Characterization and vibration isolation of building service equipment

Michel Villot
Center for Building Science and Technology (CSTB), Grenoble France.

Simon Bailhache
Center for Building Science and Technology (CSTB), Grenoble France.

Summary

Work is underway at CEN/TC126/WG7 to propose a simplified method to characterize building service equipment mounted on lightweight receivers (such as timber based lightweight building elements) as structure borne sound source. In this paper, the case of a waste water pipe rigidly fixed to a lightweight building element is presented, and its measured sound levels compared to the ones obtained when mounted on a heavy receiver. Then the WG7 draft method is presented and applied to this waste water pipe system. The result (the installed power) is then used as input data to estimate the structure borne noise radiated, which is compared to the values directly measured.

Moreover, elastic fixing components of known performance on heavy building receivers are then inserted between pipe and lightweight building element and their efficiency measured (insertion gain between acoustic and rigid fixing components) and compared to the original performance on heavy receiver.

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1. Introduction

This paper is focused on structure borne noise from waste water pipes installed on lightweight receiving building structures. The noise generated is different from the case of waste water pipes installed on heavy structures and if acoustic fixing components are used, their performance on lightweight receivers is also different. To quantitatively show such results, laboratory measurements of a waste water pipe installed on a lightweight receiver and following EN 14366 [1] are presented and the results compared to measurements obtained with a similar installation mounted on a heavy (concrete) receiver. In a second part, the structure borne noise is predicted as follows (and compared to the measured noise): (i) the source installed power is estimated from the pipe free velocity and point mobility as well as the receiver point mobility according to a new method developed within CEN/TC126/WG7 and written in draft standard prEN 15657 [2] to be soon submitted for enquiry, (ii) the receiver vibration field is obtained from an “averaged” power balance equation still meaningful for lightweight elements and (iii) the noise generated is estimated from an “averaged” radiation efficiency also still meaningful for lightweight elements.

2. Laboratory measurements

The structure borne noise generated by a waste water pipe mounted on a lightweight receiving building element is measured under laboratory conditions according to EN 14366.

2.1. Test set-up

A schematic drawing of the test set-up is given in Figure 1: a standard PVC waste water pipe of diameter 110mm is fixed on a lightweight receiving building element, which acoustically radiates in a 50m^3 receiving reverberant room. The waste water installation is set-up according to EN 14366, except that the pipe does not go through the upper and lower concrete floors present in the standard configuration and absent here. A water flow of 2l/s is used. The two fixing components can be either rigid or “acoustic”. The receiving lightweight building element is made of single OSB panels screwed on standard timber wall studs; the configuration measured is rather extreme (pipe freer than usual mounted on a very light receiver) and probably leads to the worst noise levels possible.

2.2. Results for basic fixing components

The results are presented in Figure 2 in terms of normalized structure borne sound pressure levels measured in the receiving room and compared to the sound levels obtained with a similar installation connected to a heavy (10cm concrete) receiver. The sound level generated by the lightweight receiver is more than 10 dB higher over the whole frequency range.

2.3. Results for acoustic fixing components

The results are presented in Figure 3 as insertion gains in terms of sound levels in the room between the “acoustic” and the basic fixing components; the two cases of lightweight and heavy receivers are given. The performances of the “acoustic” fixing components are similar and rather small at low frequencies but different at mid frequencies: higher for the heavy receiver and still small for the lightweight receiver.

3. Prediction

The prediction is made through the 3 steps presented in the introduction.

3.1. Installed power

The method presented in prEN 15657 allows predicting the structure-borne sound power level of any equipment installed on any receiver (heavyweight or lightweight). The calculation is made according to equation 1, where Y_{Req} is the receiver equivalent mobility, Y_{Seq} is the source equivalent mobility and L_{veq} is the source equivalent free velocity level. This equation is expressed in dB, using the reference values of 10^{-12} W for power and 10^{-9} m/s for velocity.

$$L_{Winst} = 10\log\left[\frac{Re\{Y_{Req}\}}{|Y_{Seq}|^2+|Y_{Req}|^2}\right] + L_{veq} - 60 \qquad (1)$$

Equivalent mobilities are defined as point mobilities averaged over the contacts. Point mobilities were measured using an impact hammer according to ISO 7626-5 [3], the source being disconnected from the receiver; measurements were performed directly in third octave bands, as allowed by prEN 15657. Results for the waste water pipe and the lightweight receiver are shown in Figure 4. The real part of the receiver mobility showed negative values above 2000Hz, physically incorrect, not represented on the graph and probably explained by a low signal-to-noise ratio. The power predictions have thus been limited to the range 50-2000 Hz.

The source equivalent free velocity is defined as the energetic sum of the free velocities at the contact points, the source being disconnected from the receiver and otherwise operated under normal conditions. Direct velocity measurements were performed in third octave bands according to ISO 9611. Results for a water flow rate of 2 l/s are shown in Figure 5 and compared to results measured on the same installation mounted on a heavy receiver according to EN 14366. Lower levels are obtained for the latter, the pipe being more tightly held by the upper and lower floors present in the standard configuration and absent here.

The installed power obtained using equation 1 is shown in Figure 6 and compared to the power predicted in the case of a similar installation mounted on a heavy receiver: the levels are at least 10 dB higher.

3.2. Receiver vibration field

For heavy and homogeneous building elements, the power balance equation can be used to determine the receiver spatial average velocity.

$$W_{inst} = 2\pi f m S \eta \langle v^2 \rangle \tag{2}$$

In equation 2, f is the frequency, m is the mass per unit area of the wall, S is its surface area, and η is its total loss factor.

For lightweight elements, equation 2 can only be applied if vibration fields are diffuse, which can be obtained using a “rain on the roof” excitation and which would lead to the following experimental procedure to estimate an equivalent total loss factor: (i) excite the lightweight element sequentially in several points randomly distributed by a shaker of known (measured) power, (ii) measure the receiver spatial average velocity for each excitation point, (iii) deduce an equivalent total loss factor from equation 2, using the energetic sum of the powers injected at each excitation point and the energetic sum of the corresponding averaged velocities obtained (the total mass mS of the lightweight element can easily be estimated).

This procedure was applied using 4 different, randomly chosen positions and 8 accelerometer positions for each excitation point. Results expressed as the ratio $W_{inst}/S\langle v^2 \rangle$ are presented in Figure 7, the mean value (black curve) leading to the equivalent total loss factor shown in Figure 8. The equivalent loss factor values obtained are relatively low, which seems normal for such a bare single layer element. This experimental equivalent loss factor was then used to estimate the receiver velocity from the injected power using equation 2; results are shown in Figure 9 and compared with the receiver velocity measured using 5 accelerometer positions for one particular location of the pipe. This particular result lies within 2-3 dB from the average velocity, except between 315 Hz and 500 Hz, which might be due to an overestimation of the source mobility.

3.3. Receiver sound radiation

For heavy and homogeneous building elements, the normalized sound pressure level radiated can be estimated according to equations 3 and 4, where W_{rad} is the acoustic power radiated by the building element, ρ is the air density, c is the speed of sound and σ_s the element radiation efficiency under structural excitation; p is the sound pressure and A is the equivalent absorption area of the receiving room.

$$W_{rad} = \rho c \sigma_s S \langle v^2 \rangle \tag{3}$$

$$\langle p^2 \rangle = \frac{4\rho c}{A} W_{rad} \tag{4}$$

Equation 3 and 4 can be combined to estimate the normalized structure borne noise level L_{ns} expressed in dB using the reference values of 2.10^{-5} Pa for the pressure and 10^{-9} m/s for the velocity:

$$L_{ns} = 10 \log \left[\frac{4\rho^2 c^2 \sigma_s}{10} \right] + L_v - 86 \tag{5}$$

For lightweight elements, once again, equation 5 can only be applied if vibration fields are diffuse, which can be obtained using a “rain on the roof” excitation and which would lead to the following experimental procedure (see also [4]) to estimate an equivalent radiation efficiency: (i) excite the lightweight element sequentially in several points randomly distributed by a hammer, (ii) measure the receiver spatial average velocity and the room spatial average sound pressure, (iii) deduce an equivalent radiation efficiency from equation 5.

This procedure was applied here using only the different excitation position of the pipe to estimate the equivalent radiation efficiency of the lightweight receiver. Results are shown in Figure 10, as well as the equivalent radiation efficiency obtained (black curve); two results seemed weird and have not been used to calculate the average spectrum.

This experimental equivalent radiation efficiency was then used to estimate the receiving room normalized sound pressure level from the receiver velocity using equation 5; results are shown in Figure 11 and compared with the room normalized sound pressure level measured according to the ISO standards for one particular location of the pipe. This particular result lies within 3-4 dB from the average predicted spectrum, except again between 315 Hz and 500 Hz. When considering A-weighted levels, the predicted averaged value is of 41 dB(A) and the particular measured value of 44 dB(A).

4. Conclusions

In this paper, laboratory measurements of a waste water pipe according to EN 14366 have shown that the structure borne sound radiated is much higher when installed on a lightweight building element than in the case of a heavy receiver and the performance of "acoustic" fixing components is smaller.

These measurements were an opportunity to successfully check the accuracy of a new method for estimating the installed (structural) power of any service equipment mounted on any receiving building element ; this method has been discussed within CEN/TC126/WG7 and is about to be submitted for enquiry.

The installed power was then used to estimate the receiving building element velocity from which the sound level radiated in a receiving room was deduced. However, since lightweight elements structurally excited only show diffuse vibrational fields in the case of random excitation spatially distributed over the whole element, only an averaged power balance equation can be used, leading to an equivalent total loss factor, and only a averaged radiation equation can be used, leading to an equivalent radiation efficiency. As a result, only a mean velocity response of the receiver and a mean sound pressure radiated can be predicted. The particular velocity response and sound pressure radiated obtained with a particular location of the waste water pipe lye respectively within 2-3 dB from the mean value of the receiver velocity and within 3-4 dB from the mean value of the sound pressure radiated.

Acknowledgement

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References

[1] EN 14366:2004, Laboratory measurement of noise from waste water installations.

[2] prEN 15657, Acoustic properties of building elements and of buildings – Laboratory measurements of airborne and structure borne sound from service equipment.

[3] ISO 7626 series, Vibration and shock – Experimental determination of mechanical mobility.

[4] M. Villot, C. Guigou-Carter, "Measurement methods adapted to wood frame lightweight constructions", Building Acoustics, Volume 13, Number 3, 2006.

Figures

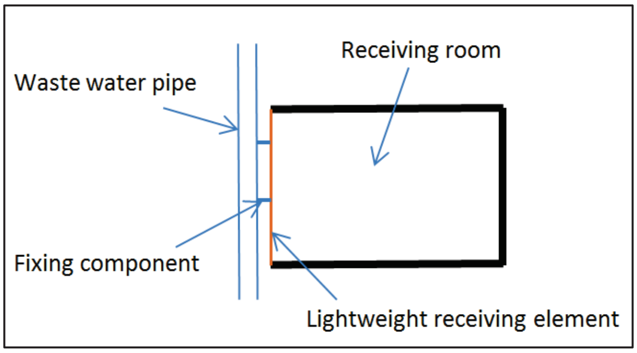

Figure 1: Schematic drawing of the configuration tested

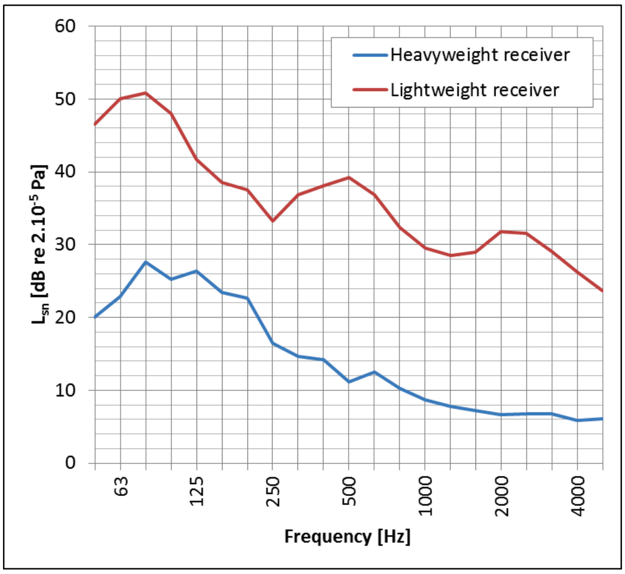

Figure 2: Measured structure-borne sound pressure level (water flow rate of 2 l/s) for different receivers

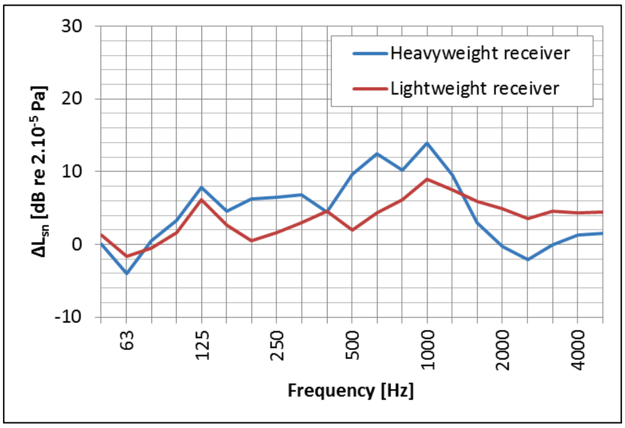

Figure 3: Performance (insertion gain) of the acoustic fixing component for different receivers

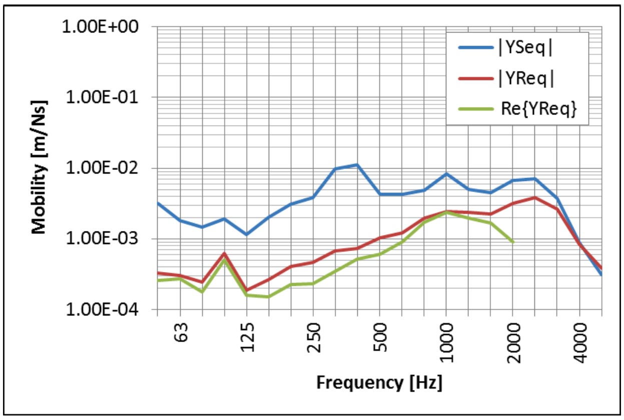

Figure 4: Measured source and receiver mobilities

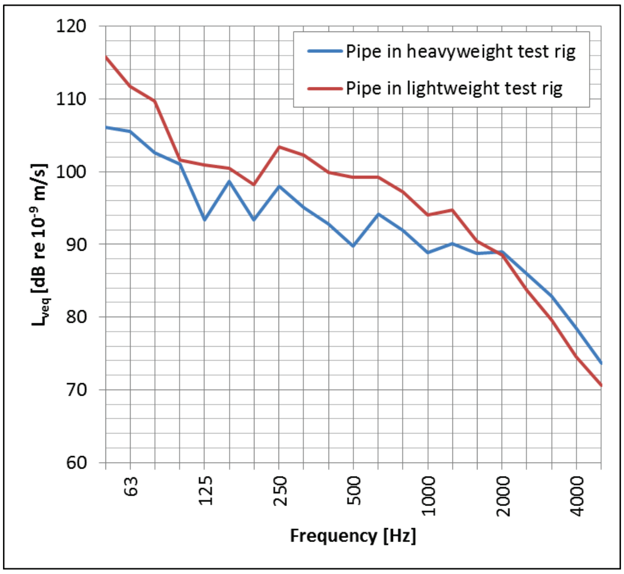

Figure 5: Measured source free velocities

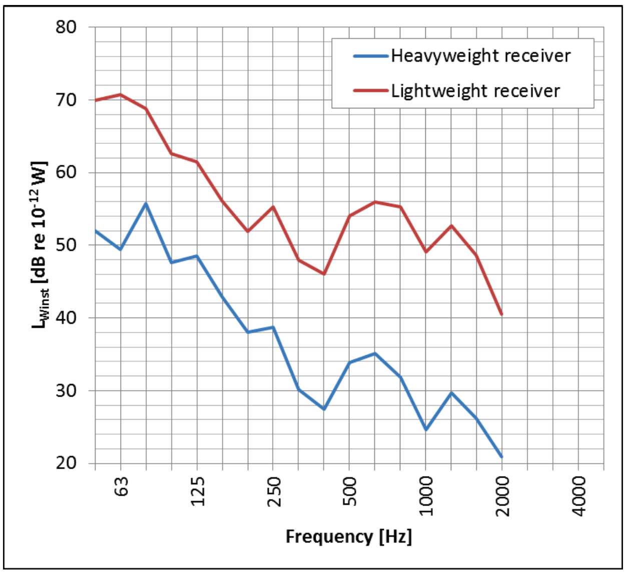

Figure 6: Installed power level (water flow rate of 2 l/s) for different receivers

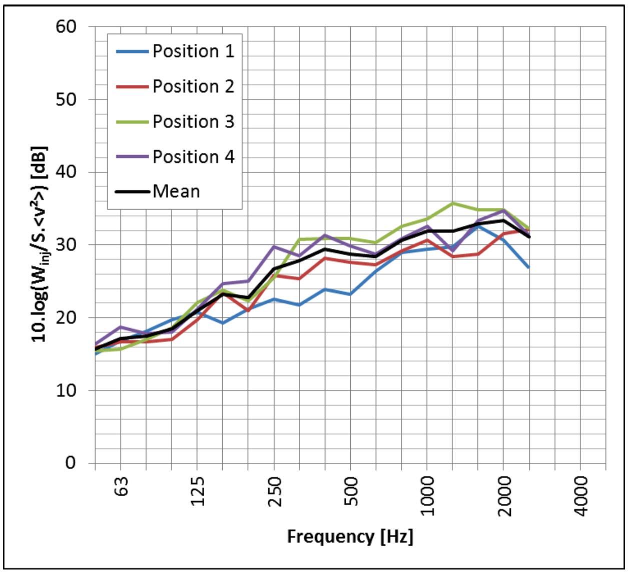

Figure 7: Measured response of the lightweight building element to structural excitation

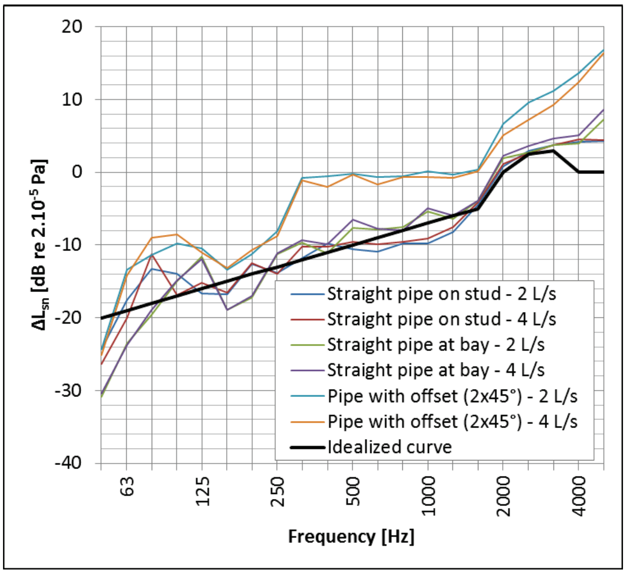

Figure 10: Equivalent radiation efficiency of the receiver (black curve)

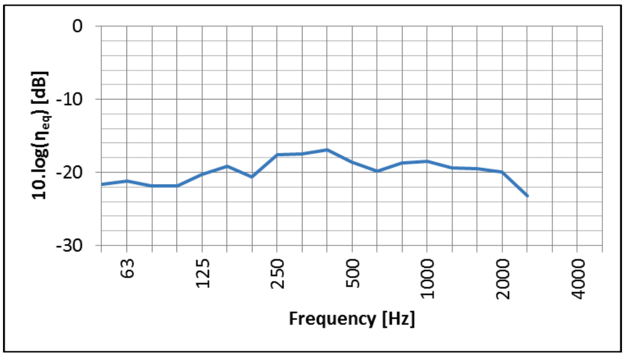

Figure 8: Equivalent total loss factor of the receiver

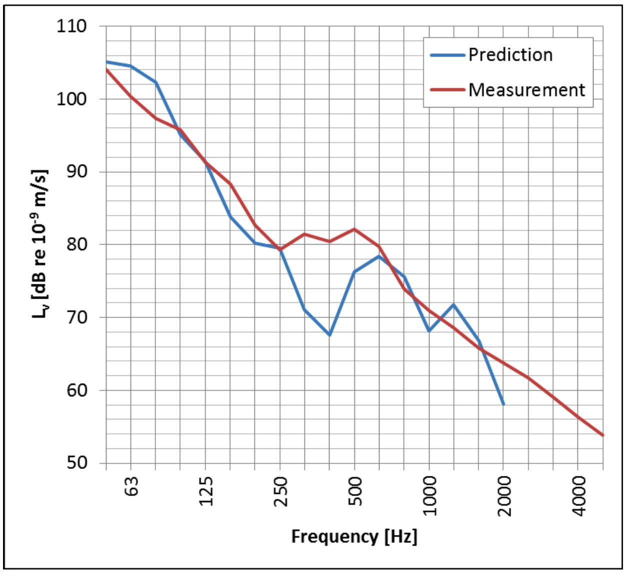

Figure 9: Velocity level of the receiver (water flow rate of 2 l/s)

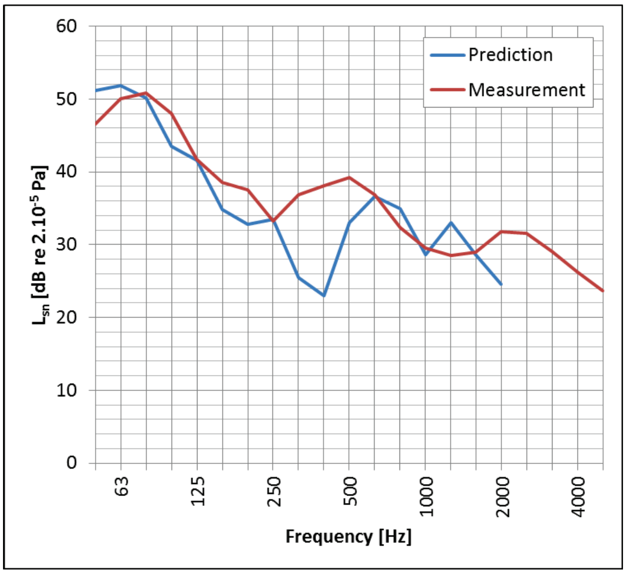

Figure 11: Predicted and measured normalized structure-borne sound pressure levels in the receiving room