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STUDY OF THE REFLECTION OF SOUND IN LAMINATED FLOORS. 2D NUMERICAL MODEL.

MARÍA GADEA José[1], SEGURA Jorge[1], JULIÁ Ernesto[1], MASIÁ Jaime[1], RAMIS Jaime[2],
(1) Escuela Politécnica Superior. Universidad Politécnica de Valencia. Campus de Alcoy
(2) Escuela Politécnica Superior. Universidad de Alicante. Campus de S. Vicente del Raspeig.
jmgadea@mes.upv.es, jsegura@mcm.upv.es, erjusan@mes.upv.es, jmasia@mcm.upv.es, jramis@ua.es

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Abstract: The new regulations concerning building acoustics are leading to the increasing use of laminated floors. These usually offer a good solution to insulate the noises caused by impacts. However, the drum sound effect generated by these floors can be problematic. In this article, we describe a parametric study carried out on the influence that the component materials of the floor have on the sound reflected. With this objective in mind, we present a numerical 2D model using the finite element method.

1. INTRODUCTION

The regulations concerning acoustic conditioning in buildings are becoming more and more rigorous. The search for satisfactory solutions has led to an increase in the use of laminated floors. These types of floors are chosen for a variety of reasons:

- they substantially increase the insulation of sound transmitted to the floor below
- they are economical
- they do not increase the calculation weight of the building floor
- they are easy to fit
- they can be fitted to buildings which are old or already in use
- they are aesthetically pleasing
- they are pleasant to use

However, impacts on this type of floor generate fairly loud reflected noise. The lower layer of less rigid material can help insulate the sound transmitted to adjacent areas, but often this reflected sound is not sufficiently reduced.

There are norms [1] UNE-EN ISO 140-6:1999 that study the insulation effect of floating floors on the impact sounds perceived by adjacent rooms or floors. In addition to this, the acoustic behavior of the sound reflected by floating floors is evaluated according to the regulations of the European Producers of Laminate Floorings. These are EPLF - Drum sound properties of laminate floorings [2], and EPLF – Laminate floor coverings - Determination of drum sound generated by means of a tapping machine [3]. These norms propose that the airborne sound in the area where it is produced is evaluated using a standard impact machine. The five hammers which strike the laminated floor generate a spectrum of sound frequencies characteristic for the type of floor. The airborne sound is recorded using a measuring microphone and later analyzed by computer. This experiment must be carried out in a semi-anechoic chamber on a laminated floor model of 2 x 2.4 square meters.

The experimental method proposed by these norms is costly. In order to obtain an approximation of the effect of the materials of which the floating floor is made, we propose a model simulation.

The model is composed of a solid block of concrete on which an underlay material is placed, which in turn supports the laminated floor. A dynamic harmonic excitation is then applied to the floor.

To be able to implement the model a series of materials often used in the manufacture of these floors are first characterized. In this way, we are able to carry out simulations varying each time only one parameter, and achieve a clearly defined parametric study. The model is implemented using the computer application ANSYS.

Once the characteristics of the materials have been defined experimentally, the two-dimensional numerical model is implemented using the finite element method. This model takes in a cross section made up of concrete, underlay and laminated floor, which is surrounded by air forming a circle whose external limit is defined as having infinite absorption. In the model, it is possible to simulate the reflection of sound waves from the floating floor when a harmonic excitation is applied.

2. CHARACTERIZATION OF MATERIALS

The materials to be characterized are the laminated floors and the underlay materials. Concerning the laminated floor, the present work is centered on a type AC4 study of resistance to abrasion, which according to norm UNE-EN 13329:2007 [4], corresponds to type 32 (Figure 1).

Figure 1. Laminated floors AC4

Concerning the underlay material located between the concrete floor and the laminated floor, we collected a range of the less rigid materials, which can be used to form the support for the laminates.

A great variety of materials, with a great diversity of behavior, can be used beneath the laminated floor. Among the materials which can be used are recycled materials, foam polyethylene, synthetic rubber, cork, latex compounds, or indeed any other material which may improve the overall performance of the flooring. Not all of these materials are ideal for the various demands placed on the flooring. There have been studies on acoustic behavior of some materials, but often acoustic improvements have come at the cost of poor functionality of the flooring [5]. Figure 2 shows a variety of underlay materials.

Figure 2. Underlay materials for laminated floors.

The parameters which have to be determined both for the laminated floor 32(AC4) and the underlay are:
- the Young modulus
- the Poisson coefficient
- density
- damping ratio.

Table 1. Characteristics of laminated floors.

Characteristics	AC4
Young modulus (Pa)	6.59e9
Poisson coefficient	0.20
Density(kg/m^3)	904
Damping ratio	0.014

The underlay materials tested have diverse characteristics. The range of values for these materials can be seen in Table 2.

Table 2. Properties of the materials to be inserted between the floor of the building and the laminated floor.

Young Modulus(MPa)	Poisson Coefficient	Density (kg/m^3)	Damping ratio
Between 0.2 and 1.7	Between 0.4 and 0.5	Between 20 and 1100	Between 0.1 and 0.25

3. 2D MODEL SIMULATION

This model simulates a cross section of concrete floor, underlay and laminated flooring, surrounded by a circle of air whose outer edge is defined as being of infinite absorption. Figure 3 shows the complete 2-dimensional model.
Around the solid part of the model, the fluid-structure interface is implemented, which is necessary in order that the vibration from the solid parts propagates through the air in the form of waves.
So that the external limit of the air does not reflect the sound waves which reach it, which would confuse the results, an infinite absorption limit must be defined. This limit simulates the working of a perfect anechoic chamber, with no reverberation whatsoever
The dimensions of the circle of air are fixed as a function of the distance between the laminated floor and the limit of infinite absorption. This distance, measured in the direction in which the user wants to measure the wave propagation, must be at least 0.2·λ, being λ, the wavelength in the fluid. Therefore, the dimensions of the circle of air will be greater when the dominant frequency of the pressure wave is lower. Supposing a minimum frequency of 40 Hz, the wavelength in the air would be:

$$\lambda = \frac{c_o}{f} = \frac{344}{40} = 8{,}6m \qquad [1]$$

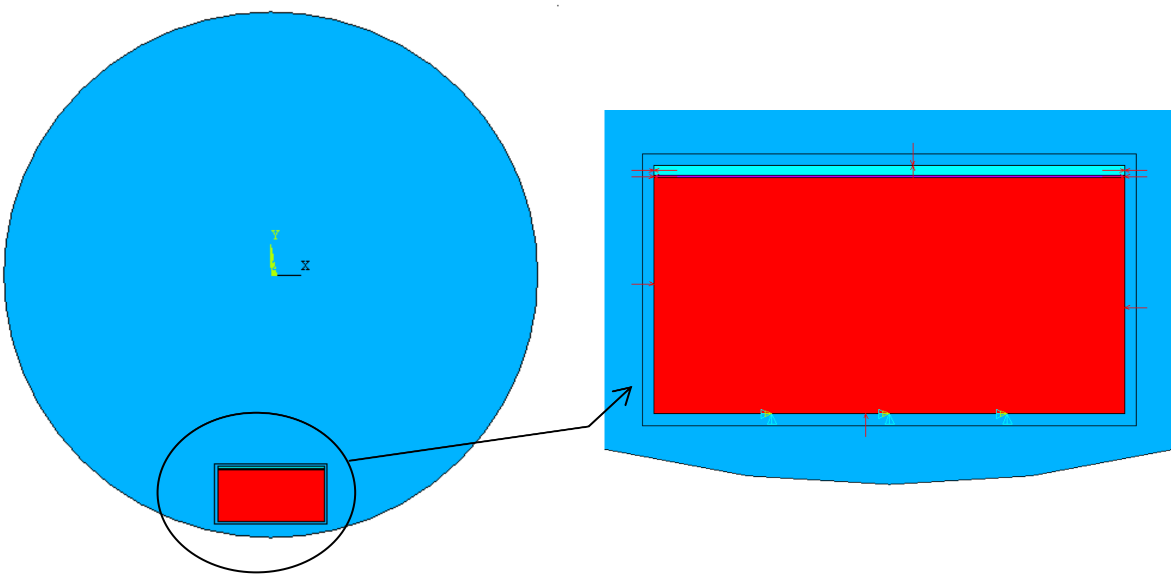

Figure 3. Model of the complete dimensions, composed of a concrete base, underlay material, laminated floor, air and limit of the solid part to define the fluid-structure interface. The exterior circumference of the circle is of infinite absorption.

Being c_o the speed of the sound in the air, and *f* the dominant frequency of the pressure wave. Thus, the distance being sought would be:

$$y_b = 0{,}2 \cdot \lambda = 0{,}2 \cdot 8{,}6 = 1{,}72\text{m} \qquad [2]$$

With this in mind, a diameter of 2 m is established, giving a y_b distance of 1,75 m. Thus we can consider that sufficient margin exists as the frequencies of interest are considerably higher than the frequency chosen (figure 4).

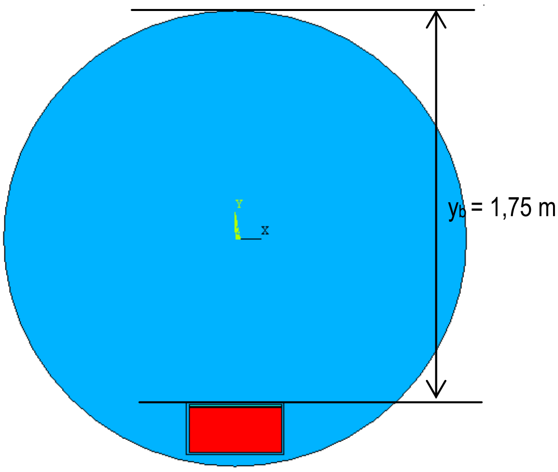

Figure 4. Distance y_b

The mesh for this model is generated with the following types of finite elements from the ANSYS program [7] [8]. *Plane 82* is an element with 8 nodes and two degrees of freedom of movement in *x* and *y* per node. It is an element with 8 or 6 nodes depending on the form taken. This element allows us to obtain greater accuracy in the mesh with irregular panels (figure 5).

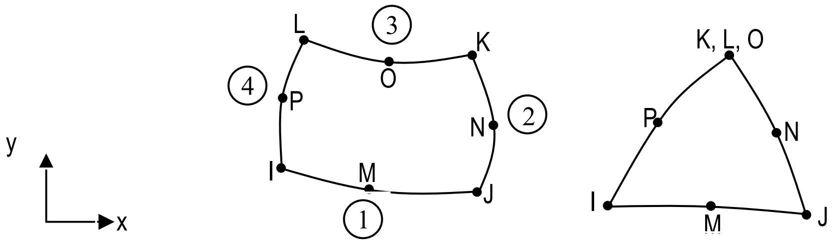

Figure 5. Element Plane 82 in its two versions forming quadrilaterals or triangles.

Fluid 29 is used to model the air and the fluid-structure interface (Figure 6). It is an element which allows the propagation of sound waves, and contains 4 or 3 nodes at its corners according to the shape of the element. Each node of the fluid-structure interface allows three degrees of freedom: two of movement in *x* and *y*, and one of pressure. The nodes of the air that does not form part of the fluid-structure interface only have the degree of freedom of pressure. In the ANSYS program, two models must be defined for this element: the *Fluid 29* without structure (only one degree of freedom for pressure), and the *Fluid 29* with structure (three degrees of freedom) for the interface.

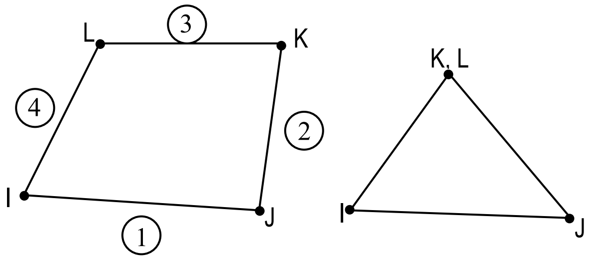

Figure 6. Element Fluid 29 in its two versions forming quadrilaterals or triangles.

Fluid 129 accompanies *Fluid 29*. This element simulates the effects of infinite absorption in a fluid. It is a linear element with two nodes, each of which has one pressure degree of freedom (Figure 7).

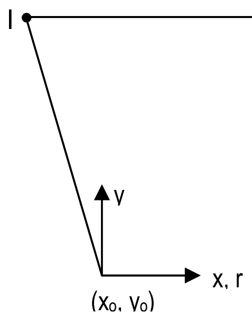

Figure 7. Element Fluid 129.

Figure 8 shows the mesh of the solid parts of the model simulation, as well as the interface which surrounds the solid, and one part of the surrounding air.

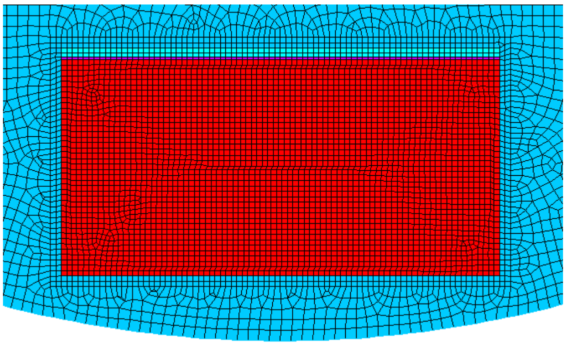

Figure 8. Mesh of the solid parts of the model simulation, the interface and the surrounding air.

The dimensions of the element are obtained as a function of the highest frequency one wishes to reach with accuracy, and also as a function of the speed of propagation of sound in the medium. As a minimum in a dynamic analysis the dimensions of the element have to be:

$$\frac{\lambda}{6} = \frac{c_o}{6 \cdot f}. \qquad [3]$$

Where λ is the wavelength, c_o is the speed of sound propagation in the air, and f is the frequency. This concept influences the fineness of the mesh, which should be greater when the frequency is also greater in order to obtain accurate data. For the air, and considering that we wish to obtain data for a frequency of 4000 Hz, the following equation is used:

$$\frac{c_o}{6 \cdot f} = \frac{344}{6 \cdot 4000} = 0{,}014 \text{ m} \qquad [4]$$

Once the model has been implemented, a force of 1 N located at 28 mm from the center is applied in order to carry out a harmonic analysis.
Figure 9 shows the functioning of this model for a harmonic analysis of a combination of particular materials. In this analysis, we can see the sound pressure (Pa) graphic with respect to the frequency (Hz) from a point situated one meter perpendicular to the laminated floor. In the same figure, we can also see a sequence of figures showing the distribution of pressure in the air for frequencies of 500, 2000 and 4000 Hz. The pressure defined for each color is identified in the bar below each graphic
It is also possible to see the progress of the waves for each frequency and the correct functioning of the infinite absorption edge, as no rebounds appear.
The results obtained with this model can be seen in the graphics in Figures 10, 11 and 12 corresponding to a parametric study which allows us to observe the influence of some properties or characteristics of the materials used in the model. This study is carried out through harmonic analyses and so we are dealing only with qualitative data. The study covered a range of frequencies from 0 to 4000 Hz.

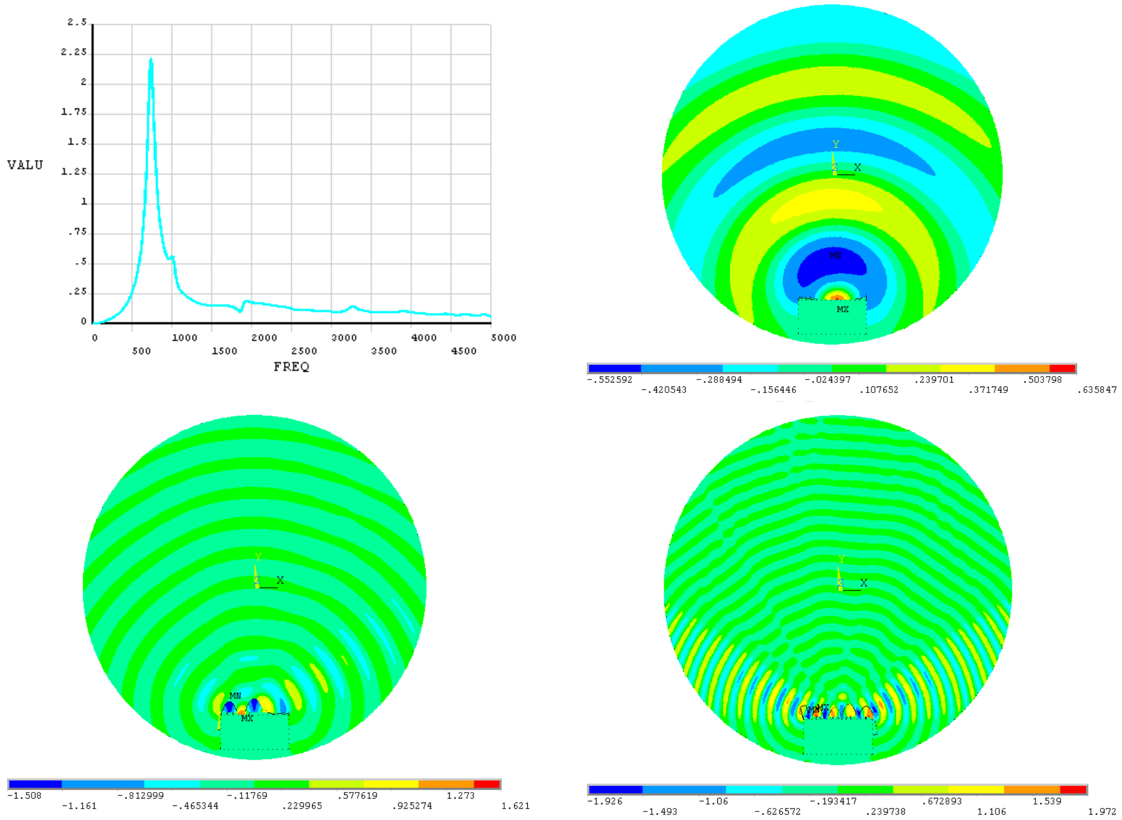

Figure 9. Distribution of pressure in Pa in the air for 500, 2000 and 4000 Hz, from lower to higher, from a harmonic analysis.

Figure 10 represents the variations in sound pressure when only the Young modulus of the underlay material is changed.
Figure 11 represents the variation in sound pressure when only the density of the underlay material is changed.
Figure 12 shows the variation in sound pressure as a function of the damping properties of the underlay material used.

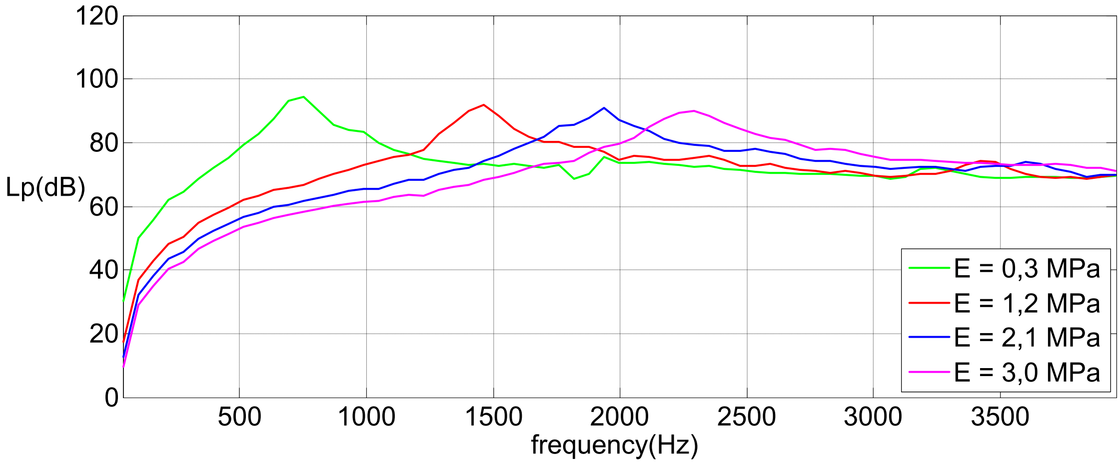

Figure 10. Parametric analysis varying only the Young model of the underlay material.

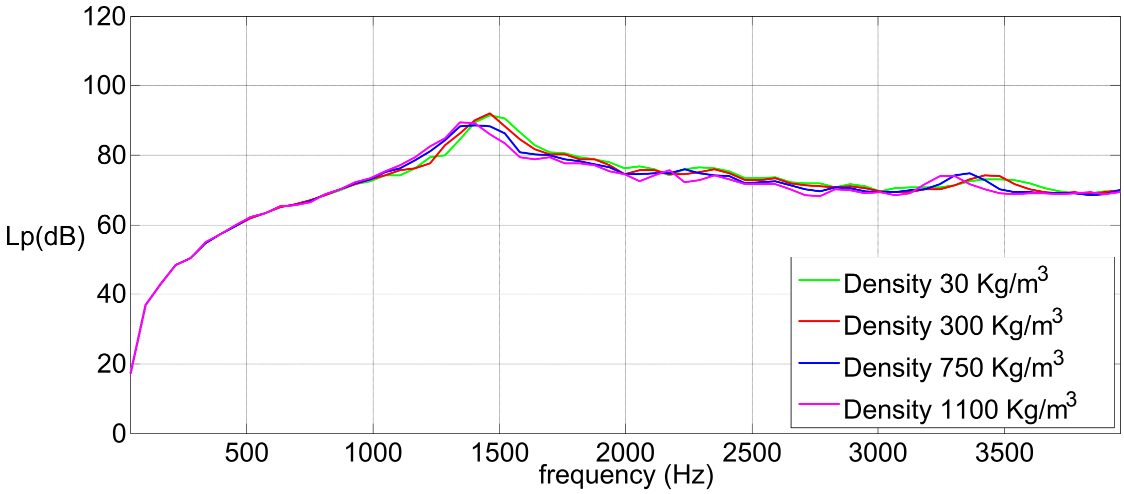

Figure 11. Parametric analysis, varying only the density of the underlay material.

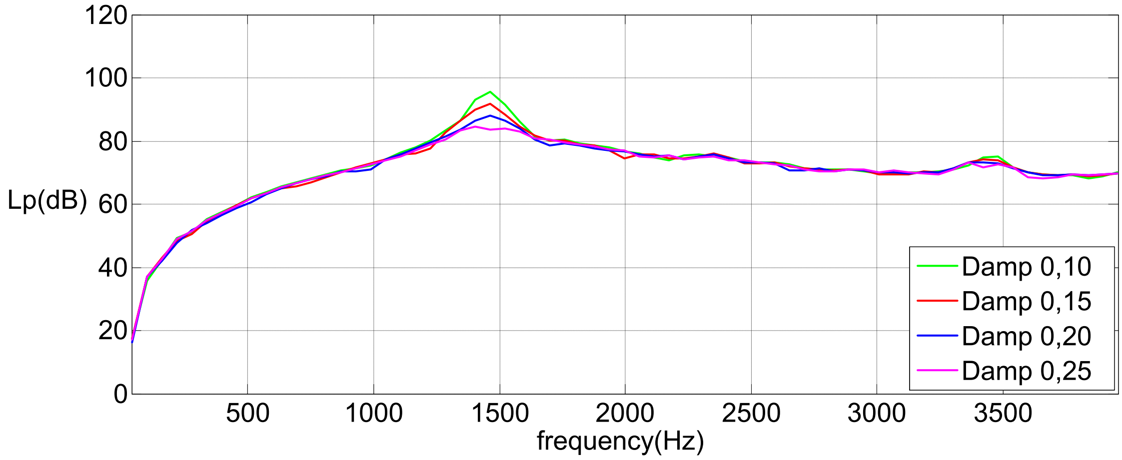

Figure 12. Parametric analysis, varying only the damping properties of the underlay material.

4. CONCLUSIONS

The results obtained with this model are shown in Figures 10, 11 and 12, corresponding to the parametric study and allow us to observe the influence of some properties or characteristics of the underlay materials used in the model.
In these graphics, we can see that the greater influence is in the Young modulus, in which there is not only a variation in resonance frequency, but also in sound pressure. For a lower Young modulus, there is greater amplitude and lower frequency resonance.
In spite of the great variation of densities introduced (de 30 a 1100 kg/m^3), this factor does not seem to influence the results of the analysis to any great degree.
The damping properties only affect the amplitude of the mode, and do not cause variations in the resonance frequency values.
The results obtained follow approximately the theoretical laws of the influence of the variable parameters.
We can conclude that the numerical model presented, even with its entry limitations and possibilities for improvement could constitute an efficient and economical tool to obtain qualitative results on the behavior of floating floors.

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