Prediction method for structure borne noise generated in buildings by tools such as drills

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Tools such as drills generate structure borne noise which propagates in the building structure and radiates loud noise even in rooms far from the source. This paper presents a method for predicting this type of noise, frequent in buildings under construction or renovation. First the structural power injected by the tool to the receiving structure (floors or walls) is estimated from field measurements of the vibrational (bending) energy stored in the receiving plate. Then the vibration propagation through the building structures and the noise radiated in the receiving room is estimated using Statistical Energy Analysis (SEA), where both bending and in plane waves are taken into account. Comparisons between predictions and results measured in an apartment building under construction show that SEA gives quite acceptable results down to 1/3 octave 50 Hz for structure borne sound sources such as drills.

1 Introduction

Different types of working tools, such as drills or jack hammers are used in building construction sites. They are often used in rooms made of bare concrete walls and floors with several openings (for future windows and doors) and smaller holes (for future waste water pipes, ventilation pipes or general plumbing). This paper shows how these tools can be characterized in the field on a power basis both in terms of airborne sound source and structure borne sound source. Section 2 describes the simplified source characterization procedures used and section 3 gives some typical results in the very common case of a jack hammer. The last section shows how the two measured powers can be used in a SEA approach (Statistical Energy Analysis) to predict noise inside the building under construction (in order to predict the noise exposure of construction workers) as well as noise outside (in order to predict the corresponding outdoor environmental noise).

2 Source characterization procedure

2.1 Airborne sound

In spite of the several openings (mainly for windows and floors) in the rooms tested, the sound fields are usually rather homogeneous and the source airborne sound power level L_{Wa} (ref. 10^{-12} Watt) can be estimated from the spatially averaged sound level L_{pa} (ref. 2 10^{-5} Pa) measured in the room and the room equivalent absorption area A according to the classical building acoustics equation:

$$L_{Wa} = L_{pa} - 6 + 10 \lg A \quad (1)$$

L_{pa} means "airborne sound level" (as opposed to re-radiated structure borne sound level L_{ps}; see section 2.2). A can be estimated from the different wall, floor and opening surfaces S_i and their absorption coefficients α_i :

$$A = \Sigma\, \alpha_i \,.\, S_i \quad (2)$$

2.2 Structure borne sound

Injected structural power

The structure borne sound power level L_{Ws} (ref. 10^{-12} Watt) injected to the receiving plate (on which the tool is working) can also be estimated on a power basis from the vibrational (bending) energy stored in the plate and its loss factor η according to the classical SEA equation:

$$L_{Ws} = L_v + 10 \lg (\eta.2\pi f.mS) - 26 \quad (3)$$

L_v (ref. 5 10^{-8} m/s) is the spatially averaged vibration velocity level of the receiving plate, m its mass per unit area and S its surface area.

It should be noted that the above power not only depends on the source, but also on the receiving structure. With the simple assumption of a force source (because of the percussive aspect of the sources considered) acting on an infinite plate (for simplification), the power L_{Ws2} injected by the source to any other receiving structure (wall or floor) can then be estimated from the initial measured power L_{Ws1} according to:

$$L_{Ws2} \sim L_{Ws1} + 10 \lg (Y_{\infty 1}/Y_{\infty 2}) \quad (4)$$

Y_∞ is the characteristic mobility of the receiving structure considered, estimated from the input mobility of the corresponding infinite plate according to:

$$Y_\infty = 1/8\sqrt{mB} \quad (5)$$

B is the plate bending stiffness.

Re-radiated structure borne sound

The averaged sound level measured in the room is composed of L_{pa} , directly radiated by the source and L_{ps} , re-radiated by the vibrating receiving plate (considered as the dominant structural source); the sound power level L_{Was} radiated by the receiving plate can be estimated from the plate spatially averaged vibration velocity level L_v according to the classical SEA equation:

$$L_{Was} = L_v + 10 \lg (S.\sigma) \quad (6)$$

σ is the plate radiation efficiency.

Combining Eq.(3) and (6) leads to the sound power level L_{Was} radiated by the receiving plate and expressed from the injected power L_{Ws} of the source:

$$L_{Was} = L_{Ws} + 10 \lg \sigma - 10 \lg (\eta.2\pi f) + 26 \quad (7)$$

The structure borne sound level L_{ps} re-radiated in the room is then calculated using:

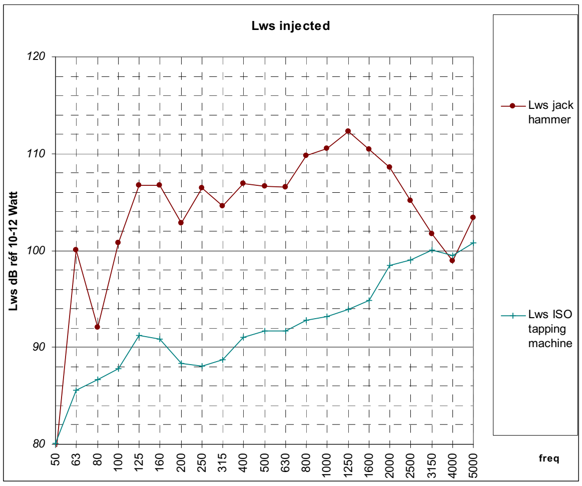
$$L_{ps} = L_{Was} + 6 - 10 \lg A \quad (8)$$

The airborne sound level L_{pa} (and the corresponding sound power L_{Wa}) can finally be obtained by energetically subtracting L_{ps} from the (total) sound level measured in the room.

3 Source characterization results: example of a jack hammer

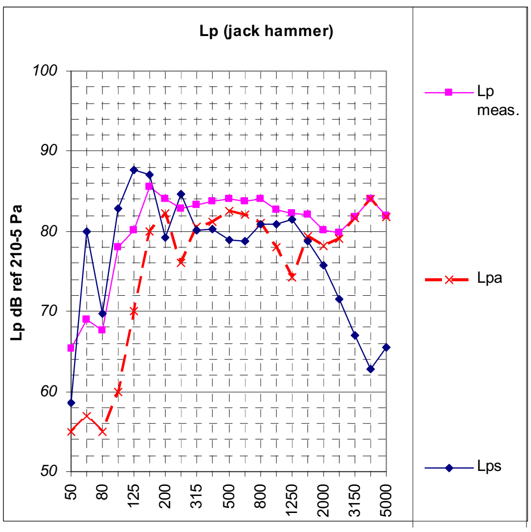
This section presents the main results obtained for a pneumatically powered jack hammer characterized with the procedures described in the above section.

The structural power injected to a 20 cm concrete floor by the jack hammer is shown in Fig.1; this power has been estimated using Eq.(3) from the measured averaged vibration velocity of the floor and an estimation of its loss factor (from the CSTB field data bank). The power obtained is compared to the power that would be injected to the same plate by the ISO tapping machine; it can be seen that over a large frequency range, the jack hammer produces levels about 15 dB higher than the tapping machine.



.Fig.1 Structural power injected to a 20 cm concrete floor by the jack hammer tested

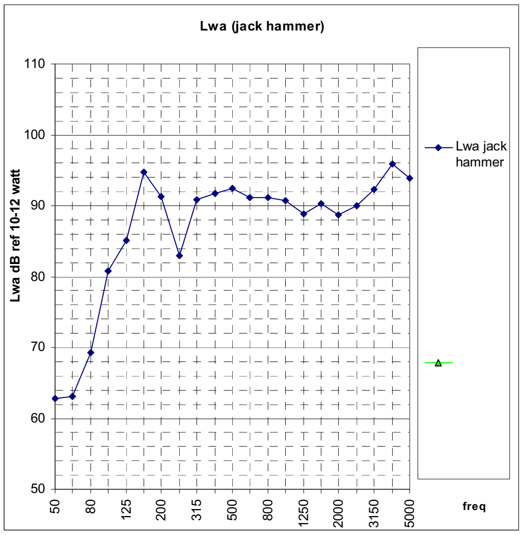
From this structural power, the sound pressure level L_{ps}, re-radiated by the floor can be estimated using Eq.(7) and (8), and subtracted from the (total) sound pressure level measured in the room in order to estimate L_{pa} ; these three sound pressure levels are plotted in Fig.2.



.Fig.2 Sound pressure levels generated in the room by the jack hammer; L_{pa} = 92 dB(A) ; L_{ps} = 86 dB(A)

Fig.2 shows that (i) the structure borne sound is dominant below 200 Hz, comparable to the airborne sound between 200 and 1600 Hz and negligible above 1600 Hz; (ii) the structure borne sound is a few dB overestimated at low frequencies (several results in this study have shown an over estimation of the SEA radiation efficiency at low frequencies, below the critical frequency of the concrete plates considered).

Finally, L_{pa} leads to the source airborne sound power level L_{Wa} (see Fig.3) using Eq.(1).



.Fig.3 Airborne sound power level of the jack hammer; L_{Wa} = 99 dB(A).

4 Structure borne sound transmission

The structure borne sound transmission was field tested in an apartment building under construction; a schematic vertical section of the building is shown in Fig.4. The ISO tapping machine is used as structure borne sound source in order to have a non destructive stationary source.

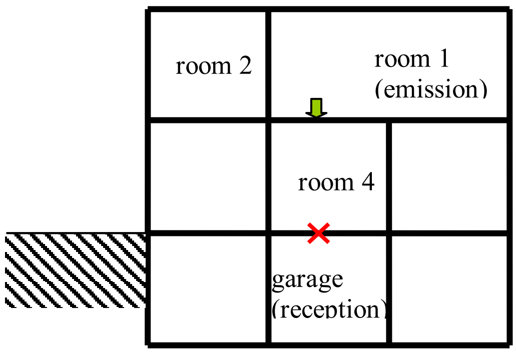
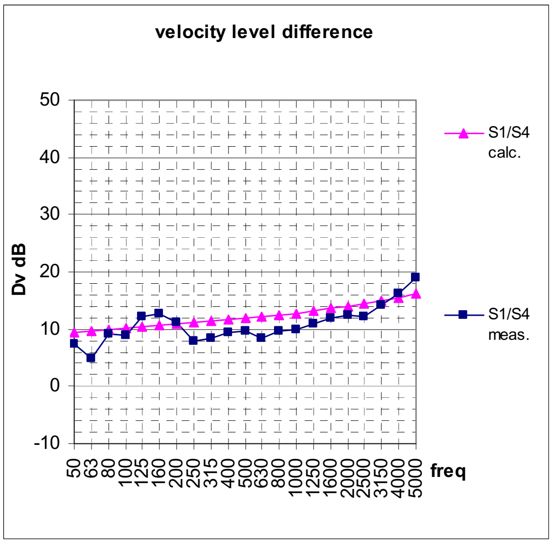
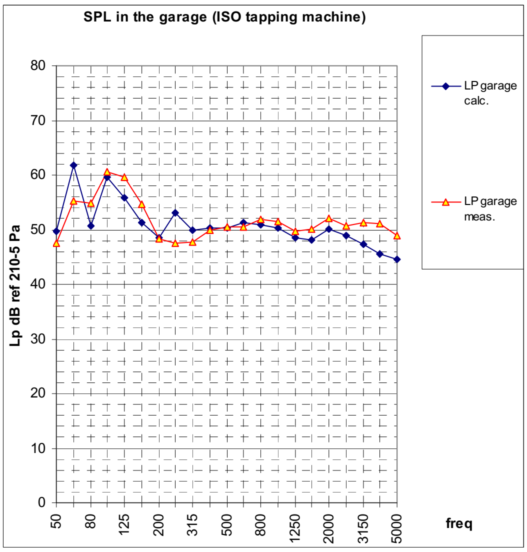


Fig.4 Vertical section of the building tested; the result given in this paper correspond to the floor marked with a red cross.

The results shown in figures 5 and 6 below correspond respectively to the measured velocity level difference between the emission floor and the floor of room 4 and to the resulting structure borne sound pressure level measured (spatially averaged) in the garage; there was no significant airborne transmission path between the emission and the reception rooms.



,Fig.5 Velocity level difference between emission floor and floor of room 4; comparison between calculated and measured results.



,Fig.6 Sound pressure level generated in the garage; comparison between calculated and measured results.

In Fig.5 and 6, the measured results are also compared to results calculated using the SEA approach (home made 4AS software); this software is a classical SEA module (see [1] for example) which takes into account both bending and in plane waves in the energy balance at plate junctions. Plates in contact with ground are set with a particularly high internal loss factor. The structure borne sound re-radiated in rooms is also estimated, calculated from the averaged velocity levels of the walls and floors and an estimation of their radiation efficiency using Eq.(6) and (8). Fig.7 below shows the geometry modeled using the 4AS software (with the different concrete wall and floor thicknesses).

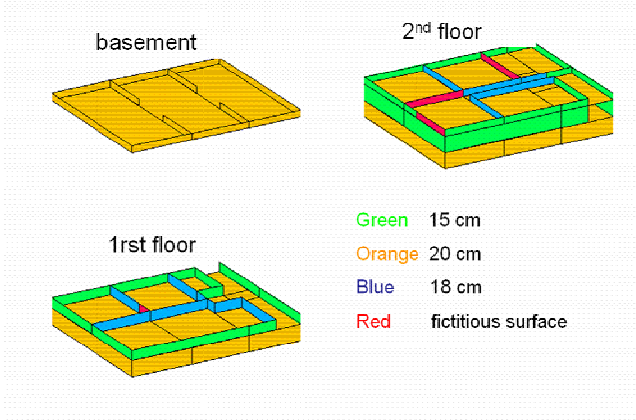


Fig.7 Geometry modeled using the SEA software.

The results given in Fig.5 and 6 show that in the case of bending excitation, SEA gives quite acceptable results, even down to 1/3 octave 50 Hz and both in terms of vibration levels and sound pressure level.

5 Conclusion

The field source characterization procedures shown in this paper, coupled with the SEA approach allows, with an acceptable accuracy down to 50 Hz, the estimation of the structure borne noise produced by tools such as drills or jack hammers and radiated far away from the emission plate.
From this work, the sound power emitted outside the building either directly by a vibrating structure (tool operating on a façade wall for example) or radiated though the openings of the emission room (where the tool is operating) can easily be estimated; using a outdoor sound propagation software, the environmental noise generated outside the building by the tool can then be predicted.

Acknowledgments

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References

[1] R.J.M. Craik, *Sound Transmission Through Buildings Using Statistical Energy Analysis,* Gower, London, 1996