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EXPERIMETAL AND NUMERICAL ACOUSTIC CHARACTERIZATION OF LAMINATED FLOORS.

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ABSTRACT

This work has focused on characterizing laminated floors from the sound perception perspective. There are two main aspects in this work. The first is an alternative proposed for experimental characterization, which consists in recording the sound generated by the impact of a steel ball when it falls on a laminated floor from a known height. The second is a numerical hybrid FEM-FDTD model. The numerical model uses FEM to simulate the mechanical part of the experiment when the ball impacts the floor. The results are implemented into a FDTD algorithm to take into account the acoustic part of the problem and to obtain the sound pressure level of the microphone. This numerical model is useful for identifying laminated floors if the mechanical properties of the material are known, and to characterize them from the sound perception perspective.

Keywords: Acoustics, Numerical Methods, Laminated Floors.

1.- INTRODUCTION

This paper intends to predict the acoustic behavior of floor coverings used in buildings. This work focuses, on one the hand, on insulation of noise due to impact forces and, on the other hand, on laminated floors as a solution in buildings.

Acoustic standards are becoming increasingly restrictive, such as Standard “DB-HR - Protección frente al ruido” from CTE [1]. This standard states that buildings must protect users from impact noises and must improve insulation conditions. With laminated floors, the inferior layer significantly contributes to improve insulation against noise from adjacent rooms. However, most problems depend on reflected sound.

Some works have attempted to study uncertainty in the determination of impact noise [2, 3]. There are also standards [4-6] that study impact sound insulation in adjacent rooms through floating floors. Nevertheless, the acoustic behavior of sound reflected from floors is evaluated by the standards of the Association of European Producers of Laminated Floors (EPLF) [7, 8].

These standards propose that airborne noise in the room must be evaluated by a tapping machine. The five hammers that impact the laminated floor generate a noise with a characteristic frequency spectrum for each floor type. Sound is recorded on a microphone and is analyzed by a signal processing system. The test is carried out in a semi-anechoic chamber for a test specimen of 2 x 2.4 square meters.

The test results are expressed simply as a percentage of improvement on the reference floor described in the standard. The test is carried out using third octave band filters. Specific resonance was represented by critical band curves (Bark) and was calculated by integrating loudness into the critical band curves. Eight measurements were recorded using a fixed combination of flooring materials. Afterward, the average of the four lowest measurements was calculated. Bark values were obtained by comparing the results between the reference floor and the tested floor. The difference between the reference floor and the tested floor was calculated as a percentage, which represents sound reduction.

The method proposed by these standards has certain disadvantages. First, the tapping machine generated a noise which interfered with the sound produced by the impact of the hammers on the laminated floor. Second, the system took into account only the resonance amplitude and did not consider other perception parameters, which may define sound as more or less pleasant. Finally, samples were quite big and tests also needed a semi-anechoic chamber of at least 30 cubic meters. These factors are significant to propose a simpler method to take measurements. The first step was done to define an experimental configuration and to check if it was possible to differentiate between different types of laminated floors. The second step was done to study the viability of a numerical model that allowed the results from materials with different characteristics to be simulated. The objective was to create a simpler method than that of the EPLF standards [7, 8].

Some works have been done with this experimental method [9, 10], and a doctoral thesis has studied this particular problem [11]. The experimental method is explained in this paper.

Moreover, more references are related with this method. Shuzo Sueyoshi et alter [12] attempted to measure the effect of the noise produced by a tapping machine on wood floors by comparing the effects of the 60 dB and 80 dB sound levels on people. These authors observed that these people’s blood pressure rose with sound levels. The work of Tongjun Cho [13] analyzed the relation between low frequencies of impact and resonances produced on floors by checking the experimental and numerical results.

Faustino et alter [14] attempted to determine the application of corn cob particleboards as sound-absorbent materials. These panels were located between the tapping machine and the floor, and the sounds level that was attenuated by the floor and the reverberation time were evaluated. In the same way, Semprini and Cocchi [15] analyzed isolation between the side walls of a room by locating resilient layers between the tapping machine and the laminated floor. In the work of Warnock [16], a series of measurements of airborne and impact sound on floors was taken using a tapping machine. These authors obtained differences in the sound attenuation for different floors with glass fiber, rock fiber, etc. Finally, the most interesting works are those of Baron [17] and Johanson [18, 19], in which the impacts on laminated floors were produced by people walking on them.

2.- PROPOSED EXPERIMENTAL METHOD

The proposed experimental set-up is seen in Figure 1, which shows the scheme of the measurement system with the different components: a conditioning semi-anechoic chamber; a Bruel & Kjaer model 4189 microphone located 1 meter from the floor; a PVC duct (0.6 m long, inclined at 30º) to throw steel balls; a computer with a Harmonie data acquisition card and the dBFA32 software; the test material on a concrete base.

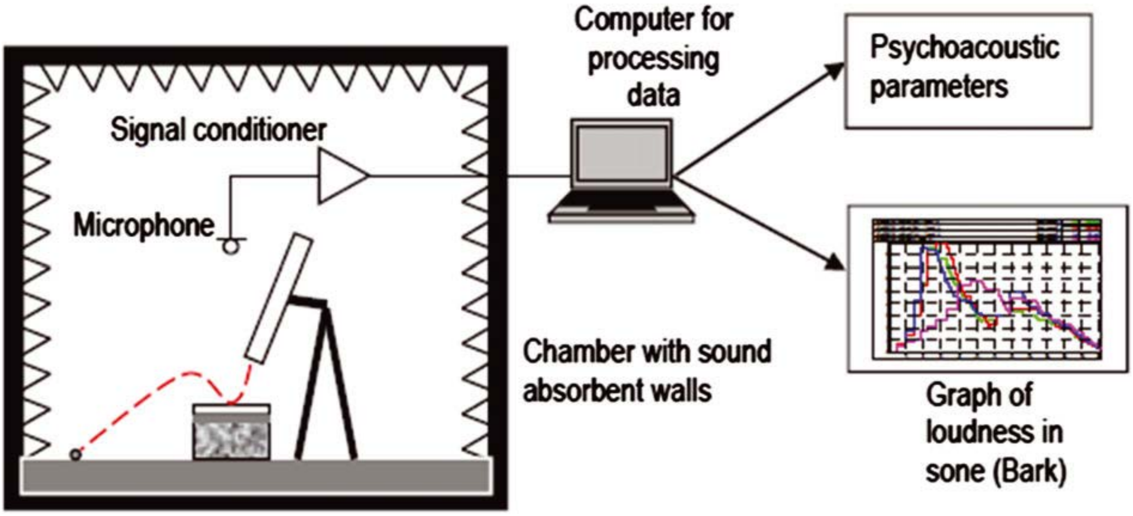

Figure 1. Scheme of the measurement system.

Figure 2 shows details of the experimental set-up that consists in a concrete base of 0.4 x 0.4 x 0.15 m^3, a tile with a mortar joint, the test underlay material, and the laminated floor sample placed at the top, which was fixed with a felt covered steel frame to support it.

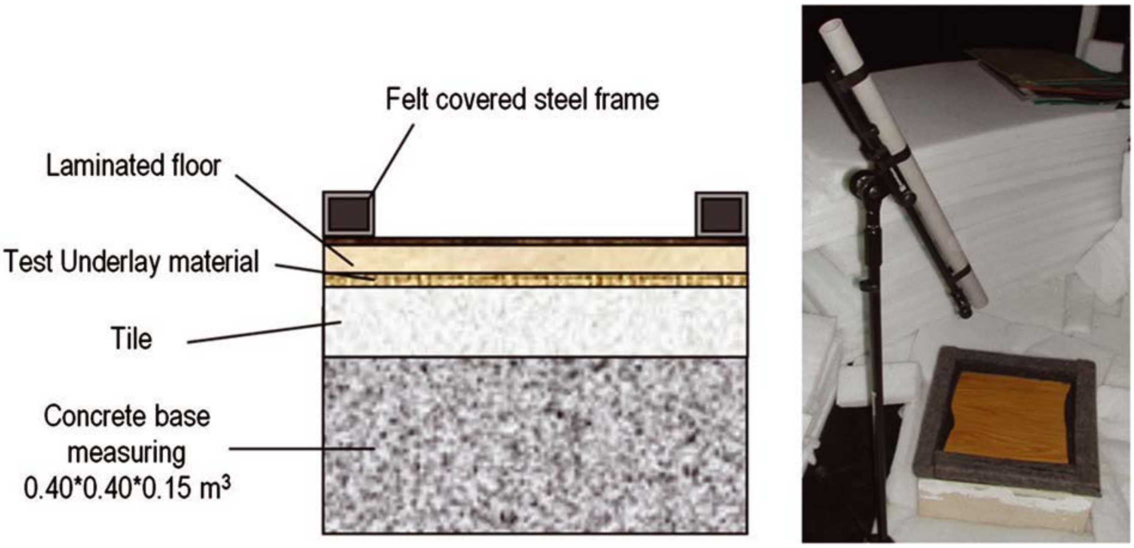

Figure 2. Detail of the experimental set-up.

At a distance of 1 meter from the flooring sample, a microphone was positioned vertically and connected to a recording system. A Harmonie analyzer was used to record the signal, which was then processed by a computer using the dBFA32 module from the 01-dB-Stell software. The recording of the sound signals produced by the impact of a ball was automatically activated with a time delay.

Balls of different weights were dropped onto the surface of the laminated floor samples from a height of 1 meter. Each ball had to strike the surface only once. In the tests carried out, the weight of the balls varied between 0.08 and 0.45 Newtons.

In order to implement a numerical model, determining the impact force (F) was necessary according to conservation of energy (Equation 1):

$$F \cdot \delta = m \cdot g \cdot H_1 - m \cdot g \cdot H_2 \tag{1}$$

where δ is the displacement of the impact point determined by the sensors; $m \cdot g \cdot H$ is the potential energy (m is the mass of the ball, g is acceleration of gravity and H is height).

It is worth noting that damping effects due to heat, sound dissipation and friction effects were not taken into account since δ was the displacement measured immediately after the first impact.

Displacement was obtained from the double integration of the signal recorded by an accelerometer that was located close to the impact point.

Figure 3 shows the scheme of dropping a ball (mass, m) from height H_1 due to acceleration of gravity.

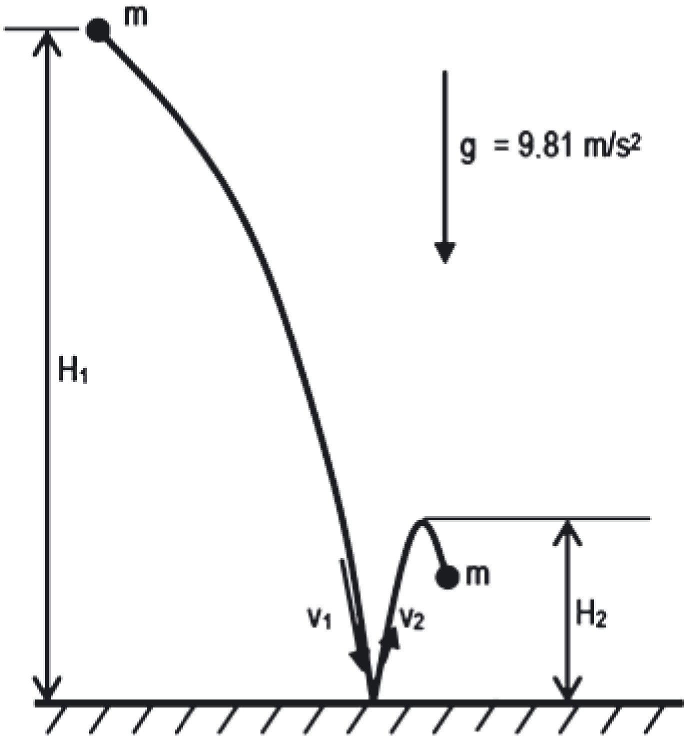

Figure 3. Scheme of the impacting ball falling.

For each combination of materials, balls of different sizes were dropped and the signal produced upon each impact was recorded with the microphone. In the tests, two types of laminated floor (AC4 and AC5) and 15 types of underlay materials (Figures 4.a and 4.b) were used. The signal recorded from each ball that impacted the floor was processed to obtain an average which gave the final result.

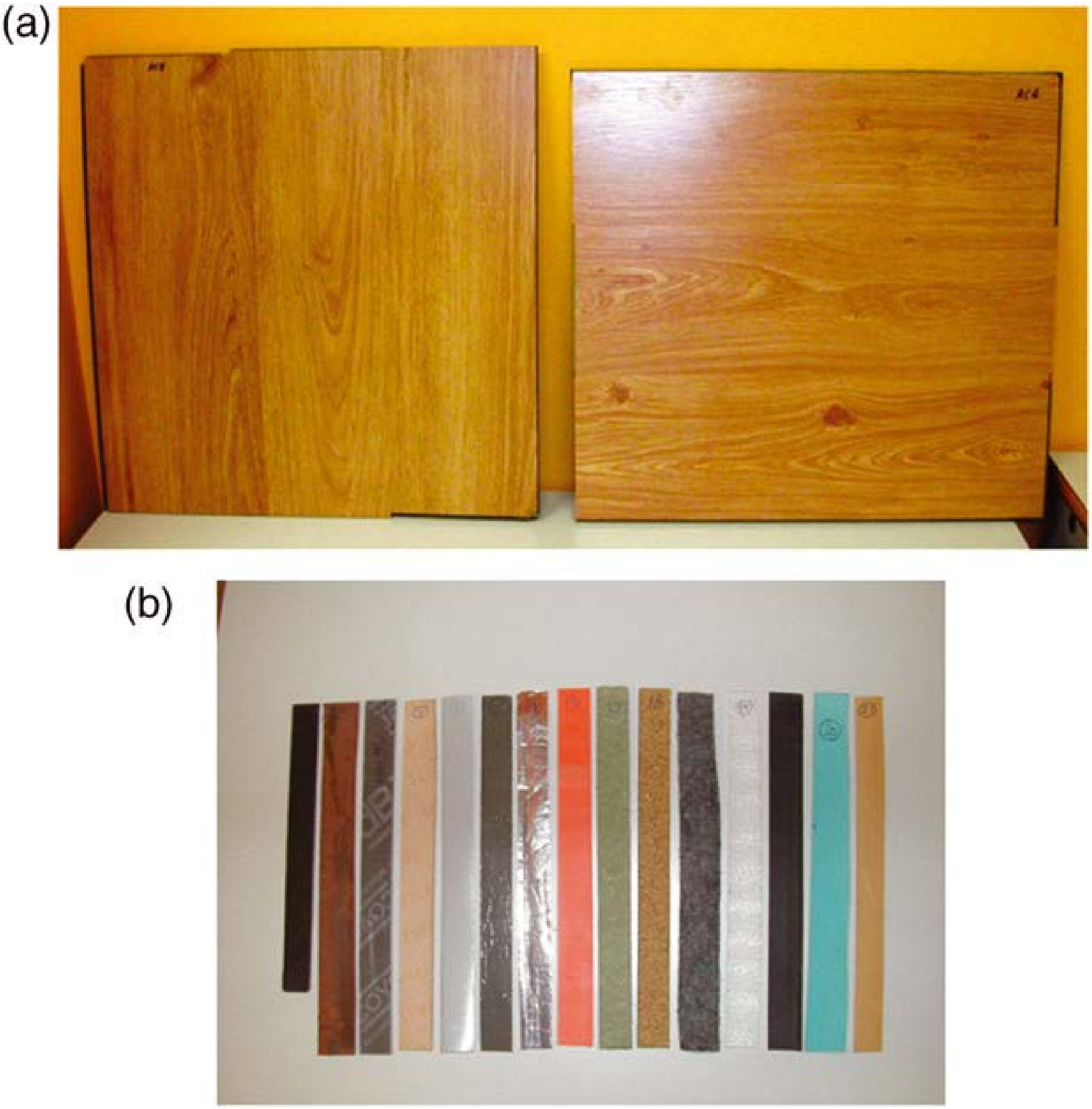

Figure 4: a) Laminated floors AC4 and AC5. b) The underlay materials used in the experiment.

The sound signals recorded for each combination of materials can be used for specific sound graphs with Bark bands or using any other psychoacoustic parameters.

The proposed experimental method differed from the current standard method in some aspects. First, the proposed method was simpler. The standard proposed a sample size of 2 x 2.4 square meters, but the present work proposes a size of 0.4 x 0.4 square meters with a concrete base. Second, the excitation system, which consisted in a tapping machine in the standard, was substituted for steel balls of different diameters and weights, which were dropped on the floor sample. The simplicity of the design did not limit its efficiency because it offered a sufficient margin to distinguish between different flooring configurations. Figures 5.a and 5.b show the Bark band graphs of some tested materials, and indicate the specific resonances per band for them all. Each curve represented the response of a combination of materials to the impulse signals produced by the impact of steel balls. For example, AC4mat1 corresponded to laminated floor type AC4, with a damping material base numbered as mat1. As seen, the experimental results allow differentiation between various combinations. Therefore, the experimental configuration can be considered valid.

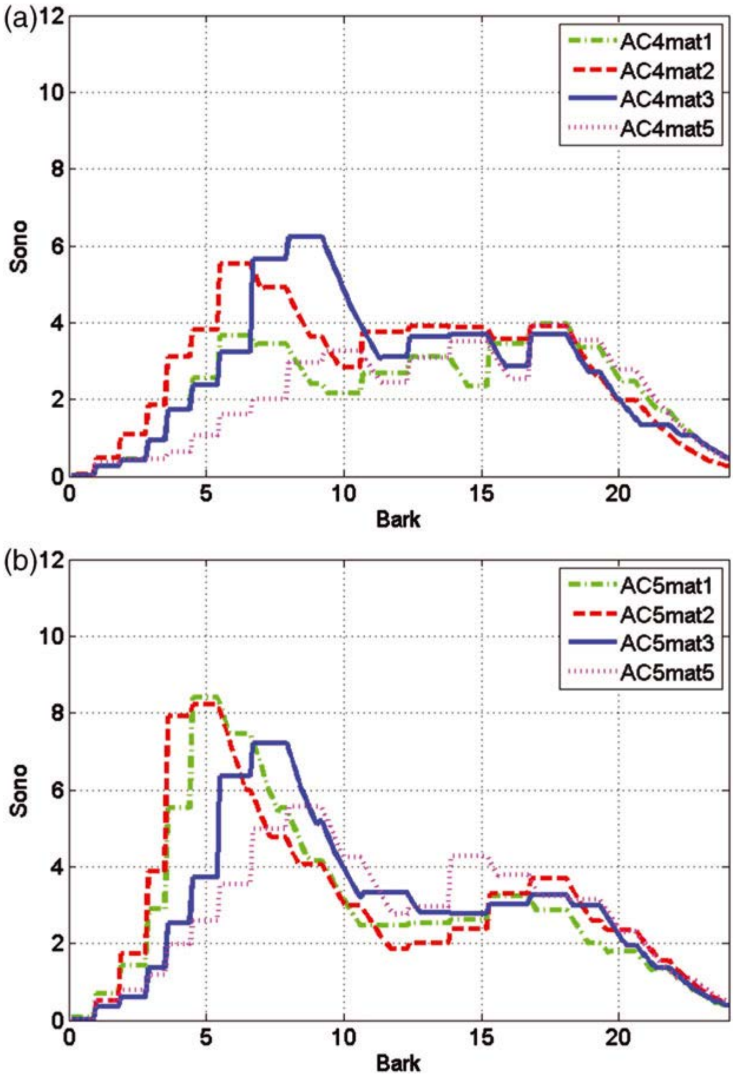

Figure 5. Resonance in Bark bands for AC4 and AC5 with different damping materials.

To characterize laminated floors from the sound perception perspective by occupants in the room, loudness and sharpness were calculated from the recorded sound signals. Figures 6a, 6b, 6c and 6e show these two typical psychoacoustic parameters with different cushioning materials.

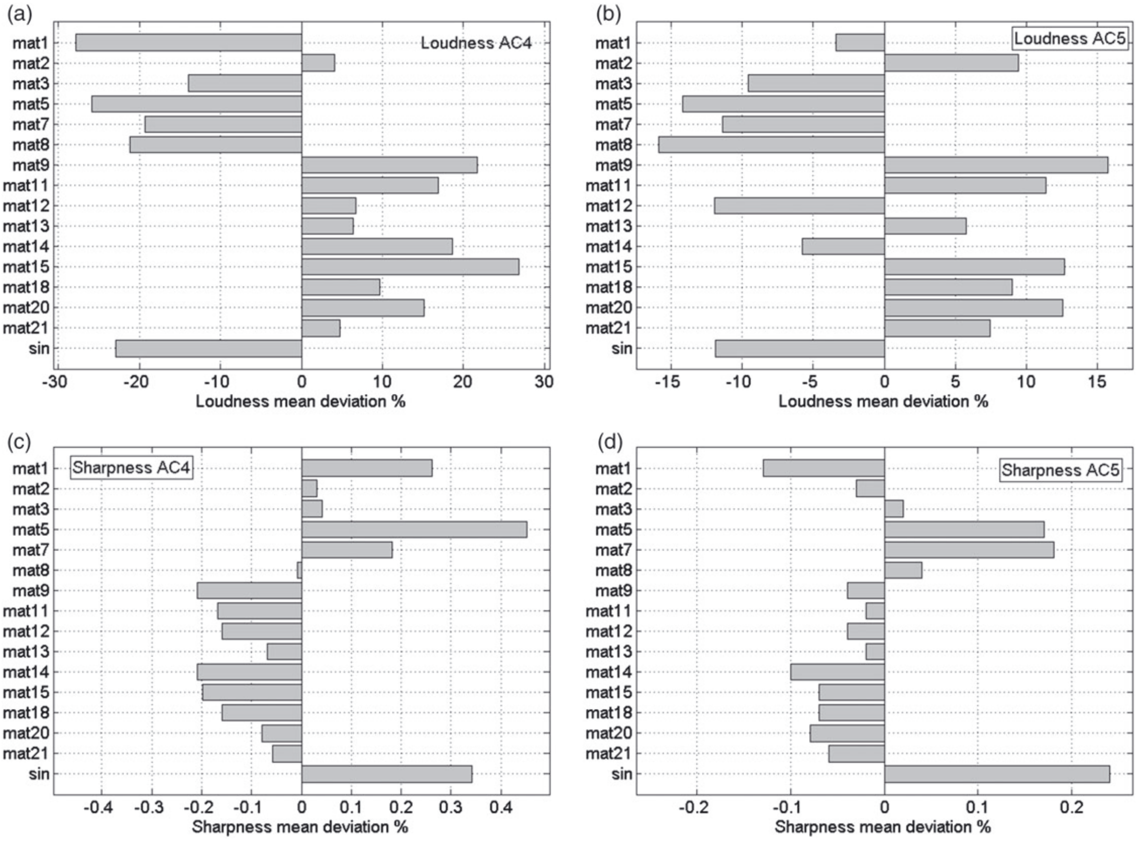

Figure 6. a) Loudness for AC4, b) Loudness for AC5, c) Sharpness AC4, d) Sharpness AC5.

3.- NUMERICAL MODEL.

As previously mentioned, the numerical model comprised two parts. The first part reproduced mechanical behavior and focused on obtaining a transient response at each point of the mesh on the surface. The second part used FDTD with a matlab function to obtain the radiated pressure at each point in the space.

3.1.- Finite Element Method (FEM).

The finite element model was defined by three layers: the damping material located at the bottom; the layer of air in the middle; the laminated floor at the top. To simulate the interaction between the laminated floor and the underlay material, the numerical model was built using 3D elements in ANSYS. For the damping material and the laminated floor, a brick 8-node solid element with 3 degrees of freedom per node was used (UX, UY, UZ). For the layer of air, a brick 8-node fluid element with 4 degrees of freedom per node was used (UX, UY, UZ and pressure). Given the simplicity of this model, it was used with a regular mapped mesh with 4000 elements, which was accurate enough for the quantitatively obtained results.

To define the boundary conditions, displacement in the UY direction at the nodes of the damping material located at the bottom was restricted. The nodes of the layer of air shared displacements (UX, UY and UZ) with solid elements. These shared nodes between the fluid and the solid defined the fluid structure interaction.

The impulse force used to simulate the impact of the ball was, in all cases, a triangular signal that lasted 0.15 seconds. When the experimental results were applied, an appropriate maximum value for load was obtained.

In qualitative terms, the results obtained from the numerical model were similar to those from the real model. The next step to improve the model was to include the “mobilized mass” idea in the impact. In fact, when a ball such as those used in the experiment impacted the floor, only one part of the plate surface vibrated, which caused radiation of sound. It was necessary to restrain the UY displacement of the nodes located at the top and close to the edge which were not going to vibrate (see Figure 7.a and 7.b). After modifying the model, the results showed significant improvement.

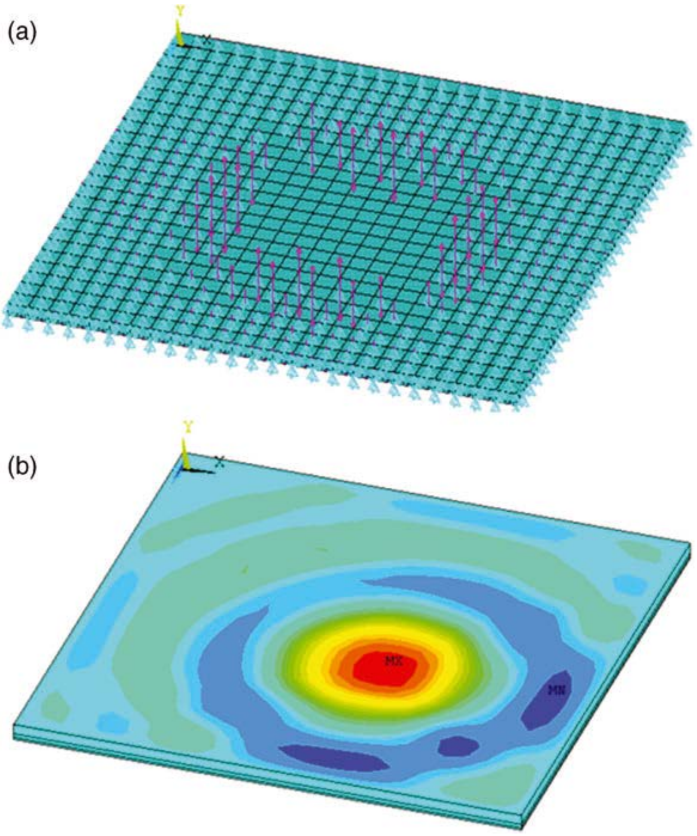

Figure 7. a) Numerical model indicating the displacement restraints; b) Displacement sum of the model at a particular time.

By differentiating the UY displacements of the top nodes of the model, the velocity of the air particles surrounding the surface was obtained. Velocity is the input data for the FDTD algorithm.

3.2.-Finite Difference Time Domain (FDTD).

In order to reproduce the experiment described in Section 3, the second part of the numerical method consisted in a FDTD algorithm [20-24]. This algorithm allowed us to obtain the pressure field at any point in the space. The pressure field was obtained at the point at which the microphone was located in the experimental set-up.

3.3.- Results.

Figure 8 shows two graphs of the simulated sound pressure transitory response for material 21 with laminated floors AC4 and AC5.

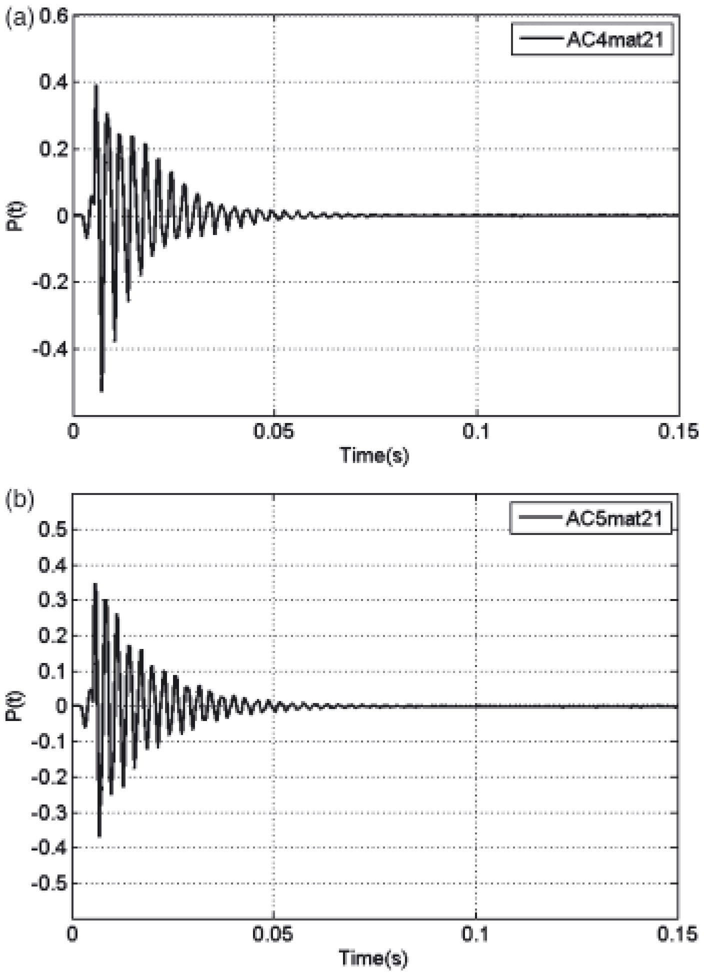

Figure 8. Simulated transitory analysis of the pressure from a point located 1 meter from the laminated floor in the normal direction.

These signals can be analyzed to obtain the specific resonance or any other psychoacoustic parameters. Figure 9 compares the experimental and simulated Bark bands of floor AC5 with materials 1 and 15.

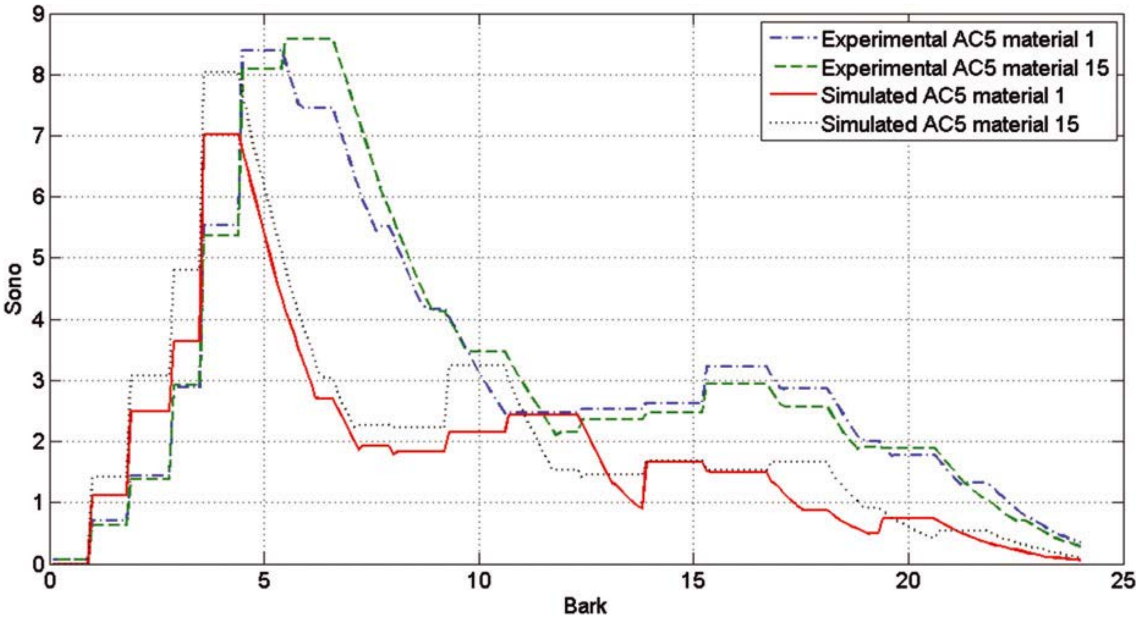

Figure 9. Experimental and simulated Bark bands of floor AC5 with mat1 and mat15.

4.- CONCLUSIONS.

This work proposes an alternative experimental method to characterize laminated floors. The simplicity of the experimental set-up and the obtained results indicate that it offers advantages over the current standard: e.g., only a small model is required. However, a more detailed study is required to guarantee degree of accuracy. This work has assessed sound perception using psychoacoustics parameters. One of these parameters is loudness, which is the only parameter currently used as a reference. To complete the study, one of the first steps for future research will be to compare the results with more psychoacoustic experiments.

This work also proposes a numerical model (a FEM-FDTD model) which reproduces the experimental test qualitatively. In this way, computational time is reduced by using FEM. In fact, the first numerical model step reproduces the mechanical behavior of the experiment: from the impulse force of the falling ball, we obtain the transient response of velocity distribution on the floor. In the second step, the acoustic problem is solved by an FDTD algorithm, according to which, the pressure level at the point at which the microphones are located in the real experiment is obtained. This numerical tool can be used qualitatively to characterize the acoustic behavior of laminated floors. With some improvements, it is possible to simulate the sound of people walking on different floors, which can then be compared before installation. It is important to consider that, currently, one limitation of numerical models is input data accuracy. In this case, input data are the characteristics of the materials (elastic modules, Poisson's ratio, loss factor and density).

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