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EXPERIMENTAL MONITORING OF A BRIDGE IN BRATISLAVA

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Abstract: *The New Bridge over the Danube in Bratislava represents an attractive steel cable-stayed bridge erected in the year 1972. The length of is its 431.8 m. The submitted paper deals with dynamic identification realized as the organic part of regular virtual monitoring on the bridge. It describes the methodology of experimental testing and brings some results of the dynamic loading test. During this test it was observed that the dilatation unit on the right water side shows some failure. Due to this failure the dilatation unit acts as a generator of vibration of the end bridge span. On the basis of the experimental testing the failure was detected and the dilatation unit was renovated.*

Key words: *natural frequencies, dynamic coefficients, dynamic loading test, experimental technique, virtual monitoring.*

1. Introduction

The New Bridge over the Danube in Bratislava represents an attractive steel cable-stayed bridge erected in the year 1972, Figure 1. It serves for taking over the express highway from Bratislava to Vienna. The structure is subjected to regular virtual monitoring in accordance with theoretical and numerical approaches presented in this paper. The reconstruction was carried out during summer days in 2004. It was the reason for control of dynamic characteristics of the bridge and for carrying out the short loading test of the bridge. The submitted paper describes the basic principles of virtual monitoring system and methodology of experimental testing. It presents some results of the loading test and gives information about dynamic deflections at selected points and information about frequency composition of vibration.

Fig. 1. *The New bridge over the Danube in Bratislava*

2. Description of the Bridge Structure

The New Bridge is steel cable-stayed bridge crossing the Danube in Bratislava. Its length is 431.8 m. The length of the middle span over the Danube is 303.0 m and the lengths of the end spans are 74.8 m and 54.0 m.

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Bearing cables are lead over sloping pylon 77 m tall. The cross section is box with two cells and two consoles on a level of upper and lower slabs. Vertical beams and horizontal slabs are stiffened by cross and longitudinal braces. Sloped diagonals fix the space stability. Width of bridge deck is 2 x 10.5 = 21.0 m. Bearing cables are anchored in the middle of cross section so the bridge is predisposed to torsion vibration. Basic dimensions in longitudinal direction are shown in the Figure 2.

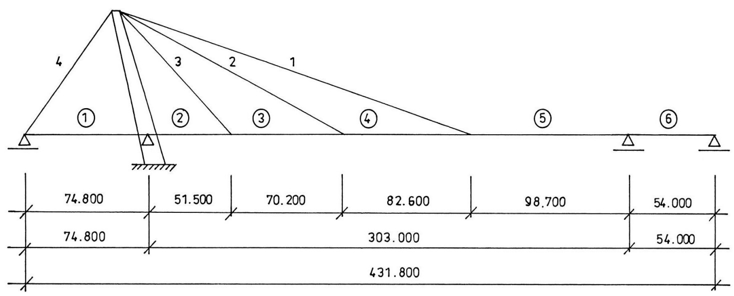

Fig. 2. *Basic dimensions of the bridge*

3. Virtual Monitoring

The system of virtual monitoring suggested consists of following operations [3]:

1. For actual technical state of the bridge, stated by the regular diagnostics and specified in the data basis of the bridge parameters, is developed the virtual model of the structure. The model contains all known actual physical data and fault findings in situ and is varied in accordance with the results of regular diagnostics and testing of the bridge.
2. With adoption of such model and of above identification approaches there are made the virtual loading and forcing tests with calculation of the time response in the ultimate behaviour of the bridge subjected to standard static and dynamic loads.
3. The verifications and modifications of the virtual model are made until coincidence of numerical and experimental results obtained.
4. With the model modified in such a way there are made all virtual loading and forcing tests in accordance with valid standards.
5. The assessment of the reliability and fatigue behaviour of the bridge is made by following operations:

- Macro- and micromechanical modelling of actual material and structural configuration of the bridge in space and time.

The calculation of deformations and stress states in each microelement of the adopted calculation model.

- Automatic comparison of the stress states in all microelements with ultimate fatigue stress curves for the material adopted (for example, the Wöhler curves for steel).
- Virtual initiation of the fatigue cracks in all micromechanical elements in which the stress trespasses the ultimate fatigue stress value.
- Repeated calculations of further virtual initiation and propagation of cracks in space and time until the total collapse of structure.

6. The results obtained are evaluated and adopted for the specification of final conclusions and reliability recommendations for the bridge studied.

4. Experimental Equipment

The main goals of the experimental measurement during short loading test were observing of vertical displacements and strains in selected points of the structure and vertical and horizontal accelerations in selected points [2]. The following equipment for the registration of those physical quantities was used: inductive sensors Bosh, tensometers Kistler 9232A and amplifiers Kistler 5011, accelerometers Brűer-Kjaer BK 8306 and amplifiers BK 2635. Sensors were localised in the middle of the pans on the bottom deck of the cross section. Signals from the sensors were leaded by means of coaxial cables to measuring central. Measuring line consists from these components: sensor, amplifier, signal cable, AD interface, operating computer. All the analyses were carried out by numerical way through the program system DISYS.

5. Results of Experimental Tests

The bridge was excited by passing of lorry Scania, total mass 31.75 t. It was found out during the loading test that the dilatation system on the Petržalka river side is not in order and it acts as a generator of vibration. Due to this reason the results concerning of the vibration of the 1st span from Petržalka river side as the most interesting are introduced in this paper. Typical time record of vibration of the 1st bridge span is shown in the Figure 3.

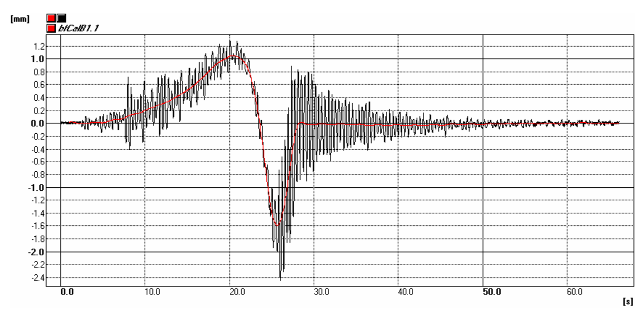

Fig. 3. *Typical time record of vibration, driving direction B - P*

It is seen from the above figure that the maximal dynamical deflection appears at the moment of passing vehicle over dilatation unit. This fact is evident very well from the Figure 4 where two-amplitudes of vibration are presented. The maximum value of the time record corresponds to the time moment when vehicle passes over dilatation unit.

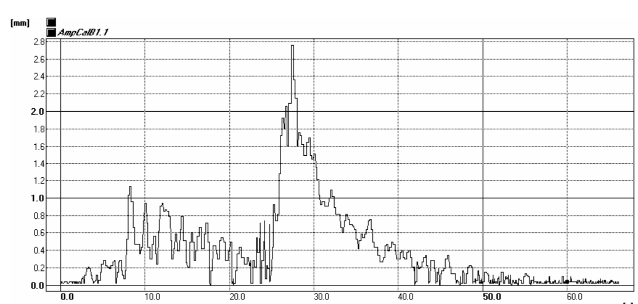

Fig. 4. *Two-amplitudes of 1st span bridge vibration*

The bearing cables are anchored in the middle of cross section and the bridge is predisposed to torsion vibration. On the Figure 5 we can see the time histories of vibrations registered by sensors B1 and B2 situated on left and right side of the structure. It is seen that except bending vibration the bridge show clear rotation.

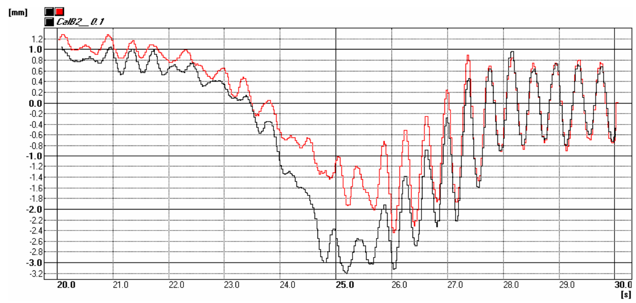

Fig. 5. *Comparison of records from sensors B1-up, B2-down*

Dynamic deflections in selected points were estimated in dependence on the speed of vehicle motion in the form of dynamical coefficients δ_{obs}. Dynamic coefficient is defined as:

$$\delta_{obs} = S_{max} / S_m , \quad (1)$$

where S_{max} is maximal dynamic deflection and S_m is maximal static deflection [1].

Dynamic coefficients were evaluated for so called smooth runs of vehicle and for runs o vehicle over standard obstacle. The dependences of dynamical coefficient δ_{obs} versus speed of vehicle motion for left and right sensors situated in the middle of the 1st span on the Petržalka water side and smooth runs of vehicle when vehicle passes over the bridge from Bratislava to Petržalka are presented in the Figure 6.

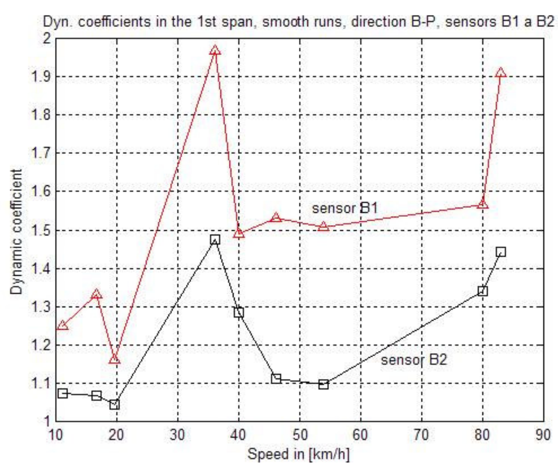

Fig. 6. *Dynamic coefficients versus speed of vehicle motion*

The critical speeds of vehicle motion at which maximal dynamical coefficients appear are in the interval from 30 to 40 km/h and from 80 to 90 km/h. Maximal value of dynamic coefficient for smooth runs is $\delta_{obs,\ max}$ = 1.96 and for runs over standard obstacle is $\delta_{obs,\ max}$ = 2.27.

From the dynamical point of view the natural frequencies represent the very important numerical characteristics defining the dynamical individuality of the bridge. The changes of these characteristics are connected with the changes of mechanical properties the bridge and they can signalise possible defect of the structure. With respect to this fact the computational simulating model was created in the year 1999. The model was harmonized with the results of experimental measurements. The results obtained from this computing model serve as reference base for future experimental tests. The power spectral densities were used for determination of individual natural frequencies. The 1st natural frequency 0.25 Hz corresponding to torsion vibration was very well evaluated, Figure 7. The 1st sharp peak in power spectral density function confirms this fact very clearly.

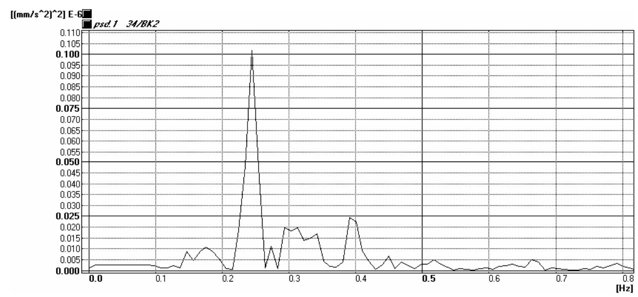

Fig. 7. *The 1st sharp peak in PSD function corresponds to the 1st natural frequency*

The frequency range from 0 to 1 Hz is a little problematic from the experimental point of view. The frequencies in this range are on the sensitivity boundary of used sensors. On the other hand it is also the problem to excite some natural modes of vibration only by passing the vehicles. For example the peak corresponding to the 2nd natural frequency $f_{(2)}$ = 0.31 Hz (bending vibration of the bridge) is not so sharp because it is practically impossible to excite the 2nd mode of natural vibration only by passing of one vehicle. The peaks corresponding to the frequencies 0.52; 1.45; 2.50; 3.52 Hz in Figure 8 clearly confirm the natural frequencies obtained

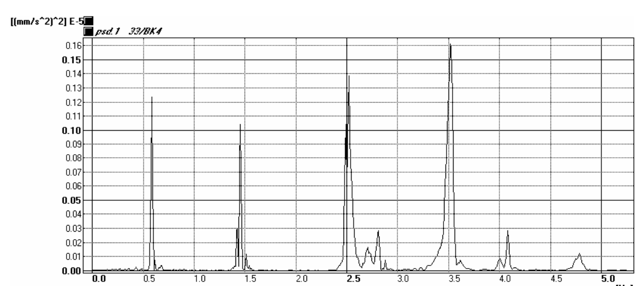

Fig. 8. *The peaks in PSD function correspond to the frequencies 0.52; 1.45; 2.50; 3.52 Hz*

by numerical way in the frequency range 0.5-5.0 Hz. Natural frequencies in the frequency range higher then 5.0 Hz were not able to excite by passing of one vehicle.

The calculated and experimentally obtained natural frequencies are compared in the Table 1. Harmony between numerically and experimentally obtained natural frequencies is very good.

Table 1

Numerically and experimentally obtained natural frequencies

j	$f_{(j)}$ [Hz]	
	calculation	**experiment**
1	0.2523	0.25
2	0.3124	0.31
3	0.4236	0.40
4	0.4728	0.47
5	0.5087	0.52
6	0.7942	0.79
7	1.4944	1.46
8	2.4757	2.50
9	3.5798	3.53
10	5.5642	-

6. Conclusion

The New Bridge over the Danube in Bratislava is an important steel cable-stayed bridge. All its dynamic characteristics are periodically monitored. Virtual monitoring approach is adopted. After reconstruction in the year 2004 the short loading test of the structure was carried out. It was found out during this loading test that the dilatation system on the Petržalka side is not in order and it acts as a generator of vibration. Passage of vehicle along this dilatation system evocates enormously the end span bridge vibration, see Figures 3 and 4. Such vibration negatively influences the fatigue processes in this part of the structure. Dynamic coefficients of deflections for this part of the structure are very high. Maximal value of dynamic coefficient for smooth runs is $\delta_{obs,\ max}$ = 1.96 and for runs over norm plank is $\delta_{obs,\ max}$ = 2.27. As we can see form the Figure 6 the zone of critical speeds of vehicles is from 30 km/h to 40 km/h, approximately 37 km/h and from 80 km/h to 90 km/h approximately 83 km/h. On the basis of experimental test the failure on the dilatation unit was detected and the dilatation unit was renovated. The system of fixation of bearing cables causes that the bridge is predisposed to torsion vibration. This fact is clearly documented on the Figure 5, where comparison of time processes of vibration from the sensors B1 and B2 situated on left and right side of the structure is shown. Frequency analysis of obtained records confirms all the frequencies obtained by numerical way in the year 1999. On the basis of this result we can say that the bearing system of the bridge does not show any defects.

Acknowledgements

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