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Improvement of impact sound insulation: A constitutive model for floating floors

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ABSTRACT

Floating floors have a high potential for reducing disturbance by impact noises in dwellings, since it greatly reduces the vibrations transmission through structures. The acoustical performance of a floating floor is quantified in terms of improvement of impact sound insulation ΔL. The improvement of impact sound insulation of a floating floor is a key parameter for the calculation of structure-borne sound insulation in buildings. Indeed, once ΔL is known, it is possible to evaluate the impact sound insulation, in *in situ* conditions, for several base floors of different building technologies and materials. ΔL can be directly determined on the basis of standard laboratory measurements, but it can be also estimated from elastic and inertial properties of involved materials, such as stiffness and mass. In this paper a constitutive model for the estimation of floating floors improvement of impact sound insulation is presented. As it will be shown, the constitutive model proposed based on force transmissibility theory, allows to accurately estimate the acoustical behavior of a floating floor, as a function of frequency, with a simple single function. Theoretical assumptions, experimental evidences and comparisons with previous computational models (e.g., Cremer-Vér model) allow to confirm both validity and effectiveness of the proposed model.

1. Introduction

Sound insulation in buildings is a fundamental requirement for *comfort* and *privacy* in dwellings. Moreover, in many countries worldwide, laws, regulations and directives state limits for airborne and structure-borne sound insulation, as well as façade insulation and equipments noise, for both newly developed buildings and existing buildings (renovation); acoustical classifications, similarly to thermal classification, are also proposed [1–3]. Acoustical properties of building elements, such as walls, floors, windows and involved materials are measured in laboratory, accordingly to current Standards (e.g., ISO 10140 series) or estimated on the basis of several computational models (e.g., EN 12354 series). Acoustical performances can be evaluated as a function of different conditions of installation and, nowadays, commercial *software* for predicting building acoustics performances is in a way available. Analytical derivation of these computational models, based on Rayleigh's theory [4], were developed in last century in particular by Cremer [5], Beranek [6], and Fahy [7].

This paper is focused on the calculation model for improvement of impact sound insulation ΔL of floating floors. As it is well-known, Cremer-Vér calculation model allows to evaluate the acoustical behavior of a floating floor as a straight line, with a slope of 30 dB (or 40 dB) per decade of frequency (in one-third octave band), starting from the resonance frequency of the analogous mass-spring system. In general terms it can be considered such as "mass-law" behavior, since an improvement of impact sound is only determined for frequencies above the resonance frequency. As observed by Cremer, below the resonance frequency, «the attenuation provided by the layer clearly is very small». As a matter of fact in calculation model, the acoustical behavior around and below the resonance frequency is neglected, or simply assumed as $\Delta L = 0$.

An alternative approach for the calculation of the improvement of impact sound insulation of floating floors, based on force transmissibility theory [8], is presented. The proposed constitutive model, considered as an extension of Cremer-Vér model, allows to accurately evaluate the actual insulation effectiveness of a floating floor, as a function of frequency, by means of a single analytical function. In particular the acoustical behavior in the low frequency range is properly achieved.

Measurements of improvement of impact sound insulation, performed in standard laboratory, are modelled with Cremer-Vér model and with the transmissibility model and comparisons are commented.

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2. Floating floor technology

A floating floor consists of a floating slab (usually a sand-cement screed) decoupled from the base floor by means of a continuous resilient layer. In general terms it can be represented as a mass-spring-dampener system on a inertial support base, in which the mass is the floating slab and the spring (and dampener) is the continuous resilient layer. In Fig. 1 a typical example of a floating floor system and the related mechanical model is schematically depicted. It is supposed that the floating slab is uncoupled from lateral walls. Reduction of impact sound pressure level can be empirically estimated on the basis of elastic and inertial properties of involved materials. In particular if elastic (and damping) properties of the resilient layer are accurately determined and the mass per unit area of the floating slab is known, the improvement of impact sound insulation of a floating floor can be obtained.

3. Empirical models: Theoretical background

Improvement of impact sound insulation of a floating floor ΔL, defined by Gösele in 1949 [9], is the difference between the sound pressure level, L_{n0}, produced in the receiving room due to the impacts on the supporting bare floor, and the corresponding sound pressure level L_n, due to the similar impact on the floating floor, i.e. $\Delta L = L_{n0} - L_n$, as currently used in scientific literature and technical standards. The empirical model for predicting improvement in impact sound insulation ΔL of floating floors derived by Cremer in 1952 [10], is based on the theory of parallel plates continuously coupled by elastic interlayer [5] and, in the present day, is collected in EN 12354-2 Standard [11]. On the other hand, due to the mechanical properties of the mass-spring-dampener system (i.e. the floating floor), the motion of the mass induced by an input force (i.e. the vibration generated by impacts) and transmitted to the base floor by means of a continuous elastic interlayer, can be empirically modelled in terms of force (or velocity) transmissibility.

3.1. Cremer-Vér model

The fundamental Cremer's result, without going into details of analytical demonstration, shows that the improvement of impact sound insulation of a floating floor is provided by the following «surprisingly simple» relation for the «locally reacting» floating floors, i.e. where the slab is highly damped or is infinite:

$$\Delta L = 40\log\left(\frac{f}{f_0}\right)\ \mathrm{dB} \tag{1}$$

in which the resonance frequency f_0 of the floating floor only depends on the inertial and elastic properties of the floating slab and resilient layer, as follows:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{s'}{m'}}\ \mathrm{Hz} \tag{2}$$

where s' ($\mathrm{N{\cdot}m^{-3}}$) is the dynamic stiffness of the resilient layer and m' ($\mathrm{kg{\cdot}m^{-2}}$) is the actual mass per unit area of the floating slab.

Over the years, as recently summarized by Hopkins [12], Cremer's model has been further investigated and refined, in particular by Vér [13,14], and several experimental works, up to the present day, allowed to verify its robustness and effectiveness [15–19]. For many floating floors, relation (1) tends to overestimate ΔL and the frequency dependence is better described by the following relation for the floors, where the floating slab is «resonantly reacting»:

$$\Delta L = 30\log\left(\frac{f}{f_0}\right)\ \mathrm{dB} \tag{3}$$

As shown by Cremer for frequencies above the resonance, in a floating floor atop a base structural floor, ΔL is independent both of the flexural stiffness and mass of the base floor and is also independent of the flexural stiffness of the floating slab: the improvement of impact sound pressure level insulation ΔL can be determined «without knowing anything about the radiation process and the acoustical properties of the receiving room». Previous assumptions allow to confirm that attenuation of the transmitted noise, generated by the vibration velocity field in the structural floor, only depends on the mechanical properties of the resilient layer and on the mass of the floating slab. On the other hand, for frequencies below the resonance (in particular at the limit for $f \to 0$), the occurring bending wave is characterized by the sum of the masses and the sum of the bending stiffnesses of the floating slab and the base floor; the spatial distribution of the displacements (in terms of modulus and phase) of the two plates are the same, and the resilient layer acts as if it is infinitely stiff [5].

3.2. Transmissibility model

On the basis of the above-described boundary conditions, improvement of impact sound insulation of a floating floor can be accurately modelled in terms of force (or motion) transmissibil-

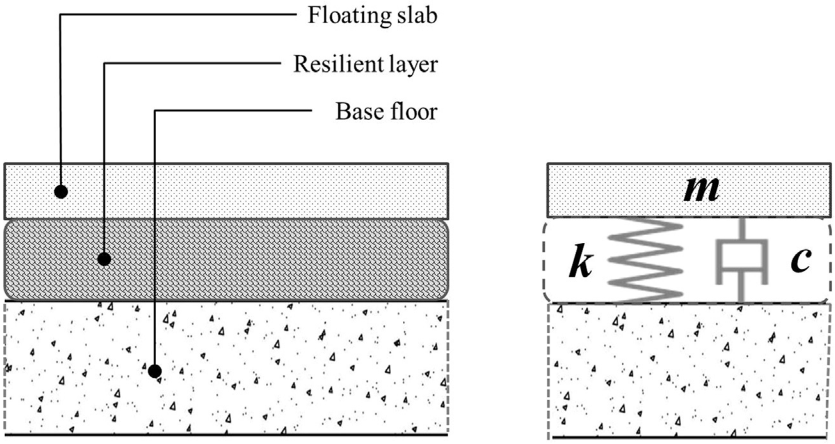

Fig. 1. Section of a floating floor built on a concrete base floor and the mechanical model, in which resilient layer is defined by its stiffness (spring of elastic constant k) and damping (dampener of dissipative constant c) and the floating slab by its inertia (mass m).