Damping variations in structures

M.A. Brossault[(1)], P. Guéguen[(2)], P. Roux[(3)]

[(1)] *PhD student, Institut des Sciences de la Terre ISTerre, Université Grenoble Alpes, CNRS, marc-antoine.brossault@univ-grenoble-alpes.fr*
[(2)] *Dr., Institut des Sciences de la Terre ISTerre , Université Grenoble Alpes, CNRS, IFSTTAR, philippe.gueguen@univ-grenoble-alpes.fr*
[(3)] *Dr., Institut des Sciences de la Terre ISTerre , Université Grenoble Alpes, CNRS, philippe.roux@univ-grenoble-alpes.fr*

Abstract

The frequency and damping of an engineering structure control its dynamic response via Newton's second law. These two modal parameters are likely to vary in time due to environmental conditions, to the appearing of damage in the system or to dynamic loading. These variations lead to a modification of its vulnerability but their analysis could thus give information on the state of health of the monitored structure. Being related to energy dissipation, damping is also a critical parameter to be determined for risk assessment for any engineering structure. Its precise evaluation is thus primordial but its measure is riddled with uncertainty considering the very strong scattering of its monitoring over time even if solicitation remains at ambient vibration level. Any dependency of damping on the noise amplitude has been ignored so far. However, experimental results on metric beams in the lab representing simplified building models exhibit a positive correlation between damping and acceleration whereas frequency remains constant. Their linear definitions command an equal relative variation of these two for any alteration of the structure's stiffness. This violation of the linear assumption is yet explained by mathematical results derived from the Helmholtz equation and the fluctuation-dissipation theorem which lead to the expression of a specific attenuation proportional to the noise intensity.

Keywords: Damping ; structures ; noise ; fluctuation-dissipation theorem

1. Introduction

Ambient vibration is widely used to monitor structures behavior since Omori's work at the beginning of the 20th century. This monitoring is performed on the two modal parameters : frequency and damping ratio. They are directly related to the stiffness of the structure and thus, any alteration of it like damage [1, 2] , dynamic loading events [3, 4] and even temperature [4] cause a variation of the two parameters. This evolution should be of the same amplitude for both variables according to their linear definition. However, Mikael et al. [5] noticed a scattering of damping over time more than one order of magnitude higher than that of the frequency. In addition to the monitoring domain where damping brings information about the state of health of the structure [6], it is also a critical parameter in the adjustment of the structural models for risk assessment [7]. The objective of this work is to determine if the unexpected damping variations can be reproduced and explained in a simplified representation of buildings such as vertical clamped-free beams subjected to an ambient vibrations like loading.

2. Experimental setup and data

The three beams - made of plexiglas, granite and limestone - visible on figure 1 are studied one after the other. An acquisition experiment consists in an air-jet blowing on the top of one beam while the acquisition program is recording data for 48 hours. All the beams are glued on a massive limestone block with epoxy glue as displayed on the picture of the figure 1. Two Brüel & Kjaer 4518-003 accelerometers are stuck with wax on each beam : one at the base and one at the top. These sensors have a very low weight, 1.5 g, and their working frequency band extends from 0.5 to 20 kHz. The sampling frequency is set to 5 kHz. The acquisition is done through a CCLD Signal Conditioner (Type 2694-A) of the same brand, and a National Instruments USB-6259 BNC acquisition card connected to the computer . Fourier transforms of one-hour vibration are given on the figure 1. The noise applied to the beams is characterized by an oscillation of its amplitude with a period of forty minutes and the room temperature is considered to vary very little and slowly.

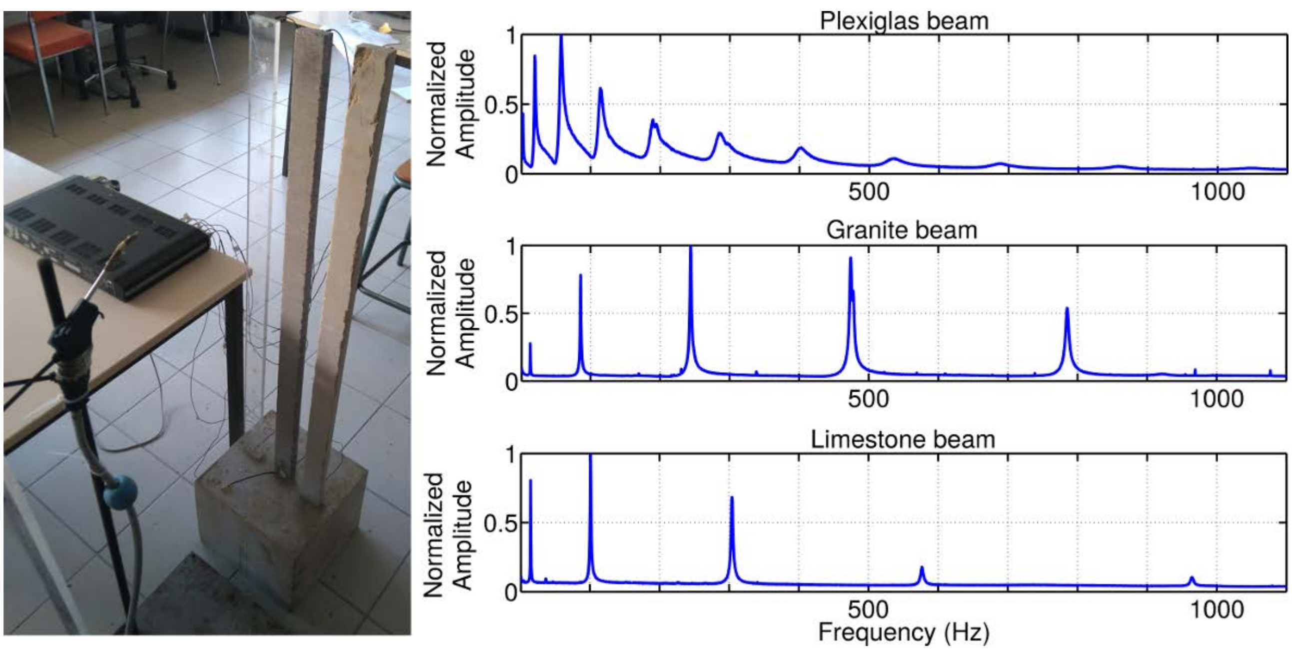

Figure 1: Photo (left) of the three beams from left to right : plexiglas, granite, limestone. Fourier transforms (right) of each beam present on the picture.

3. Processing

Noise recorded for each beam is processed with the Random Decrement Technique (RDT) in order to track frequency and damping variations over time. It has been first proposed in the late sixties by Cole working on flutter problems for NASA [8, 9, 10] and then further studied especially by Vandiver [11] and Asmussen [12], giving thus details about its theory and application modalities. A simple formula for the Random Decrement Signature (RDS) has been given by Gueguen et al. [13] :

(1)

where N is the number of windows respecting the chosen initial conditions, s is the recorded noise, t_i is the time verifying the initial conditions, τ is the time index in the random decrement signature and varies from zero to the windows duration. This signature has the same form of the impulse response of the system and can be thus fitted by an exponentially decaying sinusoid. The two adjusting parameters of this fit are the circular frequency ω and the damping ratio ξ. This operation is repeated on successive windows of noise to get the temporal tracking of ω and ξ.

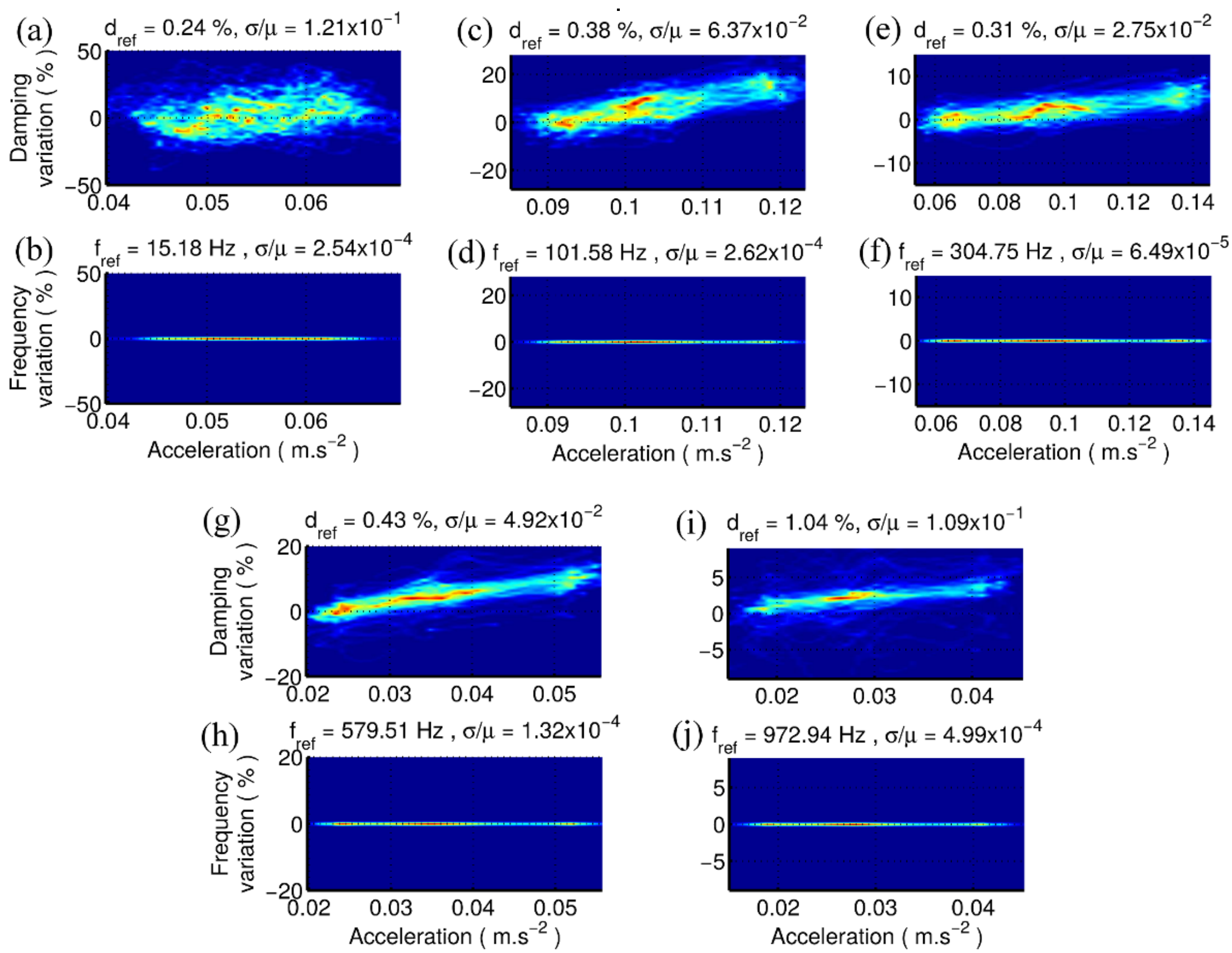

Figure 2: Damping (a, c, e, g, i) and frequency variations (b, d, f, h, j), respectively for the first to the fifth bending mode of the limestone beam, in percentage compared to the reference values f_{ref} and d_{ref}. The coefficient of variation σ/μ for each distribution of frequency or damping is indicated.

4. Results

The temporal monitoring of frequency and damping on the three beams exhibits a slow variation of frequency coherent with the little daily fluctuation of temperature in the room. A band pass filter between 3600 and 1000 seconds is thus applied to get rid of this irrelevant evolution and it allows in the meantime to smooth the tracks and reduce their dispersion. The temporal representations of frequency, damping and noise amplitude for the two rocky beams exhibit a synchronous variation of these two last ones whereas frequency remains constant. The two modal parameters remain constant over time in the case of the plexiglas beam. Figure 2 provides an illustration for the five first modes of the limestone beam. The fact that the noise amplitude has been ignored so far in the measure of damping partly explains its scattering but it shouldn't be forgotten that the evaluation of this property is more complex and thus subject to errors. This complexity results in the stronger scattering of damping even at constant acceleration as visible on the figure 2.

5. Discussion

The fluctuation-dissipation theorem has been developed in the fifties by Callen and Welton among others based on the work of Einstein, Nyquist and Onsager at the beginning of the 20th century [14]. It relates the response of a system to an external perturbation and the fluctuations of its properties in thermal equilibrium. The application of this theorem on mathematical results proposed by Campillo and Roux [15] enables to formulate a proportional relation between the attenuation of a system and the intensity of the noise it is subjected to.

This relation seems to be experimentally verified in this work for the beams made up of heterogeneous material. Figure 2 showing results for the limestone beam seems to indicate that damping can be expressed as a linear function of acceleration. But similar figures with intensity – acceleration squared – as x-axis lead to a similar observation in that case. This doubt on whether damping is related to acceleration or intensity is due to the narrow range of noise amplitude in the experiments.

The apparent condition of the presence of heterogeneities in the system to observe the previously cited relation between damping and noise intensity is still unexplained but it evokes the non classical nonlinear elastic processes called fast and slow dynamics caused by a dynamic loading in heterogeneous media [16] . The study of these is supposed to provide information on the damage state of the structure since new cracks form additional discontinuities. In a similar way, long term monitoring of damping compared to noise intensity could give a specific slope that would be modified by the creation of cracks.

6. Conclusion

This work provides an experimental observation of mathematical results derived from the Helmholtz equation combined with the fluctuation-dissipation theorem, which has never been considered in structure monitoring yet. In order to measure damping, a certain minimum solicitation is required but its intensity has been ignored so far. The consideration of this relation in future estimations of this parameter could reduce its scattering and uncertainty. It appears that the heterogeneities in the material composing the structure influence the dependency of damping on noise intensity. An interesting hypothesis to verify in future investigations is to determine whether these relations are affected by the creation of cracks in the system. This will be tested by repeating the same experimental procedure as described in this paper but on thermally cracked beams.

7. References

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