Modélisation numérique de la performance au bruit d’impact d’une chape flottante

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Acoustical improvement of multilayered floor on floating screed requires a detailed understanding of the behavior of each layer and the interactions between these layers. An indicator used to measure the acoustical performance of a floating screed is the impact noise measurement (impact of object on the floor, heel noise, etc.). This standard test is performed with a standard tapping machine as excitation and microphones localized in a reception room under the floating screed. The numerical simulation of this test provides a helpful support in the design phase of each layer of the floating screed. The finite elements software Code_Aster is used for this study. Code_Aster is an open-source software developed by EDF. The open-source software is used for pre-processing (geometry and meshing) and post-processing. The aim of this study is the implementation of a computation methodology based on standardized test in order to compare test results and numerical results from a reference configuration. A parametrical model is computed to easily modify the geometry, the mesh and input data (material properties, boundary conditions, loadings, etc.). Perspectives of this work are to have a complete numerical tool allowing to realize numerical design of experiments (materials, geometry, etc.) to help to identify simple design rules and to orient towards new technologies of floating screed.

1 Introduction

The acoustical insulation of ceilings is an important factor of the acoustic and vibration comfort in buildings and the acoustic specifications for the construction or rehabilitation of buildings are more and more constraining. The impact noise is one of the main indicators to determine the acoustic performance of ceilings. The impact noise is calculated by doing the difference between the Sound Pressure Level (SPL) between a reference floor and with the floor covering. Several prototypes and combinations of different geometries are necessary to improve the acoustics performance of ceilings and can lead to prohibitive and long-term development. One way of improvement is the use of numerical tools in the design development. A fast method to compute the impact noise is the TMM (Transfer Matrix Method) with several commercial softwares as AcouSyS or AlphaCell. One of the limitations of this approach is that only the thickness of the multilayer can be studied and not the geometry. The interest of a Finite Element Method (FEM) approach versus the TMM approach is that computations with various thicknesses and geometries can be performed.

In this work, a finite element model for impact noise calculation has been realized with the finite element software Code_Aster. Code_Aster is an open source software developed by EDF (French Electricity Company). The pre-processing and the post-processing have been computed with the open source software Salome. The main purpose of this study is to provide a computational method of the impact noise measurement to determine the impact noise indicator of multilayers from a finite element model.

Firstly, the description of the methods and model used to compute the impact noise is presented. A brief description of the standard experiment to measure impact noise is given. From the recommendations of the standard, hypothesis of the computational method, boundary conditions and loadings are then given.

Then, a validation of the computation procedure and the model is presented with the comparison between test and computation results. It is achieved with the correlation of a reference multilayer.

Finally, conclusion and perspectives are presented. Several proposals are given to improve the model: updating of damping, better understanding of the dissipation of the air, studying the influence of the localization of the microphones in the reception room or enhancements of the computational method could be some leads to improve the numerical model of the impact noise computation for multilayers.

2 Standard experiment versus FEA

2.1 Impact noise

The principle of the experiment to measure the impact noise is presented in Figure 1.

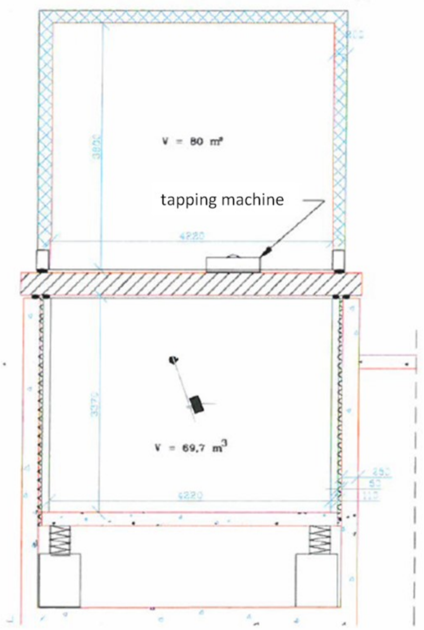

Figure 1: Principle of the experiment to measure the impact noise.

The excitation is performed using a standard tapping machine with 5 hammers. The sound pressure is then measured in various positions of the tapping machine and all the positions of the microphones in the reception room according to the standard ISO 10140-3.

The insulation performance is characterized by measuring the normalized impact sound pressure level of a ceiling without ($L_{n,0}$) and with (L_n) the floor covering to be tested versus the frequency [1]. The difference:

$$\Delta L = L_{n,0} - L_n \qquad (1)$$

is called improvement of impact sound insulation or reduction of impact sound pressure level of a floor covering. From the reduction of impact sound pressure level depending on the frequency in the range of the third octave centre frequency 100 Hz up to 3150 Hz, a single number quantity ΔL_w is determined according to the NF EN ISO 717-2 standard. It is called weighted impact sound improvement index.

In order to compute an impact noise calculation, it is important to represent not only the components and the adjacent rooms but also the excitation due to the standard tapping machine (cf. Figure 2). The paper [2] gives an overview of models for the excitation generated by a standard tapping machine taking into account the interaction between the impacting steel cylinders of the tapping machine and the vibrating surface of the floor. The one chosen for this work is the Brunskog's model [3], allowing a wide range of applications, especially for floor with high admittance (i.e. a mobility Y >> 0).

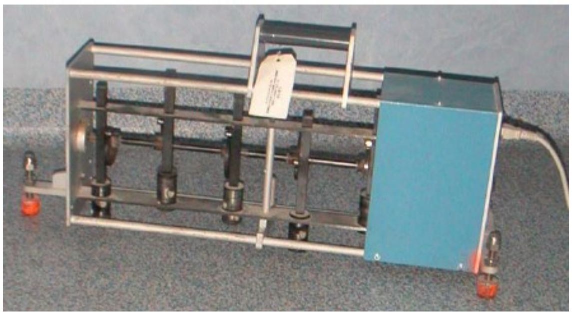

Figure 2: Photo of a standard tapping machine.

Thus, the Brunskog's model defines the excitation force $F_{\Delta f}$ for the frequency bandwidth Δf depends on the multilayer system input mobility $Y_{\Delta f}$ as:

$$F_{\Delta f} = 2\left|\frac{2mv_0}{i\omega m Y_{\Delta f} + 1}\right|\sqrt{f_s \Delta f} \quad (2)$$

where f_s, m and v_0 are respectively the impact frequency of the tapping machine (10 Hz), the hammer mass (0.5 kg) and the hammer impact velocity. The input mobility $Y_{\Delta f}$ is obtained as the integrated of the multilayer system mobility in the frequency bandwidth Δf from the ratio of the top surface input velocity v_i and the input force F_i:

$$Y_{\Delta f} = \int_{\omega \in \Delta f} \frac{v_i}{F_i} d\omega \quad (3)$$

As the tapping machine can be placed on various positions on the floor, which has dimensions of 4m by 3m, the effect o the number and positions of the excitation has been verified, according to the recommendations of the standard ISO 10140-3 (minimum distance between each point, minimum distance between the edge of the floor). It appears that the position in not an important factor on impact noise results as long as the impact is not applied at the center of the floor. After these verifications of the computation of the standard test, a convergence study has been performed on the mesh.

The element size of the model is classically chosen according to the acoustic wave length in the case of vibro-acoustic computation. As it is not possible to determine *a priori* the vibratory wave length in the multilayer, it was not considered to define the element size of the multilayer mesh.

As the performance of the multilayer is computed up to the third octave band centered at 500 Hz, the element size must be at least 6 times lower than the acoustic wave length at 630 Hz, which is given by:

$$\lambda = \frac{c}{f} = \frac{340}{630} \approx 54\ cm \quad (4)$$

Thus, a maximal element size of 5 cm is decided for the fluid elements., It is chosen to have at least three elements in the thickness dimension for the solid elements. The aim is to avoid shear locking by the numerical hourglass phenomenon. For example, for a thickness of 30 mm, an element size of 10 mm is taken for solid elements. In anyway, a convergence study is performed on the model to verify the choices of element sizes.

2.2 Computation methodology

The reference floor is composed by three different layers:

- A layer of concrete (called main floor) with a thickness of 160 mm
- A layer of expanded polystyrene (EPS) with a thickness of 30 mm
- A layer of mortar with a thickness of 40 mm

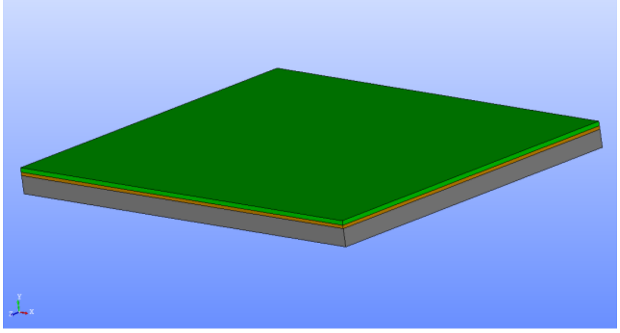

Figure 3: Multilayer description with main floor in grey, EPS in orange and mortar in green.

To well represent the conditions under which the standard test is performed, the lateral sides of the concrete layer are embedded in the model: the horizontal displacements are set to 0 and the normal displacements are free. An impedance surface condition ($Z0 = \rho_0 {*} c_0$) is applied on the external surface of the air to have an anechoic boundary condition.

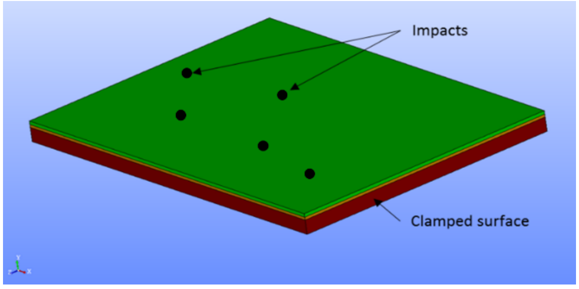

Figure 4: Boundary conditions and loading.

A nodal force is applied on the upper side of the floor at each impact localization (cf. Figure 4).

The computation of the impact noise is based on the experiment in the standard measurement. Several steps are necessary to represent numerically this test:

- Calculation of a unit nodal force on the main floor and the multilayer
- Determination of the mobility as a result of the nodal force
- Determination of the injected force of the tapping machine with the Brunskog's model
- Calculation of the vibroacoustic responses for the two configurations (fluid/structure interface)
- Determination of the ΔL

From the results of computation, the ΔL can be obtained by two different ways of post-processing:

- Determination of the SPL (Sound Pressure Level) from the computed transmitted pressure in the air
- Determination of the acoustic power at the fluid/structure interface

In this work, the first option is used (determination of the SPL) to compute the ΔL, because the access to the acoustic power is not straightforward with Code_Aster. Additional developments would be necessary.

2.3 3D model

The dimensions of the floor are chosen from the experiment dimensions (3m by 4m).

The reception room is taken into account as a semi-sphere with a diameter of 6 m. The mesh of the whole model is presented in the Figure 5 and Figure 6.

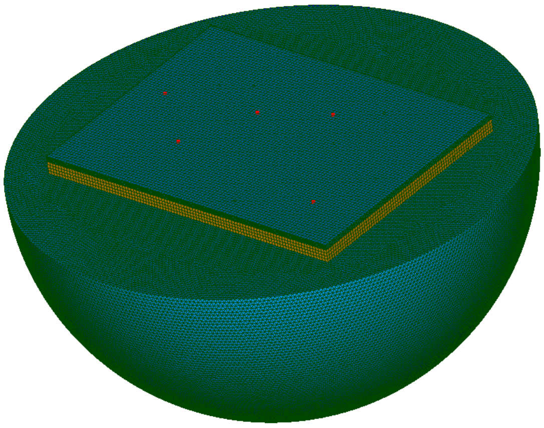

Figure 5: Mesh of the 3D model for a multilayer.

As far as possible, the fluid elements are meshed with tetrahedral elements and the solid elements are meshed with hexahedral elements.

The mesh of the fluid elements has:

- 166 484 nodes
- 843 095 tetrahedral elements

The number of hexahedral elements for each solid is:

- Concrete: 30 000 hexahedral elements
- EPS: 22 500 hexahedral elements
- Mortar: 30 000 hexahedral elements

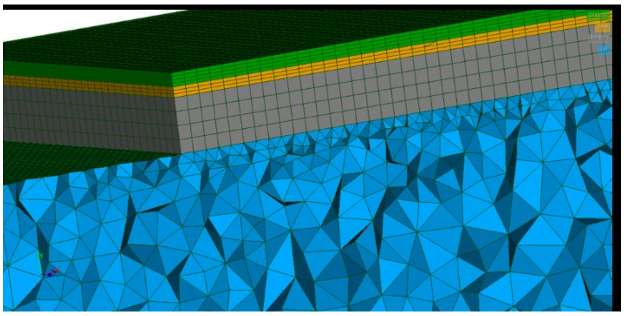

Figure 6: Zoom on a clipping of the mesh at the fluid/structure interface (air in blue, concrete in grey, EPS in yellow and mortar in green).

3 Validation with a reference

A comparison with test results is realized on a reference multilayer to validate the 3D model and the computation procedure. The reference multilayer is the one described in the 2.2 part.

The first step is the validation of the input mobility (and consequently the input force) on the model. The mobility is defined as the velocity over the force. As we use a unit force, we verify the mobility for each frequency step in narrow band from 40 Hz to 4000 Hz by extracting the velocity at the localization of the impact.

The Figure 7 shows the mobility results between test and computation. The results are the mean of the impacts of the 5 hammers on a concrete floor.

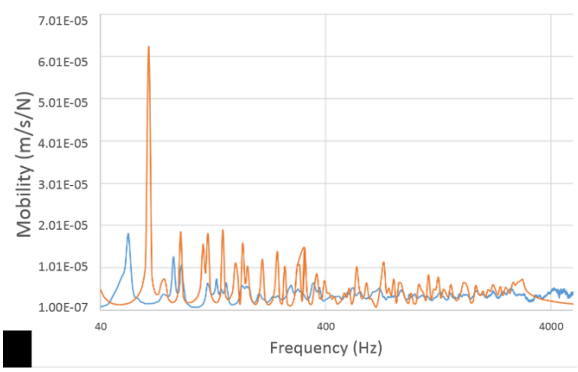

Figure 7: Comparison of mobilities between test results (blue) and computation results (orange).

One can observe that the magnitude of computed mobility and experiment is similar, except for a peak of mobility around 65 Hz. Moreover, the values oscillate around 1e-6 m/s/N, which is the analytical value expected for this type of layer. One can then consider that the computation of the input force and the post-processing of mobility are validated. Updating the damping should improve the correlation by decreasing the magnitude of the computed peaks.

From the computed mobility, the input force to inject in the model is calculated with the Equation (2) for each third octave band from 50 Hz to 2000 Hz. The results are presented in the Figure 8.

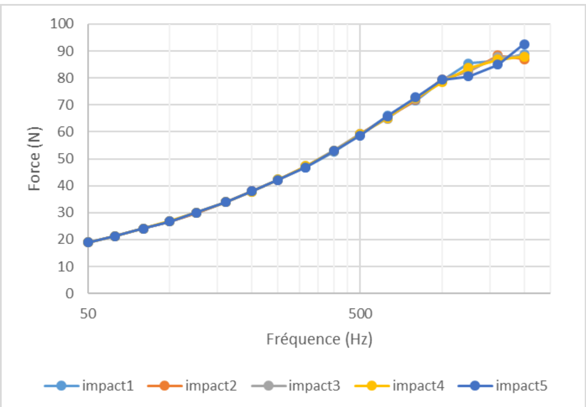

Figure 8: Computed Brunskog's force (N) for the reference multilayer for the 5 impacts.

One can remark that the input force is quite the same for the 5 impacts, except a difference of a few Newtons at high frequencies. The same calculation is performed for the main floor only (concrete layer), with exactly the same calculated input force for the 5 impacts. These results show that the localization of the tapping machine on the multilayer has no real influence for the computation as long as the recommendations in the standard are respected (not too close of the sides and of the center of the layers).

After the injected force calculation, the impact noise computation is performed in third octave band from 50 Hz to 500 Hz. The computed Bruskog's model is applied for each impact nodes. The ΔL is calculated from the SPL results extracted from nodes at different positions in the reception room. The comparison of the average of the 5 ΔL for each impact between the experiment and the computation is shown in Figure 9.

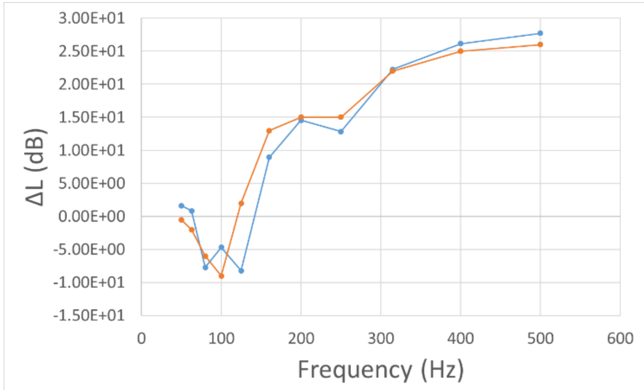

Figure 9: Comparison between the test (orange) and computed (blue) results of impact noise.

One can observe a good correlation between the experiment and the computation as the trends of ΔL are similar between the two curves. Differences can be observed, especially between 100 Hz and 200 Hz, but the fall of ΔL at 100 Hz is well computed which gives an important factor of guarantee for the acoustical performance of the multilayer floor. One way to reduce the differences could be to use a greater number of microphones (nodes in the air cavity) in the calculation of the ΔL.

4 Conclusion and perspectives

A finite element model of the impact noise measurement has been developed with the open-source finite element software Code_Aster. In order to validate the computational method, a comparison has been performed with a reference multilayer and several steps of the calculation process have been validated with test results. The results of the impact noise reduction ΔL give a quite good correlation between experiment and computation on a 3D model.

Thus, the methodology of the calculation can be applied to provide support in the design process of damped multilayer floor in order to improve the acoustical performance of these products. The parametrical model used is a powerful and simple tool to easily modify geometry, material properties or input data of the impact noise computation and realize numerical design of experiments.

However, the finite element model could still be enhanced with for example, a better awareness of air dissipation in the reception room or a study on the influence of the localization of the microphones.

Acknowledgements

This work was funded and supported by Saint-Gobain Recherche and Weber.

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