Dynamic Stiffness Of Materials Used For Reduction In Impact Noise: Comparison Between Different Measurement Techniques

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ABSTRACT: Samples of materials used for impact sound insulation in buildings are investigated. Typically, these materials can be part of floating floor constructions in dwellings, where they traditionally have shown to be very useful for reducing noise propagation. The performance of the floating floor directly depends on the mechanical properties of the insulation layer, in particular the dynamic stiffness, together with its mass per unit area. The value of the dynamic stiffness of the layer enables a rapid estimation of the weighted reduction in sound impact ΔL_w (in dB). This paper will present the results of laboratory measurements of the dynamic stiffness of several kinds of resilient materials using the different excitation methods recommended by the norm EN 29052-part1 (sinus excitation, white noise or impact impulse). Losses in the materials are also considered.

1. INTRODUCTION

Resilient materials, such as mineral wool or diverse foams, are widely used in building acoustics in order to reduce the transmission of structural vibrations. One usually uses the generic term "insulation layer" because they help to reduce the sound pressure level due to impact for instance.

They can be part of a construction called "floating floor", which consists of a slab lying on the resilient material. The performance of the floating floor directly depends on the mechanical properties of the insulation layer, together with its mass per unit area. It is therefore essential to assess the dynamic properties of this layer in order to evaluate the performance of the floating floor regarding the reduction in sound pressure level.

A rather simple way to do so is to measure the dynamic stiffness of the layer, which enables an estimation of the weighted reduction in sound impact ΔL_w (in dB). Moreover, predicting the reduction index ΔL_w of a floating floor by testing a small sample of resilient material proves to be particularly effective in terms of time since measuring the dynamic stiffness of the sample is fast, whereas performing a full scale measurement of the impact level requires a long period of time (28 days) to have the concrete ready for measurement.

2. PHYSICAL BACKGROUND

The dynamic stiffness of a resilient layer, in N/m^3, can be expressed in terms of its Young's modulus E and its initial length L_0 as, see Figure 1(a)

$$s = \frac{E}{L_0} \qquad (1)$$

(a) *at rest*   (b) *with perpendicular force acting*
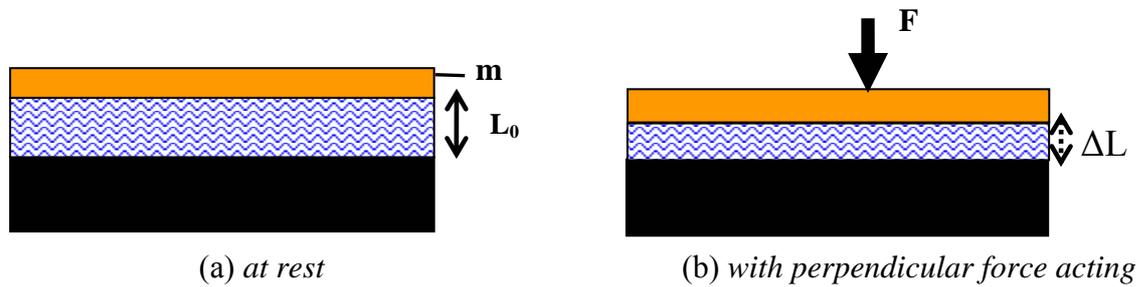
Figure 1 - *Schematic representation of a structure with resilient material*

Since

$$E = \frac{L_0}{\Delta L} \cdot \frac{F}{A} \qquad (2)$$

with F the dynamic force acting perpendicularly to the sample, A the area of the sample and ΔL the variation of length of the sample due to the force acting on it, see Figure 1(b), it comes that

$$s = \frac{F/A}{\Delta L} \qquad (3)$$

In terms of the resonant frequency, the apparent dynamic stiffness is expressed as

$$s = m\left(2\pi f_{res}\right)^2 \qquad (4)$$

Or, equivalently

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{s}{m}} \qquad (5)$$

with m the total mass/unit area placed on top of the material during the test, i.e. including the mass/unit area of the equipment used for the test (shakers, accelerometers etc.), see [1].
The influence of the air inside the material should be considered (airflow resistivity measurements) since measuring on a small sample and on a bigger one might lead to different results (apparent dynamic stiffness).
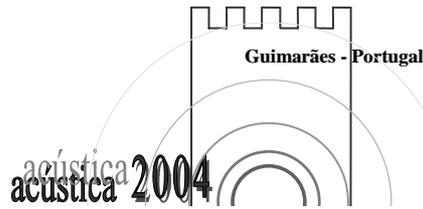
Knowledge of the dynamic stiffness proves to be very useful regarding the estimation of vibration reduction since it allows a direct prediction of the reduction in normalized impact sound pressure level, see [2]:

$$\Delta L_w = 18 + 15 \log \frac{m}{s} \tag{6}$$

3. MEASUREMENT PROCEDURE AND RESULTS

3.1 Test set-up and procedure

The set-up consists of a personal computer equipped with an FFT analyser software (Spectralab®), a charge amplifier B&K (Nexus), one accelerometer (B&K charge amplifier, type 4370V) and a shaker (Gearing&Watson, model V2). The accelerometer is glued on the top plate and connected to the computer via a charge amplifier. The plates are steel plates the dimensions of $20*20$ cm^2. In our measurements, two steel plates are used. The mass of the top steel plate used for impact hammer excitation is 7.86 kg, the mass of the other steel plate together with the shaker and accelerometer is 7.80 kg. Their mass is therefore 8±0.5 kg, including all the measurement equipment, i.e. shaker and accelerometer, as it is described in the norm EN 29052-part1.

The resilient material is placed on a 20 mm steel plate; the top steel plate is put on this resilient material. The shaker is glued to this top plate for the case of sine sweep or white noise excitation. The accelerometer is glued in the central part of the appropriate plate for the case of hammer impact.

It must be emphasized that it is vital to excite the structure and measure the response in the vicinity of the centre of the top steel plate in order to avoid the generation of flexural modes, which would result in a resonance curve showing different peaks corresponding to each mode of vibration.

Record is made of the output signal from the accelerometer after excitation has been provided. The frequency resolution chosen is $\Delta f = 0.05$ Hz, thus allowing measurement of the frequency resonance peak with 0.1 Hz precision.
The acceleration level is thus measured and enables us to identify the resonance frequency of the system consisting of the mass plate and the resilient material. Ten different sample materials have been tested, each of them with the three different excitation methods (a sine sweep signal, white noise, or the impact of a hammer).
The response from the shaker is measured and it is found to give a lower energy at the low frequencies, say below 40 Hz. Therefore, the excitation signal (in both the cases of a sine sweep or a white noise) is filtered so that the same level of energy is provided in the entire frequency spectrum.
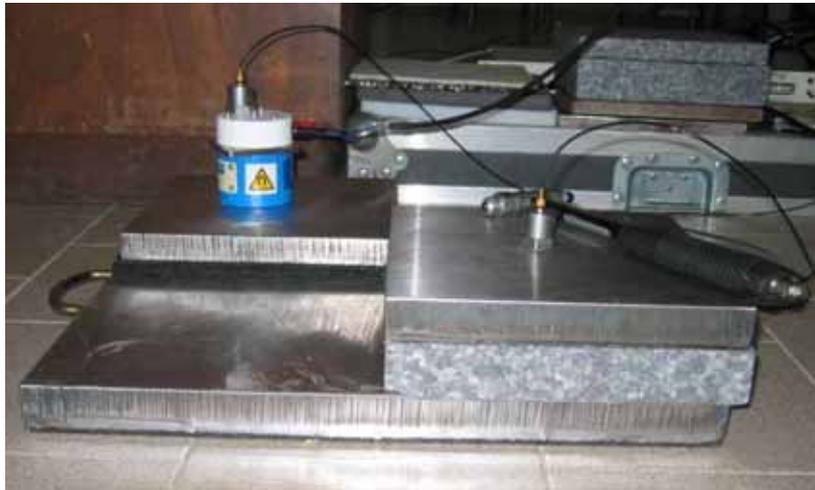
Figure 2 - *Photo of the test set-up*
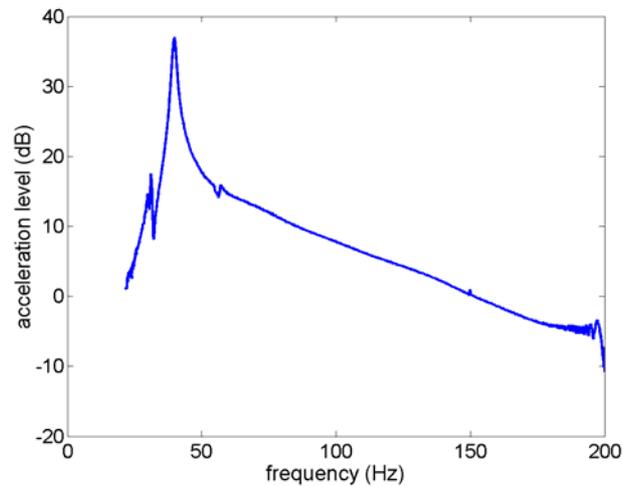
Figure 3 - *Typical resonant curve with sine sweep excitation*

The damping ratio δ is defined as

$$\delta = 1/Q \qquad (7)$$

where the quality factor Q is expressed as

$$Q = \frac{f_0}{f_2 - f_1}$$

with f_0 the resonant frequency and f_1 and f_2 the frequencies at "minus 3 dB" as shown on Figure 4, which is the resonant curve of S.P. (33 mm thickness) sample material (see the result section 3.2).
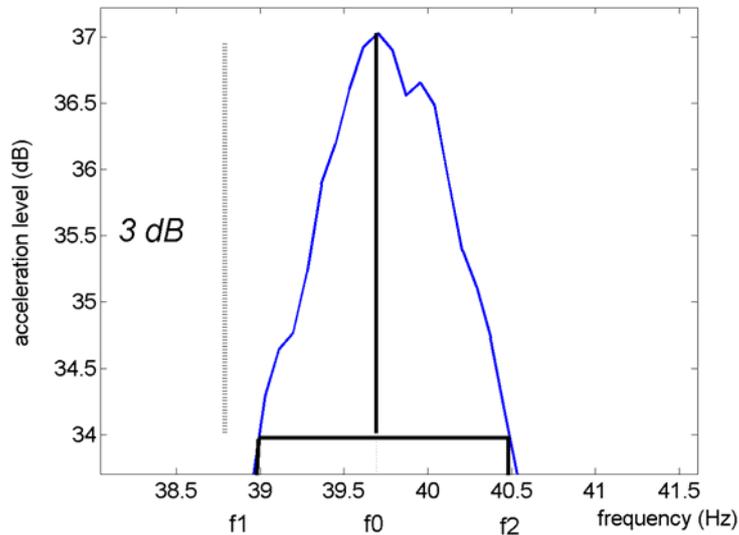
Figure 4 - *Q-factor evaluation*

3.2 Results

Table 1 shows the measured resonant frequencies for each excitation method, the damping ratio δ (in percentage), and the dynamic stiffness calculated using equation (4) for different resilient materials, whose thickness is indicated in the table.

S.P. stands for Synthetic Polystyrene; T.R. for a Treated Rubber material mixed with elastomer elements.

Table 1 - *Resonance frequencies (in Hz) measured for different excitation methods; damping ratio δ (%) and calculated dynamic stiffness*

	sine sweep	white noise	hammer	hammer with rubber end	delta (%)	dynamic stiffness(MN/m^3)
soft grey material	24.6	24.5	23.8	23.4	13	4.4
S.P. (22 mm)	42.9	42.6	42.9	42.9	5	14.2
S.P. (33 mm)	39.7	39.6	39.6	39.8	4	12.1
S.P. (33+22 mm)	28.5	28.9	28.6	28.6	3	6.3
S.P. (33+33 mm)	27	26.8	27	26.8	3	5.6
S.P. (43 mm)	33.9	33.5	33.8	33.6	3	8.8
T.R. (3.2 mm)	89	89	88.7	84.5	18	60.6
T.R. (6.3 mm)	67.6	66	69.8	64	16	37.5
T.R. (5.2 mm)	100	101	99	100	40	75.5
T.R. (4.3 mm)	57.9	59.3	56.9	56.1	20	24.9

Only the dynamic stiffness is a physical parameter that can be used in order to describe the properties of a resilient material. The resonant frequency of the mass-resilient material system varies with the mass of the top plate. In our case however, the masses of the top plate used for impact hammer excitation and that of the top plate with the shaker placed on it are almost identical. Therefore, a direct comparison of the resonant frequencies is possible.

### 3.2.1 Excitation with sine sweep, white noise, impact hammer
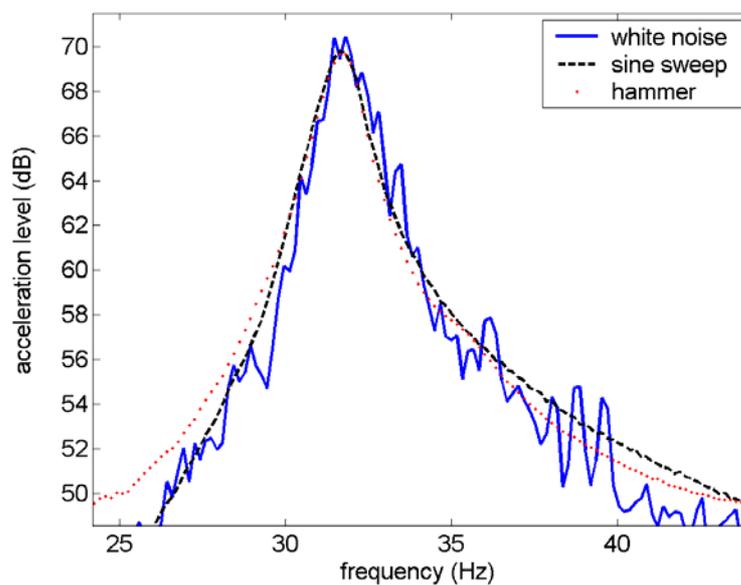
Figure 5 - *Resonant curves with the three different excitation methods*

As Table 1 shows and as illustrated by Figure 5 for the case of one particular sample, each of the three methods leads to very similar resonant frequencies. Similar curves are obtained for the other tested materials.

However, as can be seen from Figure 5, excitation with white noise provides a resonant curve very much contaminated by noise. The high level of noise in our measurements may be due to our equipment: shaker with low mass. This might be a problem for determining the resonant frequency and might even make the determination of the Q-factor impossible or result in a wrong Q-factor due to the "up and down" oscillation characteristic of a signal containing noise.

Thus, our measurements indicate that sine sweep excitation and hammer impact prove to be more adequate for determining both the resonant frequency (hence the dynamic stiffness of the sample material) and the damping ratio (or Q-factor) of the resilient material tested.

3.2.2   Impact with a soft/stiff hammer

Another series of test was conducted. It is the case of hitting the structure with a hammer in the case where a soft small rubber element has been place at the end of the hammer. An example of resonant curve is shown in Figure 6.
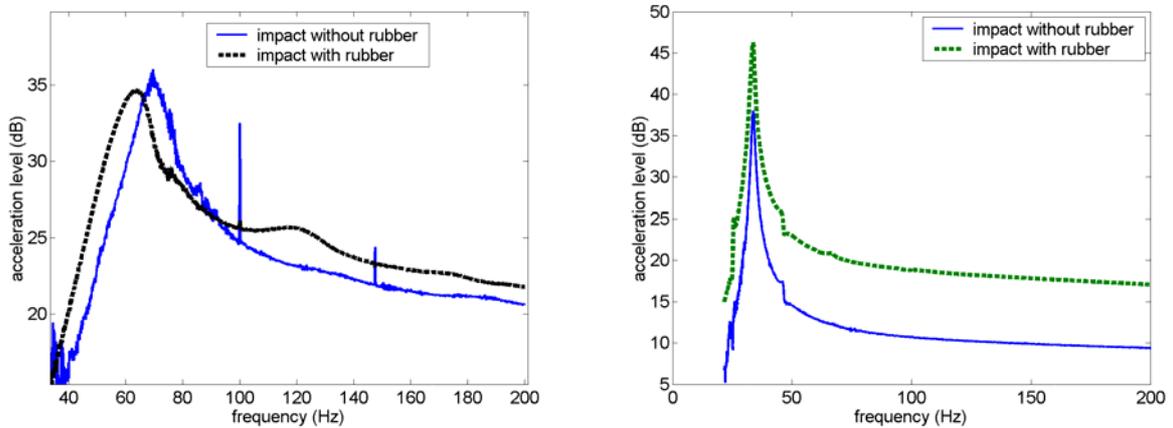
(a) Treated Rubber (6.3 mm thickness)   *(b) Synthetic Polystyrene (43 mm thickness)*

Figure 6 - *Hammer impact with/without rubber end*

The results of hitting the plate with a soft or stiff hammer are shown on Figure 6 for two different sample materials. Using a stiff or a soft hammer leads to the same resonance frequency and to a very similar Q factor, as shown in Table 2.

Table 2.- *Q-factors with soft/stiff hammer impact*

	Material 1 *(T.R. 6.3 mm thickness)*	Material 2 *(S.P. 43 mm thickness)*
Soft impact	4.9	24
Stiff impact	6.4	28
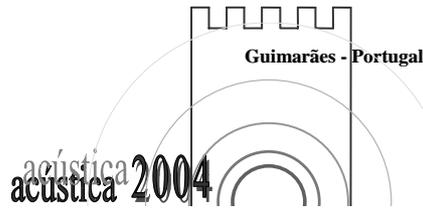
4. CONCLUSION

The different measurement techniques, i.e. the use of a sine sweep, white noise or impact hammer as an excitation signal, lead to very similar measured resonance frequencies. However, in our case one should notice that white noise leads to inaccurate results due to poor signal to noise ratio. From our series of measurements it seems therefore that, when evaluating the resonance frequency of the system described in this paper, it is advisable to use a sine sweep excitation, or to hit the structure with a hammer.
Sine sweep excitation obtained by the shaker leads to results repeatable with a high accuracy but is not so easy to implement in practice; hammer excitation is easy to use but provides results repeatable with less accuracy.

REFERENCES

[1]   Norm EN 29052-part1. Determination of dynamic stiffness, materials used under floating floor in dwellings.

[2]   Pavoni Belli, Russo, Schiavi; *Measurements of dynamic stiffness to estimate the reduction in impact sound pressure level.* Euronoise, Naples 2003