A Contribution concerning Boundary Condition Effects that need to be considered using SEA for Calculation of Direct Sound Transmission

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Abstract

The use of the statistical energy analysis (SEA) for calculations in building acoustics is increasing, especially for predictions of the sound insulation of timber-based constructions. The accuracy of the calculation results depends amongst others on the quality of input parameters like material data, as well as on the considered boundary conditions and physical effects. In this paper, the deviation between measured and predicted sound insulation is analysed and the underlying physical effects are determined, based on additional comprehensive investigations. One layer of gypsum fibreboard has been chosen as a test specimen, which shows a reproducible vibrational behaviour. In a first step, suitable values for the material properties are determined. Then, several investigations, based on measurements, are described, which have been carried out in a testing facility, that complies with EN ISO 10140 standard series. The investigations show that some of the observed deviations between measurement and calculation results may be wrongly considered to be an SEA-model-error. The differences are primary caused by a couple of physical effects influencing the measured reference data. As a consequence of the analysis, the boundary conditions of the measurement setup have been adapted with success – an obvious reduction of the deviation between measured and calculated data could be achieved.

Introduction

Statistical Energy Analysis (SEA) [1] has been used in the automotive and aircraft industry for many years. Since SEA allows fast and accurate calculations of sound transmission even at high frequencies, the SEA approach has been applied for timber constructions too. Due to differences between the acoustic properties of the materials used in timber buildings and in the automotive or aircraft industry, the frequency range, where reliable results can be expected, varies and is currently an active field of research as shown for example in [2] and [3].

In this paper, measurements carried out in a testing facility, that complies with EN ISO 10140, were compared to calculations based on SEA. A single-layer gypsum fiber board was used as a test-specimen because of its predictable behavior in terms of sound transmission.

In a first step the measured sound reduction indices of the gypsum fiber board were compared to calculated data. Deviations between the results were determined and interpreted as effects caused by sound transmission via the bed joints between test-specimen and testing facility (bypass transmission) as well as via the bearings (flanking transmission).

In a next step the deviations were minimized by adapting the measurement setup. Two major improvements are presented in this paper:

- Increase of sound insulation of the joint between specimen and testing facility by adding wooden strips and additional linseed oil putty.
- Decrease of transmission of sound energy into the testing facility via bed joints by using elastomers for static support.

Then the airborne sound transmission loss of the test-specimen was measured again with the adapted measurement setup and was compared to the calculations. The calculation results showed a reduced sound transmission index at higher frequencies which was interpreted as an influence of the niche of the opening of the testing facility aperture. The calculated radiation efficiency of the gypsum fiber board was adapted in the SEA-model to compensate this effect.

A significant reduction of the deviation between calculated and measured sound reduction indices was achieved.

Materials and Methods

All measurements of the sound transmission indices were carried out in a testing facility that complies with standard series EN ISO 10140 [4].

Initial measurement setup

One layer of a gypsum fiber board was used as a test-specimen (Figure 1). Two plates were connected to fill the whole opening of the testing facility (length/ width/ depth: 1,48 m / 1,23 m / 0,0125 m) by using an additional vertical stripe of gypsum fiber board. The bed joints between test-specimen and testing facility were filled with a layer of mineral wool to reduce coupling and were sealed with linseed oil putty.

Figure 1: Receiving room of the testing facility.

Initial calculation model

All calculations were carried out using the software SEAWOOD that is a special version of SEA+ for wood building industry [5].
The SEA model (Figure 2) was generated from analytical description and supplemented with measured and calculated data. The absorption coefficients of the rooms were calculated using reverberation time measurements.

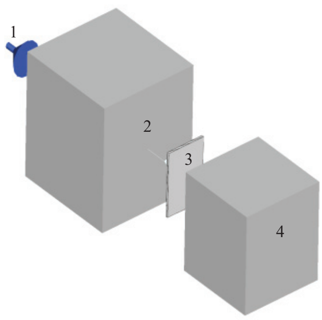

Figure 2: SEA model of the testing facility: sound source (1), source-room (2), specimen (3) and receiving-room (4)

The material properties of the gypsum fiber board were derived using a finite element method (FEM) based calculation and experimental modal analysis of the specimen.
As a starting point isotropic material properties from the product data sheet were used to calculate the modal behavior of the specimen at low frequencies. Using a linear-elastic isotropic material model optimization approach, the frequencies of the calculated modes were fitted to the measured modes. The fitting was further improved using a linear-elastic orthotropic material model for the FEM-calculations (Table 1).

Table 1: Material properties of the test-specimen

	Product data sheet	FEM study
ρ [kg/m^3]	1150	1120
E_x [Pa]	3,8e9	4,65e9
E_y [Pa]	-	2,92e9
G_{xy} [Pa]	1,6e9	1,51e9
ν [-]	0,1875	0,25

The total loss factors of the specimen (Figure 3) were calculated from structure-borne reverberation time measurements [6].

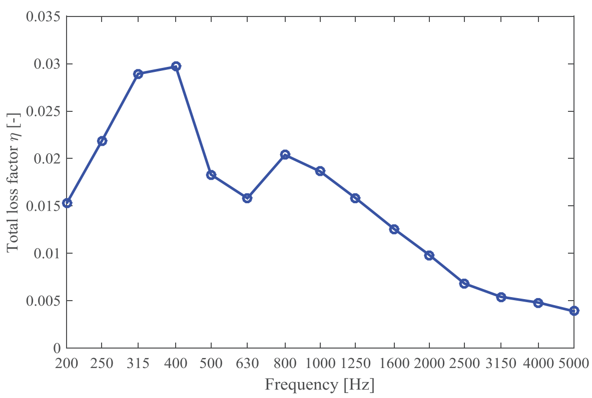

Figure 3: Total loss factor of the installed test-specimen

Results and Discussion

The measured and calculated sound reduction indices of the initial measurement setup and the deviation between are shown in Figure 4 in one-third-octave-bands.
The SEA approach requires high modal densities of the calculated sound fields. In the lower frequency range this requirement can no longer be met due to the low density of the gypsum fiber board. Therefore the deviation below 315 Hz increases with a maximum of 2,9 dB at 200 Hz. From 315 Hz to 1 kHz a maximum deviation of 0,7 dB was achieved. Above 1 kHz the deviation increases with a maximum of 6,1 dB in the frequency band of 3,15 kHz. Between 1 kHz and 2 kHz the measured sound transmission indices are less than predicted by SEA. This is caused by the transmission of sound energy into the testing facility via the bed joints and by the reduced sound insulation of the joints between test-specimen and testing facility.

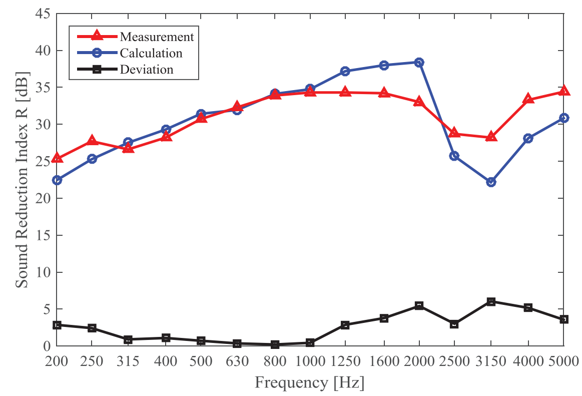

Figure 4: Comparison between the measured and calculated sound reduction indices of the initial measurement setup

Measurement setup adaptations

To reduce the deviation between measured and calculated sound reduction indices the measurement setup was adapted by several measures:

- Increase of sound insulation of the bed joints between test-specimen and testing facility (bypass transmission) by adding wooden strips and additional linseed oil putty.
- Decrease of transmission of sound energy into the testing facility via the bearings (flanking transmission) by using elastomers for static support.
- Instead of a test-specimen divided into two parts a continuous plate with a reduced width of 1,00 m was used. This was done to prevent a vertical stiffening of the plate that influences the modal behavior and maybe decreases the coincidence frequency. The remaining opening of the testing facility was closed using a construction that shows a significant high sound insulation.
- The test-specimen was mounted flush with the wall of the source room to reduce the influence of the niche in the source room.

Bypass transmission

Two frames made of wooden strips were placed on both sides of the specimen and fixed with linseed oil putty based on the requirements of EN ISO 10140-1 for measurements of glass units to increase the sound insulation of the joint between specimen and testing facility [7]. A layer of mineral wool was used to reduce the coupling between specimen and wooden frame as well as between test-specimen and testing facility (Figure 5).

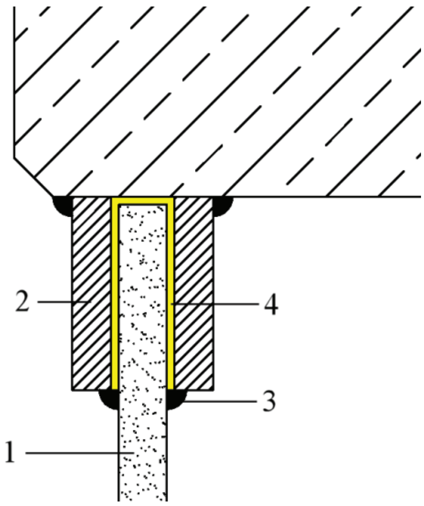

Figure 5: Adapted measurement setup: gypsum fiber board (1), wooden frame (2), linseed oil putty (3), mineral wool (4)

Flanking transmission

Two pieces of elastomer were used to reduce the transmission of sound energy via the bed joints. The elastomers were placed beneath the left and right corners of the specimen. The resulting mass-spring system showed a resonance frequency of about 8 Hz (Figure 6) with a modal damping of 8,37 %. This resulted in a partly decoupling and transmission damping of approx. -18 dB at 100 Hz [8].

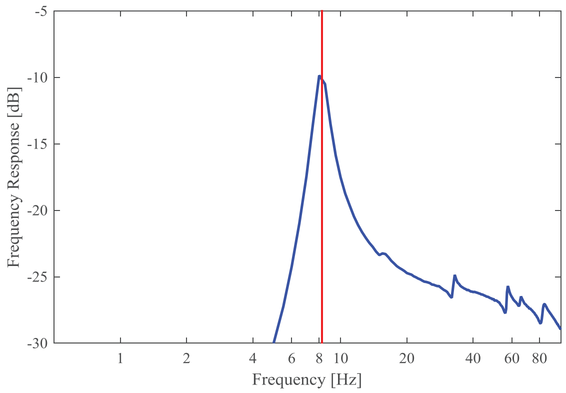

Figure 6: Resulting resonance frequency of the mass-spring system caused by the plate and the elastomer.

Decreasing the bypass transmission by adding material at the area of the bed joint led to an increasing flanking transmission from the specimen to the test frame as well as an increased damping at the edges of the vibrating plate. These effects were detected by measurements of the total loss factor of the test-specimen (Figure 7).

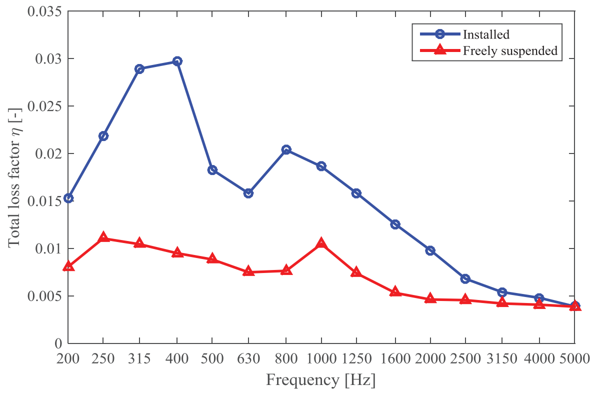

Figure 7: Comparison of the calculated total loss factors of the freely supported and the installed gypsum fiber board.

As a final step the plate was measured again with the adapted measurement setup and compared to the calculations.

Comparison of the adapted measurement setup

The measured and calculated sound reduction indices of the adapted measurement setup and the deviation between are shown in Figure 8 in one-third-octave-bands.

As expected, from 200 Hz to 315 Hz only minor changes compared to the initial measurement setup occurred. Between 315 Hz and 1 kHz the deviation was decreased to a maximum of 0,65 dB. From 1 kHz to 2 kHz a significant reduction of the deviation was achieved with a maximum of 1,2 dB at 2 kHz by decreasing the bypass transmission. From 2 kHz to 5 kHz the calculated sound reduction indices were lower than the measured, with a maximum deviation of 9,9 dB at 5 kHz. The deviation at higher frequencies was interpreted as an influence of the niche in the receiving room. This effect was compensated by adapting the radiation efficiencies in the SEA model in this frequency range.

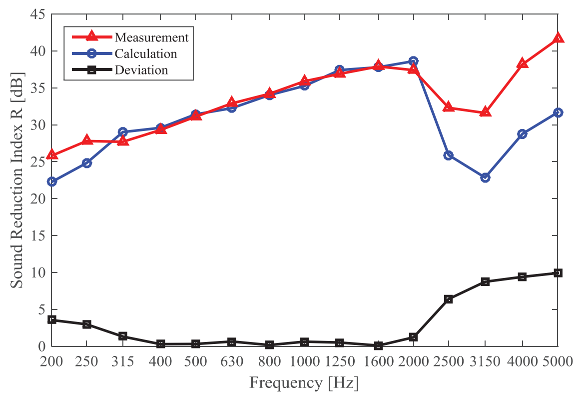

Figure 8: Comparison between the measured and calculated sound reduction indices of the adapted measurement setup.

Calculation model adaptions

At the adapted measurement setup the test-specimen was mounted flush with the wall of the source room. This caused an increase of the depth of the niche of the testing facility at the side of the receiving room. In general this niche has an influence on the sound power radiated to the sound field [9]. This effect is not taken into account in the SEA-model, therefore as a compensation the calculated radiation efficiencies were adapted in the frequency bands from 2 kHz to 5 kHz (Table 2). Future research will show the applicability of the chosen measures and corrections for other measurement setups and other specimens.

Table 2: Radiation efficiencies

	Calculated	Adapted
2000 Hz	0,15	0,19
2500 Hz	1,44	0,34
3150 Hz	2,75	0,31
4000 Hz	1,82	0,17
5000 Hz	1,46	0,17

Figure 9 shows the sound reduction indices calculated with the adapted radiation efficiencies, the measured results of the adapted measurement setup and the deviation between them.

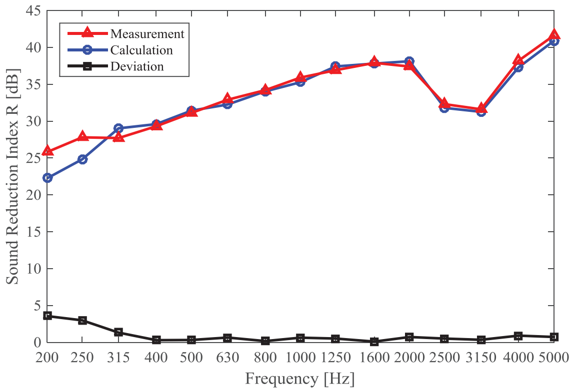

Figure 9: Comparison between the sound reduction indices measured with the adapted measurement setup and calculations with adapted radiation efficiencies.

Using the adapted radiation efficiencies a significant reduction of the deviation between 2 kHz to 5 kHz was achieved with a maximum of 0,9 dB at 4 kHz.

Conclusions

Measurements of the sound reduction indices of a gypsum fiber board were compared with an SEA-based calculation showing deviations at low and high frequencies.

While at lower frequencies requirements of the SEA are no longer met, deviations at higher frequencies were interpreted as an effect of sound transmission paths in the measurement setup that are not taken into account in the SEA-model.

In a first step these sound transmission paths were reduced by increasing the sound insulation of the bed joints between test-specimen and testing facility as well as by an improved bearing using elastomers. This led to a frequency range with a high agreement between measurements and calculations. The measurement setup adaptions caused an increase of the depth of the niche in the receiving room, which has an influence on the sound power radiated to the sound field. This resulted in an increased deviation between measurements and calculations at high frequencies.

In a final step this effect was compensated by adapting the calculated radiation efficiencies in the SEA-model.

All of these measures finally led to a high agreement between measured and calculated sound reduction indices in an extended frequency range.

Acknowledgements

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