Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 172 (2017) 634 – 639

Procedia Engineering

www.elsevier.com/locate/procedia

Modern Building Materials, Structures and Techniques, MBMST 2016

Experimental and numerical analysis of an aluminum cantilevered beam with polymer adhesive

Natalia Lasowicz[a]*, Robert Jankowski[a]

[a]*Faculty of Civil and Environmental Engineering, Gdańsk University of Technology, ul. Narutowicza 11/12, 80-233 Gdańsk, Poland*

Abstract

In this paper, experimental and numerical investigation on a composite cantilevered aluminum beam has been conducted. The subject of the study consists of two plain aluminum elements bonded with polymer adhesive of different thickness. It has been proven in the previous study that this kind of material has high damping properties. During an experimental investigation, value of damping ratios have been obtained. The aim of a numerical analysis was to determine dynamic parameters, such as modes of free vibration and corresponding natural frequencies. The results obtained from the analysis have been compared with the values estimated for plain cantilevered beam. The results of the study clearly show that bonding two stiff elements with the analyzed polymer adhesive leads to the significant increase in overall damping properties.

Peer-review under responsibility of the organizing committee of MBMST 2016

*Keywords:*polymer adhesive; dynamic load; damping ratio.

1. Introduction

Dynamic loads are the most dangerous and unpredictable type of loads acting on civil engineering structures. Wind actions, earthquakes (see, for example, [1-4]) or crowd load can be mentioned as the most common ones. Structures that are regularly subjected to dynamic actions start to vibrate [5]. That type of response of the structure may have catastrophic effects. A large number of accidents, involving structures subjected to dynamic loads, have been observed in the past. The collapse of Tacoma Narrows Bridge in 1940 during high wind is one of the example

* Corresponding author. Tel.: +48583471174; fax: +48583472044.
Email address: natmajew@pg.gda.pl

Peer-review under responsibility of the organizing committee of MBMST 2016
doi:10.1016/j.proeng.2017.02.074

of destructive effects. Hundreds of thousands of people lost their lives during the earthquake that have place in 2010 in Haiti. Also crowd load has significant influence on structural behavior [6-8]. It has been proven in previous studies that mass of the people significantly decreases values of natural frequency of the structure [9, 10]. In 1992 in Corsica, the collapse of temporary grandstand killed hundreds of spectators during sport game. It is obligatory to consider the presence of dynamic loads at the design stage [11,12]. To avoid such situations, it is necessary to provide adequate stiffness to the structure. In the case of temporary steel grandstands, the application of additional diagonal members may result in reduction of structural vibrations. Nowadays, economic and esthetic aspects are often found to be very important at the design stage, that is why much more slender and quite light structural member are used to erect such structures. These kind of elements are more easily excitable to vibrations [13].

In this paper, an idea of using polymer adhesive in reduction of structural vibrations has been considered. Six different models have been analyzed during experimental and numerical study. One of them describes plain aluminum cantilevered beam, while the rest consider composite aluminum beams with polymer adhesive of different thickness inside. The polymer mass considered in the study is a specially designed flexible two-component grout, which has high damping properties what has been proven in the previous studies [14]. The aim of the study is to determine dynamic parameters, such as modes of free vibrations and corresponding natural frequencies and damping ratios of a composite aluminum cantilevered beam with polymer adhesive inside.

2. Experimental study

The first stage of the investigation has been devoted to an experimental study. Dynamic parameters, such as modes of free vibrations, corresponding natural frequencies and damping ratios have been determined. Six different models of aluminum beams have been considered during an experimental study. One of them describes plain cantilevered beam (**Model 1**), while the rest of them consider composite beams with polymer adhesive of different thickness inside (0.5 mm - **Model 2**, 1.2 mm - **Model 3**, 1.75 mm - **Model 4**, 3.1 mm - **Model 5**, 5 mm - **Model 6**).

Models assumed in the study consist of the same aluminum cantilevered beams of total dimensions: 9x30x1250 mm. A scheme of the beam bonded with polymer mass is presented in Fig. 1.

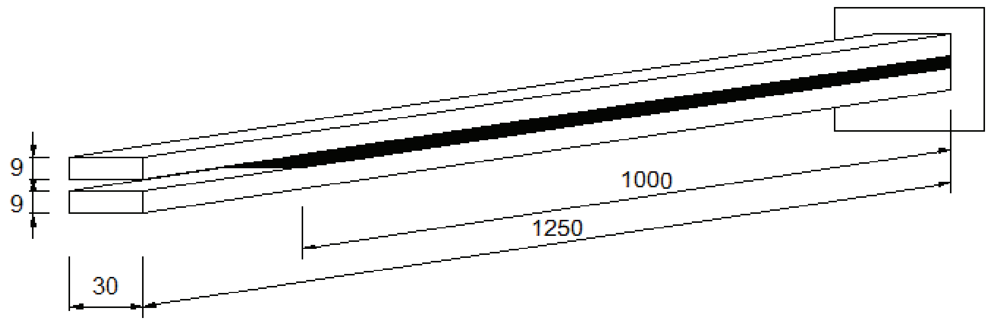

Fig. 1. A scheme of composite beam consisting of two aluminum cantilevered beams bonded with polymer mass.

All models have been induced to vibrations by applying an initial drift at the end of the beam. The behavior of the beams has been observed and recorded by two accelerometers installed on the metal side at the end of each beam. The total time of each measurement was equal to 12.5 seconds. A large number of acceleration time histories have been obtained. Based on them, natural frequencies for all six models have been calculated. Six representative acceleration time histories estimated for each model are presented in Fig. 2. It can be seen from Fig. 2. that the application of polymer mass increases the value of the natural frequency.

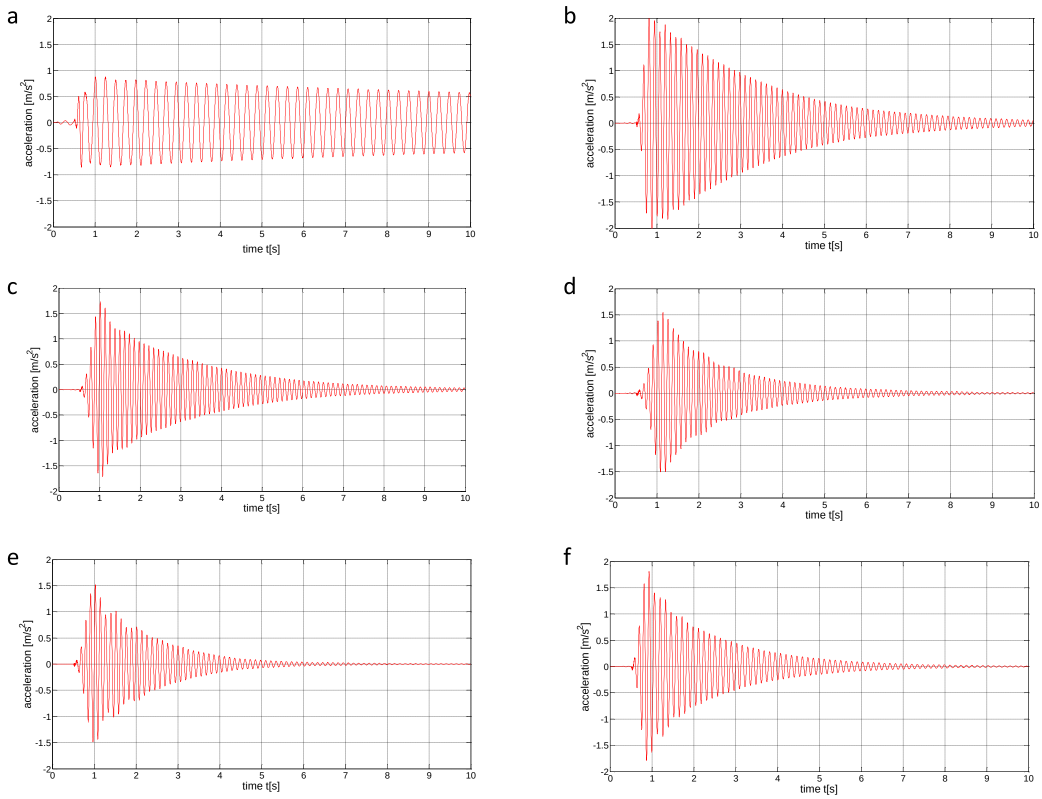

Fig. 2. Acceleration time history for model (a) Model 1; (b) Model 2; (c) Model 3; (d) Model 4; (e) Model 5; (f) Model 7.

The second stage of the experimental study has been devoted to determination the values of damping ratios that have been calculated according to the formula:

$$\xi = \frac{1}{2\pi j} \ln \frac{a_1}{a_{j+1}} \tag{1}$$

where j is a number of cycles, a_{j+1} stands for amplitude of (j+1)-th cycle. All dynamic parameters estimated for six models of aluminum cantilevered beams are summarized in Table 1.

Table 1. The natural frequencies and values of damping ratio estimated for six models of aluminum cantilevered beams.

Model	Natural frequency [Hz]	Damping ratio [%]
Model 1	4.0	0.17
Model 2	7.8	0.57
Model 3	8.3	1.00
Model 4	8.2	1.04
Model 5	8.0	1.22
Model 6	7.6	1.95

As it can be seen from Table 1 and Fig. 2, value of natural frequency determined for the plain aluminum beam is more than two times lower (reduction by 53%) than in the case of composite aluminum beam with polymer adhesive of thickness 1.2 mm. Moreover, more than ten times higher (increase by 1148%) value of damping ratio for Model 6 has been obtained comparing to Model 1 that concerns plain beam.

3. Numerical analysis

The second stage of the study was devoted to modal numerical analysis. Six three-dimensional models have been generated using commercial programme MSC Marc. All of them have been generated using eight-node solid elements (six degrees of freedom). Model 1 and Model 6 are presented in Fig. 3 and Fig. 4, respectively. The left support of the beam has been considered to be fully fixed (3 displacements and 3 rotations). The nodes of the aluminum cantilevered beam have been connected to the nodes of polymer (no relative movement between the materials has been considered). Aluminum, as a structural material, has been described by the following values of material properties: E=70 GPa, ν=0.3, ρ=2700 kg/m^3. The behavior of polymer has been simulated with the use of the Mooney-Rivlin material model that is the most frequently adopted method for modelling complex mechanical behaviour of elastomers and rubber-like solids (compare [15]). The following material constants for the five-parameter Mooney-Rivlin model have been applied: C_{10}=889,490 kPa, C_{01}=-245,840 kPa, C_{20}=-155,310 kPa, C_{11}=93,786 kPa, C_{30}=11,148 kPa. The bulk modulus has been set to be 2.5 GPa, as commonly used for elastomers and rubber-like materials. The mass density of ρ=1000 kg/m^3 has been considered in the analysis.

Fig. 3. Numerical model of a plain aluminum cantilevered beam - Model 1.

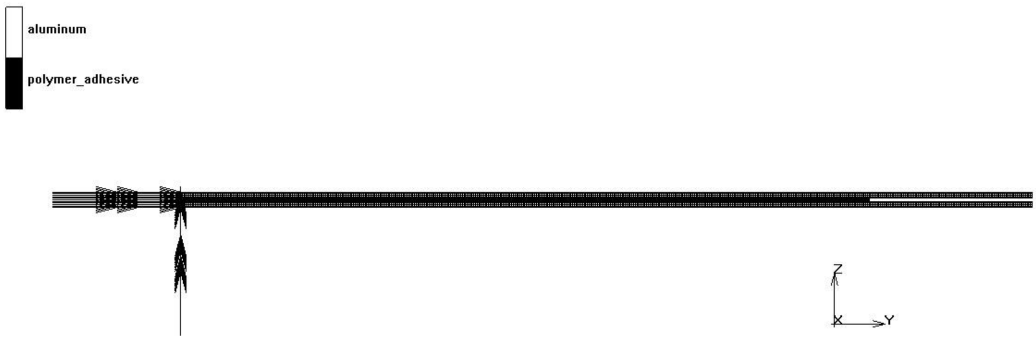

Fig. 4. Numerical model of a composite aluminum cantilevered beam with polymer adhesive (5 mm) inside - Model 6.

The aim of the modal analysis was to determine dynamic parameters, such as modes of free vibrations and the corresponding natural frequencies for both models. Table 2 shows the natural frequencies for all six numerical models. As the example, the first modes of free vibrations estimated for Model 1 and Model 6 models are presented in Fig. 5 and Fig. 6, respectively.

Table 2. Natural frequencies determined for six numerical models.

Model	Natural frequency [Hz]
Model 1	4.391
Model 2	7.866
Model 3	7.656
Model 4	8.307
Model 5	8.689
Model 6	7.521

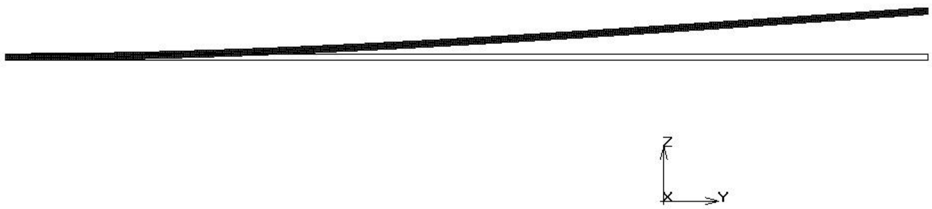

Fig. 5. 1st mode of free vibrations for plain aluminum cantilevered beam - Model 1.

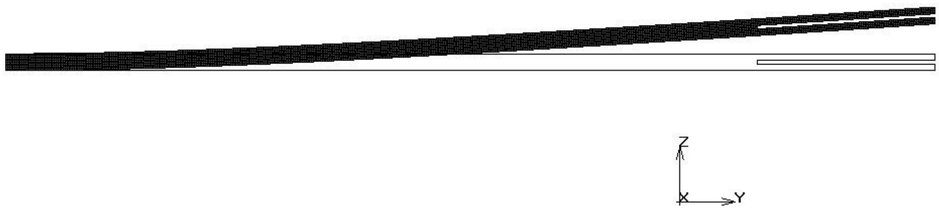

Fig. 6. 1st mode of free vibrations for composite aluminum cantilevered beam with polymer adhesive (5 mm) inside - Model 6.

As it can be seen from Table 1, in the case of plain aluminum cantilevered beam (Model 1 – see Fig. 4), for example, the natural frequency is equal to 4.391 Hz, while for the beam where polymer adhesive of thickness 3.1 mm has been applied (Model 6 – see Fig. 5) it increases to 8.689 Hz (increase by 98%).

4. Conclusions

In this paper, an idea of using polymer adhesive in reduction of structural vibrations has been presented. Six different models of aluminum cantilevered beams have been analyzed. Five of them consists of two aluminum elements with polymer adhesive of different thickness inside. Experimental and numerical investigation has been conducted, so as to determine dynamic parameters, such as modes of free vibrations, corresponding natural frequencies and damping ratios. Comparing the results from experimental and numerical study it can be noticed that estimated values of natural frequencies are quite similar (the largest difference is as small as 8%). The results of the study clearly show that the response of a composite beam with polymer adhesive is substantially different comparing to the plain beam. Higher values of damping ratio have been observed for composite beams (more than 10 times higher values comparing Model 6 with Model 1, for example). It should be underlined that bonding two stiff elements with the analyzed polymer adhesive leads to the significant increase in overall damping properties. Therefore, the application of polymer mass in structural members can be considered as an effective method in reduction of structural vibrations.

Acknowledgements

The authors would like to thank dr. Arkadiusz Kwiecień and dr. Bogusław Zając for the help in conducting the experimental study.

References

[1] R. Jankowski, Impact force spectrum for damage assessment of earthquake-induced structural pounding, Key Engineering Materials 293-294 (2005) 711-718.
[2] S. Mahmoud, R. Jankowski, Modified linear viscoelastic model of earthquake-induced structural pounding, Iranian Journal of Science and Technology 35(C1) (2011) 51-62.
[3] S. Mahmoud, A. Abd-Elhamed, R. Jankowski, Earthquake-induced pounding between equal height multi-storey buildings considering soil-structure interaction, Bulletin of Earthquake Engineering 11 (2013) 1021-1048.
[4] R. Jankowski, Theoretical and experimental assessment of parameters for the non-linear viscoelastic model of structural pounding, Journal of Theoretical and Applied Mechanics 45 (2007) 931-942.
[5] A. K. Chopra, Dynamics of Structures: Theory and Applications to Earthquake Engineering, Englewood Cliffs: Prentice-Hall, 1995.
[6] B. R. Ellis, T. Ji, J. D. Littler, The response of grandstands to dynamic crowd loads, Proceedings of the Institution of Civil Engineers, Structures and Buildings 140 (2000) 355-365.
[7] C. A. Jones, P. Reynolds, A. Pavic, Vibration serviceability of stadia structures subjected to dynamic crowd loads, Journal of Sound and Vibration 330 (2010) 1531-1566.
[8] V. De Brito V., R. Pimentel, Cases of collapse of de-mountable grandstands, Journal of Performance of Constructed Facilities 23 (2009) 151-159.
[9] N. Lasowicz, R. Jankowski, Numerical analysis of a temporary steel grandstand, in: W. Pietraszkiewicz, J. Górski (Eds.), Shell Structures: Theory and Applications 3, CRC/Balkema, Leiden, Netherlands, 2013, pp. 543-546.
[10] N. Lasowicz, A. Kwiecień, R. Jankowski, Experimental study on the effectiveness of polymer damper in damage reduction of temporary steel grandstand, Journal of Physics: Conference Series 628 (2015) 1-7.
[11] S. P. Nhleko, M. S. Williams, A. Blakeborough, Vibration perception and comfort level for an audience occupying a grandstand with perceivable motion, Proceedings of the 27th IMAC Conference and Exposition on Structural Dynamics, 2009.
[12] P. Reynolds, A. Pavic, Z. Ibrahim, Changes of modal properties of a stadium structure occupied by a crowd, Proceedings of Conference and Exposition on Structural Dynamics, 2004.
[13] D. Crick, G. Y. Grondin, Monitoring and analysis of a temporary grandstand. Structural Engineering Report 275, Alberta, 2008.
[14] N. Lasowicz, A. Kwiecień, R. Jankowski, Enhancing the seismic resistance of columns by GFRP confinement using flexible adhesive - experimental study, Key Engineering Materials 624 (2015) 478-485.
[15] S. Mahmoud, P-E. Austrell, R. Jankowski, Simulation of the response of base-isolated buildings under earthquake excitations considering soil flexibility, Earthquake Engineering and Engineering Vibration 11 (2012) 359-374.