Impact sound reduction provided by current Portuguese and Brazilian floating floors: Comparison between lab tests and EN 12354 results

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Summary
This paper presents a set of comparisons between lab results of impact sound tests exerted on small floating floors samples, using various resilient materials currently used in Portugal and Brazil, as well as comparisons between these results and those obtained by calculation with the standard EN 12354-2. Some field test results were also compared with these laboratory measurements.
For the purpose, the dynamic stiffness of 12 resilient materials has been experimentally determined. These materials were used to compose floating floors in samples of reduced dimensions that were tested in laboratory conditions using a standard tapping machine. The adaptation terms $C_{I\Delta}$ were also taking into account in this set of comparisons.
The calculated sound reduction levels using the procedure set forth by EN 12354 showed good agreement with the experimental results, in frequencies between 100Hz and 3150Hz. It was not observed significant differences between the results of same material tested with different dimensions. The same can be stated for the values of adaptation term $C_{I\Delta}$ in terms of frequency range extensions.

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1. Introduction

One of the biggest problems an acoustician has to deal with in residential buildings design is the reduction of impact noise due to daily living, such as people walking, falling of objects, sliding of chairs, etc. Besides being considered the most annoying type of noise, impact noise is really difficult to reduce, and its adverse effects hard to minimize.
The most common solution used worldwide to deal with this problem is based on a system, generally known as floating floor, which consists of a rigid layer (tiles, concrete) placed over a resilient material, loosely lying on the structural slab. The resilient materials used for the purpose should generally exhibit a very good dynamic stiffness, property that could be correlated with the impact sound reduction provided by the respective floating floor.

According to studies done by Lee [1] and Kim [2], whenever the dynamic stiffness of the resilient material decreases, it is expected that the level of impact noise reduction increases. The standard EN 12354-2 [3] provides an empiric relation between the impact sound reduction level, ΔL, and the dynamic stiffness, s', determined with the standard ISO 9052-1 [4], by frequency bands. This relation is given by:

$$\Delta L = 30 \log\left(\frac{f}{f_0}\right) dB \qquad (1)$$

Where:
$\Delta L = L_{no} - L_n$; in which L_{no} is the impact sound level radiated by bare floor and L_n is the impact sound level of the covered floor (in this case, the floating floor system);
f is the central frequency of the band;
f_0 is the fundamental frequency of the floating system, in Hz; being:

$$f_o = 160\sqrt{\frac{s'}{m'}} \quad (2)$$

For which, m´, is the mass per unit area of the rigid part of floating floor, thin slab or tiles, in kg/m^2. In this case, m' = 76.4 kg/m^2.

In this work, some comparisons between impact sound reduction experimental results and the corresponding values obtained with equation (1), were done. Schiavi[5] has confirmed the efficiency of this empiric model, making a similar comparison for frequency range situated between 100Hz and 5000Hz. However, in the present study this frequency range is extended towards low frequency bands, specifically till the band centered in 50Hz.

The analysis in the region of low frequencies is done in order to assess the behavior of floating floors taking into acount the subjective aspects of noise and the perception of users, which are not addressed by the current portuguese regulations.

For this study, it was considered a set of 12 materials (samples). Six of them are of Brazilian production, and the other six of Portuguese production.

For Portugal and Brazil, the main goal of this comparison is to check whether the common floating floor systems used in each country are appropriate to fulfill the requirements set forth by its respective legal system. In fact, Brazil is a Country undergoing a process of great rate in terms of economic development and growth, creating new needs of people comfort. And Portugal is a Country with a very well established legislation (dated of 1987).

To check the influence of dimensions of the samples used for testing on the results that could be obtained for impact sound reduction, the tests were done with small samples. This aspect is seldom very important for, in practice, it is not feasible for the manufacturers to produce large samples for testing as those required by international standards (≥ 10m^2), situation that makes the testing procedures quite expensive and time consuming. With this idea in mind, Miškinis [6] and others have compared the impact sound reduction improvements, ΔL_W, of different sizes of samples in field situation, having found an empiric relation between the samples area and the obtained values of ΔL_W. According to these researchers, this relation should duly be considered in the obtained results. In this study, all the tests were performed in lab conditions.

2. Methodology

The 12 materials studied (floating floors), which are referred sequentially by A1 to A12, were firstly tested to determine their apparent dynamic stiffness, in accordance with what is established by ISO 9052-1.

The apparent dynamic stiffness was gotten on the basis of an averaged value calculated from 3 samples of 20 cm × 20 cm each. In this study, assuming that all the materials have high flow resistivity, the dynamic stiffness of each resilient material was considered equal to the value of its apparent dynamic stiffness. For the purpose, the method of impulse excitation was used, in accordance with what is established in ISO 7626-5 [7]. The corresponding tests were done at ITeCons, University of Coimbra, Portugal.

Concerning the impact sound insulation reduction, the 12 resilient materials were applied as "springs" in conceptual systems to create floating floors whose behavior is analogous to mass-spring systems, being then tested as floating floors of small dimensions, pre-defining two groups, in the acoustics lab of National Laboratory of Civil Engineering (LNEC), in Lisbon, based on parts 1, 3 and 4 of standard ISO 10140 [8, 9, 10].

In Group 1, the 12 samples used for impact sound reduction tests were the ones previously subjected to tests regarding the determination of dynamic stiffness: the 3 samples making a rectangle of 20 cm x 60 cm were placed on the structural slab. The rigid part of the floating floor system is a stone tile, 2.8 cm thick (the width and length are the same, vd. Fig. 1).

In Group 2, the materials A7 to A12 were tested in dimensions of 60 cm x 60 cm (Fig. 1). In this case, the samples used in both situations - determination of dynamic stiffness and impact sound reduction -, were not the same.

In Table I, the description of materials used, given by the manufacturers, is presented. The materials A1 to A6 are of Brazilian type and materials A7 to A12 are of Portuguese type. The thickness and density of each material are indicated in section "Results", jointly with their dynamic stiffness.

Figure 1. Floating floors systems tested: left side (Group 1); right side (Group 2)

Table I - Description of the resilient materials

Sample	*Description*
A1	Expanded polyethylene of low density, 5 mm thick
A2	Expanded polyethylene of low density, 10 mm thick
A3	Polyethylene foam
A4	Recycled tire rubber, 8 mm thick
A5	Recycled tire rubber, 5 mm thick
A6	Glass wool agglomerated with synthetic resin and covered with an impermeable film
A7	Agglomerated cork with ruber
A8	Agglomerated cork
A9	Polyethylene in mesh
A10	Polyethylene in mesh, with a felt layer, on the lower side
A11	Polyethylene in mesh, with a needled felt layer, on the lower side
A12	Polyethylene in mesh, with a needled tissue layer, on both sides

Based on the dynamic stiffness data, the impact sound reduction levels, ΔL, were determined by 1/3 octave frequency bands, from 50Hz to 5000Hz. For this, it was used the model of Annex C of European standard EN 12354-2 (Eq. 1). This values were compared with those obtained with impact sound insulation reduction tests performed in lab conditions, and calculated in accordance with the Standard ISO 717-2 [11].
In the same way, the weighted impact sound reduction levels, ΔL_W, were determined, as well as their adaptation terms, $C_{I\Delta}$, both for the current frequency range situated between 100Hz and 3150Hz, and from 50Hz to 3150Hz, let's say extending the analysis towards the low frequency region of the normal spectra. For that, the reference curve of impact sound levels and the levels of standardized impact noise of the reference floor, set by EN ISO 717-2, had to be extended in order to integrate the frequency bands of 50Hz, 63Hz and 80Hz. This extension was made linearly.
The weighted impact sound reduction was graphically cross-related with the dynamic stiffness. A logarithmic trend line of this relation originated a function which allows the calculation of impact sound reduction improvement of this type of materials.
The ΔL_W values were also compared with values obtained in 3 *in situ* tests done in Brazilian buildings, in accordance with Standards ISO 140-7 [12] and ISO 717-2.

3. Results

The 12 materials dynamic stiffness results are presented in this section, as well as comparisons between the impact sound reduction levels of materials associated with Group 1 and 2, and the respective calculated values for the impact sound reduction. Similarly, are also presented the comparisons between the weighted impact sound reduction levels, ΔL_W, of materials related to Group 1, for the 2 sets of frequency ranges previously referred, their respective adaptation terms, $C_{I\Delta}$, a relation between the experimental values of ΔL_W and the dynamic stiffness values, and also the 3 *in situ* test results.

3.1. Dynamic stiffness

The dynamic stiffness of materials A1 to A12 is presented in Table II. In the table are also indicated the thicknesses and densities of these materials, which were provided by the manufacturers.

Table II. Dynamic stiffness of the resilient materials

Floating floor	*Thickness mm*	*Density kg/m³*	*Dynamic stiffness MN/m³*
A1	5	30	49,4
A2	10	30	22,7
A3	5	30	70,4
A4	8	600	56
A5	5	600	100,5
A6	15	60	3,7
A7	10	430	87,2
A8	5	200	134,9
A9	5	30	36,8
A10	6	30	43,4
A11	5	50	15
A12	12	40	7,3

3.2. Impact sound reduction in frequency bands

The experimental results of impact sound reduction, ΔL, in 1/3 octave bands, referred to floating floors A1 to A6, are presented in Figure 2, jointly with the respective curves obtained with Eq. (1). Generally, it can be concluded that the experimental results follow reasonably those obtained with the model set by EN 12354-2 when the frequency range is situated in-between 100Hz and 3150Hz. However, when the frequency range is extended towards both high and low frequencies (below 100Hz and above 3150Hz) the same conclusion cannot be stated. The experimental results, ΔL, of the floating floors A1, A3 and A9, show a better agreement with that model, in low frequencies region, but worst agreement in the high frequencies. For materials A6, A11 and A12, the corresponding behavior is the opposite.

In this study, it wasn't possible neither to assess nor to extract the influence of samples size. In fact, the impact sound reduction results obtained in both situations, are quite similar (materials A7 to A12). What can be noted is just a dip in the 500Hz frequency band, namely for floating floors A9, A11 and A12 – Group 2 -, which is maybe due to a specific resonance of the system.

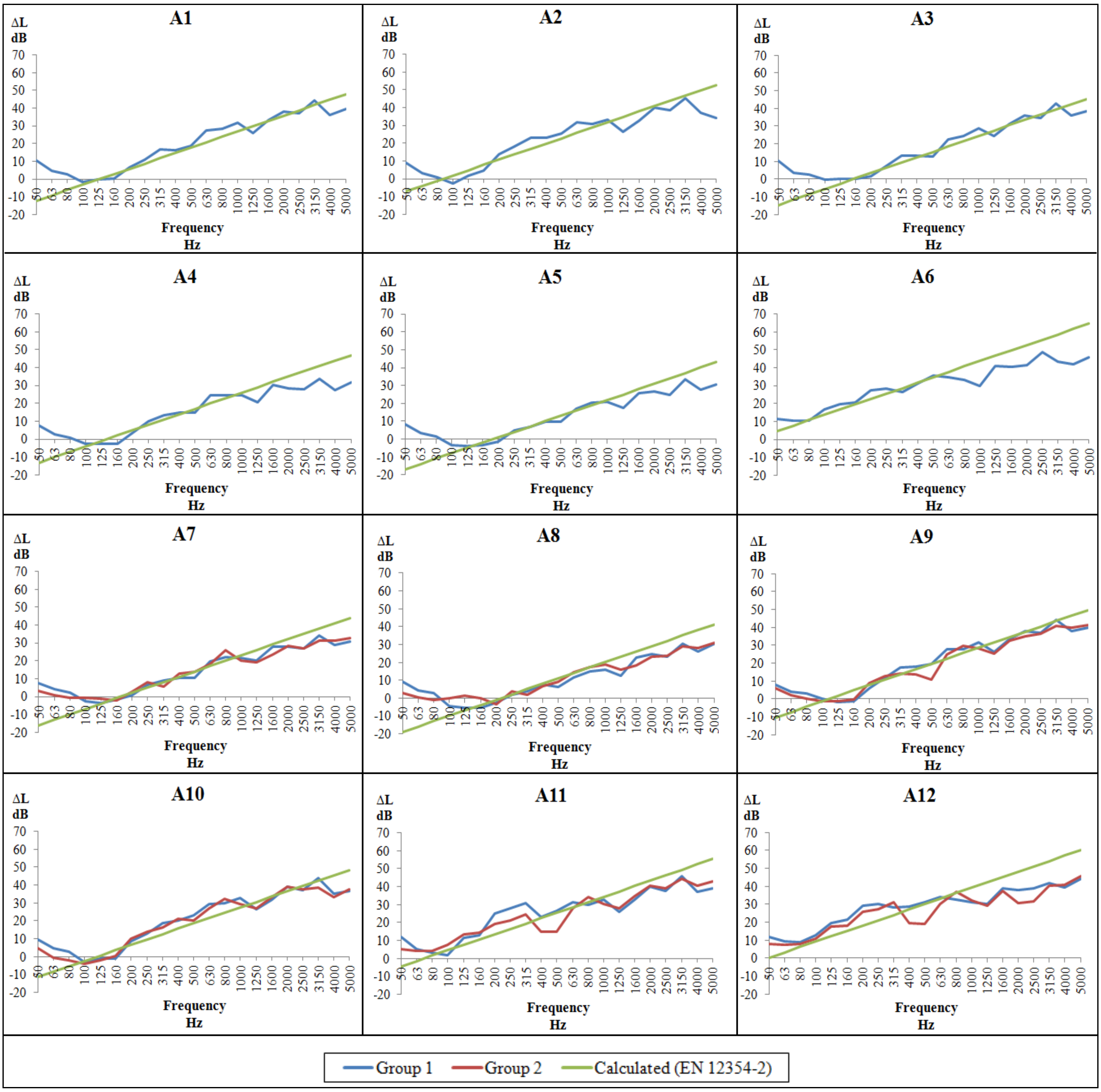

Figure 2. Comparison between the experimental results ΔL of floating floors A1 to A12 and the respective calculated values

3.3. Weighted impact sound reduction

The experimental values of ΔL_W and those calculated for the floating floors of Group 1, considering the two sets of intervals in frequency bands, respectively from 50Hz to 3150Hz and from 100Hz to 3150Hz, are presented in Table III, as well as the corresponding values of adaptation term, $C_{I\Delta}$. Comparing the calculated values of ΔL_W and those experimentally obtained, it can be concluded that there is a great discrepancy between them within the range of 50Hz to 3150Hz (for which differences of 8 dB magnitude can be found). On the other hand, the calculated values are similar to experimental ones when the interval (range) starts at 100Hz. In fact, the differences obtained are only of 2 dB magnitude, at the maximum. Regarding the experimental results for ΔL_W in both frequency ranges, it can be stated that they are close to each other (there is just a small dip of 5 dB for material A6). In most cases (A1, A3, A4, A5, A7, A8, A9 and A10), this difference is situated below 2dB.

Table III. Experimental and calculated values of ΔLw for two frequency ranges

Floating floor	50Hz to 3150Hz			100Hz to 3150Hz		
	ΔL_w *Calc.*	ΔL_w *Lab.*	$C_{I\Delta}$	ΔL_w *Calc.*	ΔL_w *Lab.*	$C_{I\Delta}$
A1	13	20	-11	21	21	-13
A2	18	21	-11	26	24	-14
A3	11	19	-11	18	20	-12
A4	12	17	-10	20	19	-13
A5	9	16	-11	16	16	-12
A6	30	32	-10	38	37	-10
A7	10	17	-11	17	18	-12
A8	7	14	-10	14	14	-11
A9	15	19	-11	23	21	-13
A10	14	19	-11	21	21	-13
A11	21	26	-12	28	30	-14
A12	26	31	-10	33	34	-9

The reference curve of impact sound pressure levels and the impact sound pressure levels of the reference floor, ($L_{n,r,0}$), both set in ISO 717-2, had to be frequency extended in order to calculate the ΔL_W parameter, including the low frequency bands of 50Hz, 63Hz and 80Hz. The corresponding values are presented in Table IV.

Table IV. Reference levels and $L_{n,r,0}$ values in 1/3 octave bands, for the frequency bands of 50Hz, 63Hz and 80 Hz

Frequency *Hz*	*Reference levels* dB	$L_{n,r,0}$ dB
50	62	65.5
63	62	66
80	62	66.5

3.4. Relation between ΔL_W and dynamic stiffness

In Figure 3, a mathematical relation between ΔL_W values, experimentally obtained, considering the frequency range 100Hz to 3150Hz, for materials of Group 1, and their dynamic stiffness is presented. This relation curve was obtained using the minimum least square differences and shows a good correlation coefficient, R^2, of 0.975. It is interesting to notice that this relation, when x-axis is in a logarithmic scale, follows a straight line with similar angular and linear coefficients as those presented in Annex C of EN 12354-2, for m' equal to 80kg/m^2 (here, m' is 76kg/m^2).

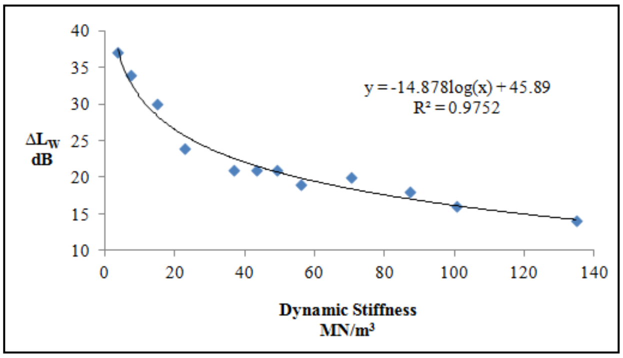

Figure 3. Relation between ΔL_W and dynamic stiffness

3.5. *In situ* results

In order to make a comparison with *in situ* results, 3 tests were done in 2 housing buildings located in São Paulo, Brazil, which are integrated in this study. Two of these *in situ* tests are referred to floating floors made with material A1, and the third one to a floor where the material A6 was applied. For the 3 tests, the slab is of concrete and the floating material is a mortar bed of about 40mm with no final covering.

The corresponding comparison (*in situ* results and those obtained in lab conditions – Group 1, range 100Hz to 3150 Hz), is presented in Table V. The floor area and the slab thicknesses are also presented in this table.

These values are comparable with each other, showing that it is unlikely the size of samples to really influence the impact sound reduction results for these kinds of resilient materials.

Table V – Comparison between ΔL_W obtained in lab and *in situ*

Floating floor	*Lab. tests*	*Field tests*		
	ΔL_W dB	ΔL_W dB	*Floor area* m^2	*Slab thickness mm*
A1	21	19	15	120
A1	21	22	9	100
A6	37	35	15	120

4. Conclusions

The dimensions of samples do not seem to have any influence on the test results for these types of materials. In fact, the obtained differences between all results of Group 1 and Group 2 (materials A7 to A12), are very small. However, it is important to do more tests using floating floors embodying these materials as resilient layers, constructed in bigger dimensions, to really evaluate the possible effects of samples dimensions. In general terms, the impact sound reduction level values determined in lab conditions by 1/3 octave frequency bands, comply fairly well with the model set by EN 12354-2, for the frequency range situated between 100Hz and 3150Hz.

The calculated values of weighted impact sound reduction levels are not similar to the values obtained in lab tests, when the characterization is done in the range 50Hz to 3150Hz. This fact enhances the need to improve the EN model or to change the reference curve accordingly, whenever the analysis is to be done within this frequency range. However, when considering the current standard frequencies interval, let's say, 100Hz till 3150Hz, the corresponding standardized indices agree in general with each other.

In what respects the adaptation term results, $C_{I\Delta}$, the calculations performed reveals that for both frequency ranges the curve trend and obtained values are similar.

The relation between the weighted impact sound reduction of these floating floors and the dynamic stiffness of the respective resilient layers is similar to that presented in Annex C of EN 12354-2, despite the reduced dimensions of the samples and, in case of floating floors with more than one layer (A7, A10, A11 and A12), the non-homogeneity of the resilient system. This fact indicates that, perhaps, the size and the non-homogeneity of materials to be tested, whenever resilient, do not have any influence on the expected results.

The Portuguese and Brazilian resilient materials have shown similar dynamic stiffness. This evidence creates enough confidence that these materials and their respective floating floors systems can be used in each Country without additional characterizations.

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