SOUND PROPAGATION IN AN ANECHOIC LONG ROOM

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ABSTRACT[*]

Sound propagation in a shooting gallery has been studied experimentally. The gallery is a long room with a ceiling and walls covered by sound absorbing materials. The sound attenuation along the room and the reverberation time were measured and analyzed. It was found that sound level decreased lineally with a distance from a source with the attenuation coefficient 0.5-1 dB/m. The reverberation time is 0.2-0.4 s at middle frequencies and it is not constant along the room. The experimental results are compared with the simulation in ODEON. It is found that the measured and calculated sound decays are very different. The linear sound decreasing coincides with the theory of sound propagation in ducts, whereas the sound field in the simulated room behaves like in free space.

Keywords: *sound attenuation, long room, reverberation time, simulation.*

1. INTRODUCTION

Acoustic comfort in rooms of different types is usually provided by means of sound absorbing treatments. In case of the long rooms, for example, galleries, corridors, tunnels and so on, we deal with anechoic non-diffuse enclosures. To describe the sound propagation in them one can use the theory of ducts with impedance walls [1] or other classical approaches [2,3]. Today the theory of sound field in long rooms is being intensively developed [4-12]. At the same time, we can observe a lack of experimental data for full-scale rooms.

This paper focuses on the case study of a long room which surfaces are covered by sound absorbing materials. Moreover, the studied room has the simplest form of a rectangular parallelepiped, which is usually considered as non-randomizing [13]. Additionally, the preliminary simulation of sound propagation in the similar room by a regular software is discussed, and the experimental results are compared with the simulation.

2. MEASURMENTS IN THE SHOOTING GALLERY

The study of sound propagation was carried out in the shooting gallery with a length of 55 m, a width of 6 m and a height of 2.5 m. The ceiling and all walls are covered by a sound absorbing treatment (25 mm wood panels with 50 mm glass wool layer), the floor is hard. So, the gallery is a good example of an anechoic long room. Its scheme is shown in Figure 1.

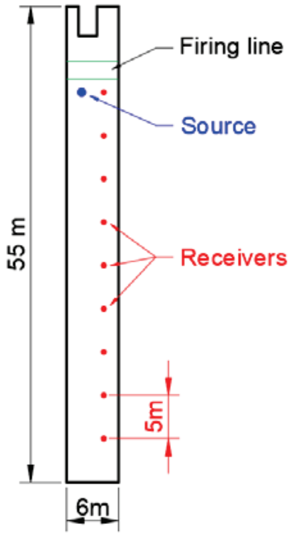

Figure 1. Scheme of the shooting gallery.

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An omnidirectional sound source was placed near a firing line, a receiver was placed in nine points along the gallery with 5 m gaps. All measurements were performed at nine source-receiver positions.

2.1 Sound pressure attenuation

The first goal was to find the sound pressure level attenuation with a distance. The source radiated wideband noise, which was recorded by the microphone in the receiver positions. After that the measurement results were analyzed in octave bands. Figure 2 shows the dependance of the sound pressure level at 1000 Hz octave band on the source-receiver distance.

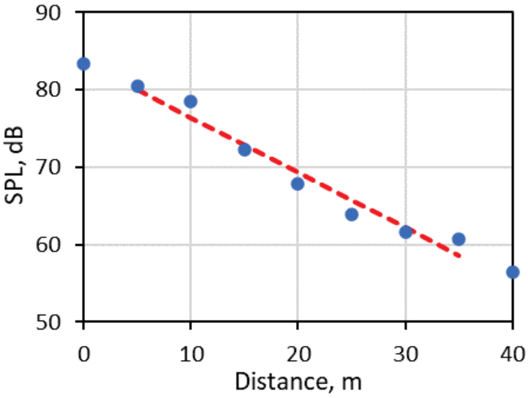

Figure 2. Measured SPL (points) at 1000 Hz for the source-receiver distance and linear approximation (red line).

We can note the points in Figure 2 are close to a linear function. Let us assume that the sound pressure level is the linear function of the distance and find the function using seven points. The nearest point is excluded to minimize the effect of a near sound field, the farest one is close to the end wall, which reflects sound slightly.

The equation of the linear regression is

$$L = a + br, \tag{1}$$

where L is the sound pressure level, dB; r is the source-receiver distance, m; a and b are regression coefficients.

The regression coefficients are found by means of the least squares approach, and their values are given in Table 1. The found approximation function at 1000 Hz is shown in Figure 2 by the red line.

The coefficient of determination R^2 is given in Table 1 as well. The usual condition $R^2 \geq 0.95$ of the reliable approximation is satisfied at all frequencies except 63 Hz.

Table 1. Regression coefficients.

Frequency, Hz	a, dB	b, dB/m	R^2
63	66.5	-0.20	0.74
125	93.8	-1.07	0.96
250	98.2	-1.15	0.97
500	84.5	-0.75	0.95
1.0k	83.6	-0.71	0.95
2.0k	81.5	-0.50	0.97
4.0k	78.5	-0.69	0.98
8.0k	66.2	-0.71	0.99
16k	44.8	-0.75	0.96

We can accept the assumption of the linear dependence of the sound pressure level on the distance to the source for frequencies 125-16k Hz. It means that the sound pressure depends exponentially on the distance as the theory of ducts predicts [1]. The coefficient b characterizes the attenuation of the sound pressure level along the anechoic room. We see that the level is reduced by 0.5-1 dB per meter.

2.2 Reverberation time

Measurement of the reverberation time T_{20} was carried out in accordance with the standard procedure [14] for the same source-receiver positions. The measurement results for all positions as well as the average value are given in Figure 3. We see that the reverberation time at 125-250 Hz differs slightly from the average value, whereas it varies greatly at 500-4k Hz. The maximum value exceeds the minimum one by about two times.

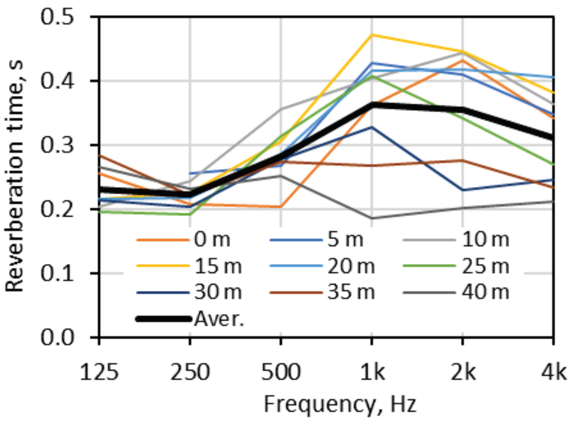

Figure 3. Reverberation time for different distances between the source and the receiver.

Figure 4 demonstrates changes of the reverberation time with the distance. At 250 and 500 Hz the reverberation time at 10 m and further does not vary significantly. But at higher frequencies it decreases at the distance of 20 m and more.

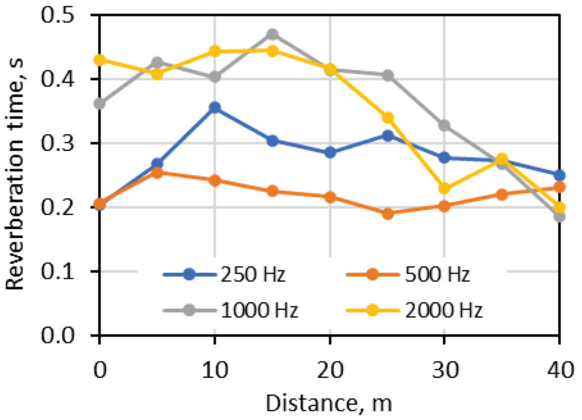

Figure 4. Changes of the reverberation time with the distance.

Note that the found variations of the reverberation time with the distance corelate partially with the previous results [6]. However, additional analysis is required to understand which theory [1-11] best describes the obtained results.

3. SIMULATION

Sound propagation in the anechoic long room was simulated in ODEON. The first case is the studied gallery shown in Figure 1. There is no exact information about absorption coefficient of acoustic treatment of the gallery, therefore the value 0.9 for the absorption coefficient was applied for the ceiling and walls and the value 0.05 for the floor. As an example the sound pressure level distribution at 1000 Hz is given in Figure 5. The simulated parameter decreases with the distance to the source. This trend is shown in Figure 6 by points. It does not look like a linear function.

We can expect that using the ray tracing simulation for an anechoic room the sound field inside it should be similar to the sound field produced by a point source in free space. Sound pressure in free space is

$$|p| \sim 1/r, \tag{2}$$

where r is the distance to the source. The decay law is shown in Figure 6 by the red line.

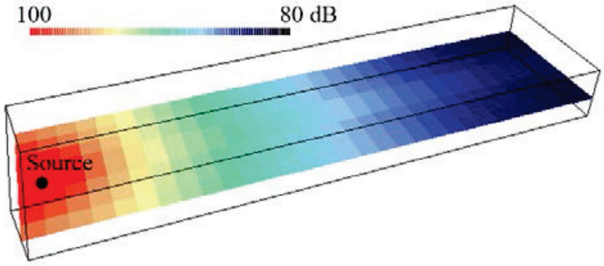

Figure 5. Sound pressure level simulated in ODEON at 1000 Hz.

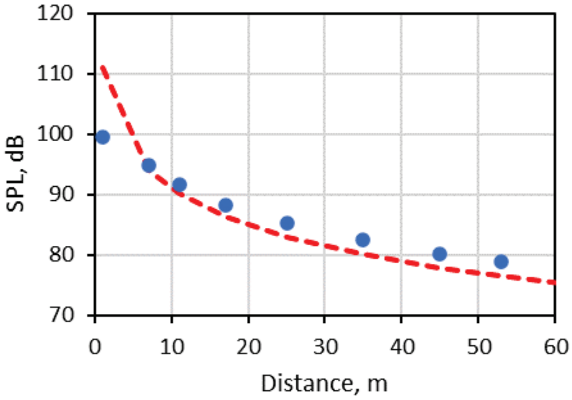

Figure 6. Comparison of the simulation (points) for the room 60 m long and theory of sound propagation in free space (line).

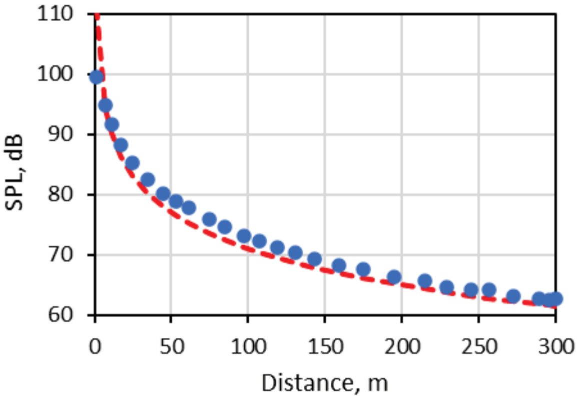

Figure 7. Comparison of the simulation (points) for the room 300 m long and theory of sound propagation in free space (line).

To compare the simulated decay law and the theory given by Eqn. (2) the sound field is calculated in the same gallery but with a length of 300 m. Figure 7 shows the decrease of the sound pressure level along the room. We can see good coincidence of the simulation and theory.

So, the simulated sound pressure attenuation in the anechoic long room and the measured one are fundamentally different. According to the experiment the sound pressure attenuates exponentially along the room, but the simulated sound pressure is inversely proportional to the distance.

4. CONCLUSIONS

Measurements of the sound level attenuation along the anechoic long room and the reverberation time are presented. It is found that the sound pressure reduces exponentially with the distance, whereas the simplest ray-tracing analysis predicts a free field sound attenuation. So, this approach is not suitable for a such kind of enclosures.

The reverberation time for different source-receiver positions varies significantly. It reduces with the distance; this trend correlates with some theories [4].

The presented results reveal the need to improve the theory of sound propagation in the long room with sound absorbing treatment for reliable predictions of acoustic conditions in different rooms including large public spaces [12, 15].

5. ACKNOWLEDGMENTS

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