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Vibration Transmission Analysis Through Mounting Elements of Wall Cladding Panels

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Abstract Vibrations in building constructions may propagate through mounting elements to wall cladding panels. It is confirmed that they can have an impact on the sound pressure level radiated from panels and might have a significant influence on the total SPL in a room. In this work possibilities for calculating a parameter determining a change of SPL value depending on the number of panels and its mounting method are presented. A computational model based on vibration velocity measurements was used to estimate the total SPL value in a room. The laboratory and *in situ* measurements are presented. Transfer function for two elastic elements used as additional elements in a junction was calculated. Finally, ΔL_p and ΔL_v were calculated, as parameters defining the impact of various panel mounting methods on the reduction of sound pressure level and vibration level value, respectively.

Keywords: impact sound, transfer function, sound pressure level, transmission paths.

1. Introduction

Vibrations may propagate freely through solid building constructions. These structural sounds are difficult or even impossible to dampen after the construction has been completed [1]. This is an unfavourable phenomenon since undamped vibrations may also propagate through mounting elements to wall cladding panels which are commonly used as treatment elements in building acoustics [2-4]. Transmission path analysis (TPA) is indispensable to predict sound transmission in structures. TPA is commonly used in mechanical vibrations [5-6,8] and was used in this work, to define the most important and modifiable junction in the transmission path, as it is confirmed that structure's vibrations radiate into a room as acoustic pressure [7]. Therefore, mounting many cladding panels on a solid wall in a room (e.g., theatre hall) may cause noise affecting the total sound pressure level in the room, which is going to be proven.

Due to the proportionality of vibration velocity and acoustic pressure, sound pressure level reduction is possible by vibration velocity reduction. There are different methods used to damp structural sound propagated through mounting elements and junctions [8]. The method used in this work is adding an extra elastic element into a junction. Vibration velocity's dependency on sound pressure makes it also possible to estimate sound pressure level value due to vibration velocity measurements. Hence, this work is aimed to find and develop a simple method for the estimation of sound pressure level reduction based on vibration velocity measurements. The parameter ΔL_p is defined as a difference between sound pressure levels before and after adding an elastic element into the junction and was invented based on [9]. The presented results are the effect of measurements taken both in a laboratory and *in situ* in the theatre hall. The description of the studied spaces and employed methods are presented in Sec. 2. Section 3 contains results, while Sec. 4 includes some conclusions and presents further planned works.

2. The studied space

The engineering method of calculating sound pressure level reduction is presented in this section. The measurements were performed in two different locations. The first was a laboratory room and the second was a theatre hall. The laboratory room is a rectangular space with concrete walls (see Fig. 1b). There is one wooden cladding panel with a width of 0.75 m and a height of 1 m mounted on a wall. The panel's thickness is equal to 2 cm. The *in-situ* measurements were taken in the theatre hall (see Fig. 1a) of the volume of 1800 m^3 (about 11 x 11 x 15 meters) with solid walls and floor. There were about 130 wooden cladding panels (0.75 m in width and 4 m in height) mounted on each wall.

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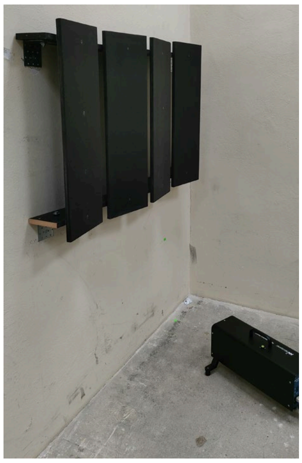
a)  b) 

Figure 1. Studied spaces: a) theatre hall, b) laboratory.

The tapping machine and hammer were used as impact sound sources, depending on the measurements taken. Vibration's acceleration was measured using two piezoelectric accelerometers.

2.1. Transmission path analysis

Transmission paths are defined by transfer functions defined as a logarithmic ratio of vibration velocity values, accordingly to Eq. (1)

$$\tau_i = 20\log_{10}\frac{v_1}{v_2} \quad (1)$$

where v_1 and v_2 are the velocities on the first and second vibrating element, respectively. In all the cases, the second element is the structure closer to the excitation point (i.e., τ_i is the ratio of vibrations measured on the wall to vibrations measured on the floor). The proposed path from a concrete floor to a cladding panel is shown in Fig. 2 and leads through a concrete wall. The measurements were taken using a tapping machine both in the laboratory and in the theatre hall.

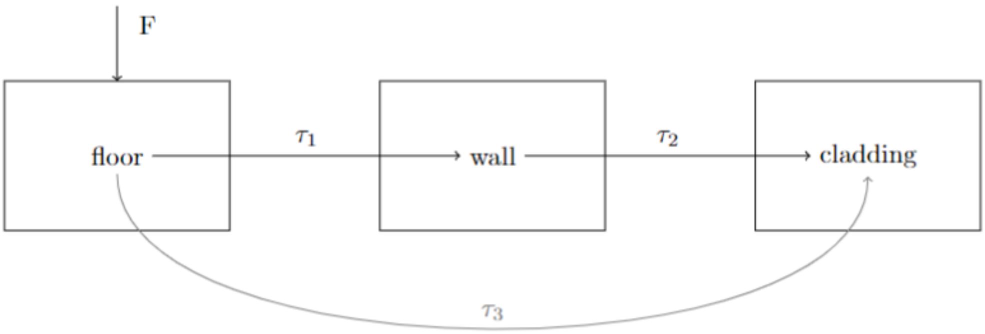


Figure 2. Transmission paths, τ are transmission paths and F is the excitation point.

To verify if τ_3 was equal to τ_1 and τ_2 sum, calculations were made. The results presented in Fig. 3 confirm the above assumption. The differences observed in the laboratory measurements are the results of insignificant and neglectable in further work flanking transmission. Therefore, the mean-squared error ε expressed as a percentage was used to determine the compatibility of the transfer functions. The values obtained in calculations are presented in Tab. 1.

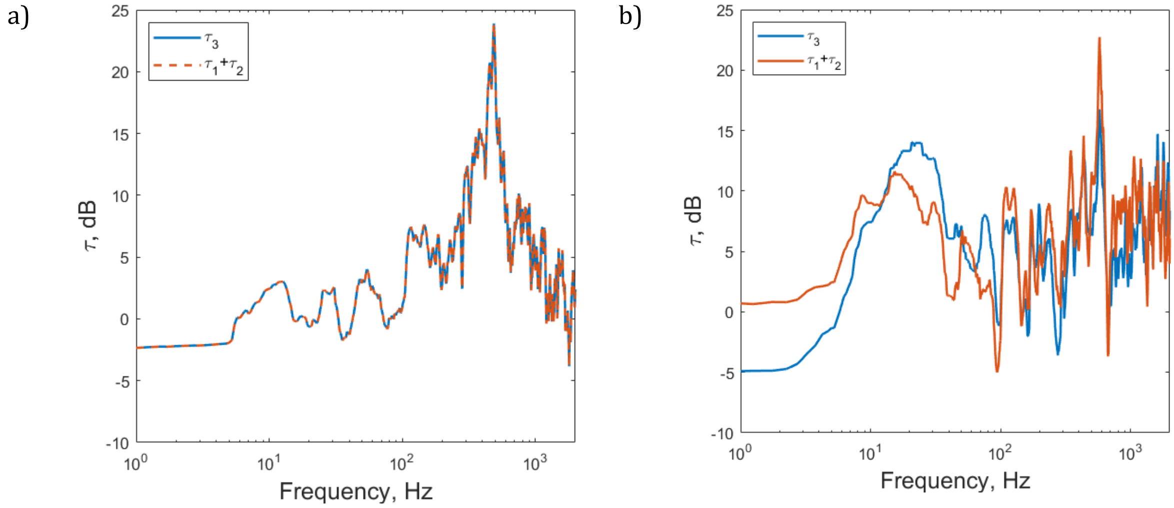


Figure 3. Transfer function (a) in the theatre hall and (b) in the laboratory.

Then, the effectiveness of the laboratory measurements was validated. For each transmission path the values from the laboratory measurements were compared to the values obtained in the theatre hall. The results are shown in Fig. 4 and confirm the efficiency of the laboratory measurements. The differences are the results of different sizes of the structures, various building methods used in both spaces, and flanking transmission observed in the laboratory. The ε values for each case analyzed are presented in Tab. 1.

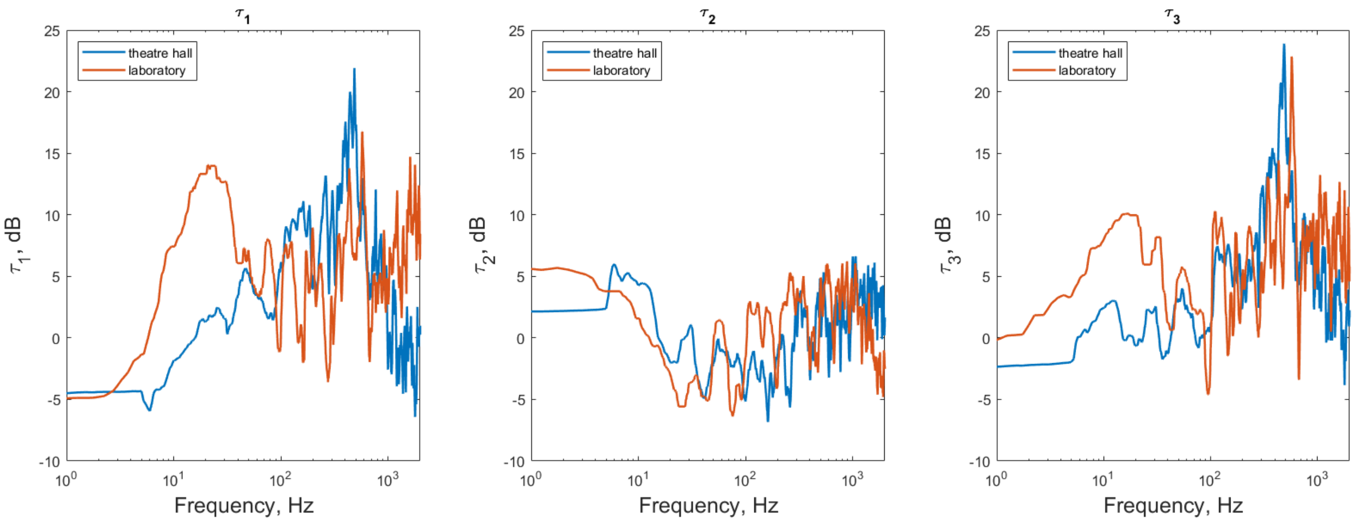


Figure 4. Laboratory and in situ measurements of the transfer functions.

To reduce the transmission path and exclude the floor from analysis, the hammer was used as an impulse impact sound source. Furthermore, the possibility of faster measurements and the hammer's weight and dimensions were significant advantages of replacing the tapping machine in the engineer vibrations velocity measurements method.

Table 1. Mean-squared error for transfer functions in laboratory and theatre hall

	Symbol	Unit	Value
τ_3 and sum τ_1 and τ_2 in the theatre hall	ε_T	%	$1{,}26 \cdot 10^{-32}$
τ_3 and sum τ_1 and τ_2 in the laboratory	ε_L	%	$2{,}4 \cdot 10^{-3}$
τ_1 in the laboratory and the theatre hall	ε_{LT1}	%	0,33
τ_2 in the laboratory and the theatre hall	ε_{LT2}	%	0,12
τ_3 in the laboratory and the theatre hall	ε_{LT3}	%	0,30

The measurements of the transfer function τ_2 were repeated using the hammer as the impact sound source. The excitation point was determined on the wall so the only possible transmission path from wall to cladding panel was through the cladding mounting elements. The results are shown in Fig. 5 and in Tab.2. The similarities in the frequency range over 100 Hz show the possibility of using a hammer instead of a tapping machine in measurements. Therefore, it is advisable to conduct the analysis from 100 Hz and omit lower frequencies since values around 0 dB indicate that signal from the hammer is not enough to excite lower frequencies.

Table 2. Mean-squared error for transfer functions measured using the hammer and the tapping-machine.

	Symbol	Unit	Value
τ_2 using a tapping machine and a hammer for the frequency range 1-2000 Hz	ε_{TmH}	%	0,18
τ_2 using a tapping machine and a hammer for the frequency range 100-2000 Hz	$\varepsilon_{TmH,100}$	%	0,02

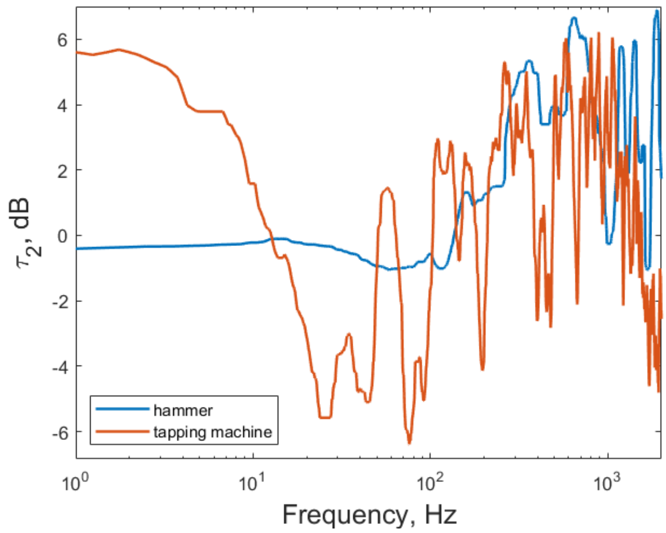


Figure 5. The comparison of the transfer functions τ_2 obtained with the use of the hammer and the tapping machine.

The above conclusions are fundamental for the further analysis and open a possibility to estimate sound pressure level values generated in the theatre hall based on the laboratory measurements. Therefore, the analysis with the additional elastic element in the wall-cladding junction was performed. The elastic element of the parameters presented in Tab. 3 has been placed on the mounting element as shown in Fig. 6. The measurements results are shown in Sec. 3.

a) b)

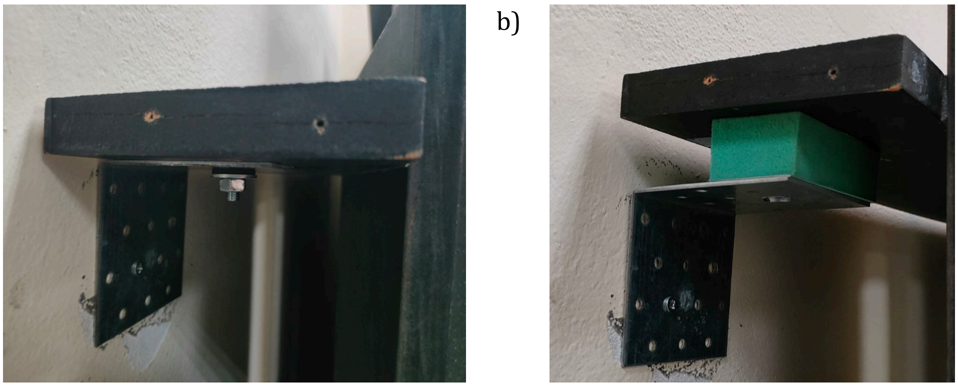


Figure 6. Junction wall-cladding: without elastic element, (b) with the additional elastic element.

Table 3. Elastic element parameters.

	Symbol	Unit	Value
Thickness	*t*	cm	2,5
Length	*a*	cm	8 (element A) 4 (element B)
Width	*b*	cm	8
Continuous Static Load	*CSL*	$\frac{\mathrm{N}}{\mathrm{mm}^2}$	0,055
Static modulus of elasticity	*E*	$\frac{\mathrm{N}}{\mathrm{mm}^2}$	0,35 – 0,58
Dynamic modulus of elasticity	*DME*	$\frac{\mathrm{N}}{\mathrm{mm}^2}$	0,68 – 1,25
Force reduction	*ΔF*	%	72

2.2. Sound pressure level

The sound pressure level generated by vibrating plate structures was calculated according to [7]. Based on the vibration velocity measurements, the velocity level was calculated according to Eq. (2) as the logarithmic ratio of the measured vibration velocity and the reference value:

$$L_v = 10 \log_{10} \frac{v}{v_{ref}}, \tag{2}$$

where v_{ref} is a reference value, equal to $10^{-6} \frac{\mathrm{m}}{\mathrm{s}}$ and v is the measured vibration velocity $\left(\frac{\mathrm{m}}{\mathrm{s}}\right)$. Then, the energy level was calculated for each structure in the transmission path as:

$$L_c = L_v + 10\log_{10} m, \tag{3}$$

where L_c is the energy level and m (kg) is the mass of the analyzed structure. Finally, the sound pressure level is expressed by:

$$L_p = L_c - 10\log_{10} V + 25{,}4, \tag{4}$$

where V (m^3) is room volume.

2.3. SPL difference

SPL difference ΔL_p is given by Eq. (5) as a level difference:

$$\Delta L_p = L_{p1} - L_{p2}, \tag{5}$$

where L_{p1} and L_{p2} are sound pressure levels before and after mounting additional element in the junction, respectively. The parameter informs about the change of the sound pressure level as a result of reducing vibration velocity level in the junction.

3. Results and discussion

Since the sound pressure level generated by one wooden plate analyzed in this work is close to 0 dB for frequencies higher than 10 Hz, there is no possibility to hear the sound. However, in the case of 130 vibrating elements, the sound pressure level value increases by about 20 dB (Fig. 7) making the sound audible. This leads to the conclusion that mounting a large number of cladding panels on a concrete wall in a theatre hall might induce noise levels of a significant impact on the total sound pressure level in the room.

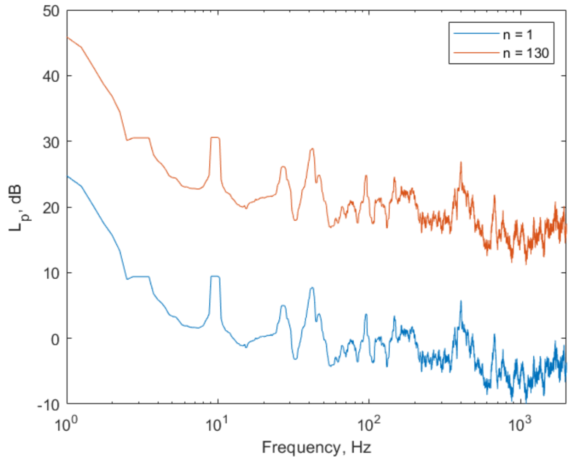


Figure 7. Sound pressure level for 1 and 130 vibrating cladding panels.

The transfer functions for three different τ_2 cases were analyzed and the results are shown in Fig. 8. Adding an extra elastic element in the junction wall-cladding makes the characteristic smoother, but has no impact on the trend – the higher the frequency, the higher the transfer function value.

Below 20 Hz, the transfer function values for all the analyzed cases are close to 0 dB, which means that all energy from the wall is transmitted unreservedly to the cladding panel. There is a peak in 100 Hz seen for the transfer function calculated for both junctions with additional elements. This is the resonant frequency of the elastic element. Above this point, the values increase slowly and there are no other significant resonances.

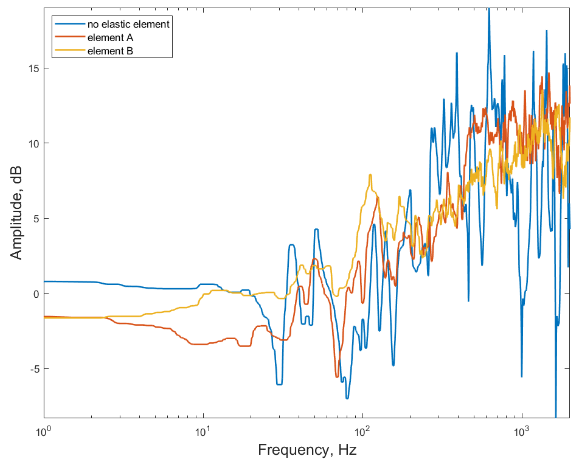


Figure 8. Transfer function τ_2 for junction without elastic element (blue), with small (element A), and with a big element (element B).

Adding an extra elastic element in the junction impacts sound pressure value as shown in Fig. 9. The values are calculated for 130 vibrating elements. The elastic element resonant frequency is about 100 Hz, which is seen as a peak for element A and element B and after which the sound pressure level decreases. L_p is equal to 0 dB in the frequency range from 1000 Hz for the junction with an additional element, which makes noise generated from the panel inaudible.

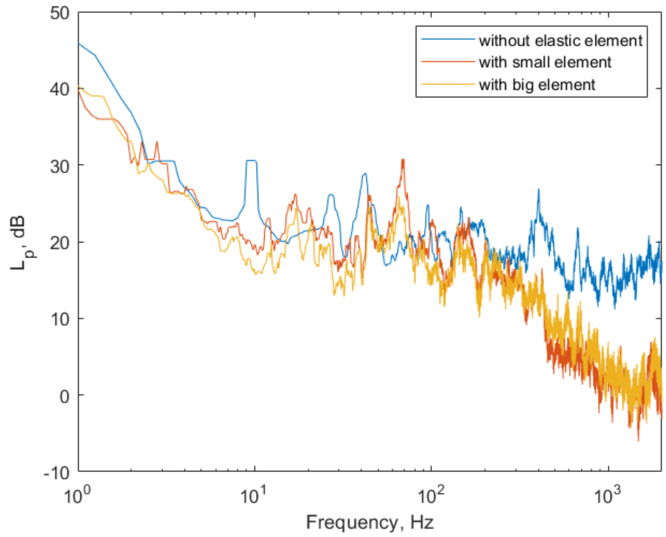


Figure 9. Sound pressure level for the junction wall-cladding without elastic element, with element A (yellow) and with element B (red).

Sound pressure level reduction ΔL_p, given as a level difference, is shown in Fig. 10. There is no significant difference between element A and element B. Up to the frequency of 100 Hz, the ΔL_p oscillates around 0 dB and above increases to 15 dB for 1000 Hz.

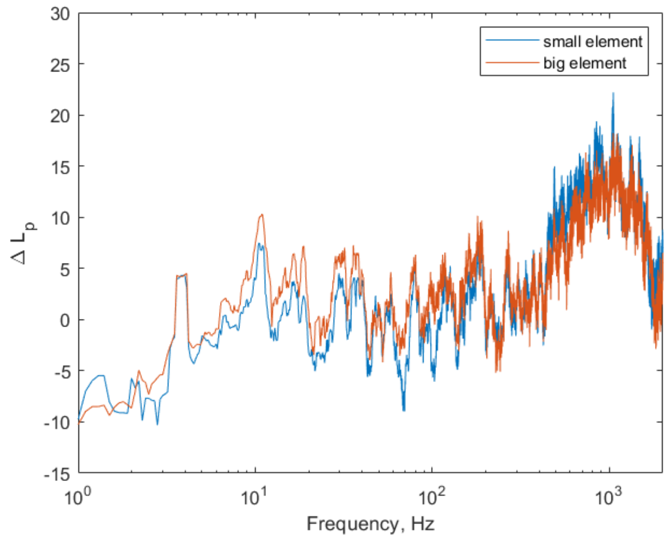


Figure 10. Sound pressure level reduction for element A (red) and element B (blue).

4. Conclusions and further work

Transfer function analysis informs about the most important junctions in a transmission path and gives a possibility to impact sound transmission reduction in building construction. Therefore, it is possible to reduce sound pressure level value by using elastic elements added to the junctions. There is a possibility of taking the vibration acceleration measurements using a hammer instead of a tapping machine in a frequency range higher than about 100 Hz as lower frequencies are not excited by the hammer.

Mounting a large number of cladding panels on a concrete wall might cause audible noise. Rigid connection contributes unreserved vibration transmission from wall to cladding panel through the mounting elements.

This work proposes a method of sound pressure level reduction calculation. The method is based on the acceleration vibration measurements and focuses on the most important junction in the transmission path. The method proposed in this paper is sufficient to estimate L_p value but requires certain detailing, which will be the subject of further research.

Additional information

The authors declare no competing financial interests and that all material taken from other sources (including their own published works) is cited and that appropriate permits are obtained.

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