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SYSTEM IDENTIFICATION OF A TRUSS BEAM

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Abstract: *The article deals with structural health monitoring (SHM) using non-destructive vibration based method. Modal analysis of a truss beam was prepared in software ANSYS 13.0. The steel truss beam was supported as a cantilever for this experimental measurement. Accelerations of the structure were measured at 22 points (12 points in the horizontal direction, 6 points in the vertical direction and 4 points were situated at the mid-span of diagonal members). We also focused on model similarity. We compared natural frequencies, also mode shapes and their mutual compliance. The conformity was good enough in many cases and so the model similarity was high. The damage was investigated at the diagonals, which were fastened by bolts to the other members. Then, the bolts were loosened and the response of the structure to simulated damage was determined. Global mode-shapes were influenced minimally by structural damage of the joint and therefore the damage should be monitored directly at the specific elements. Such monitoring can be applied to monitor real truss bridges, but it requires more sensors and hence higher input cost.*

Keywords: Structural Health Monitoring, Modal Analysis, System Identification, Truss Beam, Model Similarity.

1. Introduction

Nowadays, system identification of bridge structures is achieving popularity among scientific teams. We can introduce several examples as reasons: increasing security demands of new structures and optimization of maintenance costs during the lifetime. In addition to the examples, it should be noted that bridge structures are usually obsolete. According to the paper (Ahlborn et al., 2010), the average age of bridges in USA is 43 years. The last circumstance from Pittsburgh confirms this fact. The 94-year-old Greenfield Bridge had to be demolished. Slovakia is in an analogous situation. Bridges in Slovakia are a few years older in average, according to the paper (Paulik, 2014). The mentioned fact has caused not so good technical conditions of bridges in Slovakia. In many cases, the main reason is insufficient maintenance during service time. This situation can result into a necessity of a later expensive complete reconstruction. The structural health monitoring (SHM) of structures can help to avoid the stated situation. Therefore, this paper deals with SHM of an experimental model of a truss beam.

2. Models

Firstly, we have prepared a numerical model of the truss beam and then we have started with experimental measurements in our laboratory.

2.1. Numerical model

As the first step, a FE model was created using software ANSYS. The elements BEAM4 were mainly used. We have analyzed the truss beam (Fig. 1). Cross-sectional dimensions and other characteristics of elements of the system were carefully measured. The numerical model has also considered the weight of the used accelerometers and the exciter. It was considered to achieve the best model similarity. Concentrated mass was modelled as an element MASS21. Modal analysis was done after the model was prepared.

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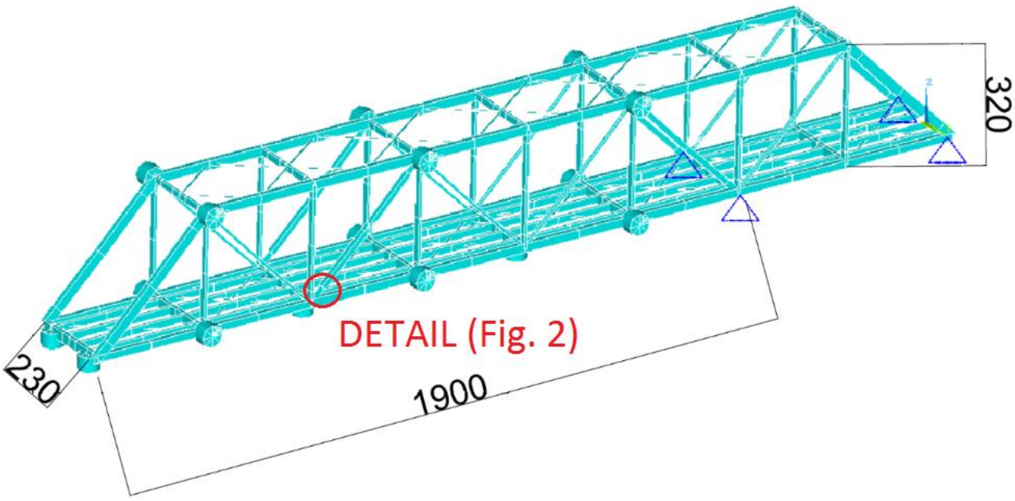

Fig. 1: Numerical Model.

2.2. Experimental model

The steel truss beam was supported as a cantilever for our measurements. The cantilever had the overhang 1900 mm long. The cross-section of the truss is closed (through truss) with a width of 230 mm and a height of about 320 mm. Diagonals of the truss beam form a 45° angle with the bottom and/or with the upper chords (Fig. 2 a). The experimental model has been weighed also.

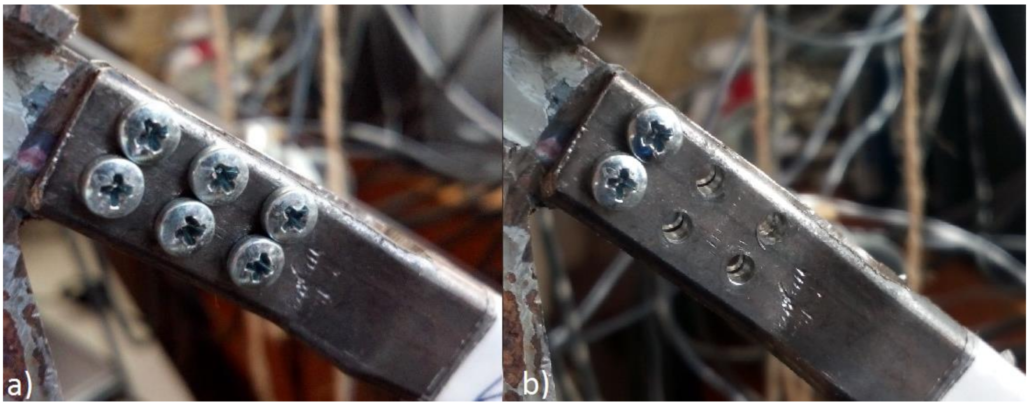

Fig. 2: Joint Detail a) intact structure, b) damaged structure.

2.3. Model similarity

The difference in weight of the FEM model and the experimental model was low (only 0.44%). The experimental model was measured after modal analysis on the FE model. Then we compared the first four global mode-shapes.

Tab. 1: Comparison of the measured and calculated natural frequencies for the cantilever truss beam.

No. of the mode-shape (direction)	Measured frequency (A)	Calculated frequency (B)	Error [%] $\frac{(A-B)}{\max(A, B)}$
1st – in Y direction	14.81 Hz	14.71 Hz	+0.675
2nd – in Z direction	25.33 Hz	25.08 Hz	+0.987
3rd – around X axis	35.42 Hz	34.93 Hz	+1.383
4th – in Y direction	77.63 Hz	77.16 Hz	+0.605

The MAC (Modal Assure Criterion) value was used to obtain a high model similarity, specifically Cross-MAC. The MAC value can also be used for the evaluation and identification of a damage of structures. The method is based on a direct comparison of mode-shapes. The MAC value can be either 0 (absolute incompatibility in mode-shapes) or 1 (for full compliance). In paper (Wang & Chan, 2009) the following formula is reported:

$$MAC(i,j) = \frac{({\phi^{A}}_{i}^{T}{\phi^{B}}_{j})^{2}}{({\phi^{A}}_{i}^{T}{\phi^{A}}_{j})({\phi^{B}}_{i}^{T}{\phi^{B}}_{j})} \quad (1)$$

where ${\boldsymbol{\phi}^{A}}_{i}$ is the i-th mode-shape vector of the intact structure (or in the other case, the FEM model for the Cross-MAC value) and ${\boldsymbol{\phi}^{B}}_{j}$ is the j-th mode-shape vector of the damaged structure (or in the other case, the experimental model for Cross-MAC value). The software ModalVIEW R2 was used for comparison of the mode-shapes through Cross-MAC values.

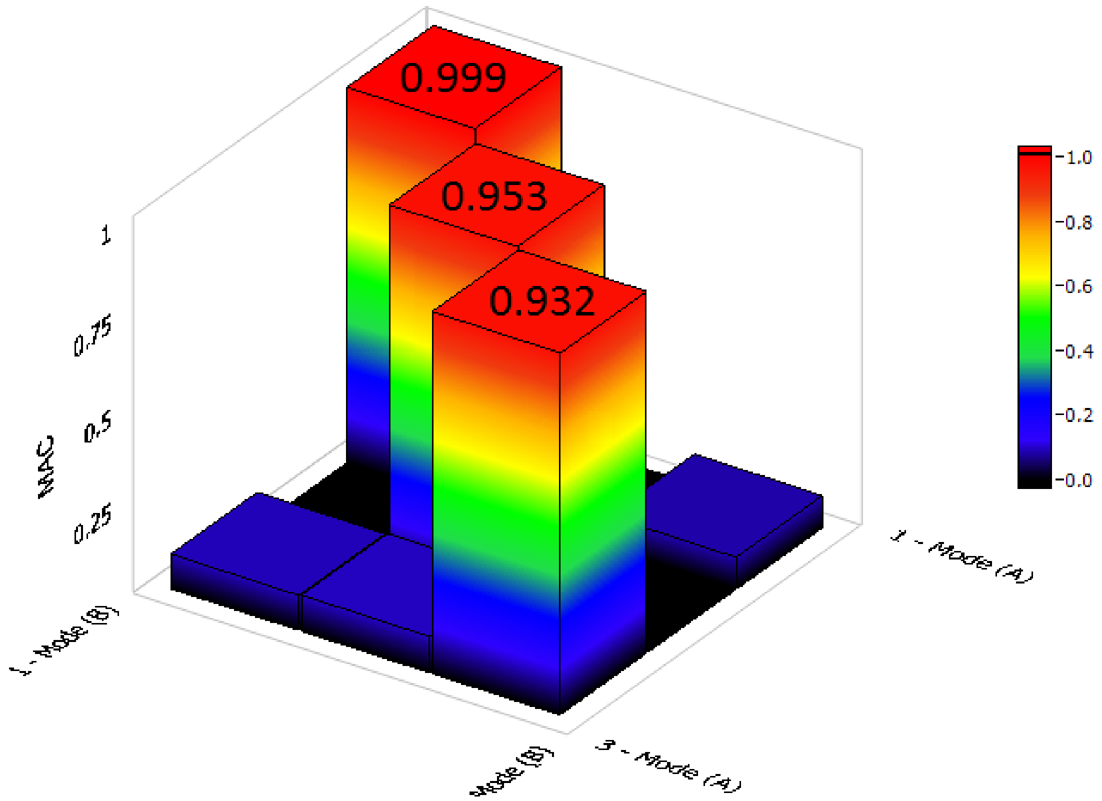

Fig. 3: Cross-MAC values (A means measured mode, B means calculated mode by FEM).

3. System identification

A number of publications are devoted to methods based on the natural frequency changes (Carden & Fanning, 2013; Kim et al., 2003; Wang, Lie & Zhang, 2016). The relationship among the changes in weight, stiffness and values of natural frequencies is fundamental for these methods. The advantage of this method is a lower demandingness of equipment for a measurement. It is theoretically sufficient to use only one sensor. So we have chosen the easiest method for initial system identification on the truss bridge model – via the mentioned method based on natural frequency changes.

Because of the high model similarity, the damage was modelled only in ANSYS software. The object of our interest for system identification was the simple supported truss bridge structure (Fig. 4). The first state was the intact structure (without damage). The second investigated state was a damaged structure. The damage was represented by loosened 4 bolts from the joint detail (Fig. 2 b). The comparison among these two states is showed in the following Tab. 2.

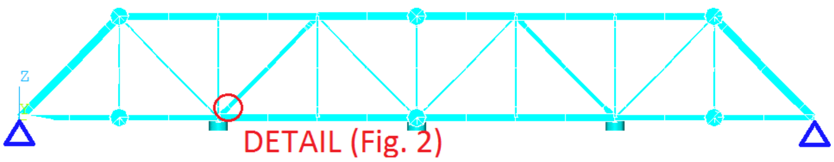

Fig. 4: Simple supported truss beam.

Tab. 2: Damage detection for the simple supported truss beam (Fig. 4).

Global mode-shapes (Global natural frequency)			Local mode-shapes (Natural frequency of diagonal member)		
Mode no. and state	Measured frequency	Calculated frequency	Mode no. and state	Measured frequency	Calculated frequency
1st – in Y direction (intact structure)	37.01 Hz	36.32 Hz	1st – in Y direction (intact structure)	145.62 Hz	144.97 Hz
1st – in Y direction (with damage)	36.97 Hz	36.32 Hz	1st – in Y direction (with damage)	141.68 Hz	141.00 Hz
2nd – around X axis (intact structure)	68.74 Hz	67.82 Hz	2nd – in Y direction (intact structure)	unmeasured	330.16 Hz
2nd – around X axis (with damage)	68.69 Hz	67.71 Hz	2nd – in Y direction (with damage)	unmeasured	325.21 Hz

4. Conclusions

The model similarity satisfied our expectations. Provided that complete characteristics of the cross-sections are available we can effectively use the model similarity for real structures in the next research.

The subsequent assessment of the damage (loosened 4 bolts) shows satisfying results. Real truss bridge structures can be, however, similarly identified by this method, but with enhancements in applied measuring equipment. There is a necessity to choose another method for identifying the damage of bridge structures over the Vah River channel which will be the aim of our next investigation.

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References

Ahlborn, T.M. et al. (2010) The State-of-the-practice of modern structural health monitoring for bridges: A comprehensive review, Michigan TECH, Michigan.

Carden, E.-P. & Fanning, P. (2004) Vibration based condition monitoring: A review. Structural Health Monitoring, 3, 4, pp. 355-377.

Kim, J.-T. et al. (2003) Damage identification in beam-type structures: frequency-based method vs mode-shape-based method. Engineering Structures, 25, 1, pp. 57-67.

Paulik, P. (2014) Bridges in Slovakia. Jaga, Bratislava.

Wang, L., Lie, S.T. & Zhang, Y. (2016) Damage detection using frequency shift path. Mechanical Systems and Signal Processing, 66–67, pp. 298-313.

Wang, L. & Chan, T.H.T. (2009) Review of vibration-based damage detection and condition assessment of bridge structures using structural health monitoring, in: The Second Infrastructure Theme Postgraduate Conference: Rethinking Sustainable Development: Planning, Engineering, Design and Managing Urban Infrastructure, Queensland University of Technology.