Predicting the acoustic performance of multi-layered structures submitted to structural excitation

Catherine Guigou-Carter, Michel Villot

Acoustics and Lighting Department, CSTB, 38400 Saint Martin d'Hères, France,
Email: catherine.guigou@cstb.fr

Introduction

In this paper, the modelling of multi-layered isotropic structures submitted to structural excitation is discussed. The behaviour of the multi-layered system is predicted using a wave approach, the structural excitation being decomposed into normal stress plane waves. Two different types of structural excitation are of interest since they correspond to measurement standards: tapping machine and rainfall. In this paper, the performance of floating systems (either concrete or lightweight) in terms of impact noise is studied both experimentally and analytically. Such systems are composed of a floating floor (either concrete or wood) separated from a heavy concrete base floor by a simple or multi-layered elastic interlayer. The different layers are described by their dynamic characteristics; the evaluation of the elastic characteristics by measurements is also discussed.

This prediction tool can be used to help industrial partners to improve their products or develop new ones.

Analytical model

A model for infinite multilayered structures is used, based on a transfer matrix approach [1]. The different layers of constant thickness can be either solid, fluid or porous (following Biot's theory) elements. A computer program (CASC software), based on this approach, has been developed at CSTB and used to predict sound transmission, sound absorption impact noise and rainfall noise of building elements. In the case of impact noise, the structural excitation distributed over a small area of the structure is decomposed into an infinite number of propagating normal stress waves. The velocity field on top and bottom interface, evaluated in the wave number domain, allows calculating the radiated acoustic intensity leading to the impact noise. The impact noise reduction ΔL of the floating floor is then deduced from the impact noise level of the base floor calculated with and without the floating floor.

The excitation force associated to the tapping machine can be estimated relatively well, as explained in reference [2] as a function of the mass and the impact velocity of the hammer, the input mobility of the structure studied and the impact frequency of the tapping machine. Note that the excitation force depends on the input mobility of the system and must be calculated for each system

Resilient layer characteristics

The dynamic stiffness of the resilient layer is evaluated from a mass-spring resonance frequency, following the standard ISO 9052-1 [3]. The loading mass required in the standard is of 8 kg for samples of dimensions 200x200 mm^2 (i.e. a density per unit area of 20 $\mathrm{kg/m}^2$, corresponding to about 10 cm of concrete). In most cases, it is not representative of the considered floating system; therefore, a mass close to the actual load represented by the floating floor is preferred and is implemented for this characterization. Furthermore, if glue is used in the floating floor system, the dynamic stiffness of the resilient layer is also measured with the same glue. This dynamic compressional stiffness measurement allows deducing the elastic modulus of the resilient layer considered (for a schematic of the experimental setup see Figure 1(a)). Indeed, for impact noise prediction, the key parameter is the dynamic (compressional) stiffness of the elastic layer; however for thin and obviously not isotropic layers, the shear modulus appears to be as well an important parameter. Therefore, a new experimental setup was developed to measure the shear stiffness of the resilient layer (see Figure 1(b)) and deduce the shear modulus. In CASC software, it is possible to introduce independently both the elastic and the shear modulus of a material.

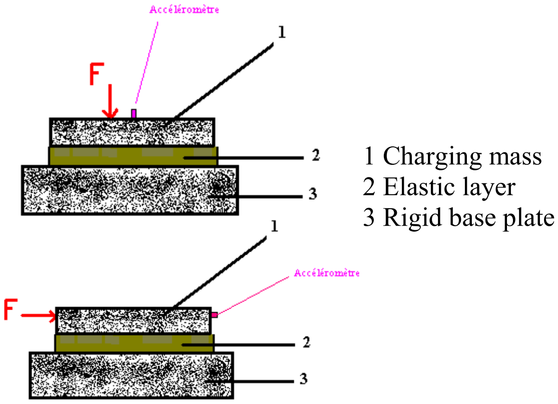

Figure 1: Experimental setup for the measurement of (a) the compressional stiffness and (b) the shear stiffness.

Impact noise predictions

In this section, the performance of multilayered systems in terms of impact noise is studied both experimentally and analytically.

Concrete floating floor

Systems composed of a concrete floating floor separated from a heavy concrete base floor by an elastic interlayer are first considered. A large number of resilient layers can be found: made of different material (cellular or not, porous or not…), and of different thickness (from a few millimetres up to a few centimetres). The reduction of impact sound level of the floating floor ΔL is calculated using the wave approach applied to this multilayered system and the measured characteristics for the resilient layer.

Figure 2 presents the impact noise reduction ΔL in the case of thick resilient layers. The first system corresponds to a 14 cm concrete base floor separated from a 4 cm concrete floating floor by a 15 mm elastic layer made of dense mineral wool (density 70 $\mathrm{kg/m}^3$); the second system to a 20 cm concrete base floor separated from a 6 cm concrete floating floor by a 70 mm polystyrene layer (density

24 kg/m^3). The impact noise reduction ΔL of these floating floors was measured according to standard ISO 140-8 and calculated using the CASC software. The dynamic characteristics of the two resilient layers (compressional stiffness and loss factor, as well as the air flow resistivity for the porous material) were experimentally estimated; only the elastic modulus characteristic was used in the predictions. The predicted and measured results compare well, at least in the low frequency region, leading to the same single value performance ΔL_w = 29 dB for the 15 mm mineral wool based multilayered system, and 16 dB for the 70 mm polystyrene based one.

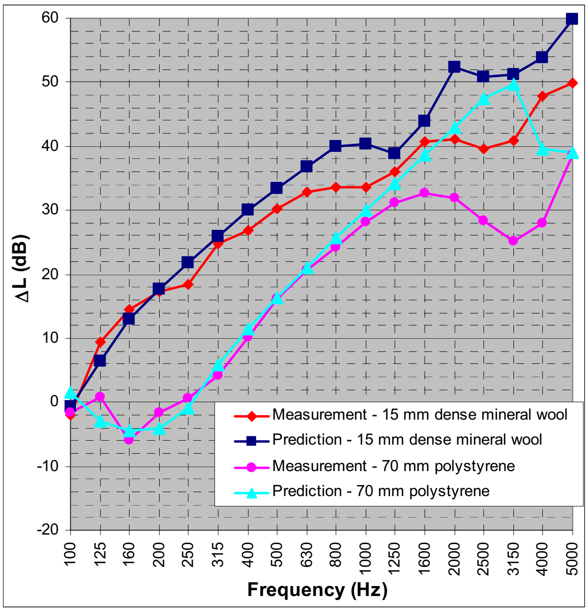

Figure 2: Measured and calculated impact noise reduction ΔL of a concrete floating floor system.

Figure 3 presents the impact noise reduction ΔL in the case of a thin resilient layer. The system corresponds to a 14 cm concrete base floor separated from a 4 cm concrete floating floor by a 3.5 mm non porous elastic layer made of polyethylene. The impact noise reduction ΔL of the floating floor was again measured according to the standard and predicted using the CASC software when considering the elastic layer characterized either (i) by its compressional stiffness only; or (ii) by both its compressional and shear stiffness measured separately using the two methods mentioned previously. Measured and calculated spectra ΔL compare much better when the interlayer is characterized by both its compressional and shear stiffness, leading to a calculated single value performance ΔL_w 1dB higher than the measured one; using only the measured compressional stiffness, the calculated reduction ΔL_w would be 3 dB higher than the measured one.

Wood flooring

System composed of oak floorboards (10 mm in thickness) combined with the fibrous resilient layer (2.5 mm in thickness) is investigated for two types of glue. The predicted results are based on the measured characteristic for the different system components. The predicted results under evaluate the impact noise performance compared to measured results (see Figure 4). In general for glued wood floaring, comparisons between prediction and measurement demonstrate the difficulty associated with the characterization of resilient layer implemented with glue. Indeed, depending on the migration of the glue within the resilient layer, the dynamic stiffness varies and thus the impact noise performance changes. However, the prediction model usually provides correct ΔL_w variations associated to a component change of the system, when compared to measurements. The change of glue type for the system composed of oak floorboards on the fibrous resilient layer yields a predicted and measured ΔL_w variation of 4 dB.

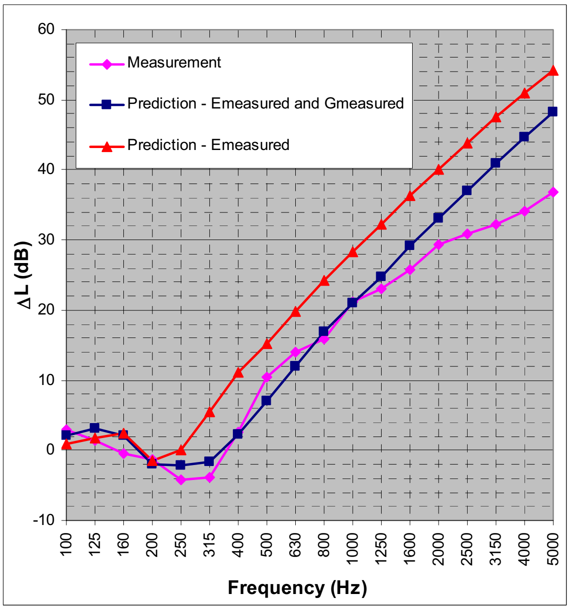

Figure 3: Measured and calculated impact noise reduction ΔL for thin resilient layer.

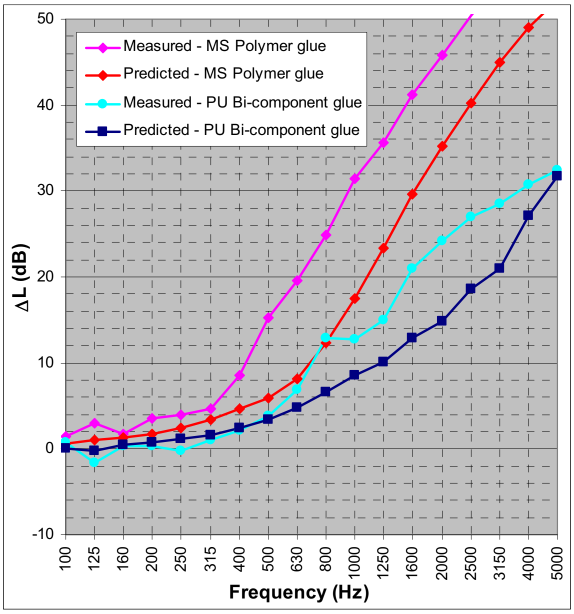

Figure 4: Measured and calculated impact noise reduction ΔL for wood flooring.

References

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