Introduction of Bogazici Suspension Bridge Structural Health Monitoring System

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SUMMARY
Istanbul has two suspension bridges in service and these bridges link two parts of Turkey and join together the European and Asian parts of Istanbul. One of them, Bogazici Bridge, forms a vitally important link for the economy of Istanbul, Turkey and the Eastern European region. Over 200.000 vehicles pass on the bridge a day. It has one of the heavy traffic-flow in the world and any failure or damage due to traffic or extreme events such as wind and earthquake might result in long term closure of the structure. Therefore, it was imperative to set up a well designed Structural Health Monitoring (SHM) system on the bridge and use the data to assess the state of the bridges. This paper gives information about SHM system on the bridge.

Keywords: Suspension Bridge, Structural Health Monitoring, Dynamic Characteristics

1. DESCRIPTION OF BOGAZICI BRIDGE

Bogazici suspension bridge was commissioned in 1973. It is gravity anchored suspension bridge with steel pylons and inclined hangers. It can be called modern type suspension bridge due to its orthotropic and aerodynamic cross-sectional deck. The main span is 1,074 m (World rank 12th). It consists of one main and two side spans. Side spans are not suspended and rest on slender columns. The main span length is 1074m, Asian side span is 255m and European side span length is 231m. Deck width is 33.4m and steel tower height is 165m. General arrangement of the bridge is shown in Figure 1.

2. DESCRIPTION OF STRUCTURAL HEALTH MONITORING SYSTEM

A comprehensive Structural Health Monitoring (SHM) system has been installed on the Bogazici Suspension Bridge, the primary aim of which is to provide the means for measuring the response of the structure before, during and after major and extreme loading events. It assists in providing a rapid assessment of the security of the structure by providing important information on the response of vulnerable components such as hangers and expansion joints, thus enabling the owner, General Directorate of State Highways (KGM), to determine the problems if occur.

The SHM system consists of data acquisition components and sensors. The system is an advanced technology system containing accelerometers, tiltmeters, force transducers, strain gauges, laser displacement, GPS, thermocouples and weather stations. In total, there are 168 sensors, using 258 channels, located at strategic positions on the bridge.

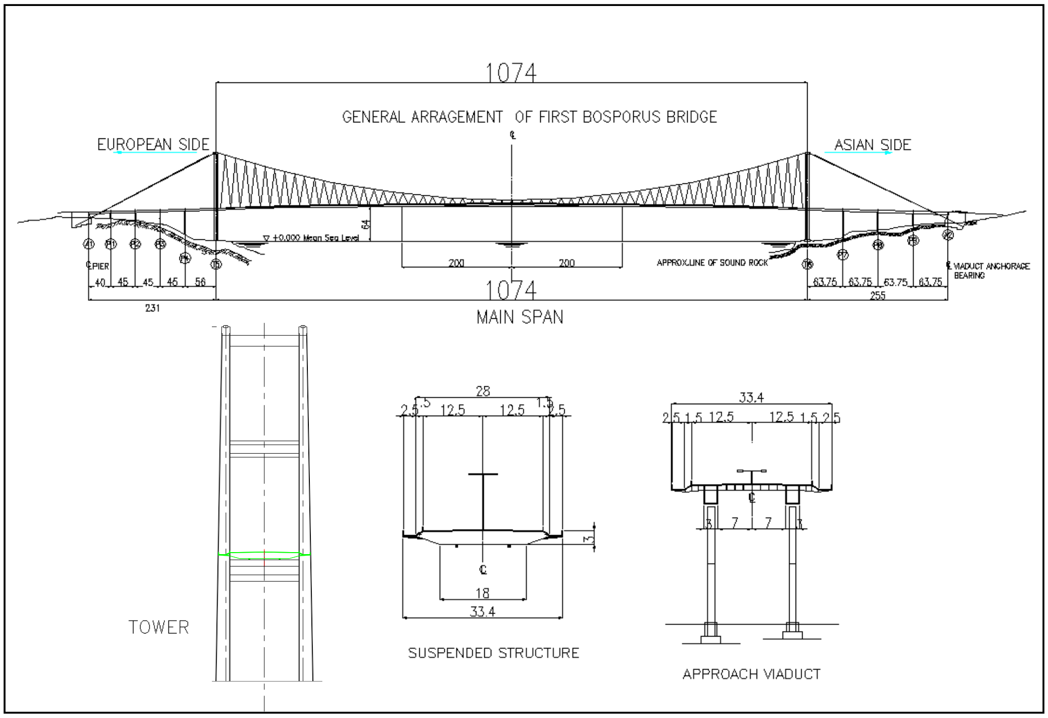

Figure 1. General Arrangement of Bogazici Suspension Bridge

2.1. Data Acquisition Components

The data acquisition components consist of site supervisor software, backup computers, data acquisition hardware (ACQ1, ACQ2 and ACQ2.2). The site supervisor is located in the KGM monitoring building and includes server tower, optical junction box, power supply, power-switch, ADSL router, UPS etc. The supervisor software has the following functions:

- Collect the live data from the backup computer on the bridge,
- Analyze the data to check if thresholds are exceeded,
- Analyze the data to check if a seismic mode shall be activated,
- Store the continuous statistical data of the sensors,
- Store the dynamic files in case of exceedence of a threshold,
- Generate automatic seismic reports,
- Perform the rain-flow counting on the selected channels,
- Allow the creation of virtual channels defined as being a combination of real physical channels on the data acquisition unit,
- Provide data analysis functionalities on the recorded data.

The backup computer is located in the Asia tower. It has the following functions:

- Collecting of the measured data of all of the acquisition system of the installation,
- Applying anti-aliasing filtering,
- Re-sampling of the signals to their burst record frequency,
- Storing of the processed data,
- Provide storage capacities in case of failure of the communication with the supervisor,
- Allow for autonomy of the acquisition in case of a power failure,
- Provide information on the status of the acquisition components,
- Provide the possibility to manually reboot the acquisition units.

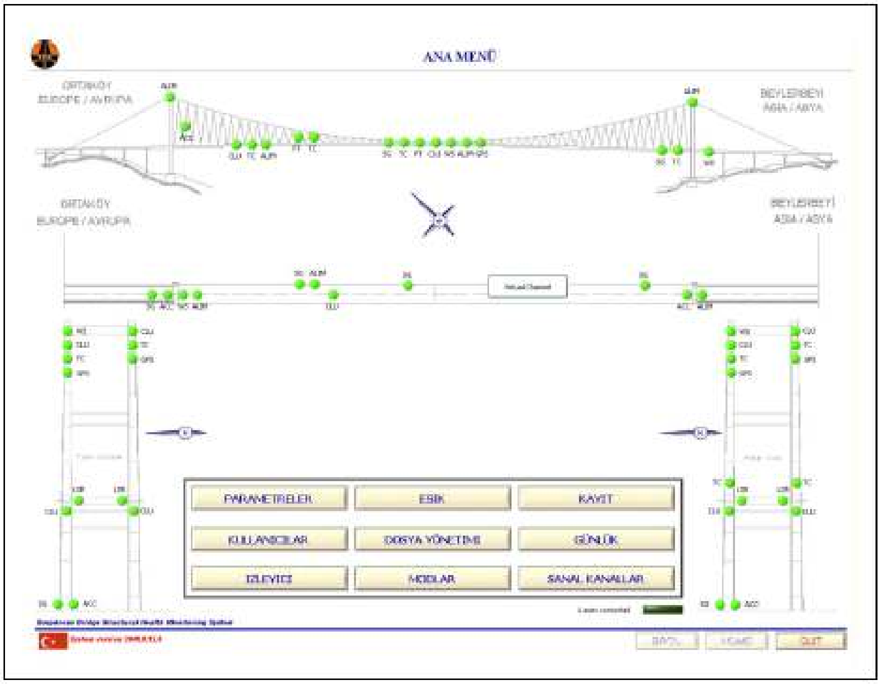

Figure 2. The location of the sensors and the main screen of the SHM software interface at the Bogazici Suspension Bridge (Bogazici Bridge Monitoring Handbook and User Manual, 2009)

The data from each sensor is acquired and stored on the backup PC (situated at the Asia Pylon), the supervisor PC then retrieves, processes, and displays this data. The monitoring system interface on supervisor PC is shown in Figure 2. It shows measurements and alerts, modifies threshold and storage parameters, detects earthquakes and creates automatic reports (Bogazici Bridge Monitoring Handbook and User Manual, 2009).

2.2. Sensors

As shown in the Table 1 below, there are 8 different types of 168 sensors with 258 channels. The pictures of each sensor are shown in Figure 3.

Table 1. The number of sensors on the Bogazici Bridge SHM system

Number of Sensors		
No.	Type	Quantity
1	Accelerometers	19
2	Tiltmeters	15
3	Force Transducer	12
4	Strain Gauges	70
5	Laser Displacement	8
6	GPS	5
7	Thermocouples	33
8	Weather Station	6
Total		168

Accelerometers: There are 19 accelometers in SHM system. Measuring range of accelometers is (g)

+/- 2.
Tiltmeters: There are 15 Tiltmeter on the system. It is a precision gravity referenced tilt sensor with high-level DC output signal proportional to sine of the angle of tilt and its measuring range is +/- 14.5.
Force Transducers: The force transducer is based on an Invar steel bar extensometer. The LVDT transducer measures longitudinal displacements of the Invar bar when the rope is tensioned. Displacements observed on the basis of measurement give strain in the rope. The distance between fixings of the bar and the sensor determines the basis of measurement. Measuring range is +/- 1.5 mm and there are 12 force transducers in the system.
Strain Gauges: There are 70 strain gauges in the system.
Laser Displacement Sensors: There are 8 laser displacement sensors in the system. Their measuring range is between 200 – 2000mm.
GPS Sensors: The GPS monitoring system was constituted by GMX 901 and GMX902. GMX 901 are sampling at 1Hz with mono frequency (only GPS mode), GMX902 are at 10 Hz with dual frequency.
Thermocouples: The thermocouples are J type thermocouple. The sensitive part of the sensor is fixed on copper plate or stainless steel collar (for hangers). There are 33 thermocouples.
Weather Stations: There are 6 weather stations.

Figure 3. The pictures of the sensors used in the SHM system at the Bogazici Suspension Bridge

3. RECORDING PARAMETERS

The monitoring system has threshold levels for each sensor. Once a channel exceeds the threshold level, the desired number of measurements needs to be registered above that threshold before an alert is declared. In Figure 2, a sample presentation of threshold leveling is given. When an alert is declared, an alert file is created, and the defined pre-trigger duration of data is added to the file, in the figure above the blue line. In this example the pre-trigger duration is 2 seconds. When the signal goes below the threshold, the channel will continue being recorded for the record duration, in the figure above in green, or until the channel overpasses once again, thus requiring 5 more values above threshold to reset the record duration progression. In this example the record duration is 4 seconds. If an alert file is being recorded when another alert is registered, data is added to the existing alert file.

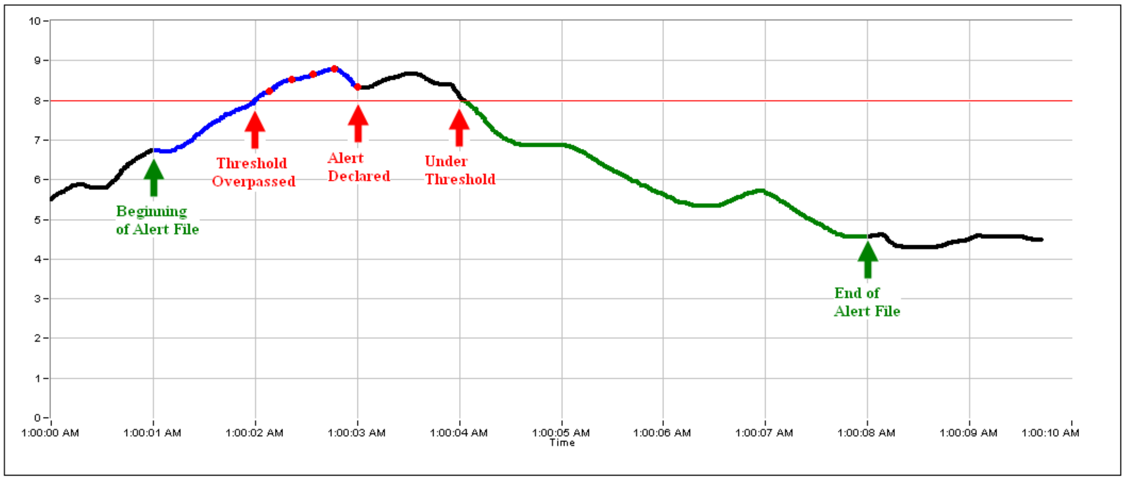

Figure 4. The illustration above demonstrates the data recorded following an alert on a channel

3. DYNAMIC CHARACTERISTICS OF THE BRIDGE

A testing data was recorded at the SHM system on April 12, 2012 noon time for 1 hour starting from 13:27:27. The accelerometer data were recorded at all accelerometers on tower top, bridge deck and base levels. The sample recordings at bridge deck mid-span transverse and vertical direction were processed in a Matlab code. The time history and Fourier Amplitude Spectrum (FAS) of the records are shown in Figure 5 and Figure 6. In Figure 5, the main frequency is observed around 0.06-0.08Hz in transverse direction and in Figure 6 it is seen around 0.10-0.20Hz in vertical direction. The test results were compared with analytical study results of Brownjohn et al. (1989), Erdik et al. (1989), Apaydin and Erdik (2000), Kosar (2003) and Apaydin (2010). The results showed good agreement in transversal and vertical directions natural modes. In Figure 7 and in Table 2, the analytical results of Apaydin (2010) are shown. The 1st natural mode is seen 0.07Hz in transverse and the following natural modes are seen in vertical direction, and these are well-matched with test results.

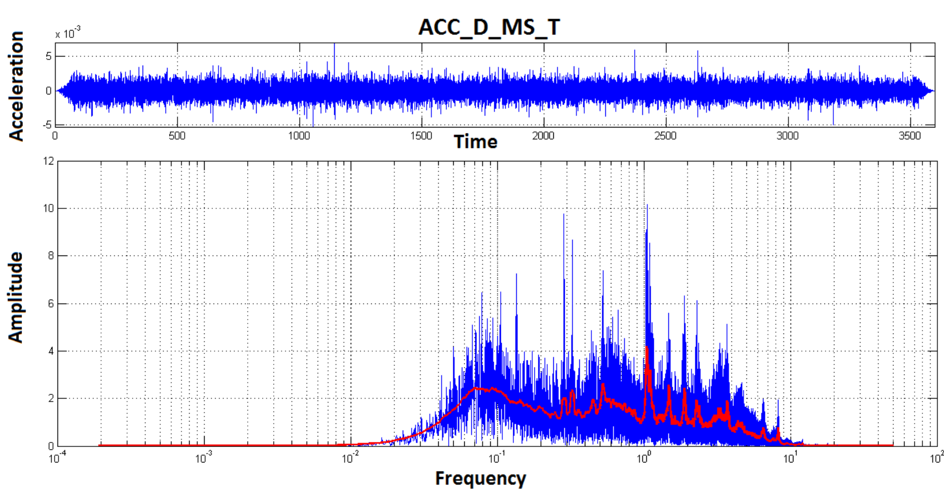

Figure 5. The acceleration-time history and FAS of the 1 hour test recording at the bridge mid-span deck level in translational direction. The red line shows average FAS.

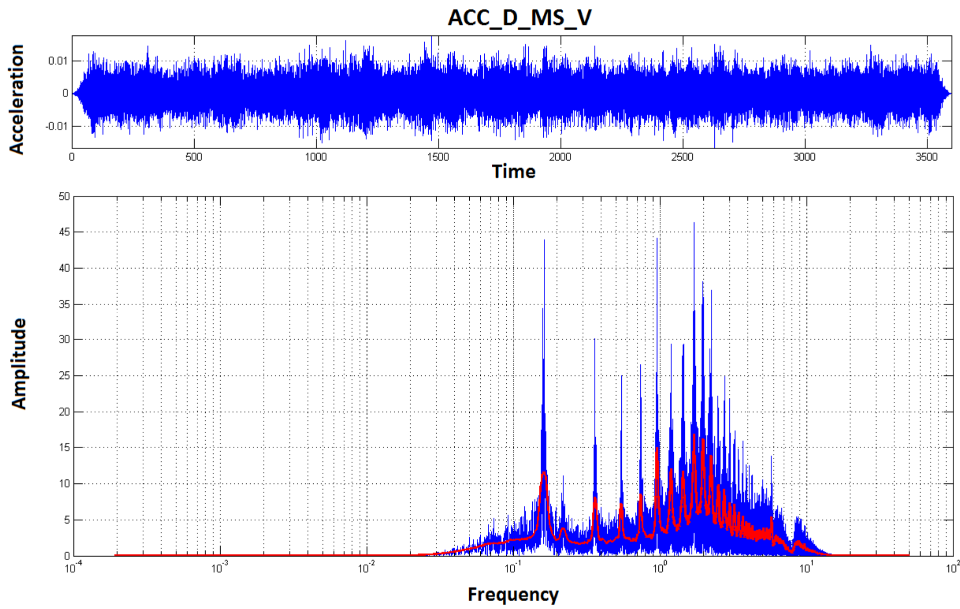

Figure 6. The acceleration-time history and FAS of the 1 hour test recording at the bridge mid-span deck level in vertical direction. The red line shows average FAS.

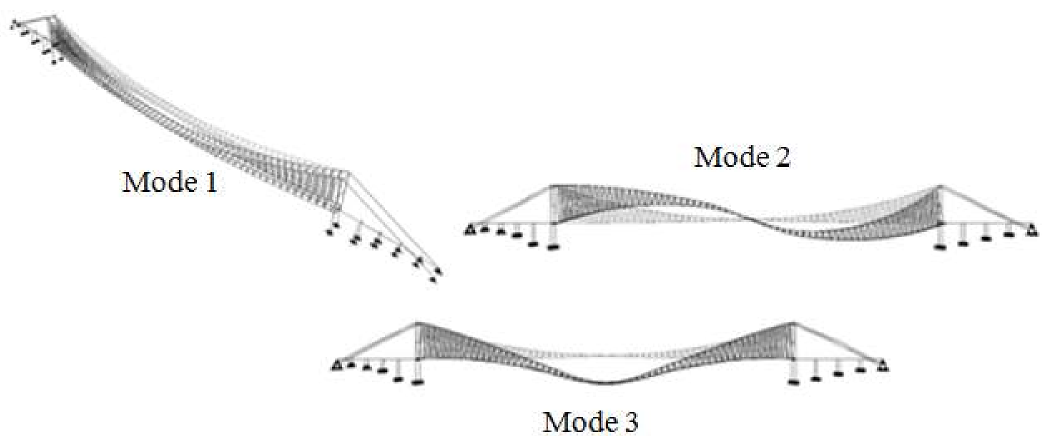

Figure 7. The analytical modes of the Bogazici Suspension Bridge (Apaydin, 2010)

Table 2. The natural modes of the Bogazici Suspension Bridge (Apaydin, 2010)

Mode Number	Mode Shape	Period	Frequency
		Sec	Cyc/sec
Mode-1	1st Lsym	13.4875	0.0741
Mode-2	1st Vasym	8.3074	0.1204
Mode-3	1st Vsym	6.3313	0.158
Mode-4	2nd Vsym	4.7673	0.2098
Mode-5	3rd Vasym	3.812	0.2623
Mode-6	1st T	3.6952	0.2706
Mode-7	1st Tw	3.5458	0.282
Mode-8	2nd Tw	3.3935	0.2947
Mode-9	Lsym, Tw	3.3922	0.2948
Mode-10	Long Vasym	3.1594	0.3165

4. RESULTS

This study introduces the Bogazici Bridge SHM system installed in 2009. It consists of 168 sensors; accelerometers, tilt-meters, force transducers, strain gauges, laser displacement, GPS, thermocouples and weather stations. In total, the system is in service with 258 channels located at strategic positions on the bridge.

The system works effectively so far. Periodically, testing records from the system are acquired and system calibration test is applied. In this study, an hourly test on acceleration sensors was carried out and the results were compared with analytical studies. The findings from the SHM system test records and past analytical studies proved the reliability of the current SHM system.

AKCNOWLEDGEMENT

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