Measurements of Diffuse Field Absorption of Audience at Low Frequencies

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Introduction

Correct absorption coefficients of audience are important to predict reverberation time in occupied concert halls. A lot of measurements were conducted, for example by L.Beranek in 1960 [1] and Kuhl&Kath in 1964 [2], but they were mainly restricted to the frequencies above 100Hz due to the lack of interest in the lower frequency range or to the sizes of available reverberation chambers. Modern sound reinforcement systems extend the reproduced frequency range down to 20 Hz, so corresponding data are required. In the present paper we aim to obtain the data from diffuse field measurements in a regular-sized reverberation chamber and to find out if there is any influence of the density of the audience on the absorption.

Measurement Method

The measurements were conducted in a reverberation chamber of 217m³ volume, 220m² surface area and reverberation time of about 4s. A group of 20 students took part in the experiment which allowed to measure three densities of the audience: 3.8 pers./m², when people stand very close to each other, 1.5 pers./m³ and 0.5 pers./m². To avoid the influence of the increase of sound pressure level close to the walls, the participants were asked to stay 0.5m away from the walls. The measurement setup is shown on fig.1.

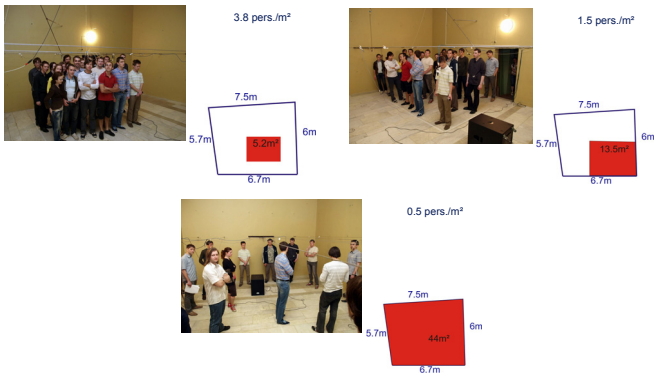

Figure 1: Measurements setup: audience of three different densities.

We are interested in total absorption per person and not area absorption coefficient, so only the total absorption was calculated. The frequency range of interest is 30Hz – 100Hz

The usual method to measure absorption or absorption coefficients is the diffuse field method according to the ISO 354. Impulse responses were measured using a sweep signal, three loudspeaker positions and four microphone positions for every density of the audience, which results in 12 impulse responses for every density.

However, the Schroeder frequency of the reverberation chamber is about 163 Hz, so the frequency range of interest is in the range of strong modes (fig.2)

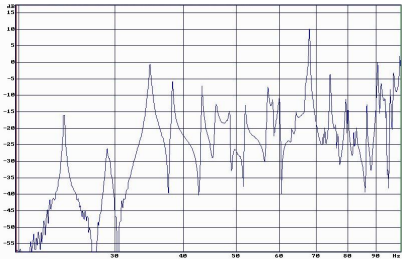

Figure 2: Frequency response of the reverberation chamber at low frequencies.

According to ISO 354, evaluation of the reverberation time and absorption should be done in 1/3 octave frequency bands which are relatively broad at low frequencies. To find out if the calculation in 1/3 octave bands still gives correct results, an alternative method was used to calculate the reverberation time and absorption of the audience:

If modes don't overlap too much, the Q-factor of a single mode can be defined from its -3dB level, and then the decay time according to fig.3.

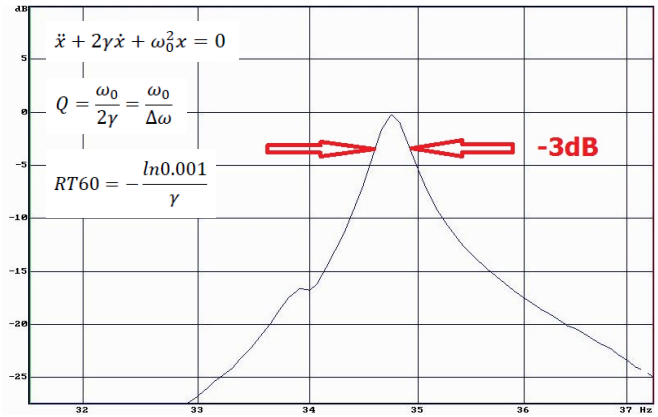

Figure 3: Calculation of modal decay time.

Five single modes (24, 34, 38, 43 and 48 Hz) were picked in the lowest frequency range to compare with the calculation according to ISO 354. The Q-factor and the decay time was calculated for all the 12 measurements for each density and the empty room, then the average decay time is calculated for each mode, and from the difference in decay times for each mode in the empty and occupied room the absorption is calculated.

Reverberation time

The reverberation time of the empty room is shown on fig.4.

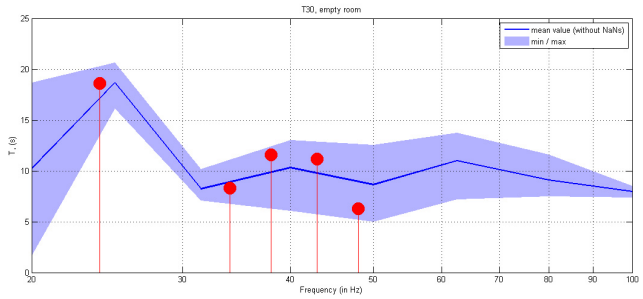

Figure 4: Reverberation time of the empty chamber. Blue line: calculated according to ISO 354, red dots: calculated from the modal decay.

Measurements results

Absorption (per person) is shown on fig. 5-7 for different densities. The calculation using modal decay corresponds well with the calculation in 1/3 octave frequency bands according to ISO 354

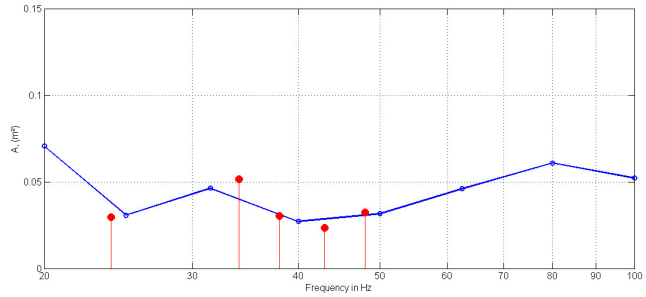

Figure 5: Absorption per person for the audience density of **3.8 pers./m²**. Blue line: calculated according to ISO 354, red dots: calculated from the modal decay.

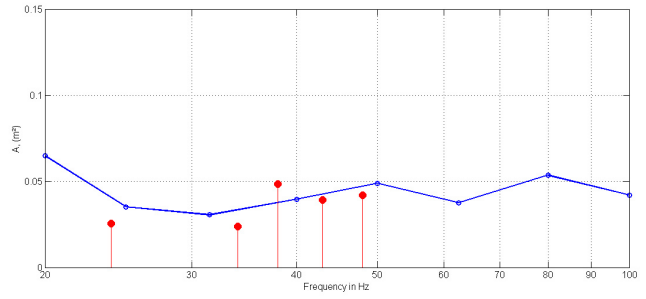

Figure 6: Absorption per person for the audience density of **1.5 pers./m².** Blue line: calculated according to ISO 354, red dots: calculated from the modal decay.

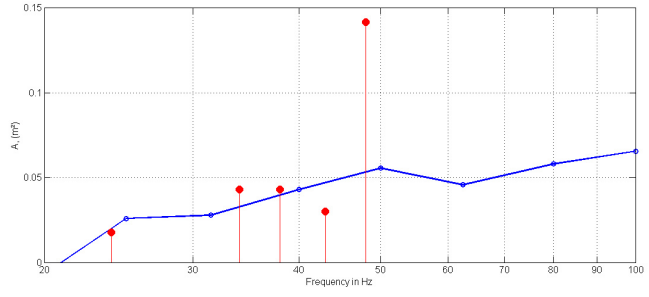

Figure 7: Absorption per person for the audience density of **0.5 pers./m²**. Blue line: calculated according to ISO 354, red dots: calculated from the modal decay.

The following picture shows absorption of the three densities together. The values are very close to each other.

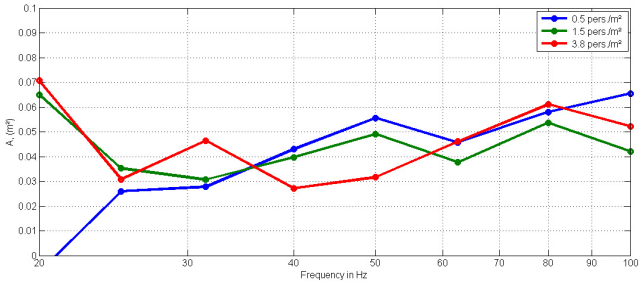

Figure 8: Absorption per person for the audience density of 0.5 pers./m² (blue), 1.5 pers./m² (green) and 3.8 pers./m² (red).

Table 1: Absorption of audience

Density, pers./m²	Frequency, Hz						
	31	**40**	**50**	**63**	**80**	**90**	**100**
3.8	0.05	0.03	0.03	0.046	0.06	0.055	0.05
1.5	0.036	0.04	0.05	0.04	0.055	0.05	0.045
0.5	0.028	0.045	0.055	0.048	0.06	0.065	0.07

Conclusions

- absorption of audience at 30Hz – 100Hz lies within 0.02 – 0.07m² per person, which corresponds well with the values obtained in [1] at 100 Hz;
- dense audience seems to absorb more at 20Hz – 40Hz
- calculation according to ISO 354 and calculation of modal decay give similar results

Outlook

Presented results provide the information about low frequency absorption of audience. However, measurements in a larger reverberation chamber, which provides a diffuse field also at the lowest frequencies, are likely to give better frequency resolution and therefore more accurate results.

Literature

[1] U.Kath, W.Kuhl, Acustica, 15 (1965) 127

[2] L.Beranek, JAES, 32 (1960) 661

[3] E.Meyer, D.Kunstmann, H.Kuttruff, Acustica, 14 (1965) 119

[4] ISO 354