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Experimental Modal Analysis of the Footbridge across Bečva River in Přerov

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Abstract: The investigated footbridge across Bečva river was built in 1983. The substantial part of the footbridge deck was overflowed by extreme floods in 1997 and 2010. The significant increase of the permanent deflection of its main span was the result of the second flood. The basic objective of the performed experimental modal analysis was the reliability verification of the footbridge structure. The measured natural frequencies and modes were compared with results of the dynamic test performed before commissioning of the footbridge. The mathematical model of the current footbridge structure was verified on the base of experimental data. The damage localization was carried out finally.

Keywords: Damage; Flood; Footbridge; Experimental Modal Analysis

1. Introduction

In the last two decades, the entire territory of the Czech Republic has been hit by a series of great floods, in which many bridges has been damaged significantly. The important question was solved frequently whether the bridge structure has to be demolished or under which operating conditions the bridge operation is acceptable.

The investigated footbridge across Bečva river in Přerov town was built in 1983. From its commissioning the footbridge was an important way for pedestrians and cyclists. The nearest bridge structure to allow crossing over the river was at a distance of about 1 km.

The substantial part of the footbridge deck was overflowed by extreme floods in July 1997 and May 2010. The significant increase of the permanent deflection of its main span was result of the second flood. The permanent deflection in the middle of its main span was increased about 1 m in comparison with the state before commissioning. This is why the footbridge was closed for all users immediately.

During assessment of the footbridge, it was decided to carry out an experimental modal analysis on this footbridge. The basic objective of the performed experimental modal analysis was primary the reliability verification of the footbridge structure.

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Fig. 1. The view on the lower face of the footbridge deck in the main span.

Fig. 2. The view on the intermediate support.

The basic goal was divided to the several partial goals:

1. Determination of the important natural frequencies and mode shapes.
2. Verification of the computational model of the footbridge, which corresponds to its immediate state, comparison of the experimental and theoretical characteristics of the natural vibration [2].
3. Comparison of the measured characteristics of the natural vibration with the characteristics measured before commissioning of the footbridge in the year 1983 [3].

4. Damage detection and localization of the footbridge.
5. The data acquirement for determination of the range and arrangement of the static load test. The static load test had to check the load carrying capacity more deeply.

2. Description of the investigated footbridge

The footbridge is made from the prestressed concrete. The bearing structure is the prestressed suspension deck with two spans, 67.4 m and 28.4 m (Fig. 1 and 2). The prestressed deck is composed from precast segments DS – L and DS – Lv made from concrete B500 and from the monolithic saddle designed upon the intermediate pier. The dimensions of segments are 3.8×0.3×3.0 m. The concrete hinge joint was made in the lower part of the pier.

3. Description of the dynamic test arrangement

The electrodynamic shaker TIRAVIB 5140 was used for excitation of the footbridge. The excitation force was measured by three force transducers S-35 LUKAS, which were interconnected to measure directly the whole driving force. The footbridge was excited by random driving force of white type noise of the frequency range from 0.3 to 20 Hz. The driving force was controlled by signal generator SG 450 ONO SOKKI. The response of the footbridge was measured by two sensor systems independently, four inductive accelerometers B12/200 HBM and four inductive displacement transducers B2/1 HBM were used. The measurement system DEWETRON 5000 was used for data acquisition and data analysis.

The response of the footbridge was measured in vertical and transversal horizontal directions in a chosen net of points (38 points – 19 cross sections and 2 points in each one) on the upper face of the footbridge deck.

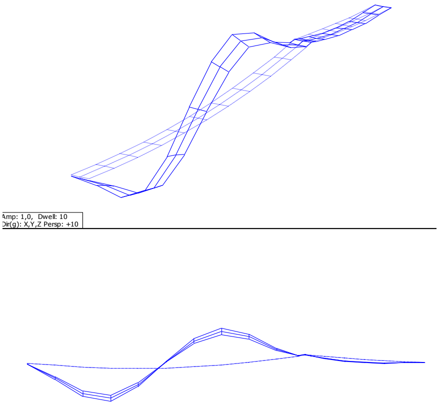


Fig. 3. The 1st measured natural mode shape of the footbridge – $f_{(1)} = 1.07$ Hz.

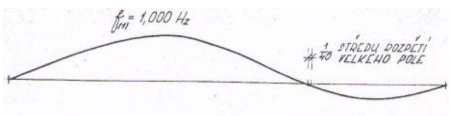
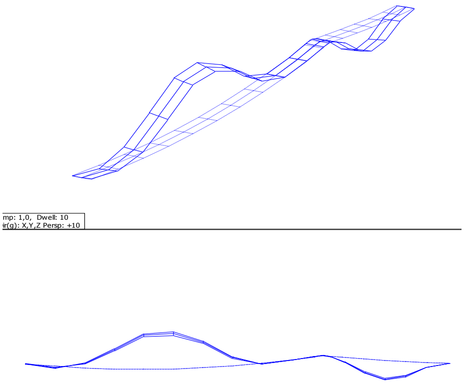


Fig. 4. The 1st measured natural mode shape of the footbridge in 1983 [3].



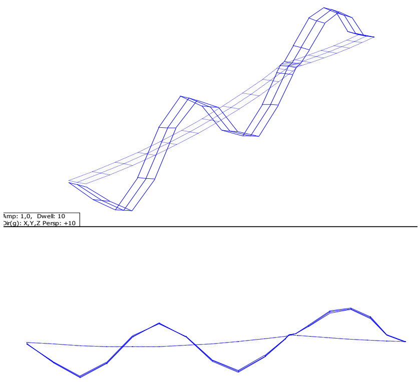
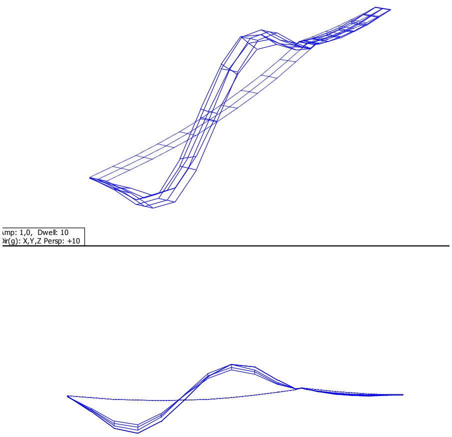


Fig. 5. The 2nd measured natural mode shape of the footbridge – $f_{(2)}$ = 1.50 Hz.

Fig. 6. The 3rd measured natural mode shape of the footbridge – $f_{(2)}$ = 1.85 Hz.



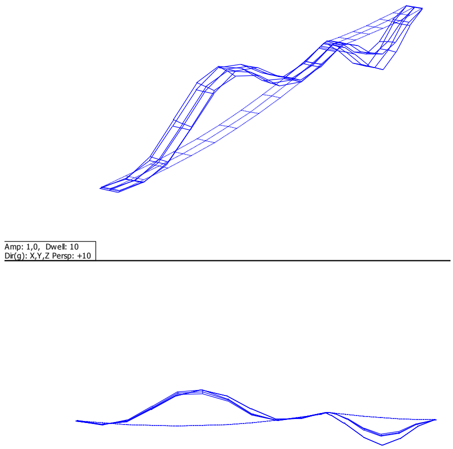


Fig. 7. The comparison of the 1st measured and computed natural mode shapes of the footbridge – $f_{(1)exp}$ = 1.07 Hz.

Fig. 8. The comparison of the 2nd measured and computed natural mode shapes of the footbridge – $f_{(2)exp}$ = 1.50 Hz.

4. The results of experimental modal analysis

The 11 natural frequencies were evaluated in the frequency range 0.5 to 8.0 Hz during the experimental modal analysis of the investigated footbridge. The chosen natural frequencies are mentioned in Tab. 1. The mode shapes corresponding to the natural frequencies were evaluated too. The chosen measured mode shapes are in Fig. 3, 5, 6, 7 and 8.

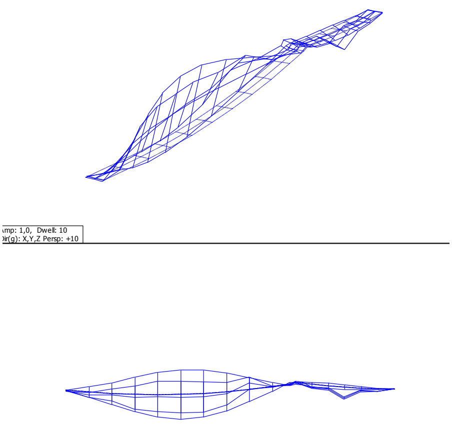


Fig. 9. The comparison of the 4th measured and computed natural mode shapes of the footbridge – $f_{(4)exp}$ = 2.16 Hz.

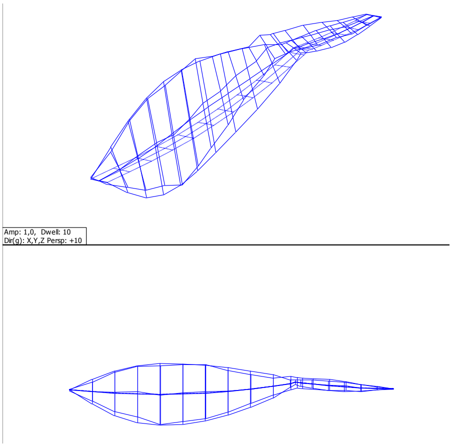


Fig. 10. The comparison of the 7th measured and computed natural mode shapes of the footbridge – $f_{(7)exp}$ = 3.49 Hz.

Table 1. The comparison of the experimental and theoretical natural frequencies of the footbridge

Number (j)	Measured natural frequency [Hz]	Calculated natural frequency [Hz]	Deviation [%]	Description of the mode shapes of the deck
(1)	1.07	1.06	-0.9	1st vertical bending
(2)	1.50	1.39	-7.9	2nd vertical bending
(3)	1.85	1.77	-4.5	3rd vertical bending
(4)	2.16	2.29	+5.7	horizontal vibration with torsion effect
(5)	2.32	2.47	+6.1	4th vertical bending
(6)	2.85	2.72	-4.8	5th vertical bending
(7)	3.49	3.66	+4.6	1st torsion vibration

5. Conclusions

The results of the dynamic load test carried out on the footbridge in the June 2010 were compared with the results of the dynamic load test carried out on the bridge in 1983 before commissioning the footbridge. The significant change of the dynamic behaviour of the footbridge was found. Especially, the basic natural mode shape has totally changed its shape (see Fig. 3 and 4). The significant changes have occurred also for all other compared natural mode shapes.

The measured natural frequencies and mode shapes were compared with calculated ones [2]. It was very important to take into account the actual geometry of the footbridge deck in the theoretical model of the footbridge. The geometry of the deck was measured geodetically in the June 2010. The result of the comparison is that the main reason of the mode shape changes in contrary to [3] is the increase of the permanent deflection of the footbridge (about one meter in the middle of the longer span).

The evaluated changes between measured and calculated natural frequencies satisfied the aptness condition. The model used for the dynamic calculation [2] was apposite enough for modelling of the immediate state of the footbridge and thus it was recommended to use it for preparation of the static load test.

The similarity of the measured and calculated natural mode shapes [2] was high (see Fig. 7 and 8). However, particular differences were found out (see Fig. 9 and 10). Based on the detailed comparison of the measured and calculated natural mode shapes, two areas were determined, where the behaviour of the real structure and the model was different. It was recommended to investigate these areas in more detail, because any damage or fault can be at these positions of the footbridge. One of these areas was near the pier. From the experiment it results that pier of the real footbridge is more flexible in the horizontal transversal direction than the theoretical model. This effect is visible from the Fig. 10 and from the comparison of the natural frequencies. Theoretical natural frequency of the horizontal natural mode is evidently higher than the corresponding measured one. During the following inspection of the footbridge, the crack was found in the area of the concrete hinge joint. After the static load test the footbridge was put into very limited operation.

Acknowledgments

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References

[1] Plachý, T. and Polák, M.: "Fatigue Damage Identification on Concrete Structures Using Modal Analysis," in *Proceedings of the 3rd WSEAS International Conference on Applied and Theoretical Mechanics*, Tenerife, Spain, 2007 (World Scientific and Engineering Academy and Society, Athens, 2007), p. 191 - 196, ISBN 978-960-6766-19-0.

[2] Karásek, P.: *Dynamic Analysis of the Footbridge "U tenisu" across Bečva River in Přerov (in czech),* Prague, June - July 2010.

[3] Pirner, M.: *Report No: 01-053/84/116 about static and dynamic load test of the footbridge across Bečva River in Přerov (in czech)*. Technical and Test Institute for Construction Prague. Prague, March 1984.