Laboratory Tests on Composite Beam - Accuracy of Modal Analysis Results

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Abstract. The primary aim of this research was to verify accuracy of results of the modal analysis on the composite beam. The research is based on the identification technique, which determines structural characteristics from the measured values of dynamic response. The method uses measured data to optimal update of the stiffness matrix to get numerical model that matched with measured data. This can be used for further calculation to determine the effect of damage to the stiffness of the beam. The experimental beam was made of wooden boards and plasterboards, which were attached to each other by a lot of screws. It was simply supported beam of total length 4m. The stiffness characteristic of beam was determined from experimental measurement of the beam deflection from a load. A total of 24 accelerometers were placed along of the beam. Accelerometers were recording vertical acceleration and the acceleration measurement record lasted for 60 seconds. We gained amplitude spectrum of acceleration from the measured acceleration values by using the fast Fourier transform (FFT). The first eigenfrequencies were determined from the amplitude spectrum. The measured value of first frequencies was $f_1 = 11.7$Hz while the calculated value of first frequency was $f_1 = 11.6$Hz. Other frequencies and shapes were also calculated and measured. When comparing them we need to be careful. The spacing of the transducers very well describes the vertical bending shapes while there is little information about torsional vibration shapes. We are planning extend these results by measurement with a pair of accelerometers located along the beam to verify torsional mode-shapes too. The conclusions and results of this experiment are used in calculations for system identification and determination the change in stiffness value of the damaged beam. The beam corrupted by removing the screws from the beam has changed the stiffness properties of the beam. This change is reflected as increment/decrement of original stiffness matrix - adjusted stiffness matrix.

1. Introduction
The system identification (SI) of the condition of bridge structures is currently in the great interest of research teams, equally in the interest of road administrators, individual bridge structures all over the world. This was due to the fact that the structures are overhauled (mostly after their planned lifetime), as well as the fact that the demands on new buildings are tightened from year to year, both in terms of safety and the usability of the building. In accordance with [1] a further reason for greater attention in bridge monitoring is the gradual aging, which is the source of potential damage [2]. In an entirely marginal case this may lead to the need for demolition and construction of a completely new construction. Absence of routine inspections or long-term maintenance can in many cases lead to
expensive and complete reconstructions. This fact is also confirmed by one of the last misfortunes in Italy. At the end of 2018, part of the 51 years old bridge, which had to be demolished and the construction of a new bridge underway, was destroyed. Structural health monitoring (SHM) of bridges can help to prevent such situations.

The main aim of the paper is to get the primary data to determine the change (a decrease) of stiffness matrix of the experimental model of composite using the optimal-update method. The article consists of the following parts: Section 2 introduces the optimal-update method; Section 3 describes preparation of finite element (FE) model; Section 4 deals with experimental measurements; Section 5 shows results and comparison FE model values with measure data; Section 6 finally presents the conclusions and future use.

2. Theory background
Dynamic measurement of construction is used for some SHM methods. Under laboratory conditions, it is possible to verify the correctness of methods that can be applied later to larger structures. The work deals with the verification of the optimal-update method for the late use in real bridge construction measurements.

Preparing a numerical model of construction is regular procedure for SHM. The process of creating a numerical model that corresponds to the measured values is called model correlation. For this approach, it is necessary to determine the structural characteristics of the experimental response measurement. It is the essence of the identification technique to determine the structural characteristics of most model correlation approaches. This problem was approached using the specific class of identification technique – matrix adjustment method. The method using the measured values to create an optimal update of the structure property matrix, stiffness matrix in our case.

The model correlation process involves several steps. After creating a numerical model and updating it, the model is adopted as a correlated model of the undamaged structure. Damage structure monitoring is equivalent to correlating the undamaged model. A numeric model of structure is generated again by means of response measurement. Correlated models (with and without structural damage) are compared to reveal damaged areas. It is necessary to pay attention to the location of the sensor to get the best information about the characteristics of the structure. Details of mentioned method have been described in [3].

3. Process of creating final element model
The experimental beam was made of wooden boards and plasterboards, which were attached to each other by a lot of screws. The main part of the beam was made of three wooden boards with dimensions of 4000 x 100 x 20 mm, in reversed U-shape. Three plasterboards were attached on top, each with 12.5 mm thick; total high of deck was 37.5 mm and wide was 300 mm (figure 1a).

![Figure 1. a) cross-section of beam, b) steel bars supply the joint supports](image-url)
The top plasterboards were attached to the beam using a pair of screws along the beam every 170 mm. The total length of the model was 4m and its total mass was approximately 53kg. The supports were realized through the holes drilled in wooden boards located in the centre of gravity of the cross-section using steel bars (figure 1b). This allowed the beam to be considered as a simple supported beam.

The FE model was created according to the properties of the existing beam. Solid elements have been used to create individual boards. An experiment was performed to determine the value of the stiffness characteristics of the beam. We measured the deflection of the beam using sliding gauges that convey data to the computer. Figure 2 shows the displacement at time of loading and unloading the beam using concrete cubes. Total mass of cubes was 23.5kg and deflection was 1.36mm. From figure 2, it can be also seen that after relieving the beam, it has returned to its original state.

![Figure 2. Beam deflection at time of loading and unloading beam by concrete cubes](image)

The weight of the accelerometers was considered as concentrated mass elements on top of beam deck for the best match of FE model with real beam. Modal analysis was performed and eigenfrequencies were calculated. Figure 3 shown the first mode shape of FE model.

![Figure 3. FE model, calculated 1st mode f1 = 11.61Hz](image)

4. Description of the experiment
The PBC Piezometrics 393B31 accelerometers with National Instruments (NI) CompactRIO 9074 device with 6 Input/Output (I/O) NI 9234 modules were used to measure with precision of measuring frequencies above 0.5Hz at intervals of acceleration between the limits ±4.9ms-2 [6]. The I/O modules in the 6 pieces allowed to measure up to 24 channels at a time (figure 4). A total of 24 accelerometers each with a mass of 800g were placed along of the beam. Accelerometers were recording vertical acceleration in each 15.7mm [7]. The acceleration measurement record lasted for 60s with sampling rate 1652Hz.
5. Results and discussions
Using the measuring equipment, we obtained the acceleration values of the structure. The data was processed using NI DIAdem software. An amplitude spectrum of acceleration was generated by fast Fourier transform (FFT). The first eigenfrequency was determined from the amplitude spectrum (figure 5a). The measured values were transferred to ModalVIEW software. We have obtained the curves of measured mode-shapes and the values of eigenfrequencies. The experimental modal analysis is shown below, figure 5b.

![Figure 5. Amplitude spectrum of acceleration, first measured eigenfrequency f1 = 11.71Hz](image)

The measured value of first frequency was f1=11.71Hz while the calculated value of first frequency was f1=11.61Hz – this proves approximately 1% error [9]. Other frequencies and mode-shapes were also calculated and measured. By comparing the normalised values of mode-shapes [10], we can say that there is a good match for the numerical model and the measured values (figure 6).

![Figure 6. Comparison normalised values of 1st mode shape](image)
6. Conclusions
The calculated values from the modal analysis of the numerical model are in good agreement with the measured data. The problem is to assemble torsional mode-shapes that cannot be determined from this measurement. We are planning to extend these results by measurement with pair of accelerometers located along the beam to verify torsional mode-shapes too. The conclusions and results of this experiment are used in calculations for system identification and determination stiffness characteristic of beam. We continue the process of optimal-update method with measurement of damaged beam. The beam is planned to be damaged by removing the screws, which will affect the stiffness matrix.

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