridge is performed through an optic fiber network that is installed along the deck. Thus, the collected data are retrieved, evaluated and permanently stored to dedicated media inside the operation building. Additionally through the SE, the end user can overview all the measurements (real time) and access/modify all record parameters (thresholds, scaling, acquisition parameters etc) that can be adjusted to each monitored event.

3 DATA RECORDS AND APPLICATIONS

Two main categories of data files are created by the monitoring system:

- History files (0.5 sec averaged values recorded every 30sec, except wind speed and direction that are 10’ average)
- Dynamic files (High sampling frequency at 100 Hz with 60 sec duration)

The History files are created continuously while the Dynamic files are recorded every 2 hours (Automatic) or when particular threshold has been over passed (Alert files) or even at user demand (Request).

All types of files (History/Automatic/Alert/Request) are very useful in order to understand the actual bridge response. Each of them can be used for different analysis purposes. In particular the History files are very useful in:

- Characterization of Environmental conditions, (wind, temperature)
- Estimation of deck creep and shrinkage
- Evaluation of static impact of wind loads
- Identification of potential loss of cable load from overall force distribution.

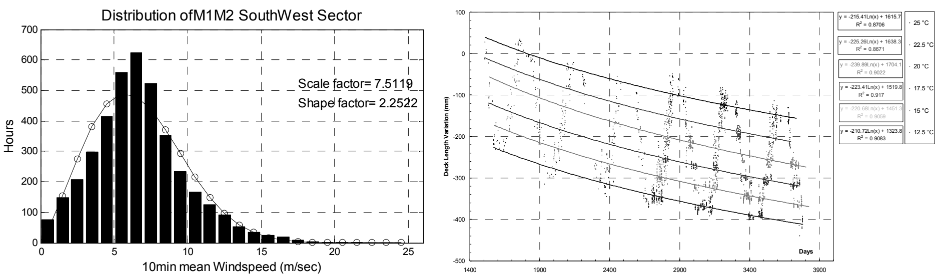

Figure 4. Wind speed distribution and deck shortening calculation (History files)

On the other hand dynamic files are used for calculating the dynamic parameters of the structure as well as to measure the response under particular loading conditions such as strong wind events, earthquakes and traffic.

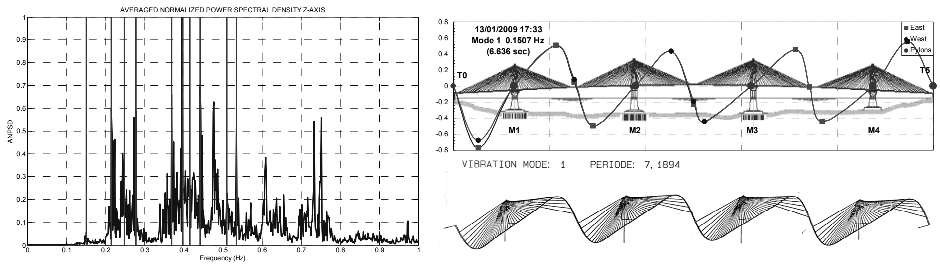

Figure 5. Identification of participating deck modes and respective shape [1]

4 AUTOMATIC PROCESS (SMART MONITORING)

Besides the analysis of the acquired data, it is essential for a structural monitoring system to automatically identify and adjust accordingly the data recording parameters, in order to answer particular demands. Moreover, a smart automated alert management can significantly decrease the, otherwise vast, volume of the recorded data. This can accelerate the required processing time and allow more elaborate analyses to be performed.

The structural monitoring system of Rion Antirion Bridge incorporates special modules that can automatically identify and perform special actions for earthquake (seismic mode) and strong wind events (wind mode).

During an earthquake event the following actions are automatically performed:

- Earthquake alert declaration in case that more than 3 channels, from different sensors (that were set as alert declarers), exceed specific threshold (5% of g) within a reasonable time window.
- Classification of earthquake intensity through the response of particular sensors (that were set as response indicators) into 3 different cases.
- Real time transmission of relevant information on control room for safe traffic management
- Notification of event via different means (email/SMS/phone message) of selected persons
- Processing of the recorded data and automatic report creation with the structure response measurements.
- Transmission of abovementioned report to dedicated persons.

Seismic mode has also the ability for self diagnosis in case that completion of the above mentioned tasks is prevented for any reason. For example in case of external communication loss, an external server that has been already informed that an earthquake occurs, will inform the dedicated people that the communication with the Bridge site is impossible and will provide the latest update regarding case classification.

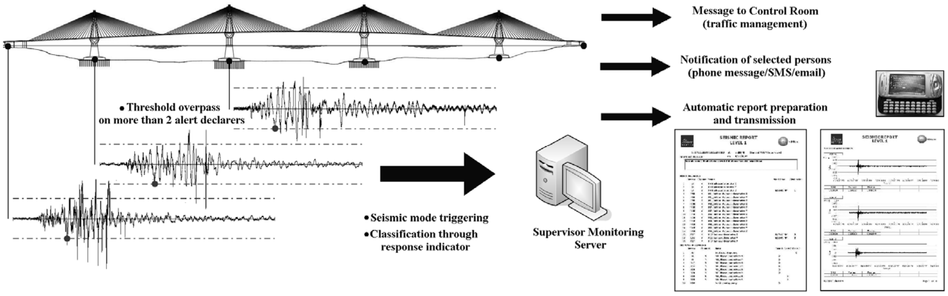

Figure 6. Overview of seismic mode functioning

The approach of the monitoring system to wind related event is similar with the seismic mode. However, there are some important differences:

- The declaration of a wind related event is based not only the wind intensity (wind speed threshold) but also in the measured response of particular elements (cables for instance). This is due to the fact that for various aerodynamic phenomena, the response of a structure is not proportional with the wind speed.
- Since the duration of a wind related event can be significant longer than an earthquake event (there are already recorded cases that wind speed was above 20 m/sec for more than 48 hours), it is necessary to reduce the acquisition frequency and increase the length of the records (i.e. the deck modal frequencies that can be excited are not above 2 Hz and cable modes with frequencies more than 10 Hz have insignificant contribution to vibration amplitude). This reduction of data volume is necessary for real time automated processing and reporting.

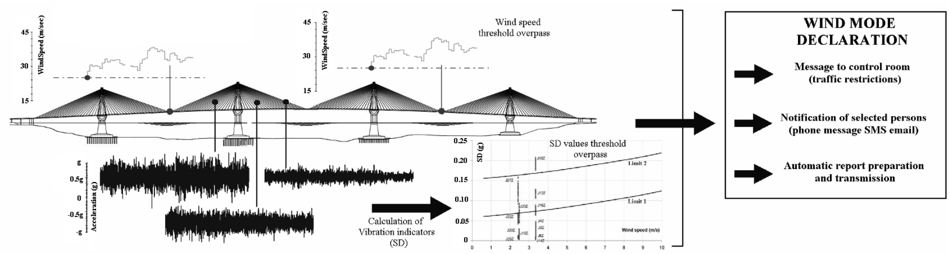

Figure 7. Overview of wind mode functioning

5 MAINTENANCE

The operation of a monitoring system that should provide important and meaningful data anytime this is required, calls for an intense and continuous follow up. The main points for ensuring proper & continuous functioning of Rion Antirion Bridge monitoring system are:

- Persistent follow up of the acquired data.
- Logging each possible malfunction and measurement quality degradation.
- Constant availability of all required spare parts, in site storehouse.
- Immediate notification of experts for troubleshooting and repair.
- Computerized annual maintenance of monitoring system (levels 1 to 3, see *Fig.2*) and specialized maintenance every 5 years, including sensors calibration.

It's worth mentioning that during 2010, the total downtime was less than 0.5%.

6 FUTURE ENHANCEMENTS

Additionally to the already mentioned maintenance actions, it is important to proceed with necessary upgrades of the system in order to improve data quality and system robustness. A new architecture of monitoring system is currently under development and will be implemented progressively in the near future. Some critical points are:

- Improvement of data synchronization (less than 1 msec tolerance), through GPS technology.
- Redistribution of computational tasks over different hardware in order to minimize failure risk and increase systems flexibility for additional sensor installation and more elaborate automatic process.
- Enhancement of anti-aliasing policy by incorporating more suitable hardware low pass filters and increase acquisition frequency.

7 CONCLUSIONS

A significant infrastructure such as Rion Antirion Bridge incorporates a structural monitoring system that can give invaluable structural response information for a wide variety of loading cases. It is also required for the safety of the users in case of special events such as Earthquake and wind. The upgrades and the constant maintenance of the system are the key points for high uptime, reliable data acquisition.

ACKNOWLEDGEMENTS

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