SHM of Golden Horn Metro Crossing Bridge in Istanbul – Initial Assessment Permanent Monitoring and Data Analysis

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Abstract A new metro bridge was constructed across the Golden Horn, Istanbul. The bridge consists of 2 approach viaducts, a cable-stayed bridge with a main span of 180 meters and a swing bridge. A metro station is situated in the centre of the main bridge. The deck of the cable-stayed bridge and the swing bridge are designed as steel structures. The bridge was equipped with a sophistic structural health monitoring solution, which will be delivered by VCE- Vienna Consulting Engineers. The paper describes the solution proposed by VCE. It covers the development and design of the instrumentation and the system for the monitoring of the behaviour, the performance and the condition of the structure. The monitoring concept consists of 3 subtasks:

- Initial measurements and investigations after completion of the structure.
- Permanent structural health monitoring.
- Portable equipment for periodic assessment.

A special focus is on the data management part, which includes data archiving, data analysis and the presentation of the monitoring data to the operation personal and to the client. Apart from the control room devices the system will include a web-user interface, which allows a secure access to the monitoring data and results with mobile devices from anywhere and anytime.

1 Introduction

This document describes the structural health monitoring system activities which are to be provided for the Golden Horn Metro Crossing Bridge in Istanbul, Turkey. It covers the monitoring concept which consists of 3 major tasks:

- Initial measurements and investigations after completion of the structure.
- Permanent structural health monitoring.
- Supply of a portable system plus software for periodic assessment of major bridge components.

The major performance concerns for operation and structural integrity are:

- Earthquakes because the bridge is located in an Earthquake prone area.
- Deformations and movements because parts of the bridge are founded in a landslide area.
- Bridge dynamic behaviour which interacts with the train dynamic behaviour (resonance).

The monitoring concept was developed in close cooperation with the bridge owner and his local expert advisors.

2 The Bridge

The Golden Horn Metro Crossing Bridge spans the Golden Horn (Halic) in Istanbul and will be part of the Metro Line M2. The bridge consists of two approach viaducts, a swing bridge and a main cable-stayed bridge with a span configuration of 90m + 180m + 90 m. The superstructure consists of a 3-cell steel orthotropic deck. The width of the deck is 13.7m and it is about 17m above water level. The steel pylon has a height of 54m above deck. The main span of the cable-stayed bridge carries a metro station of the line M2.

Fig. 1. Golden Horn Metro Crossing Bridge during construction

3 Initial Measurements and Investigations

Immediately after completion of the structure and before opening for service an initial measurement of the dynamic behaviour of the whole structure is required. The goal of these activities is to prove construction quality (warranty inspection) on the one hand and to determine the basic structural characteristics for the interpretation of future monitoring activities on the other hand. This includes vibration measurement on the resonance phenomenon at the swing bridge.
Initial inspection and initial measurements include:

1. Short visual inspection.
2. Stay cable measurements at the main bridge.
3. Deck measurements at the main bridge.
4. Pylon measurement of both pylons.
5. Deck measurements of the approach bridges.
6. Deck measurements of the swing bridge.
7. Snap-back tests at the swing bridge.
8. Vibration measurements (resonance effects) at the swing bridge.
9. Test during opening and closing of the swing bridge (e.g. emergency stop of rotation).

3.1 Stay Cable Measurements

This activity included ambient vibration measurements of all stay cables with a portable measurement system. For the measurements a highly sensitive 3D-accelerometer was fixed to each single cable about 3 meters above the deck level. The measurement data were analysed and interpreted by special software (BRIMOS®). Results of the cable measurements were:

- Natural frequencies of the cables.
- Cable forces.
- Indication on cable damping and cable stiffness.
- Susceptibility to vibrations (wind-rain induced vibrations, parametric excitation by the bridge deck).

3.2 Measurement of the Dynamic Characteristic

The dynamic characteristic of the whole superstructure including approach viaducts, swing-bridge and main cable-stayed bridge was measured and com-pared against a finite-element-model.

The most suitable method for the monitoring of the dynamic characteristic is "Ambient Vibration Monitoring (AVM)". Bridges have a significant vibration behaviour which may be addressed as "vibrational signature". This dynamic behaviour is typical for a structure and can be obtained by appropriate measurements and used for the assessment of the condition of the load bearing structure and the de-termination of damage after respective evaluation.

The analysis included natural frequencies and mode shapes, vibration intensity, energy dissipation and structural damping.

4 Basic Design of Permanent Monitoring System

The permanent monitoring system is being provided to fulfil three main requirements:

- structural health monitoring and damage detection;
- monitoring of weather loading (e.g. temperature, storms); and
- earthquake monitoring

The system which has been installed to address these needs will consist of the following:

- a total of 65 sensors, using 130 data channels, to measure environmental, load and structural response factors as described in Section 4 (see Figure 3);
- a signal acquisition solution, including signal capture from the sensors, signal verification and temperature adjustment, conversion of signal to digital format using 24 bit architecture, 1/1000 sec. signal time synchronization, signal transport to pre-processing data acquisition unit, signal pre-processing and buffering prior to transferring to data processing;
- data processing to generate reports, prompt control actions and provide alarms as may be required;
- data storage; and
- a user-friendly interface to enable necessary operational intervention, maintenance optimization and support high-level analysis such as finite element.

All components shall be able to sustain severe environmental conditions. The system is designed to sustain partial damage with undamaged parts remaining operational without losing real-time or stored data. Design assumptions are highly conservative to maximize the mean time between failures (MTBF).

Hardware and software are designed and selected to ensure that they can be engineered or replaced with commonly available alternatives in the future – for example, should the current supplier be unable to meet the need.

Authorized users will have on-line access to cur-rent and archived data. The user interface shall be intuitive and easy to use, showing "analog instrument" display in the form of a "mimic panel".

5 Data to be recorded

The following data will be recorded by the system.

5.1 Environmental Factors

Environmental conditions at the top of the pylon are recorded by a weather station, which measures ambient temperature, relative humidity, solar radiation as well as wind speed and direction.

In addition seismic events, which could have a serious impact on the entire structure, are measured at the swing bridge base, at the pylon base and on the ground at both abutments using 3D high-definition accelerometers.

5.2 Load Factors

Natural vibrations are measured by 3D-accelerometers, which are installed all over the structure.

Additionally, the main structure with the metro-station in the centre of the bridge is monitored by a video surveillance unit featuring colour cameras, capable of recording 30 frames per second and night-time usage.

5.3 Bridge Structural Response

The bridge’s deformation and movements are monitored by a GPS System with a reference station and sensors at the top of each pylon and in the centre of the main span.

Additionally, ultrasonic displacement sensors are installed to monitor the longitudinal movements of the cable-stayed bridge.

Cable vibrations are recorded by 3D-accelerometers, which are detachable to allow relocation during and after the construction phase to assist in calculation and verification of damping, as well as assessment of changes in harmonics during operation.

Tilt of the deck on each span and of the pylon is measured by inclinometers.

The dynamic characteristic and the behaviour of the whole bridge is monitored by a number of 3D accelerometers spread over all major parts.

6 Data Collection Unit at the Bridge

6.1 Master Station

The data acquisition unit is based on industrial graded cPCI systems with dual-core CPUs, running data acquisition and data calculating software. The unit controls all sensor functions and provides all measured data with source codes (name and position of sensor) and time stamps to allow accurate time synchronization. A/D-conversion is done by multi-channel, 24-bit converter modules, located as closely to the sensors as possible. All raw data measured by the sensors are stored on two independent hard discs to prevent data loss in case of disc failure. Pre-processing of the monitoring data also takes place here.

The master station is equipped with independent time sources (GPS) to ensure self-sufficiency should connection to the local network be lost. This ensures preservation of records during critical events such as traffic accidents or earthquakes. The unit is also protected by an air-conditioned cabin to enhance reliability and durability.

6.2 Power Supply

The system will be equipped with an uninterruptable power supply (UPS) in order to guarantee power supply at all times and prevent data loss, especially during a critical event. The UPS will also protect the equipment against fluctuation and voltage peaks in the public power supply. The battery capacity will be adapted to the actual power requirements in order to guarantee power during a two hour interruption of the main supply. Battery lifetime of several years can generally be expected.

7 Data Transfer from the Master Station to the Central Server

The data connection between the master station on the bridge and the central data server in the VCE home office in Vienna is based on the mobile telephone network and the internet. This system enables real-time data transmission.

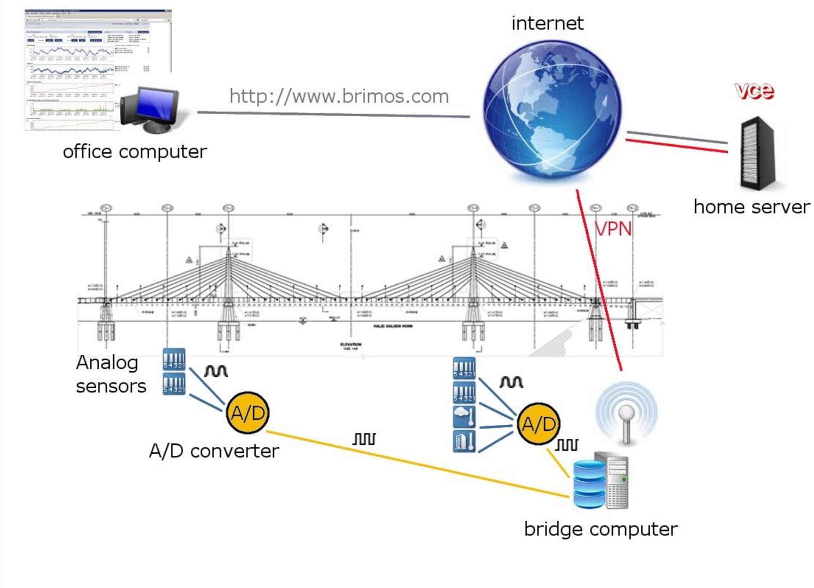

Fig. 2. Data transmission

8 Data Presentation

8.1 Web User Interface

The web user interface enables an authorized user to log on into the system and view any data which may be of interest for any period of time during which measurements were made (Figures 5 to 7). It also enables the user to input condition and event values and, if necessary, instructions for personnel. Information is presented in a user-friendly and simply understandable format. High frequency data is displayed in clear graphics (e.g. mimic panel format).

The user can also instruct the system to provide an alarm if predefined threshold values of any variable are exceeded. Such alarms can take the form of a visual notification on a monitor, or an email or SMS to a selected person.

This user interface is accessible at any time, from anywhere in the world with an internet connection.

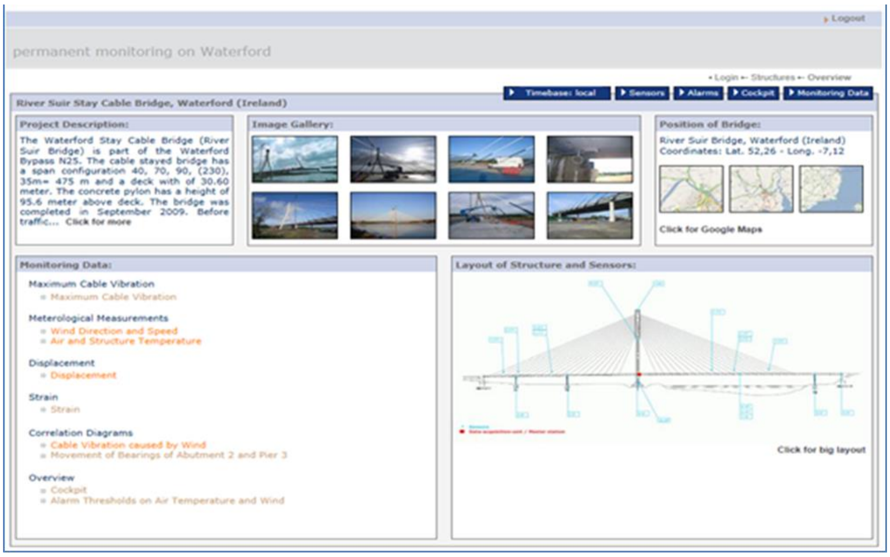

Fig. 3. "Dashboard" of user interface (example)

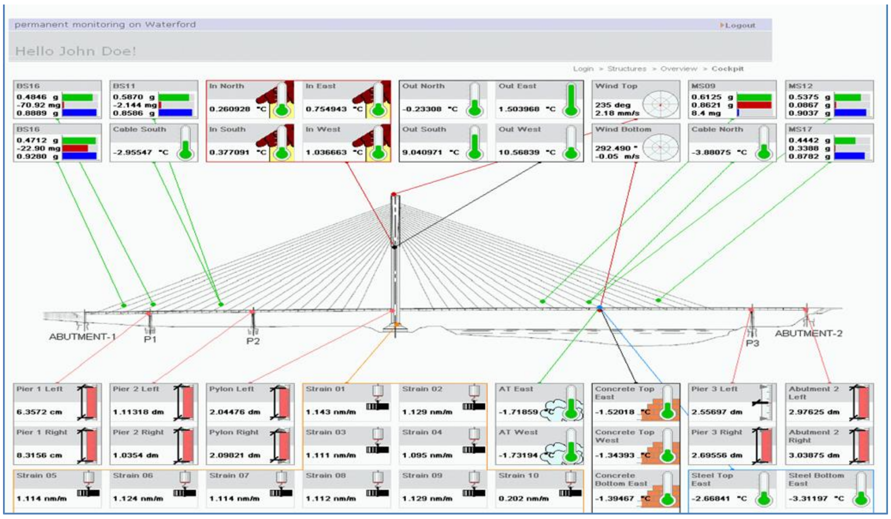

Fig. 4. "Cockpit" of user interface (example)

A live view function is available, which allows real-time access to the high-frequency measurements.

The user interface enables the download of measured data and results for any user-selected time period. The data can be exported in graphic form or, if preferred, in tabular format for ease of analysis.

8.3 Report Generation

A data file with summarized results is automatically generated and stored on the hard disc at the end of each month. This report file summarizes the month's data on environmental conditions, bridge behaviour and bridge performance. If desired, the reporting period can be adjusted to cover shorter or longer intervals.

9 Delivery of the Monitoring System

Smooth delivery, installation and operation of the system were ensured by a number of measures. First, the system was pre-assembled in the factory to enable a test of every component and of the whole sys-tem to be carried out. This also includes the initial calibration of the sensors, the creation of quality control documentation and final updates of pre-installed PC and server operating systems.

Following installation of the system (taking approximately 16 weeks), final calibration of all sensors and a function test of the complete system were carried out. This includes, for example, checking of the horizontal fixation of tilt sensors, subtraction of static offset values of accelerometers and similar tasks. It also includes the initial operation of the operator's workstations.

Operation and maintenance training was then carried out, in relation to the monitoring system on the bridge, the web interface and the user interface in the monitoring office. Maintenance tasks performed by the bridge owner's personnel include, for example, software updates, replacement of batteries and general visual inspection of components. The operation and maintenance manual defines the relevant tasks.

10 Portable Monitoring Equipment

The portable bridge monitoring system is used to carry out field measurements such as vibration monitoring of all the cables, the pylons and the deck. The vibrational behaviour of the cable can be used to calculate the actual cable forces very accurately.

For the portable bridge monitoring system the BRIMOS® Recorder 1000 was supplied. This is a very robust all-in-one-solution with internal sensor, power supply and data logger (embedded PC). It is designed as compact monitoring and assessment equipment with a simplified, intuitive and very user-friendly operating concept.

11 Monitoring Benefits

The major purpose of the monitoring activities at Golden Horn Metro Crossing is the check of the design and the construction quality and the early detection of any changes of the structural behaviour and the structural condition. Therefore a detailed data analysis will be done after one year of system operation which will result in the definition of threshold values for the monitored factors and in the implementation of an automatic alert system.

12 Summary

A comprehensive monitoring program was implemented at the Golden Horn Metro Crossing in Istanbul consisting of an initial measurement campaign, a permanent structural health monitoring system and portable equipment for the periodic assessment of the major bridge components.

The automated monitoring system provided for the bridge supplies enormous amounts of information, which will enable a precise evaluation of the condition to which the bridge is subjected as well as the structure's condition and performance with a minimum of effort. It is thus a good example of the type of comprehensive service which can be provided by modern SHM systems if sensibly conceived, detailed and implemented.

References

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