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EXPERIMENTAL MODAL TESTING OF A CONCRETE BRIDGE

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Abstract: *This paper reports on the experimental analysis of a concrete bridge. Vibration problems generated by the resonance phenomenon are often encountered in bridges. Cases such as Tacoma Narrows, Washington, USA and Millennium Bridge, London, UK, are just two examples of structures that showed problems with resonance due to the exterior, dynamic actions. The concrete bridge whose dynamic response has been measured tends to vibrate excessively under car traffic.*
Keywords: *experimental modal analysis, resonance, vibrations, concrete bridge*

1. INTRODUCTION

In nowadays structures, one of the most encountered problems is the one of vibrations. Even though the serviceability and resistance demands are being met, due to the use of higher resistance materials and larger spans, structures tend to fail the vibrations criterion.

The present paper analyses a concrete bridge over the Somes River. Built in 1967, the bridge has severe vibration problems; therefore measurements have been necessary in order to acquire more information about its dynamic behavior. After assessing the natural frequencies, several comparisons have to be made with the frequencies of the exterior, dynamic actions in order to establish the danger of resonance. If there is a match, methods of changing the natural frequencies need to be considered.

2. STRUCTURE DESCRIPTION

The total length of the bridge is 180.5 meters. The 6 spans, 27.45 m each, are made of 3 continuous reinforced concrete beams of **p** section, as shown in fig. 1. The 2 longitudinal beams, 40 cm width, with an approximate height of 170 cm (fig. 2), are coupled transversally at every 9,15 meters by floor beams. The static scheme of the bridge consists of 3 **p**-beam, each continuous over 2 spans. The beams are pinned at both ends with mobile joints. On each intermediate support, the beams are coupled at the lower part with a 6m long plate, in order to handle the compression stress better. The deck of the bridge has 1.33 m long cantilevers on each side.

According to the tests performed with a concrete test hammer, the class of the concrete that can be used in calculations is C16/20.

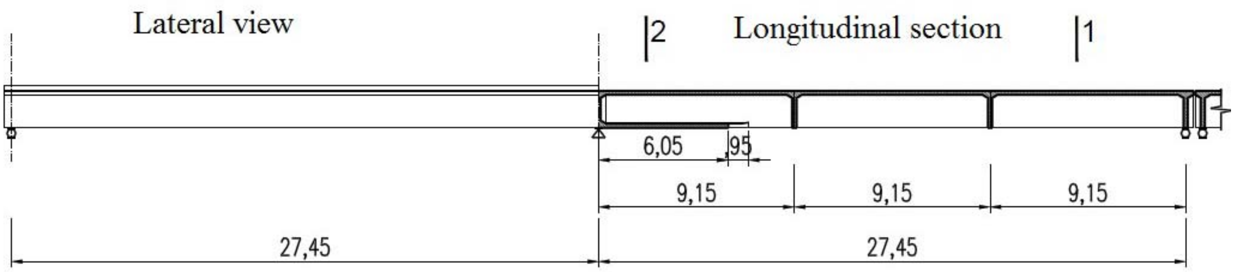

Fig.1. Lateral view and longitudinal section of the bridge

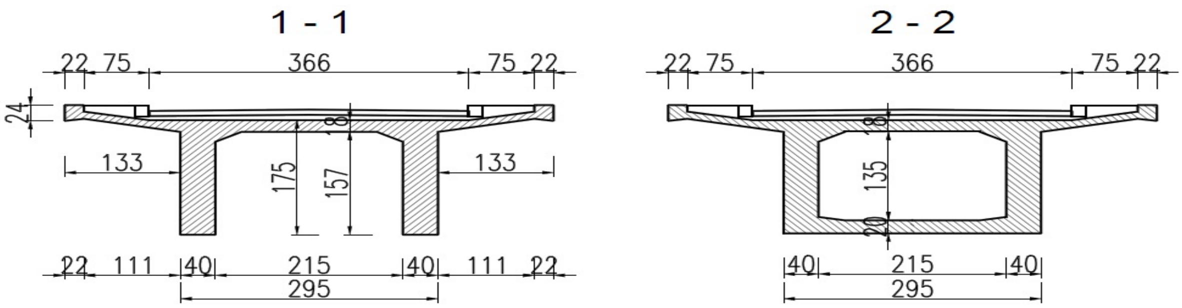

Fig.2. Cross section of the bridge

3. MEASUREMENTS

3.1. EQUIPMENT

The equipment used has been provided by Bruel&Kjaer [1] and it consisted in a Pulse Type 3560-C Portable Data Acquisition unit connected to a portable computer, an 8210 heavy duty modal impact hammer, a 8340 seismic accelerometer and 4 piezoelectric accelerometers type 4507B002.

3.2. MEASUREMENT METHODS

The measurements have been performed in two different methods: classical modal analysis [2] using the impact hammer, and operational modal analysis [3] measuring the bridge response under traffic loading.

In order to perform the measurement task for classical modal analysis, a grid of measurement points on the length of the bridge, has been marked at equal distance. In each of these points, the bridge has been excited with the impact hammer 3 times, in order to have an average of the registered impact force.

The response of the structure has been recorded in terms of accelerations with the accelerometer in a fix point. In order to compare the dynamic response of different bridge spans, measurements have been performed on the first, third and fifth span, taking in consideration the existing joints at every two spans. The interpretation of the results made with the program Pulse Labshop [1], provided by Bruel&Kjaer, has shown a difference up to 6% between the spans, which has been considered to be negligible. The first five eigenmodes have been identified, and the eigenfrequencies for each of the modes (with variation) is listed in table 1.

Table 1

Natural frequencies for the first 5 modes

Mode no	Frequency (Hz)
1	3,15 - 3,25
2	5,75 – 6,00
3	12,25 – 14,00
4	15,25 – 16,33
5	25,5 – 27,10

The fundamental mode is represented in fig. 3, for a single span, and the points defining it, can be identified in figure 4, that represents the mode shapes for two spans.

For operational modal analysis, 4 piezoelectric accelerometers type 4507B002 and the 8340 accelerometer have been used.

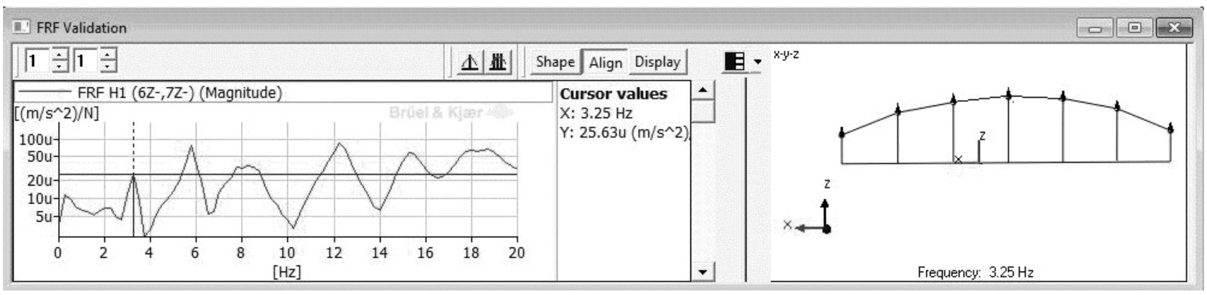

Fig.3. Fundamental mode: frequency and mode shape for a span (7 interior points) obtained from the experiment

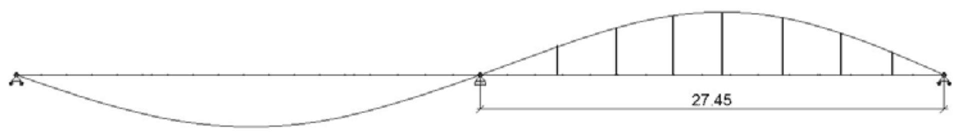

Fig.4. Fundamental mode: the mode shape for two spans from a finite element analysis software

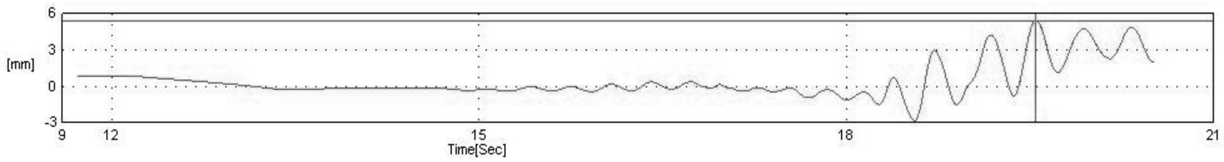

Fig.5. Displacement/time graphic

The analysis has been performed by crossing the bridge with a convoy (including a small artificial bump made from a wooden board) in three different steps of constant speed ranging from 10 to 30 km/h.

The 5 accelerometers have recorded the response accelerations of the structure on a grid of points along the spans, from the moment of the entrance on the bridge of the convoy, until the vibrations were completely damped.

3.3 RESULTS INTERPRETATION

In the case of the output-only experimental modal analysis, the interpretation of the results has been performed using the program Operational Modal Analysis Pro (OMA) provided by Structural Vibration Solutions A/S [5].

The dynamic characteristics obtained (frequency and mode shapes) are the same with the ones obtained using classical modal analysis for the first 5 mode shapes, an analysis performed directly by the acquisition software Pulse Labshop [1]. Due to the high intensity loading, other eigenmodes were identified, all having superior frequency values to those already presented.

Starting with the recorded accelerations, the displacements of the points along the spans have been determined using OMA and also a Matlab [6] code based on the so-called Omega Arithmetic algorithm [7]. The maximum/ minimum displacements have been registered during the convoy crossing with a speed of 10km/h and have the values $D_{max/min}$ = +5,4/-3,1mm. On all the displacement/time graphics, oscillations with an approximate period T = 0,3s can be observed, oscillations corresponding to the fundamental mode with a frequency F=3,15-3,25 Hz.

4. CONCLUSIONS

These oscillations have maximum amplitudes for low speeds of the convoy. It is well known that car traffic induces dynamic loads in the 1,5 - 4,5 Hz range [8]. Due to the fact that the fundamental frequency is in the same frequency range as the one of the exterior loads, the resonance phenomenon appears. Nowadays, the oscillations have low amplitudes, and have not led to a major decrease of the bearing capacity or stability of the bridge. However, the vibrations are perceived by the pedestrians and also by car drivers. Not only that these vibrations are discomfortable for the ones previously mentioned, but the danger that resonance can affect in time the structural integrity of the bridge due to uncontrolled increase of the amplitudes under dynamic loads requires immediate measures to consolidate the structure, in order to change the fundamental frequency and the bridge stiffness.

5. REFERENCES

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Analiza modală experimentală a unui pod din beton

Abstract: Lucrarea prezintă analiza experimentală a unui pod din beton. Probleme legate de vibrații generate fenomenul de rezonanță sunt des întâlnite la poduri. Cazuri precum Tacoma Narrows Bridge, Washington, USA şi Millenium Bridge, Londra, UK sunt doar două exemple de structuri care au avut probleme de rezonanță datorită acțiunilor dinamice, exterioare. Podul la care s-au făcut măsurători tinde să vibreze excesiv sub încărcările din trafic curent.

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