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Experimental investigation of a single reception plate method to obtain two source quantities required to predict structure-borne sound transmission in buildings

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Abstract

To predict the structure-borne sound power into lightweight buildings and other structures, two source quantities are required: the mobility and the free velocity or the blocked force. Using the reception plate method (RPM), the average source quantities can be measured. The combination of measurements on a thick and thin reception plate, the so-called two-stage method, allows the determination of all required quantities using the RPM. The paper by Gibbs [1] introduced a proposal that requires only one reception plate for this task. This paper shows an experimental case study using this approach. As reference, the free velocity and the source mobility are determined using measurements on the source approximating free conditions.

Keywords: Building noise control; structure-borne sound sources

1 INTRODUCTION

To obtain the source quantities required for the prediction of machinery noise in buildings EN 15657:2017 [2] describes laboratory measurement methods. For heavyweight buildings, the source mobility is typically much higher than the mobility of the receiving building structure. For this case, the source mobility can be neglected and the required activity of the source (i. e. the free velocity or the blocked force) can be determined on a 'low mobility' reception plate. EN 15657:2017 suggests a concrete plate with a thickness of ≈ 10 cm. In lightweight buildings it is likely that the source mobility is either lower, higher or in the same order of magnitude as the receiver mobility. Hence the source mobility is also required for prediction. The source mobility can be measured directly at the feet of the isolated source (elastically supported or free hanging). Alternatively the two-stage method [3] can be used to determine the source mobility as well as the activity indirectly using a high and a low mobility reception plate.

Gibbs [1] proposed an approach that requires only one reception plate to determine all required quantities. In this paper a preliminary experimental study on the application of this method is presented for two idealised structure-borne sound sources using the heavy reception plate described in EN 15657:2017. A further experiment used the source on a lighter timber plate.

2 THEORY

The theory of this method is introduced in detail in [1]. Therefore only the most important equations and notations are reconsidered in this paper.

Figure 1 indicates the measurement set-up with a source attached to the plate at the contact points, j, about the 'measurement centre', c and several random remote points, i. For each remote point and the measurement centre, the transfer mobility is measured without the source installed to give Y_i^c and with the source installed to give Y_i^{c*}. From these, the ratio, R is determined as follows.

$$R = \frac{Y_i^{c*}}{Y_i^c} \tag{1}$$

Using the measured driving-point mobility at the measurement centre, Y_c^c, the single equivalent source mobility, $Y_{\mathrm{S,eq}}$ can be determined.

$$Y_{\mathrm{S,eq}} = Y_c^c \frac{R}{1-R} \tag{2}$$

With the installed and running source, the velocity at each remote point, v_i^*, is measured, to be able to estimate the single equivalent free velocity, $v_{\mathrm{f,eq}}$, as follows.

$$v_{\mathrm{f,eq}} = \frac{v_i^* \left(Y_{\mathrm{S,eq}} + Y_c^c\right)}{Y_i^c} \tag{3}$$

In the above equations, all quantities are complex. For the conversion into one-third octave bands, magnitudes were considered in this paper.

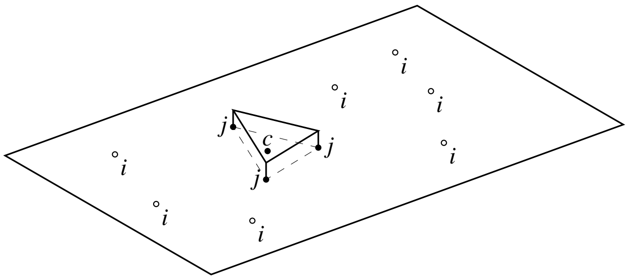


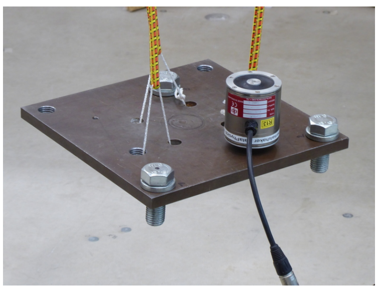
Figure 1. Experimental set-up and notation of positions. The source is attached with its feet, at positions, j, about the 'measurement centre' c. Positions i are random remote measurement positions.

3 DESCRIPTIONS OF SOURCES AND RECEIVER STRUCTURES

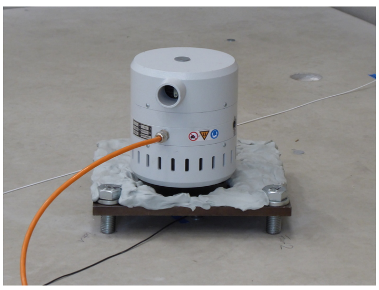
Two idealised structure-borne sound sources and two reception plates were used in the case studies presented in this paper. The sources and receivers are described briefly in the following.

3.1 Sources

For both sources the same quadratic steel plate (308 mm x 308 mm x 15 mm) with three feet, n, was used. Source A, shown in Figure 2a, was equipped with the inertial shaker, Data Physics, IV-40, at a random position within the triangle formed by the three feet. Source B, shown in Figure 2b, was equipped with the inertial shaker, TIRA, S 51125-IN. In addition a layer of Teroson® (≈2 cm) was added to increase mass and damping. In all experiments pink noise was used as signal for both sources.

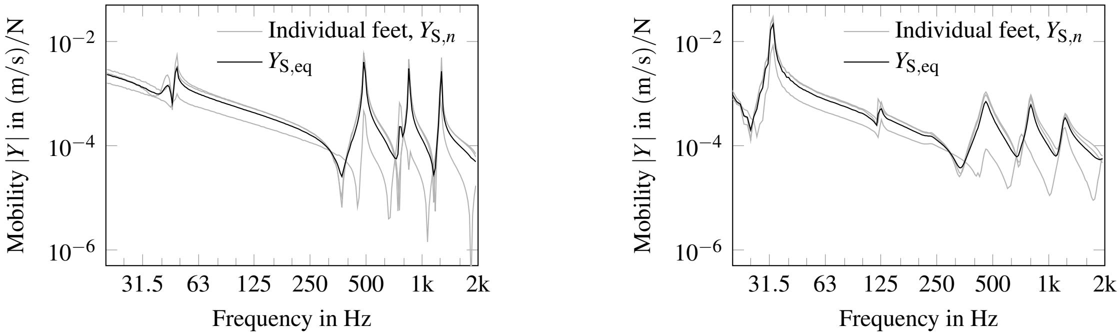


(a) Source A



(b) Source B

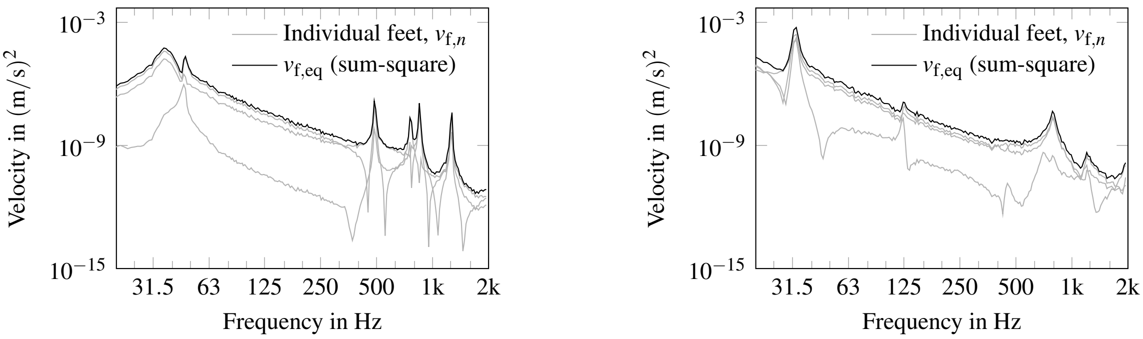
Figure 2. Structure-borne sound sources used in the presented case studies.



(a) Source A

(b) Source B

Figure 3. Directly measured source mobilities



(a) Source A

(b) Source B

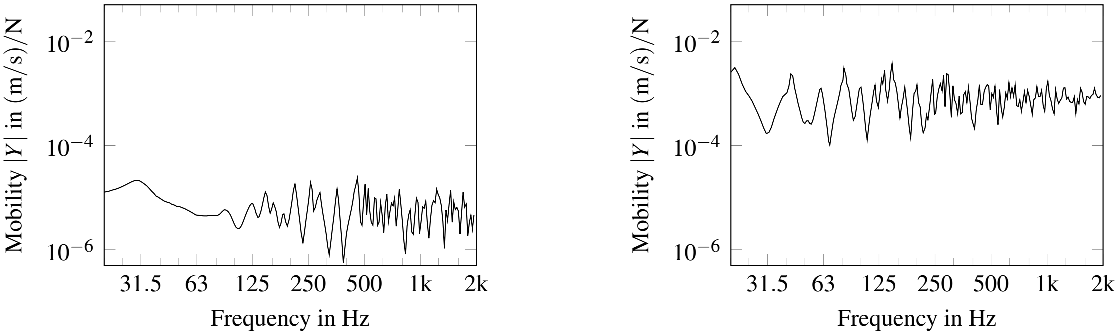
Figure 4. Directly measured source free velocities

To validate the source quantities obtained with the proposed method, the mobility and the free velocity was measured directly on the sources isolated with rubber cords.

The mobility was measured using an impulse hammer (Kistler, 9726A20000) and small accelerometers (MMF, KS91C). Figure 3 shows the directly measured source mobility, Y_S, for each individual foot and the single equivalent mobility, $Y_{S,eq}$, i. e. the average of magnitudes [2]. It can be seen that Source A has distinct resonance peaks above 500 Hz that correspond to the modes of the steel plate. For both sources, the mobility of Source B is in the same order of magnitude although it is heavier. But the resonance peaks of the steel plate are damped. At ≈30 Hz there is a resonance of the inertial shaker, which is more pronounced for Source B compared to the resonance of the small inertial shaker of Source A. The free velocity was measured with accelerometers at each foot with the source operating. Figure 4 shows the directly measured squared source free velocity, v_{Sf}, at each foot, as well as the source single equivalent free velocity, v_{feq}, i. e. the sum-square [2]. The spectra of Source A and Source B both indicate the pink noise signal with peaks at the resonances described above. For both sources the two feet at the corners differ from the third foot that more towards the centre area of the plate.

3.2 Receivers

Two reception plates were used. A heavy 10 cm concrete plate according to the test-rig proposed in [2] and a lighter timber plate. Figure 5 shows the driving-point mobilities at the chosen 'measurement centre' for both plates. It can be seen that the mobility of the concrete plate is significantly lower than for the timber plate (22 mm 3-ply panel). Both tend to a constant value towards high frequencies.



(a) Concrete plate

(b) Timber plate

Figure 5. Receiver mobilities: Driving point mobility at 'measurement centre', Y_c^c

4 RESULTS

This section shows the results of case studies for three combinations of the sources and receivers described above: Source A on the concrete plate, Source B on the concrete plate and Source A on the timber plate.

4.1 Source A on concrete plate

Source A was attached to the concrete plate at a random position. Nine remote points, i, were considered. Figure 6a shows the ratio between the source and the receiver mobility (represented by the driving-point mobility, Y_c^c). This shows that throughout the presented frequency range from 20 Hz to 2000 Hz the single equivalent mobility, $Y_{\mathrm{S,eq}}$, is at least 10 dB lower than the source mobility. However as mentioned in section 3.1 on foot differs and has slightly higher ratios compared to the other two feet. Figure 6b shows the ratio, R, according to equation (1) for the transfer mobilities, Y_i^c, with and without the source installed. It can be seen, that the source does not alter the behaviour much below 250 Hz.

Figure 7a compares the estimated and directly measured single equivalent source mobility, $Y_{\mathrm{S,eq}}$. Although the estimated mobility represents the general trend of the spectral shape, it does not pick up the modal peaks. The differences are up to 10 dB with no overlap of the standard deviation from the nine positions. However towards high frequencies the differences tend to be smaller.

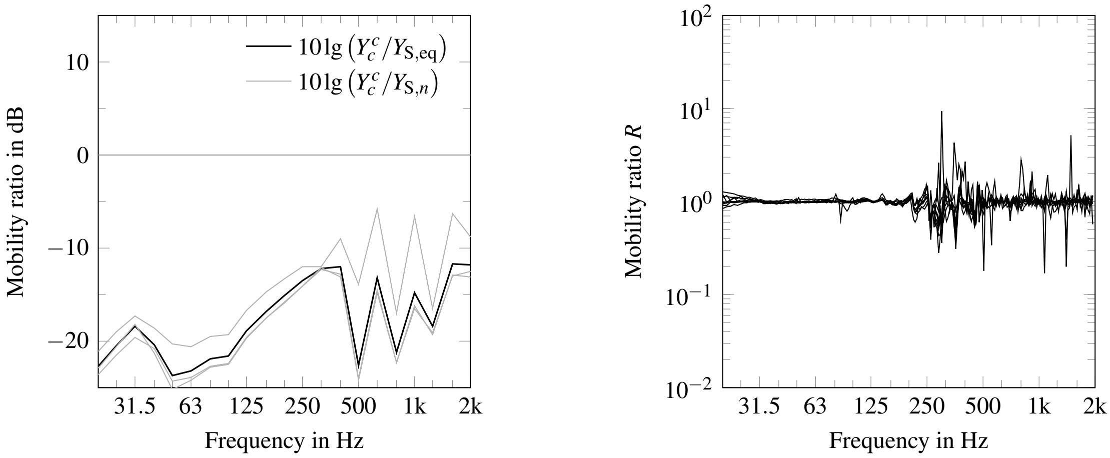
Similar observations can be made for the comparison of the estimated and directly measured single equivalent free velocity, v_{feq}, shown in Figure 7b. The differences are smaller towards higher frequencies and the general trend of the spectral shape is captured. However the differences are >10 dB for the majority of the considered frequency range.

4.2 Source B on concrete plate

Source B was attached to the concrete plate at the same position as Source A. Four remote points, i, were considered in this case. The ratio of the source and receiver mobility, shown in Figure 8a, as well as the mobility ratio, R, shown in Figure 8b, are similar to those for Source A on the concrete plate. Again, the spectral shape is captured for $Y_{\mathrm{S,eq}}$ and $v_{\mathrm{f,eq}}$ (see Figure 9). For this case, the agreement between the estimated and directly measured data is slightly better compared to Source A on the concrete plate (see Figure 7).

4.3 Source A on timber plate

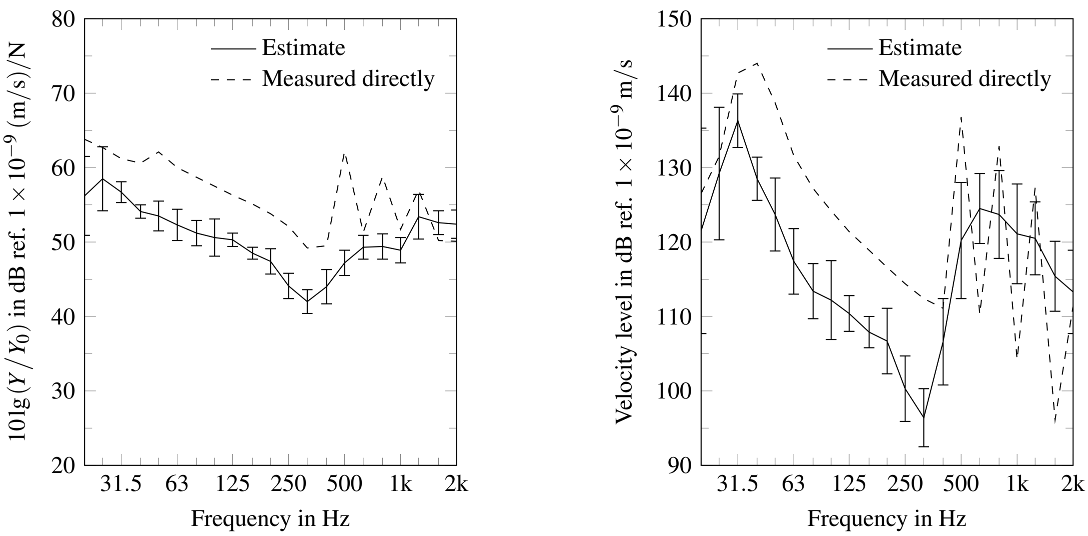
The third combination considered Source A on a 22 mm timber plate. Source A was attached about a randomly chosen 'measurement centre' and nine random remote measurement positions, i, were chosen across the plate. The ratio R (Figure 10b) is significantly larger across the whole frequency range compared to Source A and



(a) Ratio between source mobility (Figure 3a), and driving-point mobility, Y_c^c, of the receiving plate.

(b) Mobility ratio according to equation (1) using magnitudes.

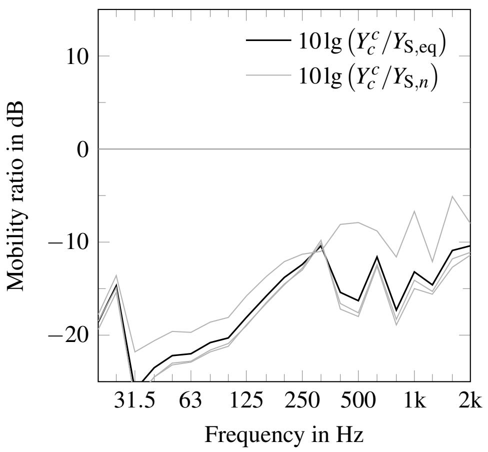
Figure 6. Source A on concrete plate: Mobility ratios.



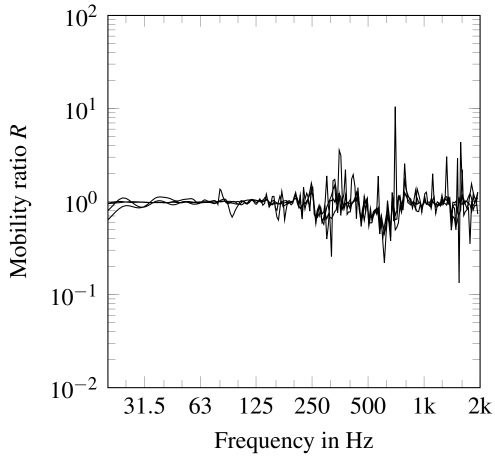
(a) Single equivalent mobility $Y_{\mathrm{S,eq}}$

(b) Single equivalent free velocity v_{feq}

Figure 7. Source A on concrete plate: Estimated source quantities according to equations (2) and (3). Average from nine positions, i, with standard deviation. Compared with directly measured data (see Figures 3a and 4a).

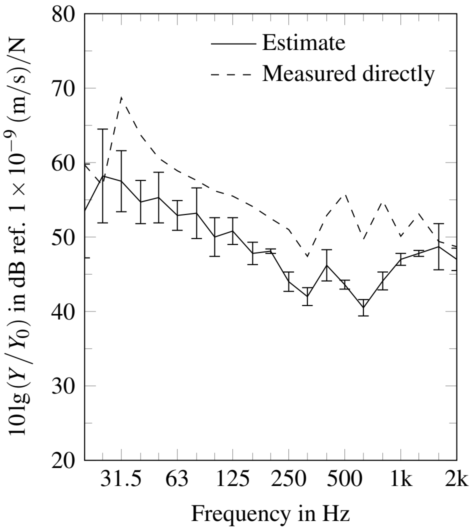


(a) Ratio between source mobility (Figure 3b), and driving-point mobility, Y_c^c, of the receiving plate.

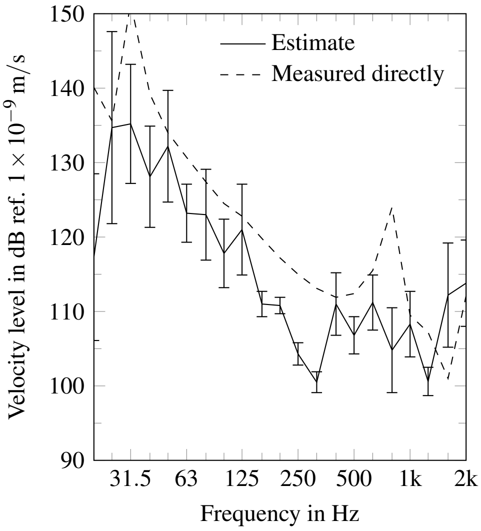


(b) Mobility ratio according to equation (1) using magnitudes.

Figure 8. Source B on concrete plate: Mobility ratios.

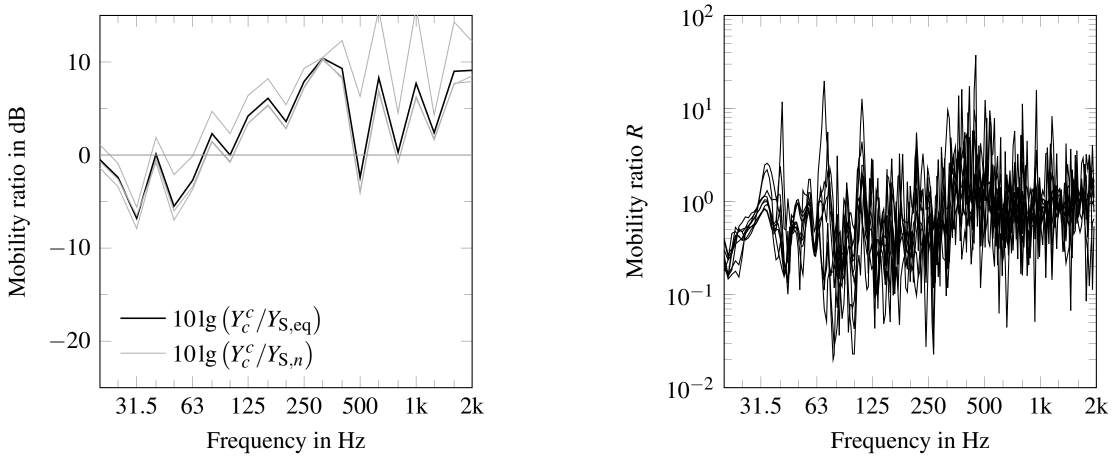


(a) Single equivalent mobility $Y_{S,eq}$



(b) Single equivalent free velocity v_{feq}

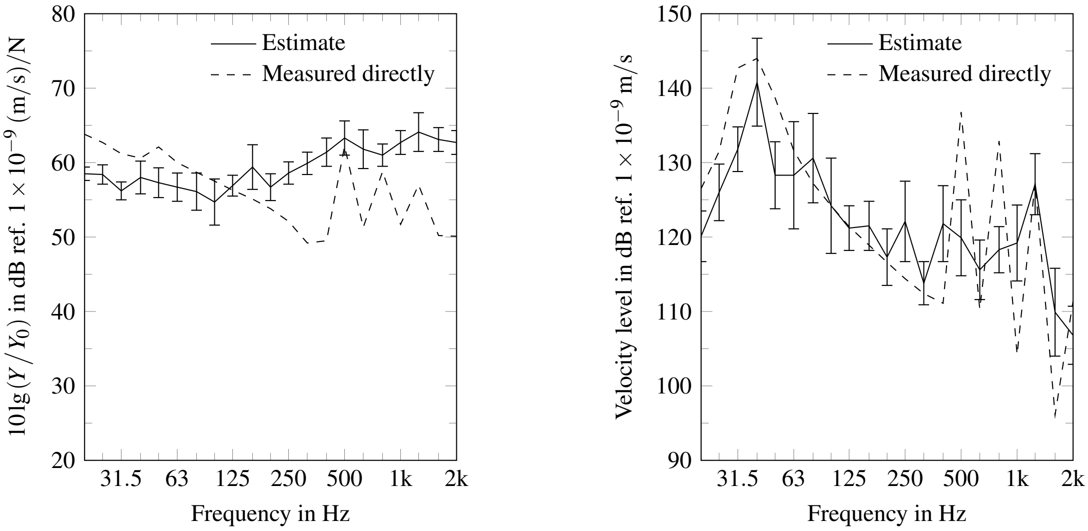
Figure 9. Source B on concrete plate: Estimated source quantities according to equations (2) and (3). Average from four positions, i, with standard deviation. Compared with directly measured data (see Figures 3b and 4b).



(a) Ratio between source mobility (Figure 3a), and driving-point mobility, Y_c^c, of the receiving plate.

(b) Mobility ratio according to equation (1) using magnitudes.

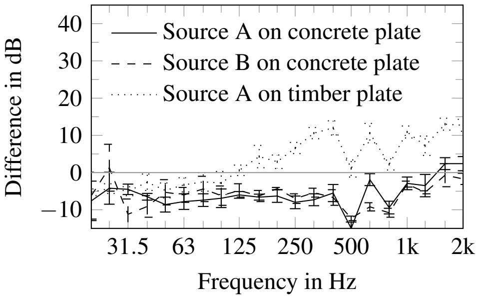
Figure 10. Source A on timber plate: Mobility ratios.



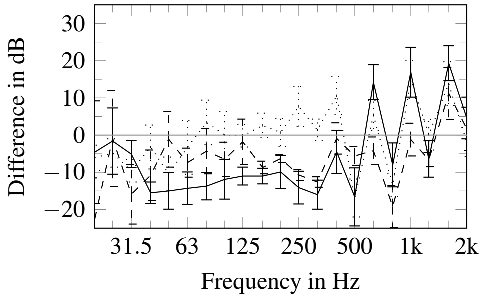
(a) Single equivalent mobility $Y_{S,eq}$

(b) Single equivalent free velocity v_{feq}

Figure 11. Source A on timber plate: Estimated source quantities according to equations (2) and (3). Average from nine positions, i, with standard deviation. Compared with directly measured data (see Figures 3a and 4a).



(a) Single equivalent mobility $Y_{S,eq}$



(b) Single equivalent free velocity $v_{f,eq}$

Figure 12. Differences between the estimated and directly measured quantities for all three case studies.

Source B on the concrete plate (Figures 6b and 8b). Hence the source alters the plate behaviour which can be explained by considering the mobility ratio shown in Figure 10a. This shows that the difference between $Y_{S,eq}$ and Y_c^c is within ± 10 dB. However, as described above, one foot differs from the other two feet.

Although the estimated source mobility does not capture the trend of the spectral shape from the directly measured data, the agreement is better compared to the measurements on the concrete plate at frequencies below 125 Hz (see Figure 11a). The single equivalent free velocity follows the spectral shape of the directly measured data but does not capture the resonant peaks above 500 Hz. The agreement is within ± 5 dB between 80 Hz to 400 Hz with overlapping intervals of the standard deviation. Below 80 Hz and above 400 Hz the differences are within ± 15 dB.

5 SUMMARY AND DISCUSSION

The experiments indicate the potential of the method as the spectral shape for the single equivalent mobility and the single equivalent free velocity could be captured on the heavy reception plate. However for all three considered combinations of sources and receivers, the estimates differ by ± 10 dB (using 10lg) for the mobility and by ± 15 dB for the free velocity (Figure 12). The agreement with directly measured source data tends to be better for higher mobility ratios, R although the frequency trend could also be reproduced for low values of R.

For the considered sources, one foot differed from the behaviour of the other two. In addition the sources had only a few but very distinct resonance peaks in the considered frequency range. Further work could investigate the limitation of this method when the individual contact points differ significantly.

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