Room acoustic modelling of a reverberation chamber

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ABSTRACT
This paper aims at comparing measured broadband reverberation time values in the reverberation chamber of Scientific and Technological Research Council of Turkey - National Metrology Institute (TUBITAK-UME) in Gebze, Turkey with the simulated reverberation time values from the room acoustical modelling of the same reverberation chamber. The reverberation chamber in TUBITAK-UME has a volume of 263 m³, total inner surface area of 262 m² and 16 diffusers made of Plexiglas and hung randomly in the room. The majority of the diffusers have hyperbolic shapes. There are also six absorbers to adjust the reverberation time of the room. Indications of difficulties in the calibration of the acoustic model with reference to the measured values and different frequencies are given and the modelling and measurement uncertainties and limitations are discussed.

Keywords: reverberation chamber, Plexiglas diffusers, acoustic modelling, prediction.

1. INTRODUCTION
It is the aim of the present paper to discuss the architectural surveying and acoustic modelling of the Scientific and Technological Research Council of Turkey - National Metrology Institute, referred as TUBITAK-UME in the rest of this paper, reverberation chamber and the calibration procedure of the computational model in a ray-tracing software. The program used is ODOEN, version 12.0. This paper also aims at comparing measured broadband reverberation time values in the reverberation chamber with the simulated reverberation time values from the room acoustical modelling of the same reverberation chamber.

The reverberation chamber in TUBITAK-UME has a volume of 263 m³, total inner surface area of 262 m² and 16 diffusers made of Plexiglas and hung randomly in the room. The majority of the diffusers have hyperbolic shapes. There are also six absorbers to adjust the reverberation time of the room. Indications of difficulties in the calibration of the acoustic model with reference to the measured values and different frequencies are given and the modelling and measurement uncertainties and limitations are discussed.

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2. ARCHITECTURAL SURVEYING

In-situ architectural surveying measurements were made at the reverberation chamber of TUBITAK-UME which is located in Gebze, Turkey. The architectural measurements were made with the aid of a laser meter and a traditional measuring tape. The reverberation chamber is almost a rectangle room. However, the in situ measurements indicated that one of the longest walls was 9.7m and the other long wall is 9.69m. One of the shortest walls is 6.6m; while the other short wall is 6.61m. Therefore, the walls are not completely parallel. The height of the room is 4.1 m. The volume of the room is approximately 263m³. The total inner surface area of the walls is 262 m². Figure 1 below shows the schematic section drawing of the reverberation chamber. The room is built as a box within a box and it has been isolated from the surrounding building. The inner box which form the reverberation chamber stands on large springs that separates its floor from the main building. Access to the room is provided by double access doors which are 1.04m wide and 2.08m high.

![Figure 1](image)

Figure 1 – Schematic section drawing of the reverberation chamber at TUBITAK-UME. (The drawing was taken from TUBITAK UME Acoustics Laboratories)

Reverberation chambers are required to create a diffuse incidence sound field so that the sound from any sound source should be reflected many times to produce a non-directional or diffuse sound field within the room. In order to create this diffuse field, 16 diffusers of various dimensions were installed in the room. These diffusers are made of Plexiglas and hung from the ceiling at different heights in the room. Figure 2 below gives a general interior view of the reverberation chamber and the diffusers.
There are four types of diffusers in the room based on their dimensions. These are named as Type A, Type B, Type C and Type D. Big diffusers are located at the corners of the room. The types, numbers, dimensions, and surface areas of the diffusers are given in detail in Table 1 below.

<table>
<thead>
<tr>
<th>Type</th>
<th>Dimensions (m)</th>
<th>Surface Area (m²)</th>
<th>Quantity</th>
<th>Total Surface Area in the room (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.00x1.20</td>
<td>2.40</td>
<td>3</td>
<td>7.20</td>
</tr>
<tr>
<td>B</td>
<td>1.50x1.20</td>
<td>1.80</td>
<td>4</td>
<td>7.20</td>
</tr>
<tr>
<td>C</td>
<td>1.20x0.80</td>
<td>0.96</td>
<td>4</td>
<td>3.84</td>
</tr>
<tr>
<td>D</td>
<td>2.00x1.50</td>
<td>3.00</td>
<td>5</td>
<td>15.00</td>
</tr>
</tbody>
</table>

The in situ locations of each diffuser in the room are determined and measured. There was already a document which described the approximate location of the diffusers on the plan of the room. (1) This document was prepared by TUBITAK UME Acoustic Laboratories. However, this document shows the diffusers as perfect rectangular shapes on the plan. In reality, each diffuser makes a hyperbolic paraboloid shape. This means the projection of the diffusers on the plan are not rectangle anymore and the height of each corner of the diffusers are different. The coordinates of four corners of each diffuser was determined and measured.

The determination of the exact location of each diffuser was a difficult task. The diffusers are hung from the ceiling by three rods. Therefore, they were swinging. In order to solve this problem a rope with a heavy metal material at its end was hung from the corner of each diffuser. After the oscillation stopped, the projection point of each corner on the floor was marked. (Figure 3) After the x and y coordinates were determined and then the length of the rope was measured and this gave the z coordinate of each corner point. After all the coordinates of the corners were determined, the height of the apparent midpoint of the diffuser was measured as well. Figure 3 below shows the architectural measurement procedure and the location of real projection points of each diffuser on the floor.
Figure 3 – The architectural measurement procedure indicating the use of a rope with a heavy metal material at its end (Left figure) Schematic diagram of real projection points on the floor for each diffusor.

All surfaces in the room are painted by epoxy hard concrete paint. On the wall surfaces, there are six absorbers (tuners) to adjust empty reverberation time of the room. Figure 4 below shows three of the absorbers in the room.

Figure 4 – The absorber panels in the reverberation chamber.

3. MEASUREMENTS AND SIMULATIONS

In order to build up the acoustic model of the reverberation chamber in ODEON, insitu measurement values are required to acoustically calibrate the model. Previous insitu measurement data was used as a basis while building the acoustic model. These were reverberation time measurement data. Two sound sources were used to provide broad band noise in the reverberation room. One of them covers low frequency range and was kept fixed at a specific corner of the room in the measurements. The other one is omnidirectional sound source and was located in three different corners in the room during the measurements. Six microphones, which were located at different heights and positions, were used in the measurements. The locations of sound sources and microphones are shown in Figure 5 below. Measurements were performed at 1/3 octave band center frequencies in the frequency range 100 Hz to 10000 Hz. Environmental conditions during RT measurements were monitored and recorded for each measurement. The measured reverberation time at 1000Hz is approximately 7.65 sec. The measured reverberation time values per frequency are given in Table 2 below.
Figure 5 – The source and microphone positions during the measurements. The red circles indicate the source positions while the blue circles indicate the microphone positions.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>7.3</td>
<td>8.86</td>
<td>8.5</td>
<td>7.65</td>
<td>5.91</td>
<td>3.41</td>
</tr>
</tbody>
</table>

The physical model of the reverberation chamber was developed in 3dMax and AutoCAD. Especially difficult was to create the 3d model of the diffusers that were hung from the ceiling. They were modelled as mesh objects with maximum smoothness. Then the geometrical model was imported to ODEON. The wireframe ODEON model is shown in Figure 6 below.

Figure 6 – The 3D wireframe model of the reverberation chamber in ODEON.
The most important task in the modelling was the assignment of the materials to the surfaces. All interior surfaces have epoxy paint, the diffusers are of Plexiglas and there are six absorbers in the room. Since there are no published sound absorption coefficient data for epoxy paint and Plexiglas, a qualified estimation of the absorption coefficients were made. The absorption coefficients of the absorbers were also unknown. Therefore, many runs of the simulations were made with various absorption coefficient estimations. The estimated absorption coefficients for epoxy paint, Plexiglas and the absorbers in the reverberation room are shown in Table 3 below.

Table 3 – Estimated absorption coefficients for epoxy paint, Plexiglas and absorbers.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy paint</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Plexiglas</td>
<td>0.045</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Absorbers</td>
<td>0.01</td>
<td>0.025</td>
<td>0.07</td>
<td>0.11</td>
<td>0.20</td>
<td>0.15</td>
</tr>
</tbody>
</table>

A good match between the measured and simulated values were reached by the estimated absorption coefficients to the surfaces in the reverberation chamber. The calculated reverberation time at 1000Hz is around 7.2 sec. A comparison of the measured and simulated reverberation time values are shown in Table 4 below. Figure 7 below demonstrates calculated reverberation time grid response in the reverberation chamber. The reverberation time grid response also indicates a very good even distribution of reverberation time values across the room.

Table 4 – Comparison of measured and simulated reverberation time values

<table>
<thead>
<tr>
<th>Frequency</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
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<tr>
<td>RT</td>
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<td>8.5</td>
<td>7.65</td>
<td>5.91</td>
<td>3.41</td>
</tr>
<tr>
<td></td>
<td>7.4</td>
<td>8.3</td>
<td>8.35</td>
<td>7.2</td>
<td>5.8</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Figure 7 – Calculated reverberation time grid response in the reverberation chamber at 1000Hz.

4. CONCLUSIONS

The procedure of acoustic modelling of reverberation chamber in TUBITAK UME by ODEON room acoustic modelling software is discussed in this paper. Preliminary results of the acoustic modelling of the reverberation chamber is presented in this paper. An in situ architectural survey of the reverberation chamber was made. The reverberation chamber was almost a rectangle room with 16 diffusors (which have hyperbolic paraboloid shape) hung from the ceiling and six absorbers in the
A three dimensional geometrical model of the room was developed and imported to ODEON. Since no published data existed for the absorption coefficients of the epoxy paint, Plexiglas and since the absorption characteristics of the absorbers were not known, a qualified estimation of absorption coefficients were made. Reverberation time values were calculated in ODEON. Then measured and simulated reverberation time values were compared. The results indicated that a good match between the measured and simulated values could be reached with estimated absorption coefficients. The results also indicated that the room has good diffusion characteristics and the reverberation time distribution across the room was very even as can be seen from the grid response. However, comparison of sound pressure levels between measured and simulated values is required to be done for a more reliable calibration of the model. The absorption coefficients of the absorbers and Plexiglas are required to be determined by measurements in the future. Moreover, scattering coefficients of the diffusors in the ODEON model should be investigated.

ACKNOWLEDGEMENTS

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REFERENCES