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ACOUSTIC RADIATION OF MULTILAYERED STRUCTURES EXCITED BY IMPACT NOISE

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INTRODUCTION

The CASC (Calcul Acoustique des Structures en Couches) software was initialy developed at CSTB, in order to predict the acoustic behaviour of plane multilayered structures. The software allows the modelling of porous media using Biot theory[1], isotropic[2] or orthotropic[3] solids, and fluid layers, with or without contact between layers. As sereval equivalent models[4], the absorption coefficient as well as the sound reduction index can be calculated for single or random incident plane waves. Although this kind of approach sometimes seems to be far from realistic, compared with numerical methods, it provides many advantages such as short calculation time or capacity of modelling complex structures (number of layers, thickness of layers, interface conditions ...). Moreover, it is very well suited for sensitivity analysis, even at low frequencies where average tendancies are not masked by modal phenomena.

For the same reasons, the use of such a powerful approach is also interesting for the prediction of impact (footsteps) noise. This major acoustic problem in buildings involves most of the time a hard covering (plastic, ceramic, wood) associated with a soft material (cork, polymer foam, mineral fiber) put on concrete or lightweight floors. Standardized measurements are performed using a tapping machine and the associated radiated power is characterized by the normalized impact noise level (EN-ISO 140-6) :

$$L_n = L_p - 10\log\frac{10}{A} \quad (1)$$

where A is the total absorption area of the receiving room.

This quantity characterizes the acoustic power radiated by the floor, excited by the impact of a 500 g rigid mass (the hammer), falling with a known velocity (1 m/s), five times per second.

In order to calculate this impact noise, the classical plane wave approach had to be modified to include point force loading, and to calculate the spectral characteristics of the impact. In this paper it will be shown that these two modifications can be deduced from the response of the multilayered structure to given wavenumbers. The impact noise can then be analyzed in terms of impact force attenuation and/or radiated power.
The modified software is applied to the case of a floating wooden parquet, put on a concrete floor.

RADIATION OF AN INFINITE MULTILAYERED PLATE EXCITED BY A POINT FORCE

Let us consider the two dimensionnal problem described on figure 1.
The behaviour of a multilayered structure excited by a given plane wave- which trace over the structure shows a wavenumber *k*- may be written, using a multipole approach as the following relationship between pressures and velocities on both sides:

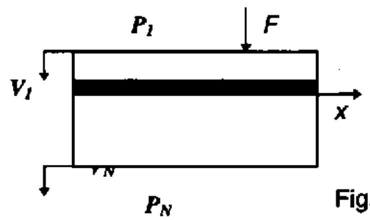

Fig.1

$$\begin{bmatrix} P_1(k) \\ V_1(k) \end{bmatrix} = \begin{bmatrix} Q_{11}(k) & Q_{12}(k) \\ Q_{21}(k) & Q_{22}(k) \end{bmatrix} \begin{bmatrix} P_N(k) \\ V_N(k) \end{bmatrix} \tag{2}$$

where P_i and V_i are respectively the amplitude of the total pressure and velocity on interface i (i=1 for the source (top) side, and i=N for the receiving side), and **Q** is the quadripolar matrix obtained after elimination of internal unknowns.
Equation (2) is solved by introducing a free field radiation condition at the receiving side:

$$P_N(k) = \frac{\omega\rho}{\sqrt{\left(\frac{\omega}{c}\right)^2 - k^2}} V_N(k) \tag{3}$$

The radiated power may then be calculated, from the receiving side velocity as:

$$\Pi(k) = \mathrm{Re}\{P_N(k)V_N^*(k)\} = \mathrm{Re}\left\{\frac{\omega\rho}{\sqrt{\left(\frac{\omega}{c}\right)^2 - k^2}}\right\}|V_N(k)|^2 \tag{4}$$

In our case, the structure is not acoustically excited but point driven. Any spatially distributed loading can be decomposed into waves through a spatial Fourier Transform (FT). Thus, the FT of a point force F, at x=0, is :

$$\mathrm{FT}\{F\delta(x)\} = P_1(k) = F \tag{5}$$

Introducing (5) -and again (3)- into (2), leads to the Fourier Transform of the velocities on both sides of the multilayered structure.
Real space velocities at any point of the structure may be obtained by Inverse Fourier Transform. For example, the velocity at the loading point is:

$$v_1(0) = \int_{-\infty}^{+\infty} V_1(k)dk \qquad (6)$$

Note that all velocity components from -∞ to +∞ are needed to calculate the real space velocity. Fortunately, power calculation are simpler; according to Parseval's theorem, the radiated acoustic power can be written :

$$W = \int_{-\infty}^{+\infty} p_N(x)v_N(x)dx = \int_{0}^{+\infty} \mathrm{Re}\{P_N(k)V_N^*(k)\}dk = \int_{0}^{\omega/c} \Pi(k)dk \qquad (7)$$

Equation (7) shows that a single integration of the spectral components of the power (4) for propagative wavenumbers ($k<\omega /c$) leads to the overall radiated power.
Figure 2 shows sound power levels produced by a concrete floor (160 mm thick) excited by a normalized point force, with and without floating parquet. One may notice two peaks of radiation; one at the critical frequency of the concrete floor, and the other at the resonance frequency of the floating parquet. At this frequency, for the same input force, the parquet brings an increase of the power radiated. At higher frequencies, the covering reduces the floor vibration and radiation.

IMPACT FORCE SPECTRUM

In the previous section, a given input force is considered as plate excitation. In fact, an impact results from an interaction between the hammer and the top layer. As any contact problem, this interaction is highly non-linear, due to contact area, material local response etc. Anyway, accurate calculation can be performed using a simplified expression -proposed by Cremer [5]- for the force spectrum :

$$F = F_0\left(\frac{Y_M}{Y_M + Y_1(0)}\right) \qquad (8)$$

where $Y_M = \dfrac{1}{j\omega M}$ is the hammer mobility,

$Y_1(0)$ is the multilayered structure mobility at the contact point,

and F_0 is the amplitude of the ideal impact force spectrum (white noise).

The force spectrum appears to be mainly related to the input mobility of the structure. This mobility can be calculated as the velocity response of the structure at the excitation point and for a unity input force. As shown by expression (6), the calculation involves an infinite integration. This difficulty is avoided by replacing the point force by a constant pressure over the section of the hammer; this is equivalent to a low pass filtering in the wavenumber space, insuring numerical convergence.

Figure 3 shows the modification of input force spectrum brought by the floor covering. The force spectrum is lower at any frequency, due to a structure mobility increase.

IMPACT NOISE LEVEL-CONCLUSIONS

The impact noise level of the floor with and without covering, is obtained by combinating the results presented figures 2 and 3. The comparison of the calculated 1/3 octave impact noise reduction with laboratory measurements is well satisfactory; main tendancies are fully described over the whole frequency range.

More than a calculation method, the proposed approach is a good analysis tool because it makes the difference between shock absorption, and structure response and radiation. Its application field is wide, due to the multiple possibilities of the basic model used. Moreover, it applies to any hammer-like shock over a plane surface, i.e. to many industrial problems.

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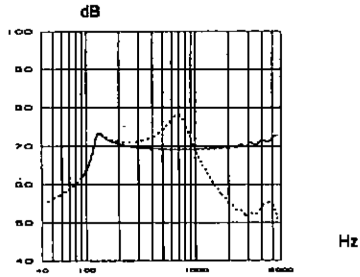

Fig. 2 : Radiated sound power level for a normalized point force

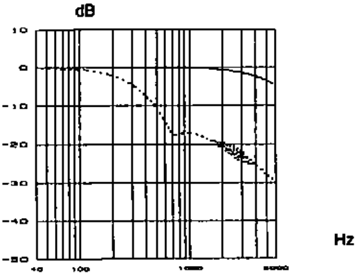

Fig. 3 : Force spectrum of the impact

——— concrete floor ·········· concrete floor +floating parquet