Identification of the numerical model of FEM in reference to measurements in-situ

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Abstract

The paper concerns analysis of the measurements results of the railway bridge subjected to dynamic loading. The study included the measurement of the acceleration values at structural members at the time of the passage of a train. In order to verify the obtained results appropriate finite element analysis model of the structure was made. Static, modal and dynamic analyses were conducted. Structural validation was made for different values of train speed. Calculations were made with use of Autodesk Simulation Multiphysics software.

Keywords: finite element method, modal and dynamic analysis, vibration measurements, Fourier transform

1. Introduction

The 21st century is a period of dynamic development of the railway infrastructure. Increase in speeds of moving trains determines performing complex static and dynamic analyses of both existing as well as newly built bridge objects. Poland is one of many countries in which the program of the high-speed rail construction is being implemented. Unfortunately most of the bridges on the railway tracks are old structures, inadequate or not designed for such loads. Each such structure requires verification of the behavior under the design dynamic load. The mentioned verification is based on actually measured values of accelerations at the bridge elements (generated by the known loading) and comparison of them with theoretical research, i.e. with the attempt to model an object with the given dynamic load. Based on the results, verification of the theoretical research is made by checking if it is reliable and compatible with the reality. This enables us to perform forward analysis, i.e. check whether the designed structure is able to bear the predicted load, or if it requires redesign, strengthening or if construction of a new bridge is mandatory.

2. Description of the analyzed structure

The authors of the paper make an attempt to assess the potential use of the railway truss bridge for high speed rail, referring to the applicable provisions of the limit values for the accelerations of structural vibrations [5, 6]. In Polish literature there are many items concerning dynamic tests of bridges [2, 3, 4]. The main purpose of such analysis is to determine the dynamic characteristics of the structure, such as natural frequencies, logarithmic decrement of damping, dynamic gain coefficient. These types of analyses allow detecting dangerous phenomena, which may even lead to the structural disasters [1].

The analyzed structure is of simply supported static scheme. The bearing system is a lattice structure with bottom loading. The object, in the cross section overall dimensions, is suited for the double track, but it is only used for single line. Theoretical span of the bearing structure is 55.06 m and the cross section width is 9.45 m. The whole structure is reinforced with cross-bars, arranged in 4.58 m spacing and wind beams as top bracing. Rails are based on oak bridge sleepers which are supported at steel longitudinal members.

3. Experiment

Dynamic measurements were carried for three train runs. The purpose of the measurements was to identify free vibration frequencies of the bridge structure, an attempt to find out the actual dynamic gain factors and the determination of the actual damping coefficients for the basic frequencies of free vibrations and vibrations spectrum. The measurements were made with use of the equipment allowing registration of the time series of vibration accelerations of the structure span with a sampling frequency equal to 600 Hz. Accelerometers were fixed in ½ and in ¼ of the theoretical span. The speed of the train at each trial run was registered. Exemplary time series of vibration accelerations measured in the middle of the bridge span, while the train was moving with a speed equal to 58 km/h, are shown in Figures 1 and 2.

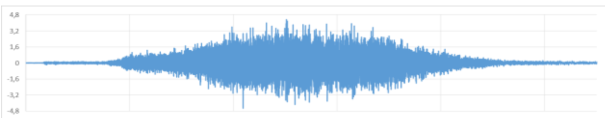

Figure 1: An example of the accelerations of vertical vibrations in the middle of the bridge span.

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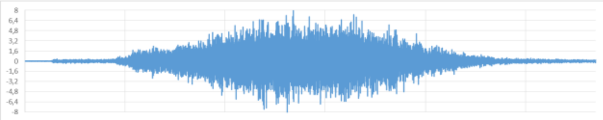

Figure 2: An example of the accelerations of horizontal vibrations in the middle of the bridge span.

The received acceleration runs were subjected to frequency analysis carried out with use of Fast Fourier Transform algorithm (FFT). Below, in Figure 3 the results of the analysis are shown. Major dominant free vertical vibration frequencies may be observed in the graph.

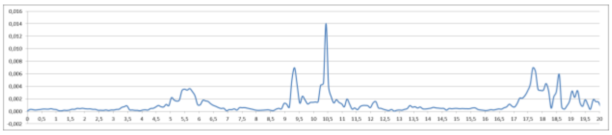

Figure 3: Major dominant frequencies of free vertical span vibrations – main peak at 10.43 Hz.

4. Numerical Analysis

In order to verify the measured values from the in-situ studies, a three-dimensional model of the bridge was made with use of Autodesk Simulation Multiphysics. The model is shown in Figure 4.

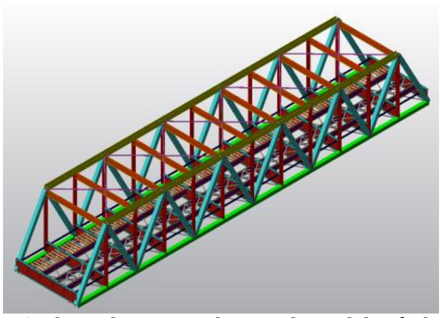

Figure 4: A three-dimensional spatial model of the railway bridge.

The spatial model was classified as the class ($e1$ + $e2$; $p3$) [1]. The symbols $e1$ and $e2$ refer to the dimension of the used elements, while the symbol $p3$ refers to the space in which the model is made. The structure of the bridge was modeled with use of beam and truss elements. Three analyses were carried out:

- static analysis, resulting with the specified theoretical deflection of the span loaded with the weight of train in the middle of the span (static load),
- modal analysis, resulting with the first 10 natural form shapes and frequencies,
- dynamic analysis, modeling the movement of the train with variable speeds.

Based on the dynamic analysis, the authors compared the results of the measured values of the span accelerations with the theoretical ones, obtained from the numerical analysis. The compliance of the 3D model of the bridge with actual values was found. In addition, the train runs with speeds of 50 km/h to 210 km/h with increments of 20 km/h were modeled. This approach made it possible to check which value of the speed is critical for the analyzed object, based on the limit values in accordance with the regulations in force i.e. PN-EN 1990, A1/2008, pt. 2.4.4.2.4 (P) and [7], where the maximum design value of the vertical deck acceleration is given as γ_{bt} = 5.00 m/s^2. Detailed results of the analysis are presented in the full version of the paper.

5. Conclusions

Dynamic analyses give the ability to verify the existing bridge objects for possible use as structures adapted to the changing requirements of the load standards. This is a positive economic aspect, as the costs of building of the new bridge object are counted in millions of dollars. Unfortunately, the proper implementation of such analysis is a challenge for many designers. Complicated geometrical and technological properties result with a difficult mechanical task. Despite the rapid development of computer technology, some numerical tasks are impossible and require many simplifications.

When referring to the presented case and studied literature [2, 3, 4], it should be noted that slender and less bulky structures, most likely will not comply with the requirements of objects for high speed rail. However, the advisability of carrying out dynamic analysis, despite such statements, is most justified. According to the authors, one should also pay attention to the rail bridges of theoretical spans less than 21.0 m, which according to Polish legislation do not require the dynamic analyses.

References

[1] Bęc J. and Jukowski M., Static and Nodal Analysis of the Solidarity Bridge in Płock, *Budownictwo i Architektura*, nr 1, vol. 15, pp. 177-189, 2016. (in Polish)

[2] Łaziński P., Salamak M. and Owerko T., Test Loads of Bridges in Poland Based on Selected Examples, *VII Ogólnopolska Konferencja Mostowców – Konstrukcja i Wyposażenie Mostów*., pp. 83-98. Wisła, 28-29 maja 2015 r. (in Polish)

[3] Pradelok S., Jasiński M., Kocański T. and Poprawa G., Dynamic Analysis of an Arch Bridge Loaded with a High-speed Train Moving, *VII Ogólnopolska Konferencja Mostowców – Konstrukcja i Wyposażenie Mostów*, pp. 193-206. Wisła, 28-29 maja 2015 r. (in Polish)

[4] Szcześniak W., Hypki M., Skulski B. and Śledziewski K., Static and dynamic study of a railway bridge with a surface-to-ground structure, *Logistyka 6/2014*., pp. 10252-10261. (in Polish)

[5] PN-EN 1991-2:2007 Eurocode 1. Actions on structures. Traffic loads on bridges

[6] Technical Standards. Detailed technical conditions for the modernization or construction of railway lines to speed V_{max} ≤ 200 km/h (for conventional rolling stock) / 250 km/h (for rolling stock with pivot box). PART III. Railway engineering objects. PKP Polskie Linie Kolejowe S.A., Warszawa 2009. (in Polish)

[7] PN-EN 1990:2004/A1 Eurocode. Basis of Structural Design.