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COMPARISON BETWEEN DIFFERENT METHODS OF CHARACTERIZING ELASTIC LAYERS

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Abstract

New legislation all over Europe makes the prediction of the transmission level of impact sounds of flooring very necessary. This is why analytical models have currently become a very important active research area. In general, these models use the mechanical properties of elastic layers as these can predict the dynamic stiffness and loss factors required.

Also, elastic layers based on polymer foams have recently increased in prevalence. The measurement of the mechanical properties of these materials presents problems such as a double resonance peak in the impact response spectrum. As a consequence it is difficult to apply these methods to such samples, and these problems must be overcome.

In this paper, a comparison is presented of three different methods of determining the resonant frequency and the damping of such materials when loaded by a mass plate and subjected to impact. A brief statistical-based analysis is performed to study the behaviour and the possible causes for the variability in the data sets.

INTRODUCTION

The use of elastic layers in floor construction to improve the insulation of impact noise is commonplace in building acoustics. This is specified by the reduction in the sound pressure level (SPL), ΔL, in the room underneath a floor that experiences a mechanical impact. ΔL can be related to the dynamic stiffness of the resilient layer (s') and the mass per unit area (m') of the supported floor layer. The reduction may be calculated for locally reacting floating floors as detailed by Cremer et al [1]

$$\Delta L \approx 40\log(\omega) - 20\log(s'/m'), \tag{1}$$

although in the literature other expressions for another scenarios [2, 3, 4] can be found. The dynamic stiffness may be measured according to standard EN ISO 29052-1:1992 [5] in which the floating floor is modeled as a section of the resilient material on which a solid metal mass is placed. The system is considered to act as a simple one degree of freedom mass-spring system. The standards specify the size (20 × 20 cm) and the mass (8 kg) of the plate, which is equivalent to a mass per unit area of 200kg m^{-2}. The mass is excited either with a continuous force signal, applied by a mechanical shaker, or by an impact delivered by an impact hammer as shown in Figure 1.

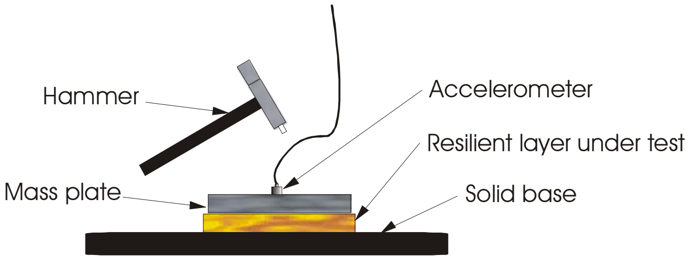


Figure 1 – Schematic of the determination of the frequency response of the mass plate supported by the resilient material under test.

The dynamic stiffness can be determined through measurement of the resonant frequency, f_o, of the system as [4]

$$s' = 4\pi^2 m' f_o^2 \; . \tag{2}$$

This is realized by measuring the acceleration of the plate using an accelerometer usually placed in the plate center, and impacts (usually in a central area around the accelerometer) are delivered by an impact hammer.

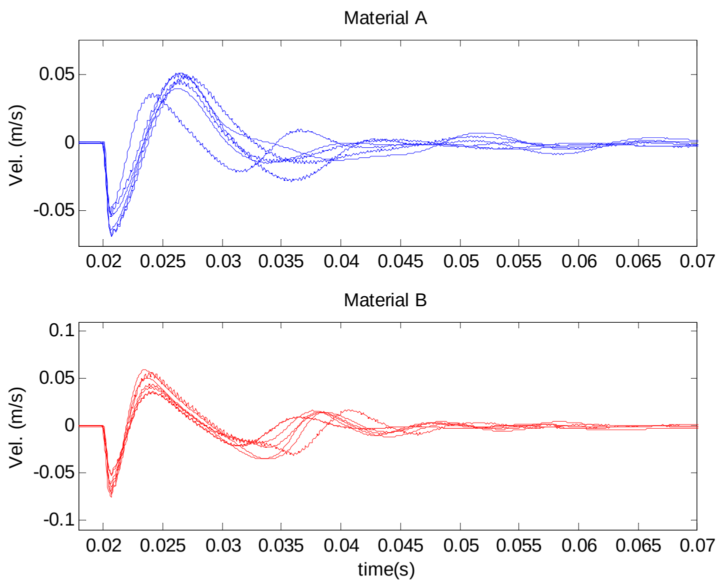


Figure 2 – Ensembles of impact responses of two resilient layers under test, as described in this paper. Key: Top - Material A, bottom – Material B.

In practice, the system is found to act in a more complex way than the simple mass-spring system model envisaged. Figure 2 shows two ensembles of the velocity responses for two commercial resilient layer materials which are detailed in Table 1.

Material label	Thickness (unloaded)	Density (g/cm^3)
A	9 mm	0.034
B	2 mm	0.14

Table 1 – Description of basic details of the two resilient layers studied.

The variation between the responses from different impacts is obvious. Also, for Material B, it is seen that the response after impact does not appear to be of sinusoidal form. It is seen that the resonant frequency must be determined from a heavily damped signal of possibly only two or three periods in length, and whose time response deviates from the assumed simple model.

This suggests that first, a statistical measure should be taken in order to specify the material stiffness in face of the variability although this is not discussed in the Standard. Secondly, it is found that the resulting frequency spectrum deviates from the idealised single resonant peak response and in many instances that the determination of the resonant frequency or the damping is hindered by this. Two examples of typical frequency responses are shown in Figure 3. The closely spaced peaks make the determination of the resonant parameters difficult, and in some instances the “main” peak is not clearly evident –resulting in the possibility of two resonant frequencies for the system. Additionally, to evaluate the damping the half-power points are required to be clearly defined, and these are obviously affected by the presence of a second resonance in Figure 3.

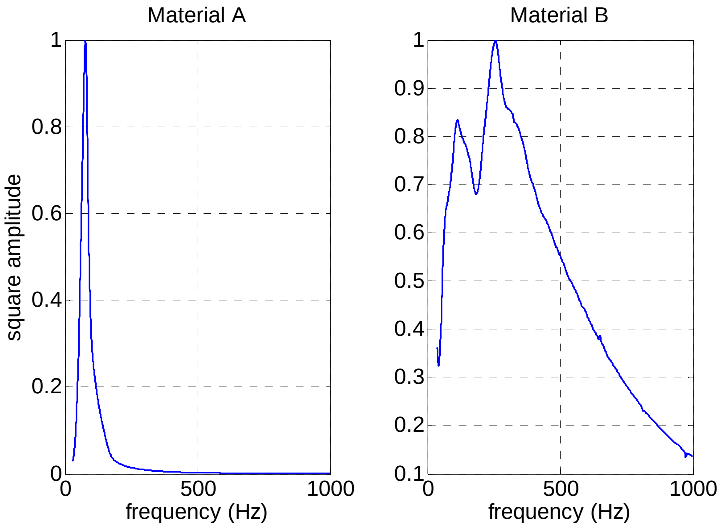


Figure 3 –.Two typical frequency responses. The first (left) show a response that is similar to the idealised response. The second (right) is a response containing two closely spaced resonant peaks such that the determination of the resonant parameters is hindered by the presence of the other peak

BRIEF STATISTICAL ANALYISIS OF MEASURED DATA

Experimental data was collected for the type of test described above. In all 576 data sets were collected from impact tests for materials A and B. Not only was the variability of the data responses of interest, but other variables were also measured or controlled in order to try to understand the variability of this type of test. Tests were performed over 6 days and the ambient temperature was monitored. Two types of resilient layer materials were tested and for both materials six samples were used. The impact test was performed at specific time intervals after the mass plate was first placed on the resilient material. It was aimed to maintain constant impact strength, but the natural (human) variation that occurred was measured as the impact energy (integrated force-time response). Due to constraints of space here, the analysis here is limited to the variables: resilient material type, resonant frequency, damping and the impact energy. Two main methods were used to determine the resonant parameters of each response and are briefly described.

1. Determination of resonant parameters from magnitude of frequency response

The damped natural frequency is determined from the maximum value of the magnitude of the frequency response, f_o (**Method 1**), see Figure 4. The damping is determined from additionally determining the half power bandwidth ($f_b - f_a$)

$$\zeta = \frac{(f_b^2 - f_a^2)}{4 f_o^2} \ . \tag{2}$$

The natural frequency of the system has to then be derived from these two parameters

$$f_o = f_n \sqrt{1-\zeta^2} \ . \tag{3}$$

2. Determination of resonant parameters from real and imaginary parts of the frequency response

In this method, damped natural frequency f_o, is determined from the real part of the response spectrum. This is defined when the response is the value mid-way in between the positive and negative peaks either side of the resonance (**Method 2**). The position of the positive and negative peaks either side of the resonance defines the half-power bandwidth. A variation consists on obtaining the damped natural frequency from the minimum of the imaginary part of the response spectrum (**Method 3**). Methods 2 and 3 are illustrated in Figure 4. The natural frequency and the damping are determined as above in eqns (2) and (3). For further information see [6].

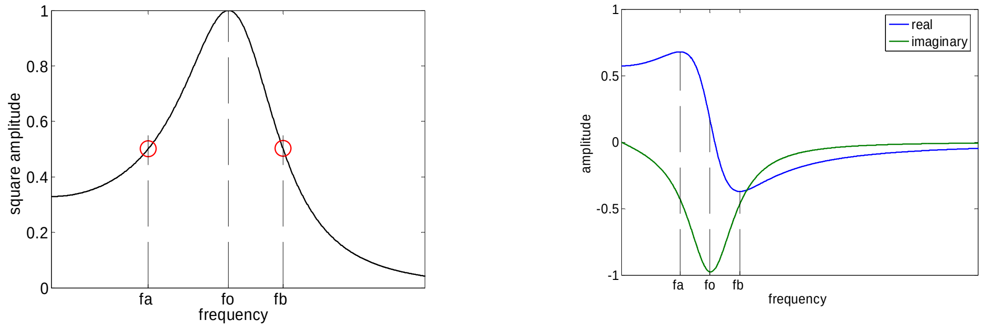


Figure 4 –. Schematics of the determination of the damped natural frequency and the damping from the frequency response. a) using the magnitude of the frequency response, b) using the real par and the imaginary part of the frequency response.

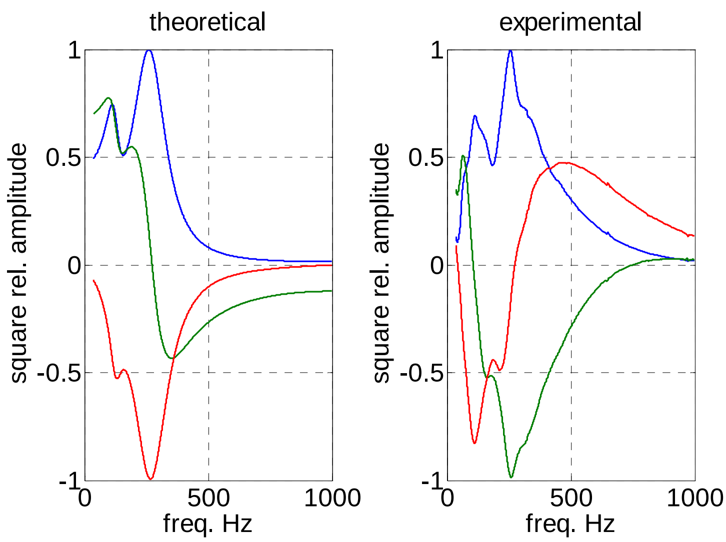


Figure 5 –. The modeled mobility spectrum of a system with two closely spaced modes (left) and the measured mobility of material B (right).

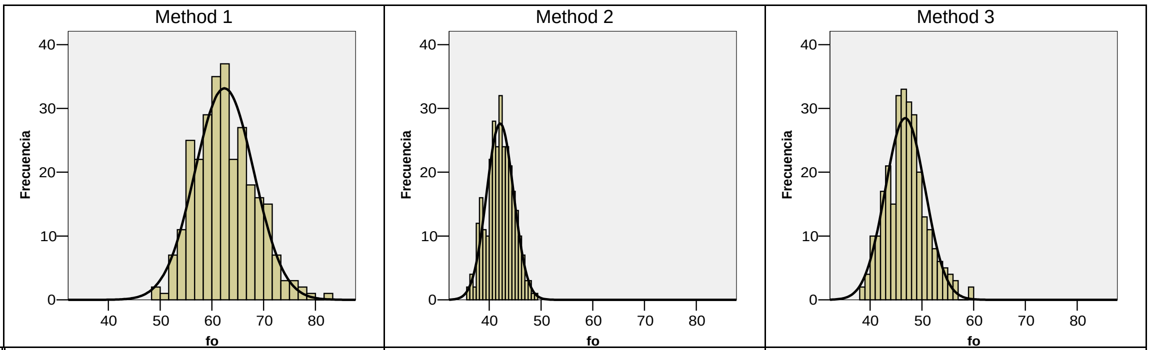
RESULTS

Experimental data was collected as described above. The acceleration signal measured was converted to velocity by integration, and then the frequency spectrum was calculated. Using MATLAB, the three methods of determination of the resonant parameters were implemented on a fully automated basis.

The existence of two resonant peaks distorts the results obtained for all the methods. The peaks are shifted away from their true value. For Method 1 in general there is not sufficient unaffected resonant bandwidth to measure damping, and for Methods 2 and 3 the maximum and minimum values of the real part of the spectrum is often hidden by the influence of the adjacent mode (see Figure 5).

The data was analysed using the SPSS statistical application [7], in the written paper only a brief analysis of the data is given for a few of the parameters recorded.

First, histograms are shown in Figure 6 for distribution of the resonant frequency for material type A. The variability of the method is apparent and a significant difference for the damped frequency can be observed between distributions for each method. It is also noted that there was a 15% spread on the impact energy.



f_o	62.42 Hz	42.10 Hz	46.78 Hz
$\sigma(f_o)$	5.696	2.598	3.868

Figure 6 – Histogram of damped resonant frequency for material A using the three methods studied. Mean values and standard deviation are shown under each plot.

Scatter plots are shown in Figure 7 for material type B for the four parameters studied here: the damped resonant frequency, the damping ζ, the impact energy and determination method. The natural resonant frequency was determined from eqn (3). The results obtaining for material A showed such a large variation in f_o and ζ due to the general indeterminability of these variables that they are not discussed further here.

For material B the general variability of the parameters and any relation between them becomes apparent, even though formal statistical analysis would confirm evidence for a relationship. The difference in the evaluation of the damped frequency due to the method employed is apparent, and Method 1 generally provides the higher determined value. Similarly with the evaluation of damping, Method 1 gives in general the lower values. It appears that there is a relationship between the value of the impact energy and the damped natural frequency for all the methods. The higher the impact value, the lower the frequency. This may indicate a non-linearity of the system, something that might well be concluded from the impulse responses in Figure 2. However, the value of damping appears to be only weakly or unaffected.

SUMMARY

In the impact testing of resilient materials described here, the variability of the results should be analysed statistically. Using a large data set for two materials a brief qualitative analysis is given here, to illustrate the general problems. Apart form the natural variation of this type of testing, different variable values are clearly obtained depending on the method. A more detailed analysis will be given in the presentation.

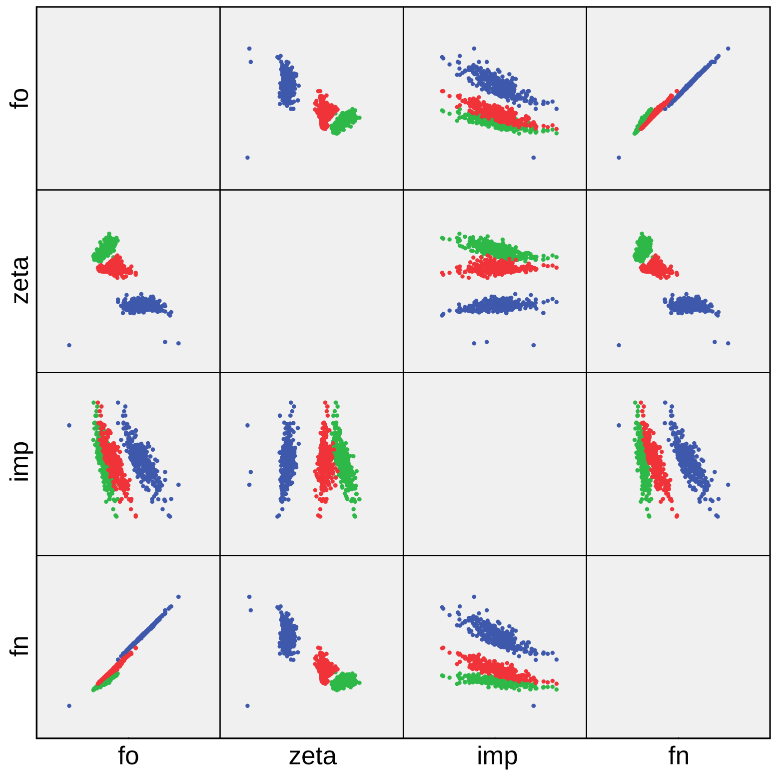


Figure 7 – Scatter plot for damped and undamped resonant frequency, damping and impulse energy for material B. Results for three different methods are shown method 1 (blue), method 2 (green), method 3 (red).

ACKNOWLEDGEMENTS

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REFERENCES

[1] L. Cremer, H. Heckel, E. E. Ungar, *Structure Borne Sound*. (Springer−Verlag, Berlin, 1988)

[2] H. A. Metzen, "Estimation of the Reduction in Impact Sound Pressure Level from Dynamic Stiffness of Insulation Layers", Building Acoustics, 3(1), (1996)

[3] L. L. Beranek, I.L. Vér, *Noise and Vibration Control Engineering*, (John Wiley & Sons, 1992)

[4] A. Schiavi, A. Pavoni, F. Russo, "Dynamic Stiffness Measurement: an empirical Model to Estimate the Reduction in Impact Sound Pressure Level and its Relative Improvement Curve" Proceedings of ICA, Kyoto, 2004

[5] EN 29052−1:1992. "Acoustics − determination of dynamic stiffness; part 1: materials used under floating floors in dwellings"

[6] D.J. Ewins, *Modal Testing: Theory, Practice and Application* (RSP Ltd., Exeter, 2000)

[7] SPSS 13.0.1. SPSS Inc. 1989 – 2004.