Bridge health monitoring: the Davtashen bridge example in Yerevan

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Abstract. AcceloAI system was developed by NUACA Chair of Roads and Bridges for the purpose of frequency-based bridges monitoring. The system allows measuring accelerations and determining the frequency of vibrations in real time, at four points of the bridge span simultaneously. The system provides the capability of making measurements both at the pier and the span. AcceloAI system has been used for monitoring of vibration frequency in the superstructure of Davtashen Bridge in Yerevan (Armenia). Davtashen Bridge has been chosen as a model for creating a Bridge Monitoring system for large bridges in Armenia. The results of the system usage and the analysis of measurements over the last years are presented in this paper.

Introduction
Periodic inspections of the technical condition of bridges are made to ensure their safe operation. In particular, this applies to large-span railway and road bridges failure of which may lead to long traffic interruptions.

The technical condition of a bridge superstructure or piers can be assessed by a visual inspection or through special testing. Visual inspection of the bridge structure does not require special equipment and can be done many times a year. According to the applicable Armenian norms and regulations, a visual inspection of a bridge must be done at least two times per year, generally in spring, and in autumn.

For the purpose of special tests special measurement equipment needs to be installed on the structures, test loads need to be used, and even more important is that the bridge needs to be closed to traffic for the duration of the test.

It is clear that visual inspections can help reveal only visible defects, but cannot be used to assess the capacity of the structure. This type of inspections can only give indication of the overall health of the structure, whereas bridge testing can provide a clear picture of structural health, but cannot be arranged often for the above mentioned reasons and due to significant organizational and financial costs incurred.

Nowadays, permanent structural health monitoring technologies are becoming increasingly popular due to development of microelectronics, communication systems and appropriate software that makes a variety of sensors and recording devices [1,2] available.
Methodology

One of the main components of structural health monitoring is the usage of sensors which can indicate changes in the materials and in the dynamics or geometric properties of the structural system in real time. Sensors can be installed in a way not to interfere with traffic on the bridge, yet providing a real picture of the behavior of the structure as a whole and of individual node points. This way, acceleration of structure vibration can be used as an easily measured parameter. The bridge superstructure and piers are constantly under dynamic load created by vehicles moving along the bridge. Therefore, measuring vibration is not a big issue in case of bridges and can be easily done in real time. It is one of the reasons why vibration measurements became one of the most popular indicators for structural health monitoring in bridges [2,3].

It is known that vibration frequency in beams or columns depends on their stiffness. Thus, changes in frequency spectra with time can be indicative of, first, changes in stiffness of structure [3, 4, 5, 6]. Stiffness of structure depends on the material used, its geometrical characteristics and on the condition of joints between the general elements of the structure. Thus, acquisition and comparison of frequency measurement data can provide the real picture of the changes in the structure.

For this purpose, specialists of NUACA Chair of Roads and Bridges developed a system of sensors that can be used for real-time measurements of structural vibrations in bridges and evaluation of frequency spectra. The developed system named “AcceloAI” consists of four sensors and a receiver (Figure 1).

Each sensor allows you to simultaneously record acceleration of vibrations in three directions (X, Y, Z). Sensors can be located independently from each other, within a radius of 20m from the receiver. The sensors are created on the basis of MPU6050 type accelerometers (Figure 2). The system is developed in a manner to allow for vibration measurements using one, two or three sensors only and not necessarily four sensors every time.

Accelerograms for the measured vibrations are recorded in text (*.txt) format, in a separate file for each direction. Then, the obtained data are processed using the special software developed along with the system. The measurement data can be also processed by popular signal processing software tools or Matlab, Excel, or other software for performing mathematical operations with Fourier transform.

As it has been mentioned, the sensors were created on the basis of MPU6050 type accelerometers and their frequency response is 100Hz. The sensors can filter measured frequencies for 5, 10, 21, 44, 94, 184, 260 and 500Hz which allows using them for different vibration conditions.

![Figure 1. Principal scheme of AcceloAI system.](image-url)
Figure 2. View of the sensor developed on the basis of MPU6050 accelerometer.

AcceloAl system has been tested and is currently used for monitoring of Davtashen Bridge in Yerevan (Armenia) (Figure 3).

Figure 3. Measuring of vibration acceleration with AcceloAl system on Davtashen Bridge.

Results
Since 2012 vibration acceleration has been measured every year for the middle of the central span of Davtashen Bridge superstructure. Based on these measurements Fourier spectra have been developed. Amplitudes of the spectra for main vertical vibration frequency by years are shown on Figure 4 and samples of Fourier spectrum are provided on Fig. 5. As it can be seen from Figure 4, there are differences in the main frequency amplitude between main beams on the southern and the northern sides of the bridge.
**Figure 4.** Chart demonstrating the changes in vertical vibration frequency in the period from 2012 to 2018 years.

**Figure 5.** Examples of Fourier spectra (measurements done in 2018), a – the southern side of the superstructure, b – the northern side of the superstructure.

This can be explained with the location of the bridge superstructure stretching from the east to the west, with its southern part in the sunlight throughout the day, and the northern part in the shadow. This aspect can be extremely important if one bears in mind that the width of the bridge is 32m and that the superstructure is a continuous steel beam with total length of about 365m. In order to check this assumption, the specialists of Chair of Roads and Bridges developed a new device, DeflectoAl-H, for measuring temperatures and deformations of the superstructure in real time over years. Temperature measurements are taken in parallel with vibration measurements, and correlation of these two measurements may point to the cause of the difference between the vertical frequencies in the south and the north beams of the superstructure.

The Fourier spectra developed on the basis of the measured vibrations were compared also with theoretical Fourier spectra of the areas where the sensors were installed. It is mandatory to provide an initial set of basic theoretical data to the database for monitoring process. This allows evaluating the order of change in the received measurements. For the case of Davtashen Bridge the 3D finite element
model of superstructure was developed. The theoretical Fourier spectrum of the vertical frequencies for the middle of the central span of the north side beam is shown in Figure 6.

![Figure 6. Theoretical Fourier spectrum for the central part of each span of Davtashen Bridge superstructure.](image)

Based on the available measurement data and future measurements, a database will be created [7], to be used as a bridge health monitoring model.

**Summary**

Measuring the frequency of vibrations in the superstructure cannot give full information about the health of the bridge. For having the full picture of the structure monitoring it is necessary to receive complex data such as deflation/incline, frequency of structural vibration. In the near future new measurement systems for pier inclination measurements, wireless accelerometers and new generation sensors are going to be developed and installed not only on Davtashen Bridge, but also on the other large span bridges of Armenia.

Vibration frequency measurements have been taken on Davtashen Bridge since 2012. They showed that the availability of a database with measurement results and analysis of this data can not only reveal changes in the structure associated with damage or other external influences, but also become an indicator of the actual behavior of the structure as opposed to the theoretical one and, along with monitoring of the design features, can contribute to a better operation of the bridge.

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