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ANALYSIS OF INFLUENCING FACTORS THAT CONCERN THE UNCERTAINTY OF MEASUREMENT OF SOUND INSULATION IN SMALL TRANSMISSION ROOMS

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ABSTRACT

This paper is focused on analysis of the Laboratory of Building Acoustics 1 (the Faculty of Civil Engineering of Slovak University of Technology in Bratislava (STUBA)). The aim of the presented work is to show a quasi-complete analysis of the given laboratory, that consist of definition of its limits, summarizing weak points and proposal for optimized measurements. The paper consists of two main parts (i) the assessment of sound field in the receiving room and (ii) the determination of the maximal measured sound insulation in the transmission suite. Soon, the fundamental reconstruction and innovation of the laboratory will be undertaken. Therefore, all achieved results and information should be implemented into the new project.

INTRODUCTION

The airborne sound insulation is defined as a ratio between an incident sound energy on the separating structure (from the one side) and radiated energy (from the other side). In technical acoustics, the measurement of sound transmission is typically based on measurement of an average sound pressure level in a sending room, average sound pressure level in a receiving room. However, sound pressure in enclosed environment strongly dependent on the acoustic field, e.g. boundary conditions such as volume and shape of the room, sound absorbing properties of interior surfaces etc. This is also one of the reasons, why theoretical calculation of sound reduction index (e.g. without taking rooms into account) give often different results in comparison with measurements, especially in frequency range affected by non- diffuse field. It is known that the sound field is one of the factors that directly influence an uncertainty of laboratory measurement. The assessment of uncertainty level is usually performed by so-called inter-laboratory tests (Round robin tests). Without participation on such tests, only so-called within-laboratory analysis of the standard deviation and reciprocity of the laboratory measurements can be done [1]. The Faculty of Civil Engineering of Slovak University of Technology in Bratislava (STUBA) includes two Laboratories of Building Acoustics: (1) “Central laboratory of the faculty of civil engineering” in Trnávka and the (2) “Laboratory of Building Acoustics 1” inside the building of the Faculty of Civil engineering (Radlinského 11). This paper is focused on analysis of the Laboratory of Building Acoustics 1 which was built in 70ties of 20th century [2]. This laboratory is mainly used for uncertificated measurements of sound insulation of facade specimen prototypes and research purposes.

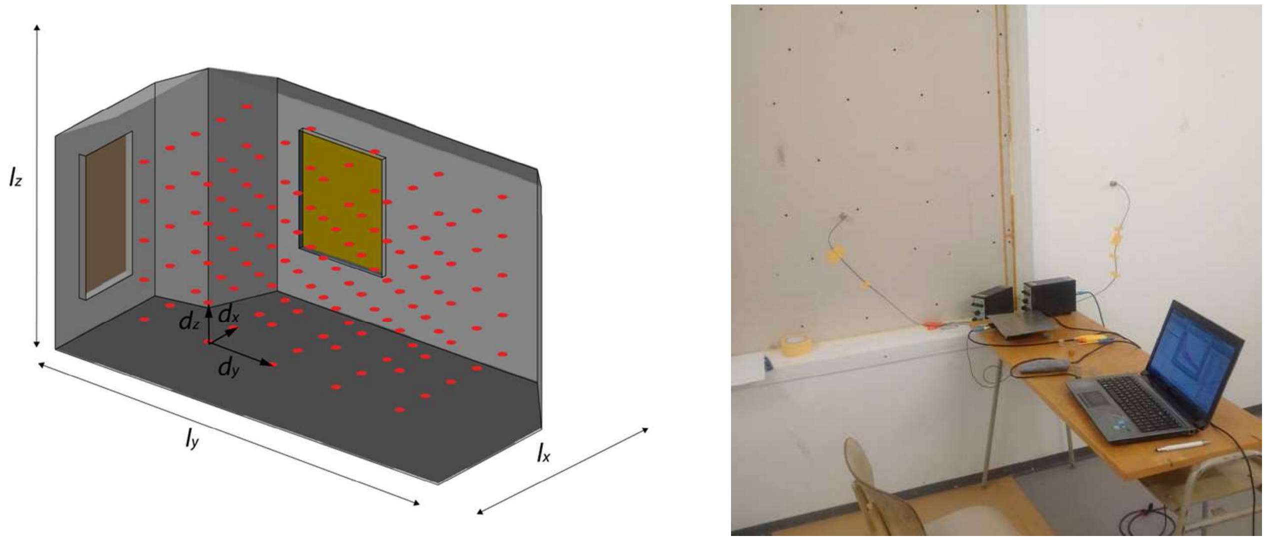
The aim of the presented work is to show a quasi-complete analysis of the given laboratory, that consist of definition of its limits, summarizing weak points and proposal for optimized measurements. The paper consists of two main parts (i) the assessment of sound field in the receiving room and (ii) the determination of the maximal measured sound insulation in the transmission suite. Soon, the fundamental reconstruction and innovation of the laboratory will be undertaken. Therefore, all achieved results and information should be implemented into the new project.

SOUND TRANSMISSION SUITE DESCRIPTION

The laboratory consists of four rooms. On the 1st floor, there is a control room, sending room (SR) and receiving room (RR) used for tests on vertical constructions (walls, windows doors). On the 2nd floor there is sending room used for tests of horizontal constructions (such as ceilings and floors). In this paper, we focus on rooms SR and RR on the 1st floor. The volume of SR (or RR) is reaching just the minimal limit value of 50 m^3 given by the standard ISO 10140-5 [3]. The laboratory testing wall consists of masonry core wall of thickness 0.45 m with testing opening of size 1190x1500mm /1290x1550mm in accordance to the standard. In the past, the improvement in the maximum measurable airborne sound reduction index was needed and therefore the testing wall was acoustically improved by additional plasterboard lining (layer of plasterboard glued on the porous absorptive layer Audiotec of 40mm). The other walls in the RR and SR were lined too. The second reason for application of additional sound insulation, was to decrease a background noise and flanking transmission during measurements. The testing opening was specially lined by steel plates.

SOUND FIELD ANALYSIS IN RECEIVING ROOM

Both transmission rooms (RR and SR) are of comparable volume and shape. From the practical reason the sound field analysis was carried out just in receiving room with maximal interior dimensions 5.95 x2.85 x3.4m (Fig.1).



a) b)

Figure 1 a) The scheme of microphone positions spacing (room maximal dimensions l_x=2.9m; l_y=6m; l_z=3.44m; the measurement mesh resolution d_x= 0.48m; d_y=1m; d_z=0.57m) b) The vibrometry analysis measurement setup.

One of the disadvantage in this laboratory is the fact, that all opposite walls are parallel. For reason of increasing the diffusiveness of the sound field inside the room, a gypsum board lining has been applied at some corners. This, thought a good idea however makes the room volume even smaller.

Calculations

First the room modes were calculated. The two calculation approaches were used, the 3D FEM model and analytical model based on eq.(1), where *n* denotes the room mode order.

$$f = \frac{c}{2}\sqrt{\frac{n_x^2}{l_x^2} + \frac{n_y^2}{l_y^2} + \frac{n_z^2}{l_z^2}} \tag{1}$$

The Schroeder frequency was calculated by means of eq. (2) where *T* is reverberation time of the RR. This frequency is considered as the limit frequency at which the sound field becomes to be diffuse.

$$f_{Schroeder} = 2000\sqrt{\frac{T}{V}} \tag{2}$$

Measurements

In the 2nd step, the room impulse response measurement were performed in situ. The measurement setup consisted of condenser reference microphone Behringer ECM8000 charged by DAQ Roland duocapture-ex. The measurement hardware was driven by home-made Matlab routine. The sound source used during the measurements was an omnidirectional dodecahedron loudspeaker Nor276 amplified by sound amplifier Nor280. The excitation signal was logarithmic sweep signal. The measurement were performed on 125 measurement points, forming a very fine grid with 5 nodes in each axis (Fig.1). The spacing of the nodes, e.g. the mesh resolution was d_x= 0.48m; d_y=1m; d_z=0.57m.

Based on the measurement, the average reverberation time of the room was calculated (Fig.5) and reverberation radius r_c was calculated according to the Eq.3., where γ denotes the sound source directivity factor.

$$r_c = 0.057\sqrt{\frac{\gamma V}{T}} \qquad (3)$$

The room geometry (the length of the laboratory is twice as long as its width) motivated us to analyse also the sound distribution in the room by means of room acoustic prediction software in a 3D model. Room acoustic predictions were performed in software CATT acoustic and ODEON.

TESTING THE LIMITS OF MEASUREMENT OF SOUND INSULATION OF WALL

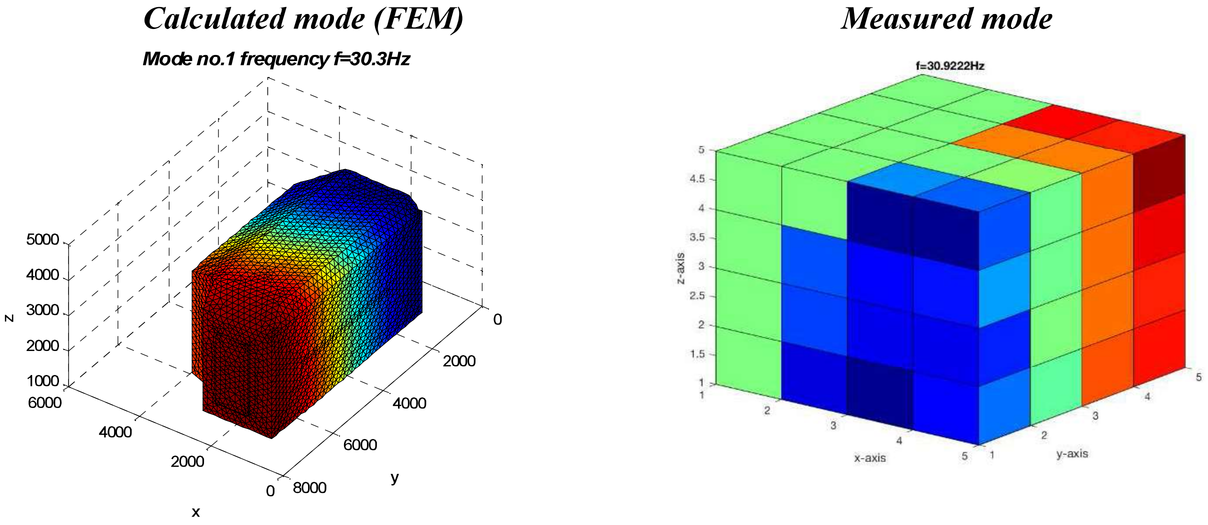
The testing wall (or opening) limits were measured by using two approaches. The first one was based on the laboratory airborne sound insulation measurement done in accordance to the standard ISO 10140-2 [4]. The measurements were taken by Norsonic measurement setup. The principle was to achieve the highest measurable R spectrum. The tested specimen has been partially improved by adding additional layer (and measured) until the R spectrum didn't significantly changed anymore.

The second approach was based on the vibrometry measurement approach in accordance to the ISO 10848-1 [5]. The reason was to check if the vibration amplitudes measured on the specimen surface were smaller than vibrations at the testing wall surface during airborne sound excitation. Vibration amplitude spectra were evaluated as average velocity levels L_v (dB). The additional measurement of L_v at the steel opening lining was done. To obtain the information about a junction between elements (in our case between specimen and the testing wall), the vibration reduction index K_{ij} (dB) was also determined. Vibration measurements were done by using Bruel&Kjaer hardware and home made software in Matlab.

RESULTS

Sound field analysis

The RR modes were calculated and measured as well. For sake of simplicity and limited length of this paper, the comparison of room modes was performed only for first four room modes (Fig.2). It can be seen that the measured and calculated modes and frequency responses are rather comparable. The first mode of the SR is at 30Hz. The spectrum of the room response achieved by the microphone measurement is shown on figure 3.



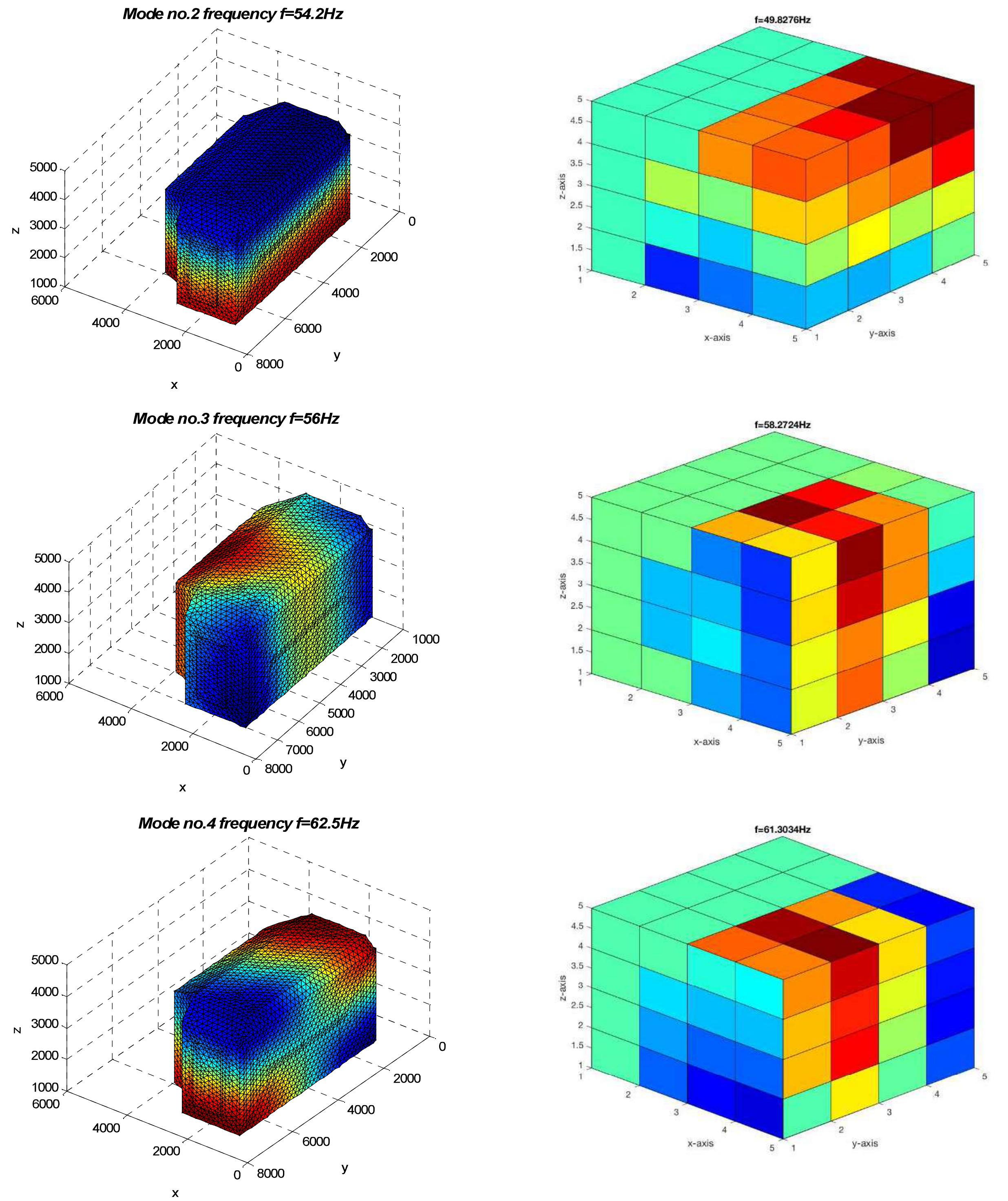


Figure 2 The comparison of calculated and measured firs four room modes.

The peaks in the frequency spectra of mean sound pressure level measured in the specific plane in [xy], [xz] and [yz] coordinates denote the room modes. The vertical dashed lines denote the Finite Element Model (FEM) calculated eigen modes.

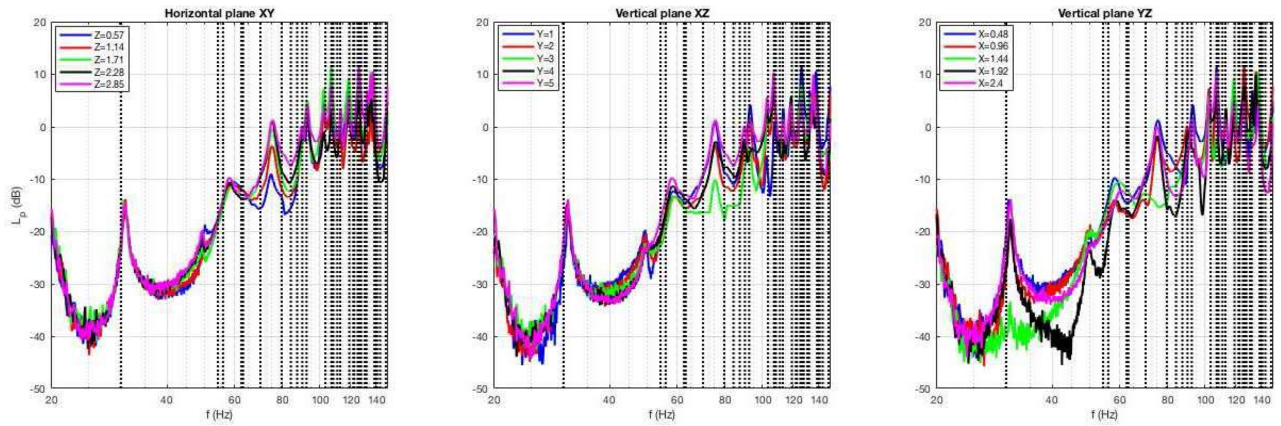


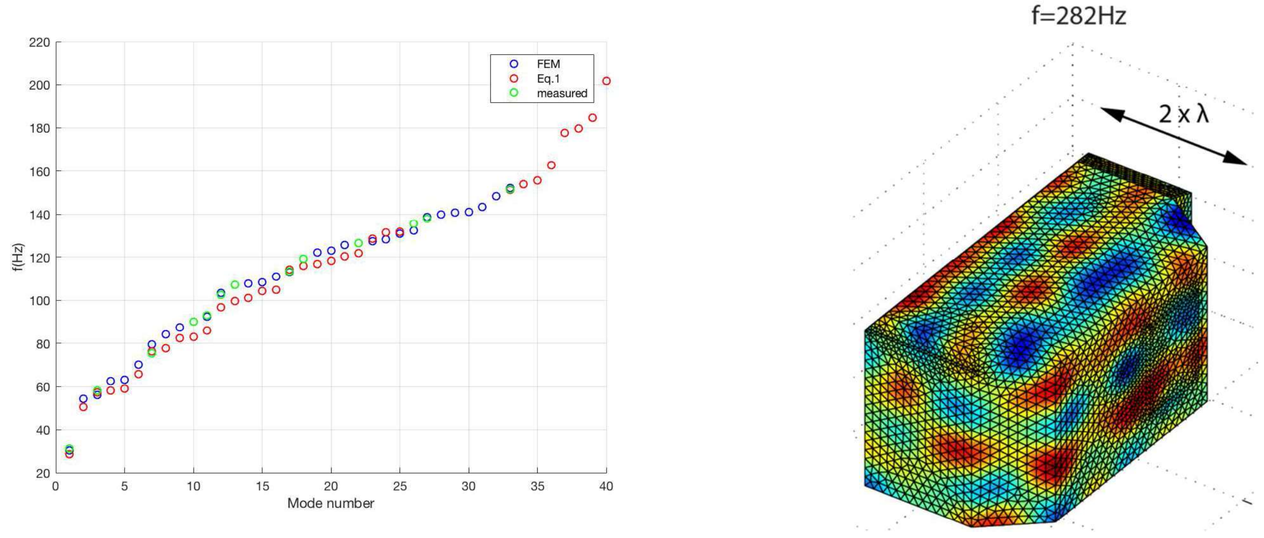
Figure 3 Acoustic field response in XY, XZ and YZ measurement plane in frequency range from 20 to 150 Hz.

The comparison of resulting calculated and measured room modes is shown in Figure 4. FEM calculated and measured results fit quite well. Some divergences are in comparison with results achieved by eq. (1) probably caused by simplification of geometry in simple calculation formula. Equation 1 considers the room as a simple block and all influences of the skewed edges are neglected.

The calculated Schroeder frequency was around 340 Hz. By precise digging in the modal analysis data, the possibly highest problematic mode caused closest parallel walls occurs at frequency 282 Hz (Fig. 4b). The reverberation time in the sending room was analysed as well. The average third octave T_{30} (s) values are plotted in the Figure 5. The recommended T in the transmission rooms is in the range from 1 to 2 s. Analysis of the reverberation time results yield in rather unusual spectrum of reverberation time, with a significant dip at low frequencies. The dip might be caused by high sound absorption properties of plasterboard lining in low frequencies. The lining possibly behaves as planar absorptive resonator. Resonance frequency analyses was therefore calculated by Eq.(4), where the mass and cavity thickness filled by absorptive material are given by m(kg/m^2) and d(m).

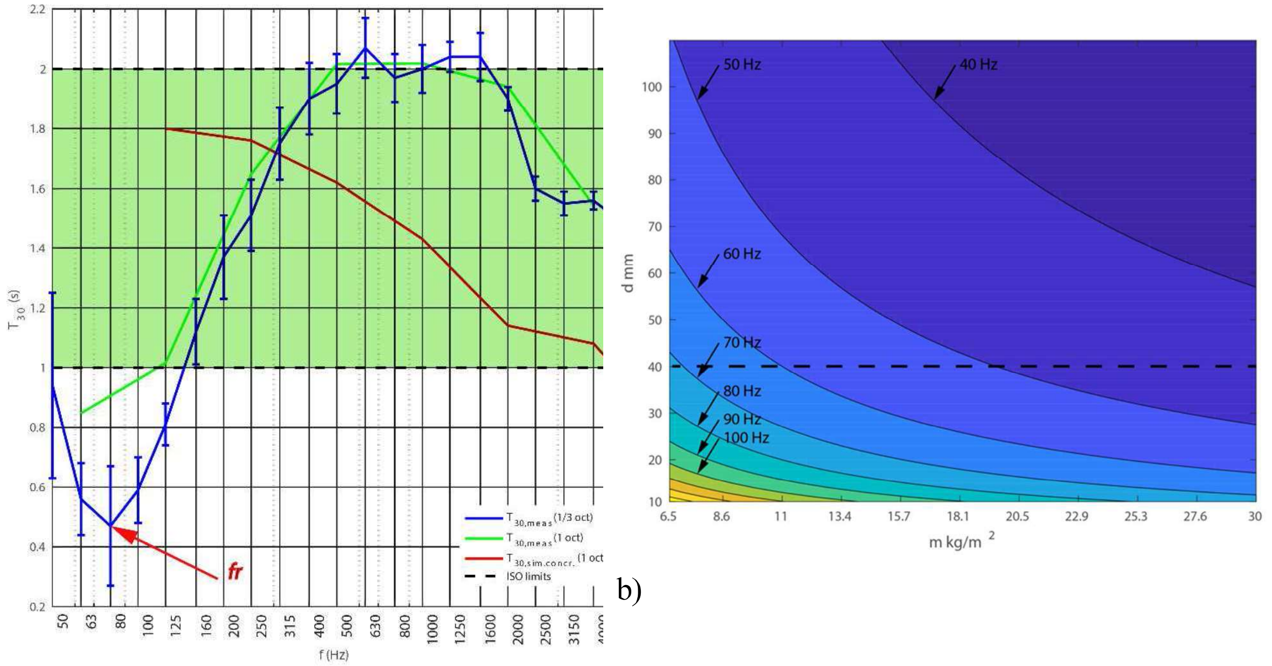
$$f_r = \frac{60}{\sqrt{(\mathrm{m.d})}} \tag{4}$$

The exact thicknesses and material properties were not known, therefore a certain estimation based on experience was necessary. The mass and the cavity thickness variables were given in the range m= 6.5 to 30 kg/m^2 d=50 to 150 mm (Fig.5b). The analytical calculation shows the theoretical ‘effective absorptive resonance’ is in the range from 50 to 80 Hz, which confirms our hypothesis.



a) b)

Figure 4 a) The comparison of calculated and measured first 40 room modes. b) The 4th dominant mode in x-axis.

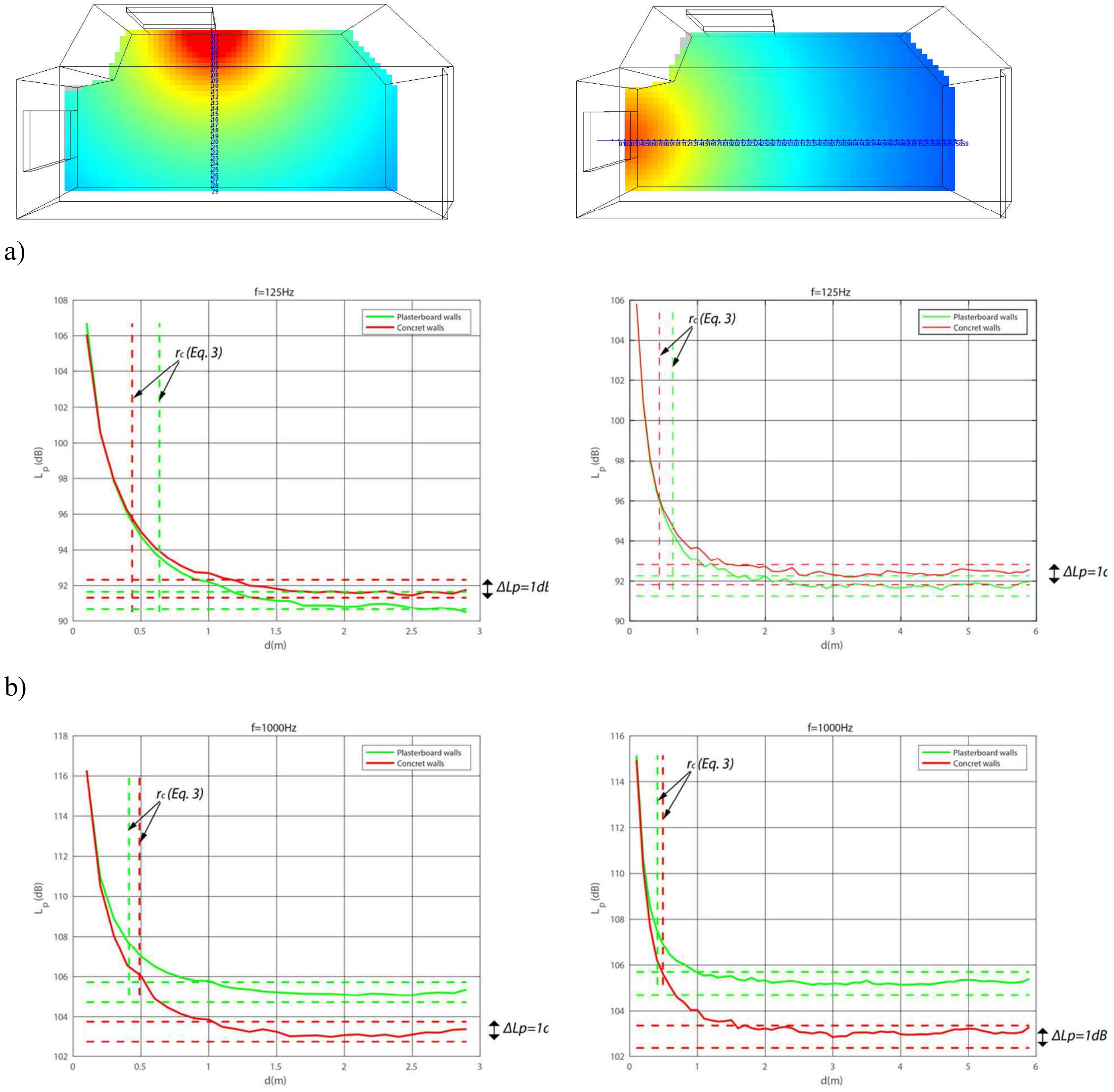


b)

a)

Figure 5 a) Measured *T_{30}* in third octave band with *STD* (blue line) and in full octave band (green line); predicted *T_{30}* with concrete walls in SR (red line). The recommended reverberation time range in accordance to the ISO 10140-5 (green area). b) Calculated dependence of planar absorptive resonator frequency on the mass and absorptive cavity thickness.

In the next step, the unusual shape of the laboratory room was considered. With respect to the ISO requirements and the relatively small size of the room in x-direction, the reverberation radius was theoretically examined. Two approaches were used: (1) calculation based on T_{30} measured data (Eq.3) and (2) the analysis of the sound pressure level L_p distribution from point source Fig.6. by means of 3D simulation model in CATT acoustic and calculation of the surface source in ODEON software. L_p distribution on a cross and longitudinal direction from the source in step of 0.1m was examined. Analysis was done for current situation and for case if the plasterboard wall were replaced by concrete rigid wall. The T_{30} spectrum of this theoretical case is shown in figure 5a (red). The goal was to find distance from the source, where L_p will not be decreased or fluctuated more than 1dB to be considered as stable (denoted by horizontal lines for each case Fig. 6). The reverberation radius r_c was calculated and implemented to the figure as well. The r_c and L_p is frequency dependent. Based on the calculated and measured data it can be concluded, that the r_c for case of the concrete wall surface is shorter in low frequencies caused by higher sound reflectivity. The L_p seems to be stable in distance >1.2 m from the source for f=125Hz and in distance >1m for f=1000Hz (in cross dimension). Therefore, to achieving stable sound pressure level area for airborne sound insulation measurement, can be used are of 0.8x3x1.5m.



a)

b)

c)

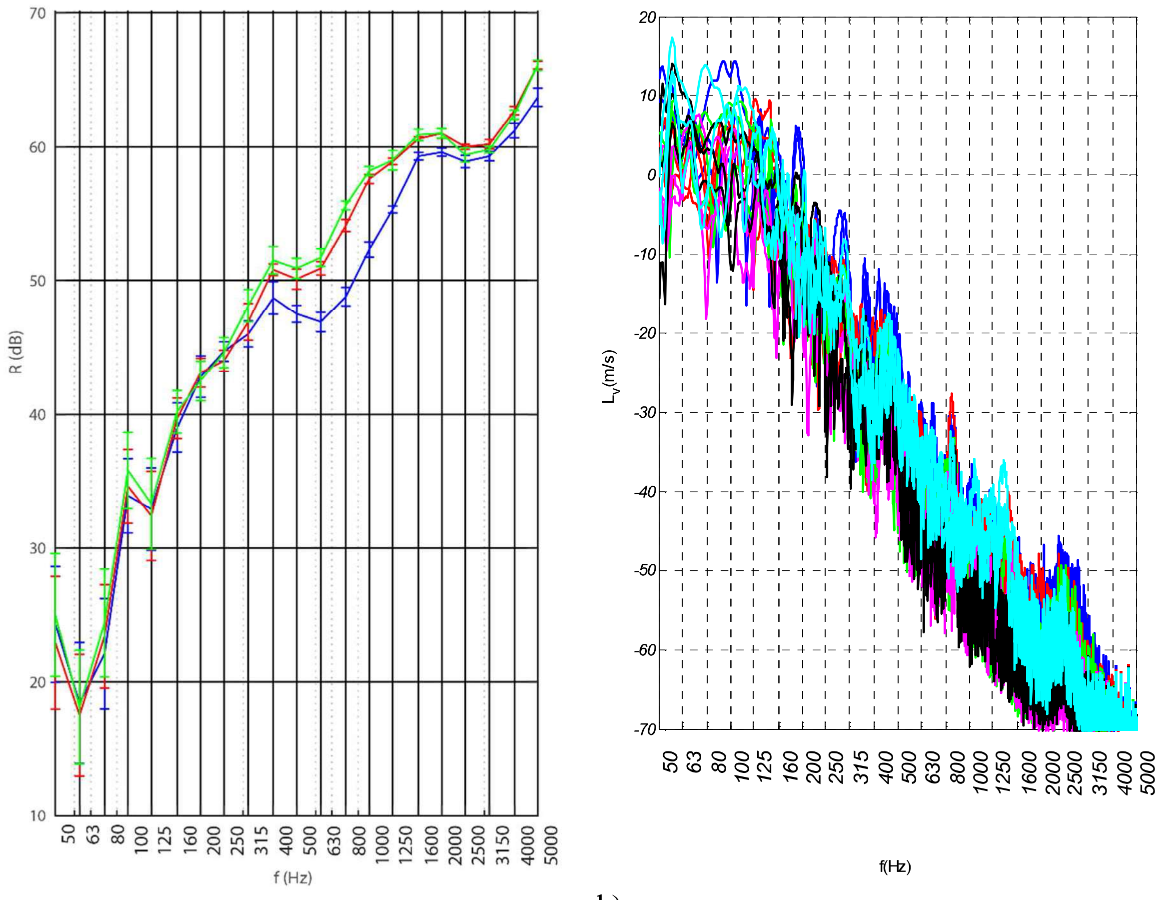
Figure 6 Sound pressure level distribution from point source in the cross and longitudinal direction. a) L_p propagation map in current situation for f=1kHz. b) L_p as function of the distance from the source for f=125Hz and c) for f=1kHz.

The testing wall limits measurement

The main goal of this examination was determining the maximal airborne sound insulation that can be measured in the laboratory by a standardized approach. The procedure used in this experiment can be described as follows: first, a massive core was mounted to the opening and R value was measured. Subsequently the additional layers were applied in steps until the R spectrum stopped to change. To reach this situation, just three variations were necessary.

The 1st variant (the basic massive core) consisted of double leaf concrete wall (2x40mm of concrete). The gap between was 20mm thick filled by porous absorptive material based on recycled foam material. The resulting rate number in accordance to the standard ISO717-1 [6] is shown in the table 1. The airborne sound insulation spectra with measurement *STD* included can be seen in figure 7a (blue). As we see, the *STD* is from 3 to 9dB up to f=200Hz. It is caused by significant room acoustic influence on *Lp* measurement uncertainty. The measured airborne sound insulation index was $R_w(C; C_{tr})$=53(-3;-6) dB.

The 2nd variant was built by adding additional layer-structure from one of the sides. The layer-structure consisted of three layers of dense absorptive material *STERED* (recycled material based on textile and rubber- the waste from car industry material used for car interiors). The absorptive layer was closed by double layer of screwed plasterboards of thickness 2x12.5 mm. By adding the additional layer, R spectrum was improved in range above f=250Hz. All differences in spectra below can neglected refer to high *STD* in low frequencies.



a) b)

Figure 7 a) Measured sound reduction index *R* spectrum (variant 1- blue; variant 2- red; variant 3- green). b) Testing wall lining vibration response. The acceleration in the frequency range from 50 to 5000 Hz.

In the 3rd variant, an additional layer from the opposite side (of the previous case) was added. The lining consisted of 50 mm layer of mineral wool closed by doubled plasterboard 2x12,5mm. In this case, the R spectrum (or its parts) haven’t significantly changed anymore. One would say, there could be still some improvement in the range 500 to 1kHz. However, change the investigation didn't continue further.

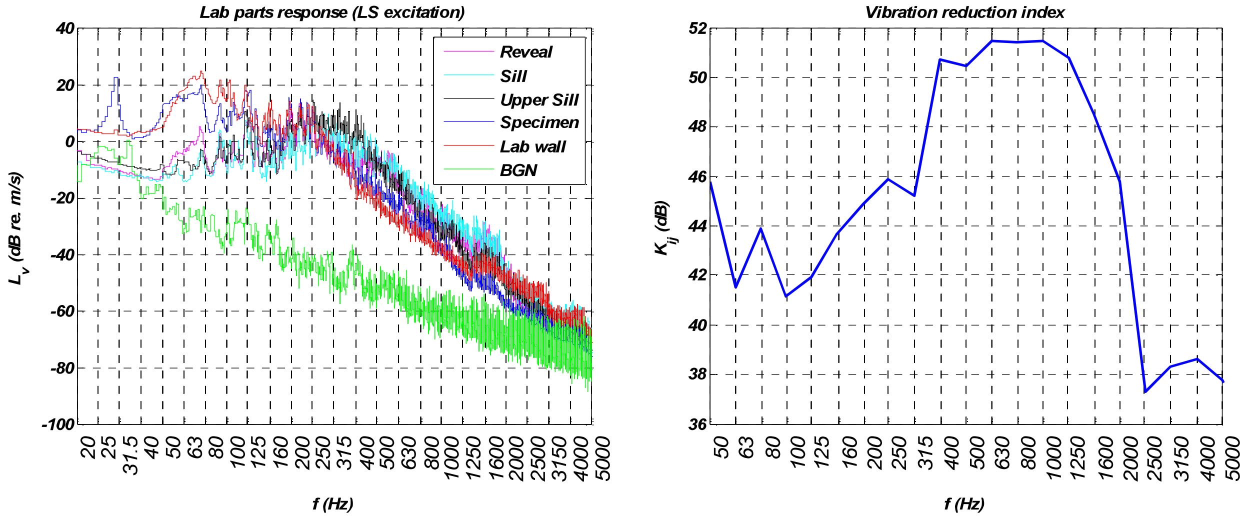
Table 1 Results of the single number rating of airborne sound insulation

Variant	R_w (dB)	C (dB)	C_{tr} (dB)	$C_{50\text{-}3150}$ (dB)	$C_{tr,50\text{-}3150}$ (dB)	$C_{50\text{-}5000}$ (dB)	$C_{tr,50\text{-}5000}$ (dB)	$C_{100\text{-}5000}$ (dB)	$C_{tr,100\text{-}5000}$ (dB)
1	53	-3	-6	-5	-15	-4	-15	-2	-6
2	55	-3	-7	-6	-17	-5	-17	-2	-7
3	55	-2	-7	-6	-16	-5	-16	-1	-7

The second approach was to determine the mean velocity level at surfaces of testing wall, specimen and opening lining as well.

Vibration measurements were done under airborne sound excitation and by impact noise excitation afterwards. The loudspeaker excitation surface vibration responses are on figure 8a. It needs to be noted, that even just by touching the specimen, testing wall and surrounded walls by hand, it was possible to feel significant differences in vibration amplitudes. (The testing wall and surrounded walls (or its lining) vibrated much stronger), which confirms, that the specimen´s transmission loss was higher than the testing wall. The vibration distribution by the lining system to the bounded walls is pointed as a weak point of the receiving room. The acceleration response of the opening steel lining was measured. In almost the full range of sound insulation spectrum, the specimen vibration response was lower or equal to the testing wall. Just in frequency range between 500 and 1000Hz the specimen vibrated slightly more. This agrees with the dilemma mentioned in the section above (space or improvement of a specimen in this frequency range).

Interesting is also the resonance peak at f=30Hz of a specimen (possibly the first natural mode) luckily located out of the sound insulation range. Interesting are also results on the testing opening linings. In the range above 250Hz, the steel plate lining started to resonate stronger than other surfaces. Opening linings resonances were not uniform, caused by ununiformed fixing of the plates. Anyway, the occurred resonances could negatively influence the measurement data. For the vibration reduction index K_{ij} determination, the impact noise excitation was used (impact excitation by hammer). The rough response of testing wall lining was measured (Fig.7b). The receiving and excitation points were chosen randomly. Several of them were possibly situated in the node of the construction modal response. It explains the acceleration magnitude variation of the measured peaks. Anyhow, the first three peaks (possibly lining modes) were in the range 50 to 80Hz. The K_{ij} results are in Fig8b. The energy propagation by junction between elements denoted by K_{ij} shows the specimen was best attenuated in spectrum from 400 to 1600Hz.



a) b)

Figure 8 a) The vibration response spectra (loudspeaker excitation). b) The vibration reduction index between specimen and testing wall.

CONCLUSIONS

This work was focused on the determination of the limits of airborne sound insulation measurement and on sound filed analysis in the building acoustic. The Schroeder frequency has been found in the range of 280 to 340 Hz. Based on reverberation radius analysis the field where the sound pressure level doesn´t fluctuate more than 1dB was specified. The relatively high sound absorption of walls in RR at low frequencies were measured and confirmed by calculation. It is caused by lining system on the wall corners, what behave as bass traps. It was both confirmed by ray-tracing calculations and by vibration measurements. The vibration measurements show in the frequency range with high absorption also high velocity values of the lining. The measured limit sound reduction index was estimated to be R_w = 55dB. The high measurements STD in spectrum below 250 Hz caused room acoustics problems was measured. The testing wall and specimen vibration response was measured by vibrometry technique. Unfortunately, the lining system propagates the vibrations all around the RR walls. Also, negative influence of testing opening by steel plate lining and its ununiformed connection was observed. In this analysis the flanking transmission via surrounded walls ceiling and floor and the transmission in the vertical direction from the sending room upstairs was not examined. This room exceeds the booth transmission rooms below. This assessment should be done as well in the future. The entrance doors to the transmission rooms need to be replaced. The problems caused by high background noise level caused by operation in sport and technical facilities in the adjacent rooms. This needs to be examined in future as well.

ACKNOWLEDGEMENTS

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