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SIMPLE SUPPORTED COMPOSITE BEAM – PREPARATION FOR DAMAGE ASSESSMENT

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Abstract: *The paper is dedicated to some parts of structural health monitoring (SHM) using non-destructive vibration-based methods. An experimental model was made from two materials – wood and plasterboard. Supports could be alternatively considered, but the simply supported beam was considered in this research. Modal analysis was performed from recorded data (18 accelerometers along the experimental bridge in vertical direction and six sensors in horizontal directions). Two artificial exciters were used for harmonic excitation. The placement was asymmetrical. Dynamic characteristics as natural frequency, damping ratio and corresponding mode-shape were obtained using two methods (Discrete-Time Fourier Transform and stabilization charts using the Stochastic Subspace Identification method). Comparison of the methods was prepared. Some mode-shapes were processed for identification of the damage by application FE model updating method.*

Keywords: composite beam, experimental testing, artificial excitation, DTFT, SSI

1. Introduction

Nowadays, the non-destructive testing (NDT) of civil structures achieves popularity among research teams (Bayer, 2017 and Ároch, 2016 or Zenunovic, 2015 or Kratochvil, 2014) because of increasing demands on safety and reduction of maintenance costs. Another reason is that many bridges are obsolete - almost 40 % of American bridges are 50 years old or older as it is mentioned in the Infrastructure report card 2017 published by the American Society of Civil Engineers (ASCE). In accordance the document, 10 % of bridges is structurally deficient due to the lack of long-lasting maintenance or periodic inspections. It can sometimes result in a need of expensive renovation. Early damage detection can help to avoid mentioned situations and to increase structural health of bridge structures. Because of that, this paper is devoted to some stages of SHM of an experimental bridge model – the composite beam. Two ways were assumed for modal analysis: The Discrete-Time Fourier Transform (DTFT) and stabilization charts using Stochastic subspace identification (SSI) method. This technique has big advantage where the modal density becomes high due to close modes with high damping (Moller, 2014).

The experimental model of the bridge was made from three wooden planks and three plasterboards. The wooden boards were used for the main beam, and the bridge deck was made of three standard plasterboard layers of height 12.5 mm. The deck was 300 mm wide and 37.5 mm high. The plasterboard layers were screwed every 170 mm into the main wooden beam. The cross-section of the experimental

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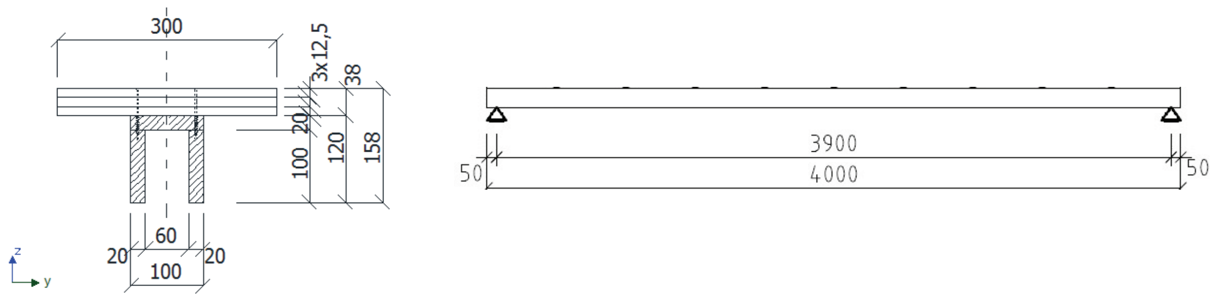
model is shown in Fig. 1 a). The whole length of the model was four meters with joint supports, see Fig. 1 b).



a) b)

Fig. 1: The experimental model a) Cross-section b) Side-view (dimensions in mm).

2. Experimental testing

Used National Instruments devices allowed us to measure up to 24 channels parallelly (Fig. 2). The NI 9234 modules allowed us to measure with the sampling rate of approximately 1651 samples per second for each channel. 19 sensors (mainly PCB Piezotronics 393B31 – black circle) were placed for a measurement of vertical accelerations. Five other MMF KS901.100 sensors were in operation during measurements in horizontal directions (marked as dashed circles). They were mounted on the structure using magnets.

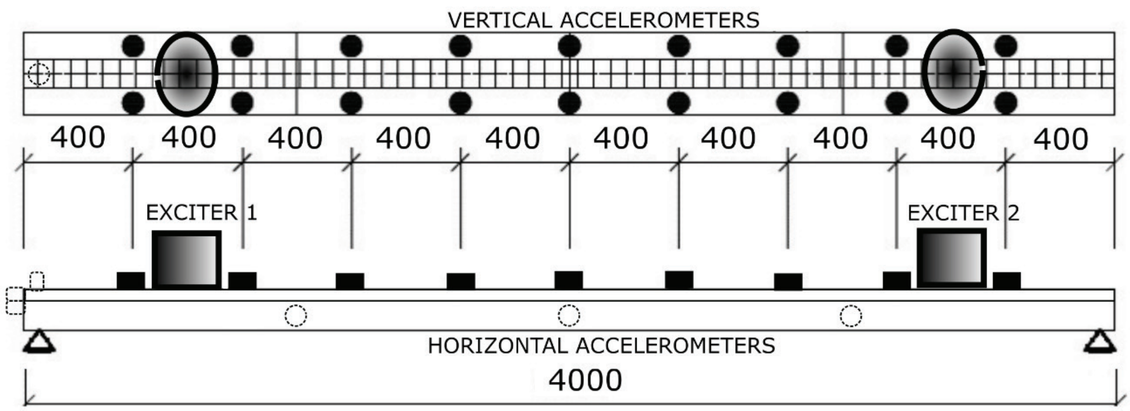


Fig. 2: The layout of accelerometers for measurements.

The harmonic vibrations in the frequencies of the following values (11 Hz, 13 Hz, 15 Hz and 29 Hz) were excited by two electromagnetic exciters with a moving mass of 0.6 kg. Finally, four 10-second data records were acquired, including the last five second period after stopping the exciter. Subsequently, this part was clipped for further analysis. Input signals were not measured. The layout of accelerometers in combination with exciters allowed us to identify with sufficient accuracy only some mode-shapes (the 1^{st}, the 9^{th} and the 10^{th} frequency and its mode-shape).

2.1. Discrete-Time Fourier Transform (DTFT)

Very short data records were a reason why the DTFT was used for acquisition of dynamic parameters. Although, amplitude spectra using the Fast Fourier Transform (FFT) were also prepared. For example, Wang (2016) summarized advantages over the FFT method. The similar results are presented in Fig. 3. It shows response spectra computed using the DTFT in comparison to the FFT. Both were calculated from the time data no. 1. The DTFT gave more precise results because the FFT depends on the number of samples in the transform. In the case of clipped five second period, the frequency resolution was 0.2 Hz. Whereas the DTFT resolution was assumed 0.005 Hz.

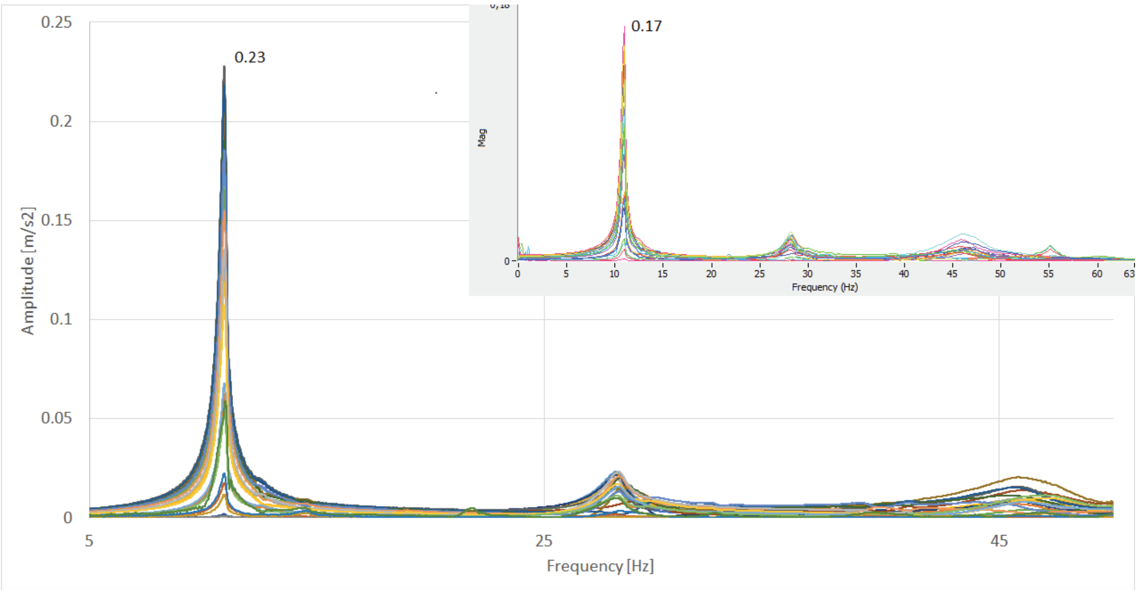
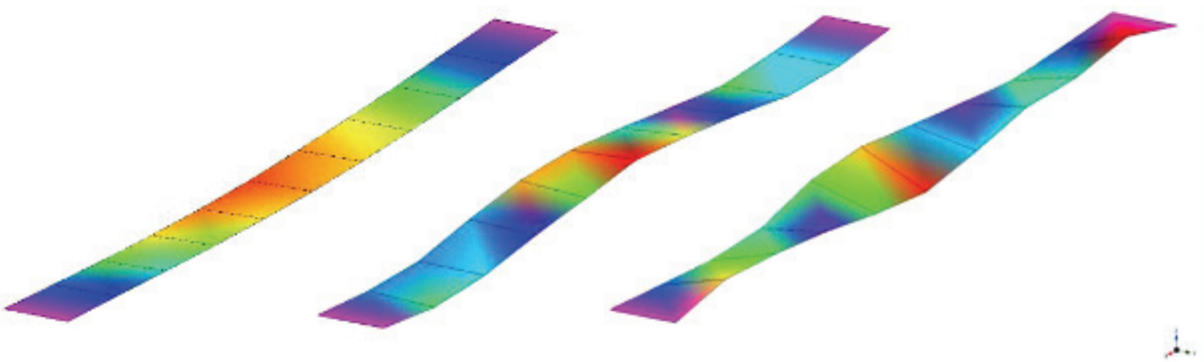


Fig. 3: Spectrum from the record no. 1 by using DTFT and FFT (smaller one).

2.2. Stochastic subspace identification (SSI)

The measured and pre-processed data were analysed in another way, using ModalVIEW software. Software possibilities (stabilization charts) were used for extracting modal parameters as natural frequency, damping ratio and matching mode-shape. Stabilization charts were calculated using the Stochastic Subspace Identification (SSI) method. The method is suitable when input signals are unmeasured or cannot be measured (Peeters, 2000) and only output data are available. In this case, stability criteria were chosen according to Lau (2007). The assumed values were 1 % for frequency stability, 5 % for damping stability and 2 % for eigenvector stability. In accordance with mentioned criteria, some mode-shapes and their natural frequencies and damping ratios were extracted (Fig. 4). The 1st mode-shape represents vibration in Z-direction. The 9th natural frequency is associated to the 3rd vertical mode-shape. The 3rd torsional mode-shape (the 10th natural frequency) was also extracted.



a) b) c)

Fig. 4: Extracted model parameters by ModalVIEW (using SSI method) a) the 1st mode-shape b) the 9th mode-shape c) 10th mode-shape.

3. Comparison of achieved results

Natural frequencies and damping ratios were compared in this chapter. Damping ratio was calculated for the 1st mode-shape. The damping ratio from SSI method equalled to 0.814% and damping ratio calculated from the spectrum prepared by the DTFT was 0.915%. The damping ratio for the 9th mode-shape from SSI method was equalled to 3.706% and damping ratio calculated from spectra was 4.344%. The damping ratio was also calculated for the 10th mode-shape. SSI method equalled to 2.137% and damping ratio calculated by the DTFT was 3.508 %. Damping ratios could also be calculated from time series, but now they were not determined in that way. The natural frequencies are compared in the following tables (Tab. 1), obtained by the DTFT and by stabilization charts using the SSI method.

Tab. 1: Comparison of the 1st measured frequency (in Hz).

The 1st frequency			The 9th frequency			The 10th frequency		
No. of record	**DTFT**	**SSI**	**No. of record**	**DTFT**	**SSI**	**No. of record**	**DTFT**	**SSI**
1	10.93	10.85	1	45.83	45.83	1	47.02	46.95
2	11.00	10.97	2	46.67	46.83	2	47.73	47.60
3	10.98	10.97	3	45.15	45.14	3	47.23	46.74
4	11.00	10.97	4	45.99	45.88	4	46.51	46.12

4. Conclusions

Three natural frequencies (the 1st, the 9th and the 10th frequency) obtained by two different methods were compared in this paper. Stabilization charts using the SSI method calculated comparable mode-shapes and other dynamic parameters to the spectrum by the DTFT. The difference in the 1st mode-shape and corresponding natural frequency was negligible. Another advantage of the SSI method, besides the input signal can be unknown, is that mode-shapes are extracted directly. Thanks to that, the results can be used for damage detection as in Sokol (2017). Other compared natural frequencies were less accurate because of the higher number of the identified mode-shapes. The number of used sensors for the higher mode-shapes was on the edge of possibilities. The next research could also be prepared with measured input signals for even better results.

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