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Vibration Characteristics of Bogazici Suspension Bridge using Structural Health Monitoring Data

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ABSTRACT: Bogazici suspension bridge in Istanbul has a strategic importance and it is one of the critical vital links in Istanbul city transportation system. The daily number of vehicles crossing the bridge is more than 200.000. The high seismic risk in the city and heavy loading condition on the bridge led the Highway Authority to take serious precautions. An advanced Structural Health Monitoring (SHM) system was developed and installed on the bridge. SHM consists of high precision sensors placed at critical locations on the bridge. This gives the Highway Authority an opportunity to monitor and assess the response of the bridge to both daily and extreme events. The system consists of 168 sensors, recording 258 data channels from accelerometers, GPS sensors, tilt meters, strain gauges, force transducers, laser displacement sensors, thermocouples and weather stations. The monitoring system has been operational for two years. In this study, the acceleration records which were taken during the storm on April 18, 2012 were studied. The characteristics of vibration occurring on the bridge due to excessive wind were examined.

1 DESCRIPTION OF BOGAZICI SUSPENSION 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 1074 m, Asian side span is 255 m and European side span length is 231m. Deck width is 33.4 m and steel tower height is 165 m. Record Book Bogazici Köprüsü(1973). General arrangement of the bridge is shown in Figure 1.

2 INTRODUCING OF STRUCTURAL HEALTH MONITORING SYSTEM

A Structural Health Monitoring (SHM) system was installed on 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, thus enabling the owner, General Directorate of State Highways (KGM), to determine the problems if occur.

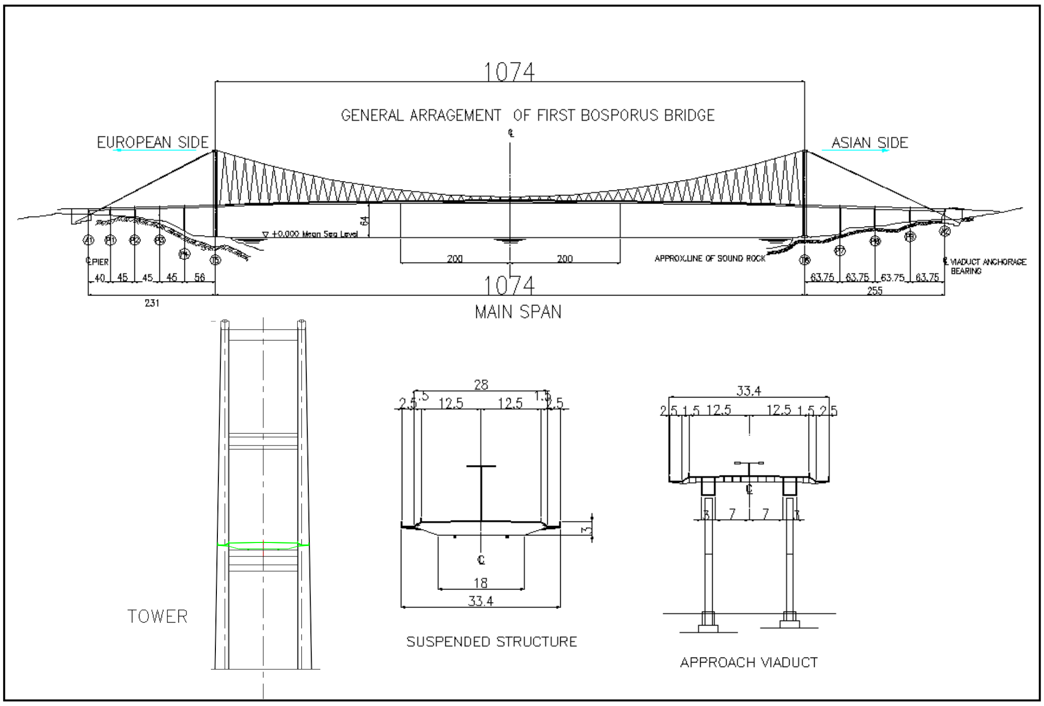

Figure 1. General Arrangement of Bogazici Suspension Bridge

The SHM system consists of data acquisition components and sensors. The system contains accelerometers, tilt meters, 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. In Table 1 types of sensors with 258 channels are listed and their locations are shown by means of schema of the SHM software interface in Figure 2. 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 3, 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. Bogazici Bridge Monitoring Handbook and User Manual. (2009).

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

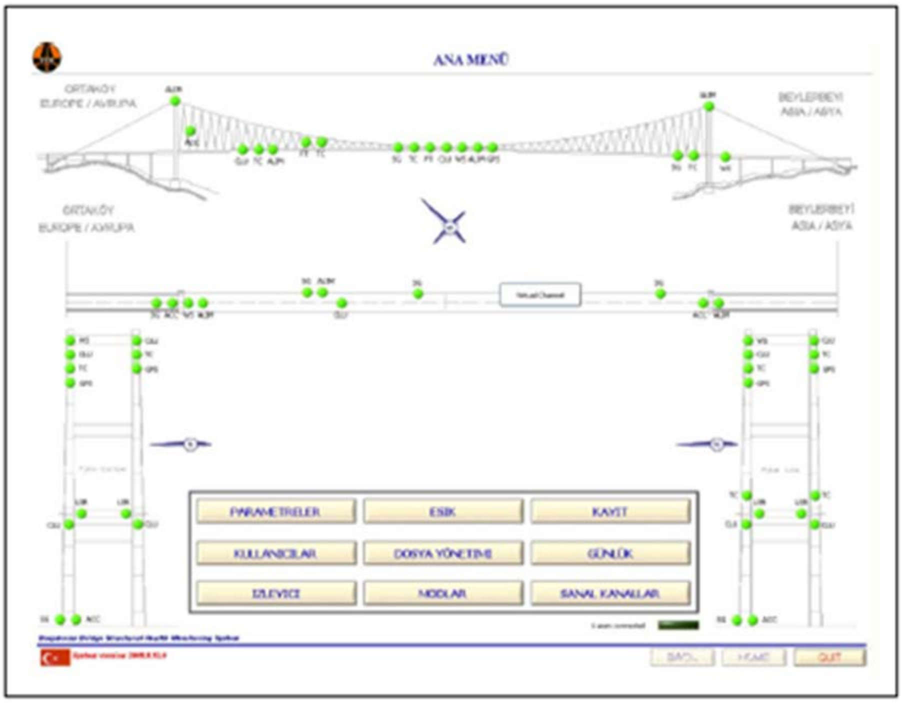

Figure 2. The location of the sensors and the main screen of the SHM software interface at the Bogazici Suspension Bridge, Bogazici Bridge Monitoring Handbook and User Manual (2009)

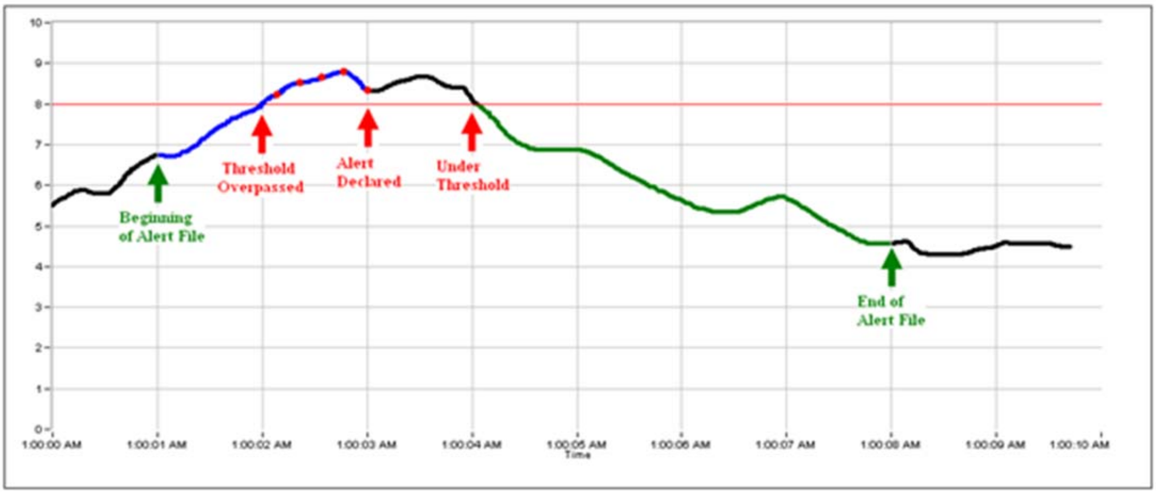

Figure 3. The illustration above demonstrates the data recorded following an alert on a channel

3 WIND RESPONSE OF THE BRIDGE

3.1 Overview of April 18, 2012 high speed wind

Strong winds are not very frequent in Istanbul because it is located on inland sea. On April 18, 2012 day time, a strong storm occurred in Istanbul city. It was the first time, the bridge experienced such a high winds. The maximum wind-speed reached to 122 km/h. The bridge was closed to the traffic for a period of time as a precautionary measure. The change of wind speed with time is shown in Figure 4. As it is seen from the figure, the average wind speed before the storm was around 20 km/h. However, it suddenly increased to 122 km/h in 10 minutes. From 13:15 to 13:25 the wind speed increased 20km/h to 122 km/h. The wind direction was approximately 180^0 , so it was mostly transverse to the bridge deck. Storm effected the bridge very short period, the temperature stayed almost constant.

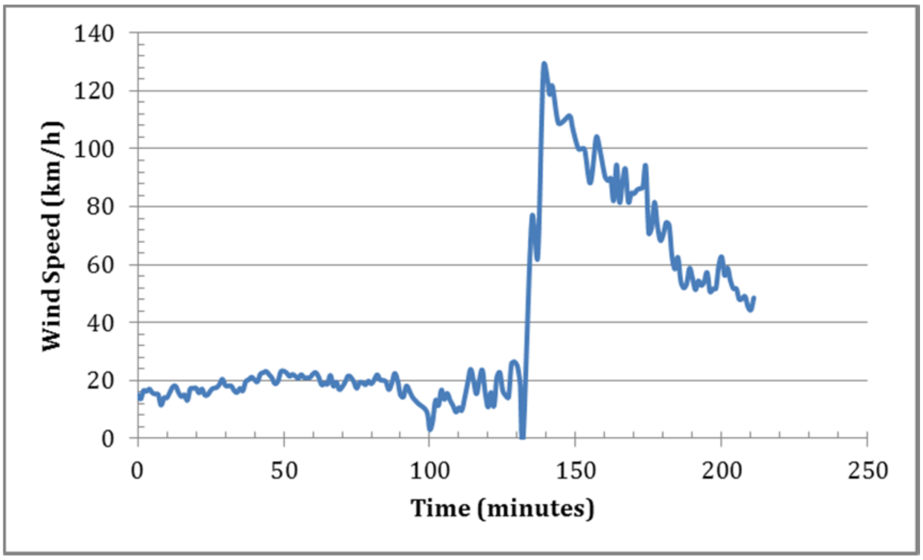

Figure 4. The variation of wind speed with time during the storm on April 18, 2012

3.2 Response of the Bridge

In this study, the accelerometer data during the high-speed wind has been analyzed and response of Bogazici Suspension Bridge was determined. During the extreme wind event the SHM system was working on the bridge. For this purpose, the SHM accelerometer data from the bridge deck in the transverse and vertical directions were selected and acceleration time graphs were drawn. Then the peaks of the points of this graphics were determined and fourier spectrum analysis was performed. Thus, fourier amplitude spectra changing over time were measured.

The data of 133 minutes which was recorded on the bridge mid-span in transverse and vertical directions was processed. The acceleration-time history records of both transverse and vertical directions data in Figure 5 and Figure 7 show high amplitudes between 1000s to 2500s which is the duration of the high-speed wind on the bridge.

The acceleration data between 1000s to 2500s in Figure 5 and Figure 7 (between red dotted line) was further analyzed for the time-frequency representation both for transverse and vertical directions in Figure 6 and Figure 8, respectively. It is shown that the dominant frequency occurs around 0.060-0.065Hz with higher amplitudes which comes across to the high-amplitudes in the time histories in Figure 5 and Figure 7. When the results are compared with those obtained from a routine time, it is seen that amplitudes increased by 3-4 times.

From the analysis results, the dominant frequencies of the high-speed wind data were determined around 0.060-0.065Hz. The past experimental studies of the various researchers Erdik et al.(1988), Brownjohn et.al. (1989), Apaydın&Erdik (2000) and Kosar (2003) on the Boğaziçi suspension bridge refer to normal conditions range in 0.072-0.073 Hz. When these results are compared with our findings, it can be concluded that the period of the bridge increased during the extreme wind event.

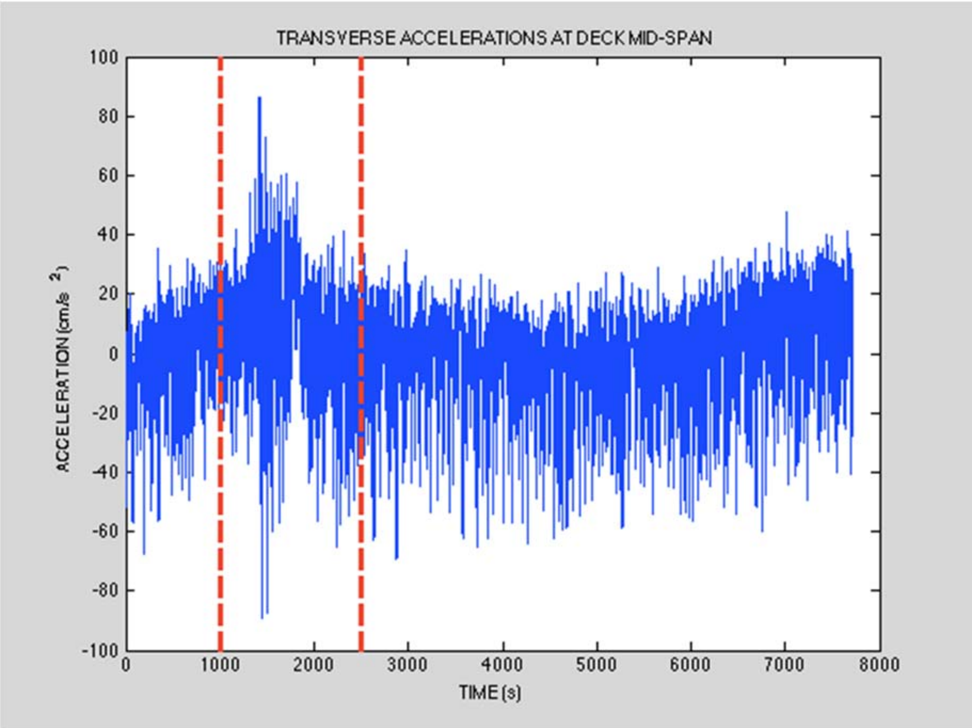

Figure 5. Acceleration-Time history at deck mid-span in transverse direction

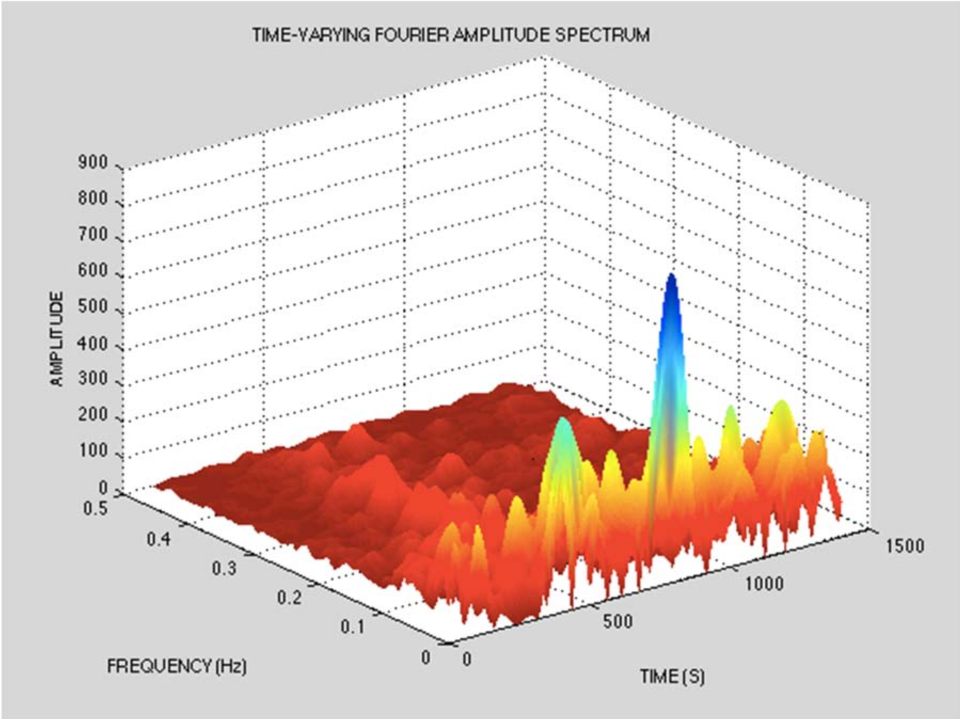

Figure 6. Time-Frequency representation at deck mid-span in transverse direction

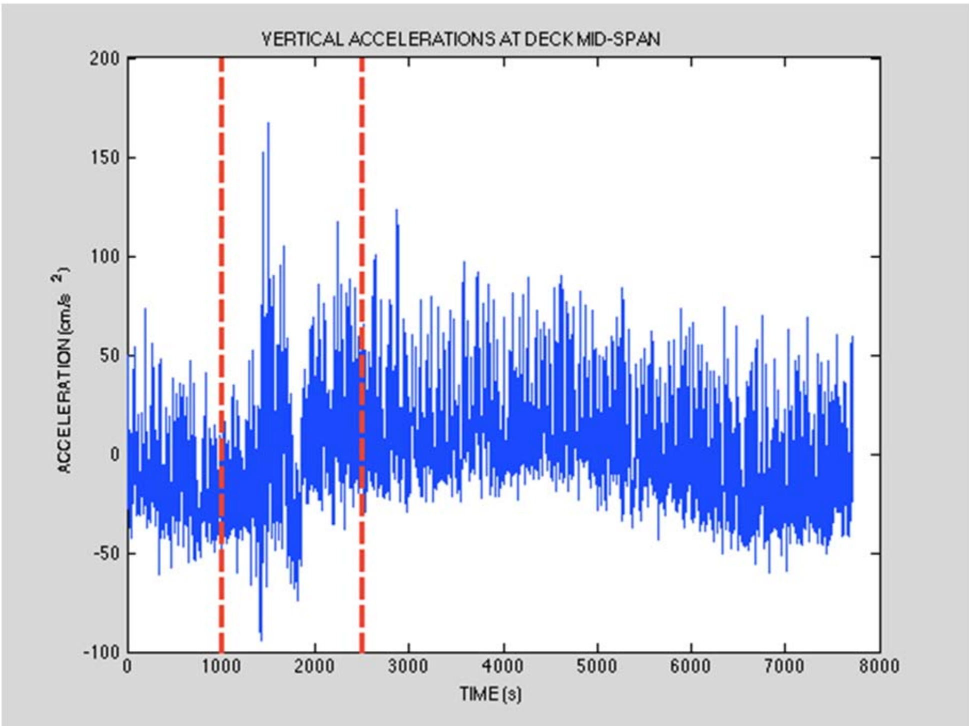

Figure 7. Acceleration-Time history at deck mid-span in vertical direction

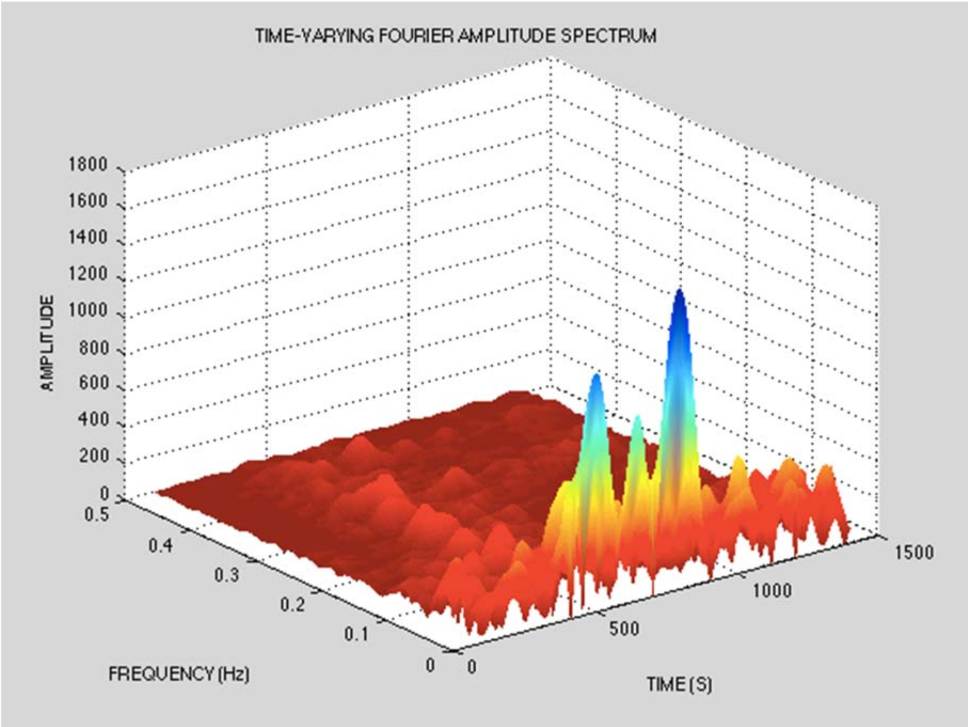

Figure 8. Time-Frequency representation at deck mid-span in vertical direction

4 RESULTS

This study includes information about the SHM system installed on Boğazici Suspension Bridge and results of vibration analysis of the bridge during the storm.

The SHM system 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 on the bridge works effectively so far. On April 18, 2012 day time, a strong storm occurred in Istanbul city. The maximum wind-speed reached to 122 km/h. The bridge was closed to the traffic for a short period as a precautionary measure. SHM system recorded the data during the wind event. For the identification of the bridge response, acceleration records during an extreme wind event were analyzed. From the analysis results, the dominant frequencies of the high-speed wind data were determined around 0.060-0.065Hz. The past experimental studies of the various researchers on the Boğaziçi Bridge refer to normal conditions range in 0.072-0.073 Hz. When the results are compared with those obtained from a routine time, it can be concluded that amplitudes increased by 3-4 times and the period of the bridge increased during the extreme wind event.

ACKNOWLEDGEMENT

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REFERENCES

Apaydın, N. and Erdik, M. (2000). Structural Vibration Monitoring System for the Bogazici Suspension Bridge. KGM, FHWA and TRA Workshop on Earthquakes in Turkey 1999, November 6-10, Ankara.

Bogazici Bridge Monitoring Handbook and User Manual. (2009). General Directorate of State Highways, 17th Division Directorate, Istanbul, Turkey.

Brownjohn, J.M.W., Dumanoglu, A.A., Severn, R.T. and Blakeborough, A. (1989). Ambient Vibration Survey of the Bogazici Suspension Bridge. Earthquake Engineering and Structural Dynamics, 18, 263-283.

Erdik, M. and Uçkan, E. (1989). Ambient vibration survey of the Bogazici Suspension Bridge, Report No: 89-5. Department of Earthquake Engineering Kandilli Observatory and Earthquake Research Institute, Bogazici University, Istanbul, Turkey.

Kosar, U. (2003). System identification of Bogazici Suspension Bridge, M.Sc. Thesis, Department of Earthquake Engineering, Bogazici University, Istanbul, Turkey.

Record Book: Istanbul Bogazici Koprusu (Bogazici Suspension Bridge). (1973). KGM matbaası, General Directorate of Highways, Turkey.