22nd International Conference
ENGINEERING MECHANICS 2016
Svratka, Czech Republic, 9 – 12 May 2016

HEALTH MONITORING OF BUILDING STRUCTURES: PRELIMINARY CONSIDERATIONS ON A CASE STUDY

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Abstract: *Ageing, erosion, local damage or increase of the operating loads can decrease the reliability and load bearing capacity of building structures. Vibration monitoring may provide a promising solution of this problem, however robust health monitoring techniques are needed before wider practical applications. The presented analytical and experimental case study on a simple supported steel beam is an introductory practical investigation into this topic. It shows the sensitivity of chosen parameters to artificially induced damage and outlines possible directions or further research in conclusions. Special attention is paid to simultaneous monitoring of deformations and strains which can provide us with a useful information about the stress redistribution in monitored or tested structures.*

Keywords: Damage Detection, Dynamic Loading Tests, Modal Parameters, Relative Strain Vibration, Comparison of Analysis and Experiments

1. Introduction

Vibration monitoring of bridges, historical towers, high-rise buildings, dams or off-shore platforms are quite frequently cited in professional literature (e.g. Alampalli 2008, Foti 2012; Fujino 2010). These are usually case to case different research investigations which is far from standard use for health monitoring purposes. But the technological progress together with advances in theory promises new practical applications.

A very good overview about damage detection using vibration monitoring gives Doebling et al., 1989. A few authors point out (e.g. Padney 1991, Montazer 2014, Yu 2014) that measuring of strains (or strain modes) may provide a more sensitive parameters for damage detection than measuring just the displacements. This was also the incentive to focus beside the frequencies also on strains.

In the beginning there was a question if it is possible to indicate gradually increasing damage before the ultimate limit state (ULS) of bearing capacity is reached? As the answer to this question is not an easy one in general case a special case of a simple supported beam loaded to 60% of the ULS was chosen. Then a damage was induced at another place than where the maximum stresses from the dead load occurred. The damage was gradually increased in three stages until the ULS was reached at the damaged location.

The influence of the progressing damage on natural frequencies, transfer functions and strains was studied using numerical analysis and experiment.

2. Analysis

The investigated structure is shown on the Figure 1. It was made out of hollow steel profile 40/10mm, thickness 2mm. In the frequency band up to 100 Hz there are 8 natural frequencies, which means 5

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bending frequencies (three symmetrical and two anti-metrical). Under the dead load 60% of the first ultimate limit state was reached in the middle section. Than a damage was assumed 910 mm from the end of the beam in the form of a cut into the upper flange of the length 17, 28 and 34 mm subsequently. The calculation was made by the program ANSYS.

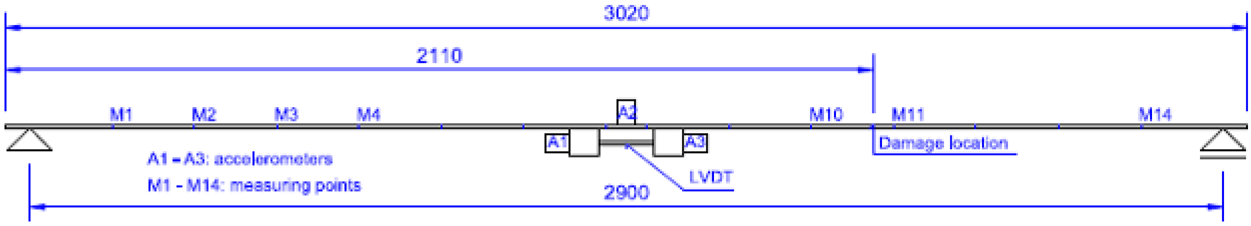

Fig. 1: The geometry of the structure

The changes of natural frequencies are presented in the Table 1. The relation of strains and displacement in the middle of the span (further designated as relative strains) and there changes are shown in the Table 2. The question is if the resolution of the measuring devices will be sufficient to reflect the damage also experimentally.

Tab. 1: Changes of natural frequencies due to the damage

bending modes	no damage	Damage DMG1 (cut 17 mm)		Damage DMG2 (cut 28 mm)		Damage DMG3 (cut 34 mm)	
	f 0,i [Hz]	f 1,i [Hz]	Δ1,i [%]	f 2,i [Hz]	Δ2,i [%]	f 3,i [Hz]	Δ3,i [%]
1	2,487	2,482	-0,17	2,471	**-0,61**	2,458	**-1,16**
2	14,38	14,34	-0,26	14,24	**-0,94**	14,1	**-1,78**
3	26,71	26,69	-0,07	26,64	-0,26	26,58	-0,49
4	54,02	53,99	-0,04	53,94	-0,15	53,9	-0,28
5	79,74	79,57	-0,21	79,14	**-0,75**	78,62	**-1,41**

Tab. 2: Changes of relative strains due to the damage

bending modes	no damage	DMG0	DMG1 (cut 17 mm)		DMG2 (cut 28 mm)		DMG3 (cut 34 mm)	
	f 0,i [Hz]	δ [m/strain]	δ [m/strain]	Δ1,i [%]	δ [m/strain]	Δ2,i [%]	δ [m/strain]	Δ3,i [%]
1	2,487	20,13	20,20	0,35 /**0,34**	20,37	1,22/**1,16**	20,59	2,31/**2,17**
2	14,38	2,921	0,830	-	1,152	-	1,227	-
3	26,71	0,928	0,927	-0,05/**-0,83**	0,927	-0,06/**-3,13**	0,927	-0,07/**-6,08**
4	54,02	1,726	0,251	-	0,228	-	0,216	-
5	79,74	0,166	0,167	0,26/**4,18**	0,168	1,00/**13,86**	0,170	1,92/**23,63**

The transfer function for the relative strains (see Fig.2) have a convenient property: it does not have extremes at the natural frequencies – it is monotonous which means that you can use for the comparison of changes the integral values around the natural frequencies. These values are written in bold in the Table 2 and it is obvious that these relative changes are much more sensitive to the damage than the discrete values on peaks which is promising from the monitoring point of view.

3. Experiments

Analytical results were verified also experimentally using two types of excitation: ambient vibrations simulated by stream of air pressure and deterministic excitation by hammer equipped with a load cell.

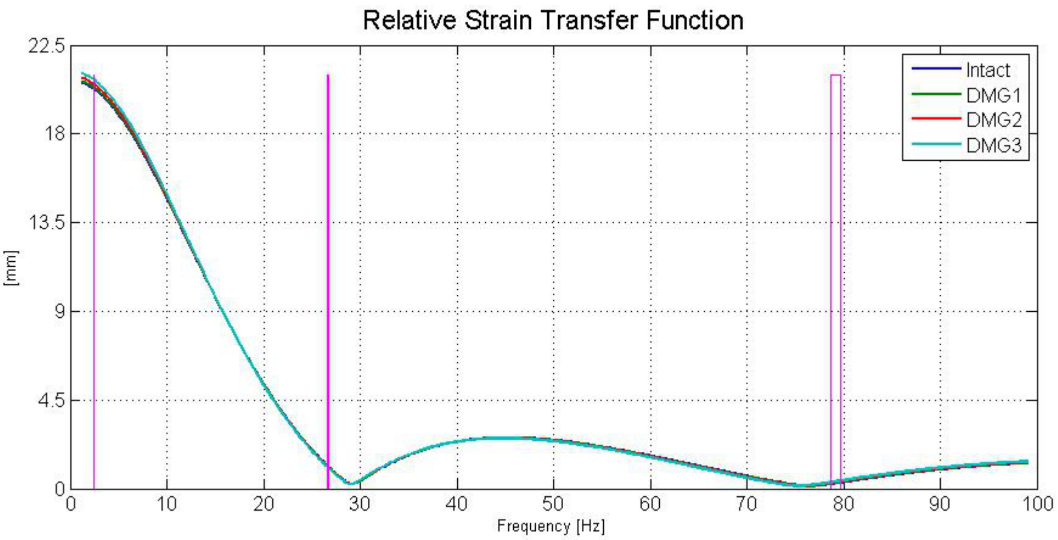

Fig. 2: The relative strain transfer function (displacement/strain)

Tab. 3: Changes of natural frequencies from the experiments

Bending modes	No damage	DMG1 (cut 17 mm)		DMG2 (cut 28 mm)		DMG3 (cut 34 mm)	
	f 0,i [Hz]	f 1,i [Hz]	Δ1,i [%]	f 2,i [Hz]	Δ2,i [%]	f 3,i [Hz]	Δ3,i [%]
1	1,962	1,955	-0,36	1,952	-0,51	1,945	-0,87
2	13,277	13,277	0,00	13,17	-0,80	13,1	**-1,63**
3	25,99	26,05	0,20	26,03	0,13	25,94	-0,19
5	78,65	78,57	-0,10	78,20	-0,57	77,52	**-1,43**

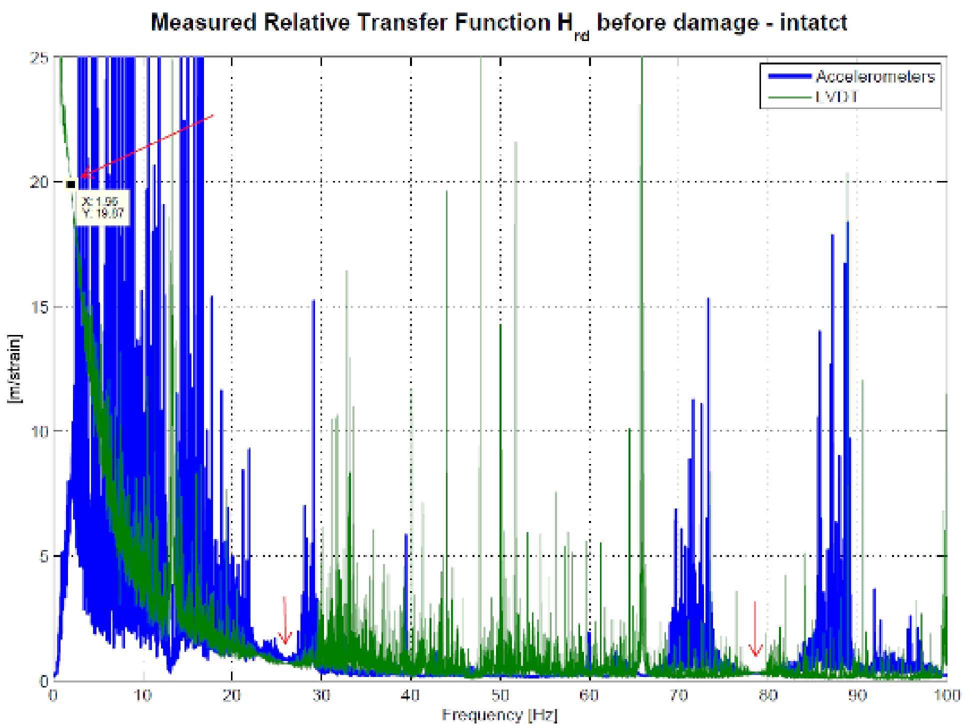

Fig. 3: Measured relative transfer function between the displacements and strains

There were no essential differences between the two sets of experimental results, therefore just the evaluation from “ambient” vibrations is presented here. The changes of natural frequencies from experiments are presented in the Table 3. The whole spectrum of frequencies was lower than the calculation but because the relative changes were of interest the model was considered to be sufficient and was not updated to the experimental results. Both experimental methods proved to be sensitive enough to reflect the stages of the progressing damage. So the measurement of natural frequencies could indicate the “dangerous” condition before the ultimate limit state would be reached.

The strains were measured as displacements on the basis of 20 cm with an LVDT-0,5mm sensor. There was also made an attempt to measure the displacements with two accelerometers. The arrangement can be seen in the Fig.1. The measured transfer function between displacements and strains corresponding to the one in Fig.2 is plotted in the Fig. 3. The measurement of displacements on low levels is covered by noise. Nevertheless, in the vicinity of frequency peaks, (marked with red arrows in the Fig. 3) the level of noise much lower. But in spite of it and of the promising theoretical premises the measurements of changes of relative strains hasn´t been quite successful until now because of very low levels of measured displacements.

4. Conclusions

The experiments confirmed that natural frequencies were sensitive enough to warn in time before the ultimate limit state would be reached in the chosen case.

The relation of displacements and strains represents a quantity that is sensitive to damage and thus promising from the health monitoring point of view, however it is quite difficult to measure.

It is desirable that the vibration measurements provide a save prevention against damage in any location which is going to be the direction of future investigations. A damage localization using dynamic test is also the next planned research program. The measurement uncertainties coming from various sources like environmental effects, limits of equipment applied etc. is another field that imposes limits on health monitoring of building structures and has therefore be focused on before practical applications.

Acknowledgement

There is very appreciated the sponsorship by the grant GAČR 15-01035S and institutional support RVO 68378297. Many thanks also to my colleges in ITAM, who helped me to carry out the experiments.

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