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Measurements of the Sound Absorption Coefficient and the Sound Transmission Loss at the Kobayashi Institute of Physical Research

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During the past three years, five reverberation chambers were constructed in out institute. These chambers are now used for the measurements of the sound absorption coefficient and the transmission loss. Chamber No.1 has a volume of 513 m^3 surrounded by nonparallel walls, and the reverberation time of this chamber is greater than 20 sec at 500 cps. In this chamber, the position of the microphone and test specimens does not affect the absorption coefficient. Chambers No.3 and No.4, which are used for transmission loss measurements, have a volume of 164 m^3,
respectively. The shape of these chambers is similar to chamber No.1. The opening between these two chamber is 3.3 m by 3.3 m. Under chamber No.4, there is chamber No.5, which is used for the receiving room for impact sound transmission loss measurements.

INTRODUCTION

In present-day acoustics, noise control or sound conditioning in rooms is one of the most important problems. Under these circumstances, it is necessary to measure the sound absorption characteristics of wall and ceiling materials and the sound insulation characteristics of partitions, windows, or doors.

To this end, five reverberation chambers were constructed in our institute. Two of them were completed in 1956 and have been used for the measurements of the absorption coefficient. One has a volume of 513 m^3 which is surrounded by nonparallel plane walls, and the usual measurements are carried out by using this chamber. The shape and volume of this chamber were determined on the basis of the model room experiments. The other chamber is a rectangular parallelopiped with a volume of 120 m^3 and provided with an air-conditioning apparatus.

The other three chambers are used for the measurements of airborne and impact sound transmission loss.

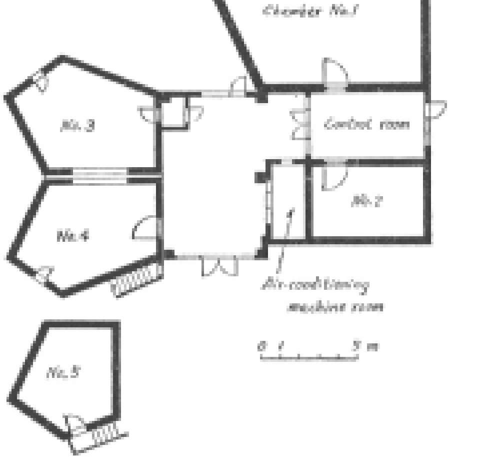

FIG. 1. Plan of the five reverberation chambers used for the measurements of the sound absorption coeficient and the trans-missionloss.

These were constructed in 1959 on the basis of experience with the previously mentioned two reverberation chambers. Two of them have volumes of 164 m^3 each, and the remaining one has a volume of 68 m^3. All of them are surrounded by nonparallel plane walls.

In this paper, a description of these chambers and their fundamental characteristics is presented. Also, several problems concerning measurements of the sound absorption coefficient and the transmission loss are mentioned.

1. DESCRIPTION OF REVERBERATION CHAMBERS

1.1 Basic Concept for the Design of the Chamber

In order to measure the absorption coefficient and transmission loss accurately, a requirement of diffuse distribution of sound energy should be fulfilled throughout the chamber. So far, many attempts have been made to approach this condition by considering the room shape, diffusers, use of microphone and loudspeakers, the position of a sample material, and so on [1]. But, most of the typical reverberation chambers were constructed before the requirements for a diffuse sound field were apprehended from the viewpoint of the present wave theory of acoustics, and so these counterplans have mostly been taken up empirically.

In a sense, as mentioned in the foregoing, we investigated the effect room shape on the sound field in rooms by using two and three dimensional model rooms, in relation to the characteristics of the reverberation chamber. The results of these model room experiment have already been reported elsewhere [2]. There, we gave basic consideration to the characteristics of the normal modes of vibration in rooms. As a result of these experiments, it was made sure that in a properly shaped room with nonparallel plane walls, nodal lines of successive normal modes were distributed at random throughout the room. It was also confirmed that the

[1] G.W.C.Kaya, J.Acoust.Soc.Am. **7**, 167-177 (1936); P.E. Sabine,ibid.**10**, 1-5(1938); Botsford,Lane,and Watson,ibid. **24**, 742-744(1952); V.L.Chrisler, J.Research Natl. Bur. Standards **13**, 169-187 (1934)
[2] K.Sato and M.Koyasu, J.Phys.Soc.Japan **14**, 365-373 (1959).

Table I. Dimensions of five reverberation chambers.

Chamber	Use	Volume (m^3)	Surface area (m^2)	Wall thick - ness (cm)	Remarks
No.1	Absorption coeff.	513	382	40	
No.2	Absorption coeff.	120	148	26	Air - conditioning apparatus
No.3	Transmission loss.	164	179	30	Receiving room
No.4	Transmission loss.	164	179	30	Source room
No.5	Transmisson loss.	68	102	30	Mainly for impact sound - receiving room

fluctuation in decay rate of all the normal modes became smaller for this case than for the case of a rectangular room. This was adopted for our basic design of the reverberation chambers.

1.2. Details of the Reverberation Chambers

Figure 1 shows the plane of the five reverberation chambers and the attached control room and so on. A photograph of the exterior view is shown in Fig.2. Reverberation chamber No.5, which is used for the measurement of impact transmission loss, is located under chamber No.4. Dimensions of these chambers are shown in Table I.

Two Reverberation Chambers for Absorption Coefficient Measurements

On the basis of the model room experiments, the shape and volume of chamber No.1 were determined by considering the frequency range of measurements to be from 60 to 4000 cps. This volume, 513 m^3, seems to be reasonable from the viewpoint of the number of normal modes.[3] That is, the number of normal modes included within a $\frac{1}{3}$ octave band is about 40 at 100 cps.

Chamber No.2 was constructed with air-conditioning apparatus. This is because of the exceedingly humidity in the summer time in Japan. Only the highfrequency regions would be affected by the humidity, and so a rectangular parallelopiped was adopted for the shape of this chamber.

Polished concrete was adopted for the finishing of the interior wall surfaces of chambers No.1 and No.2. This has a small absorption and a small change of surface properties in the course of time. Doors of these chambers are 2m by 1m in dimension and 12cm in thickness. Both sides of these doors were made of steel plate of 6mm thickness and the cavity was filled with concrete. Also, in the chmaber No.2, there are two openings of 20-cm diam for air conditioning and these openings are closed with air-tight panels during measurements.

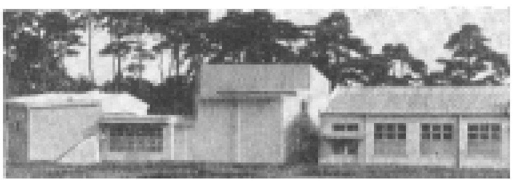

FIG.2. The whole view of the architectural acoustics laboratory.

[3] P.V.Bruel, Sound Insulation and Room Acoustics (Chapman and Hall, Ltd., London, 1951).

Three Reverberation Chambers for Transmission Loss Measurements

Experimental results in chamber No.1 furnished information for the construction of these three chambers. For transmission loss measurements, we set as our objective measurements above 100 cps. Chambers No.3 and No.4 were designed having a shape similar to that of chamber No.1, but the dimensions were reduced to $\frac{2}{3}$ of those of chamber No.1. Thus, the volume of each chamber becomes 164 m^3. Also, chamber No.5 has a volume of 68 m^3 with nonparallel walls. The ceiling of the chamber No.5 corresponds to the floor of the chamber No.4. So, the floor of chamber No.5 was inclined with respect to the ground.

The finish of the inner surface of these chambers is not so important at it is in the case of the absorption coefficient measurements and so the mortar surface was dressed with a trowel. Dimensions of the doors are 2.4m by 1.3m for chamber No.4 and 1.5m by 0.8m for the other two chambers. These doors were made of concrete with a steel frame and the surface was finished with polished concrete. Chamber No.3, which is used as the receiving room, has double doors for a sound lock.

Also, in chambers No.3 and No.4, there are openings of 60cm by 60cm in dimensions, which are used for the ventilation openings to dry up partitions of wet construction. These openings are closed by the windows with the same construction as the above mentioned doors.

The dimensions of the openings for the test partitions between chambers No.3 and No.4 (vertical plane) are 3.3m by 3.3m, and between chambers No.4 and No.5 (horizontal plane) there is an opening of 2.1m by 2.1m.

One of the important factors for transmission loss measurements is to avoid sound entering the receiving room through paths other than through the test partition. For this purpose, chambers No.3 and No.4 were built on separate foundations. Further, wood layers were put in between the boundary walls of both chambers.

2. CHARACTERISTICS OF THE CHAMBERS

2.1. Reverberation Time of Empty Chambers

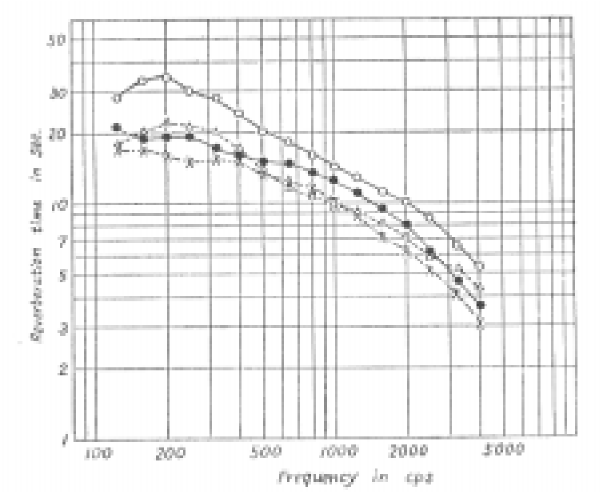

FIG.3. Reverberation times of five reverberation chambers without test specimens. –○—chamber No.1, ----△---- No.2, —●—No.3 and No.4, —・×・—No.5.

time. Center frequencies were chosen at $\frac{1}{3}$ octave intervals from 125 to 4000 cps. Output of the microphone was recorded on a high-speed level recorder through an amplifier and $\frac{1}{3}$ octave filters.

It was found that the reverberation time was affected by the absorption of the loudspeaker especially at low frequencies.[4] Here, Fig.3 shows the reverberation time frequency characteristics obtained under the conditions that for chambers from No.1 to No.4 a 10-in. loudspeaker (enclosed in a closed cabinet with a volume of 0.18 m^3) was used and for chamber No.5 an 8-in. loudspeaker (closed cabinet of 30cm by 30cm by 30cm) was used. In the case of the three reverberation chambers which are used for transmission loss measurements, the openings between each chamber were closed by the adequate partitions.

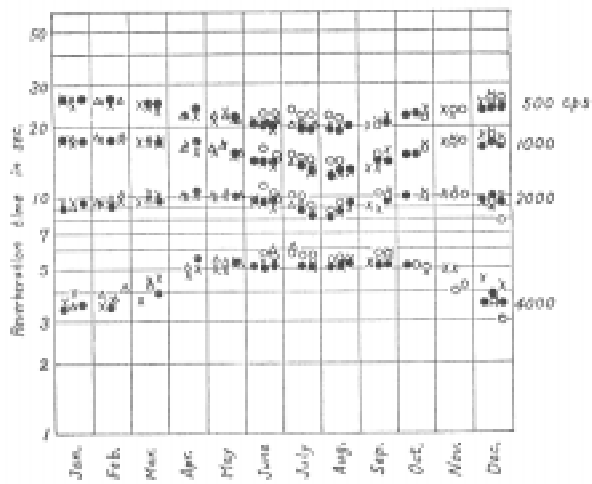

FIG.4. Variation of reverberation time of chamber No.1 for three years. ○1956, ●1957, ×1958, △1959.

[4] K.Sato and M.Koyasu, J.Phys.Soc.Japan 14, 670-677 (1959).

As was shown in Fig.3, the reverberation time at low frequencies came to nearly constant values. This would be the effect of the absorption of the loudspeaker as was mentioned earlier. Using another loudspeaker, having a smaller absorption, the reverberation time of chamber No.1 amounts to above 40 sec at 500 cps.

These measurements were carried out at different times and so the humidity would be different at each time. Thus, it is not possible to compare the reverberation time of each chamber, especially at thigh frequencies. As an example of the variation of reverberation time, measured values obtained in the chamber No.1 for the past three years are shown in Fig.4. Only the values obtained in 1956 show a little deviation, but after that, the reverberation time repeats the cyclic variation with season. This would be caused by the absorption of sound in air, but the correlation between the absorption and the weather condition will be discussed in the future.

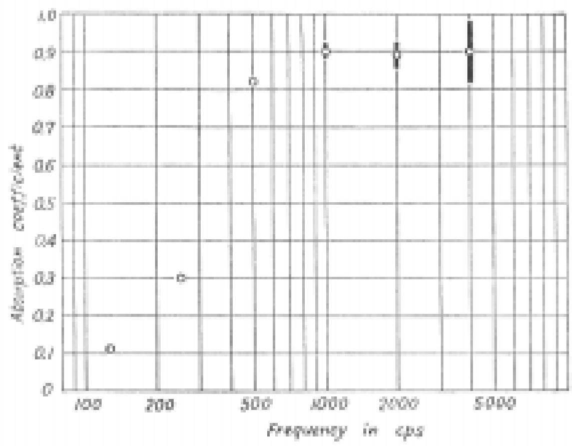

FIG.5. Effect of the microphone position on the absorption coefficient of test specimens. Lines show the deviation of absorption coefficient when one microphone moves to seven positions and twenty decay curves are measured at each position.

2.2. Absorption Coefficient Measurements

In order to make accurate measurements of absorption coefficient, the so-called Sabine's assumption must be fulfilled in the reverberation chamber. Here, experiments are mentioned, which were conducted to investigate the sound field in chamber No.1.

First, Fig.5 shows the effect of the microphone position on the absorption coefficient of test specimens. This figure shows the deviation of the absorption coefficient obtained when one microphone is moved to seven places in the chamber and twenty decay curves are measured at each microphone position. Of these seven points, four were located within 100cm from the wall surfaces and another three were at the central part of the chamber. In this case, test specimens of 10 m^2 were placed on the center of the floor.

Then, locating the microphone at only one position, the effect of the position of test specimens was investigated. Test specimens of 10 m^2 were placed respectively on the center of the floor, along the edge of the floor, and then separated on three faces. The measured absorption coefficients for these mounting positions are shown in Fig.6.

From these results, it is concluded that the position of the microphone and the test specimens would not affect the measured absorption coefficient. Thus, the usual measurements are being conducted under the conditions that the test specimens of 10 m^2 are placed on the center of the floor and one microphone is located at an optional place.

2.3. Transmission Loss Measurements

For the measurements of transmission loss, it is necessary to measure the average sound pressure level difference between the source and receiving rooms. Locating the sound source in chamber No.4, the variation of the sound pressure level was measured at each chamber. These results are shown in Table II. Here, the microphone position marked "near wall" means that the microphone is located within few centimeters of the wall surface (excluding the test partitions). These results show that the sound pressure level near the wall is several decibels higher than for the central part. This would be the effect of the reflection from the wall surface. Except for this effect, the level difference is remarkably small throughout the central regions of the chamber.[5]

When we want to calculate the transmission loss from the level difference, it is necessary to correct for the absorption of the receiving room. The difference of the correction term, owing to the deviation of reverberation time throughout the receiving room, comes within one

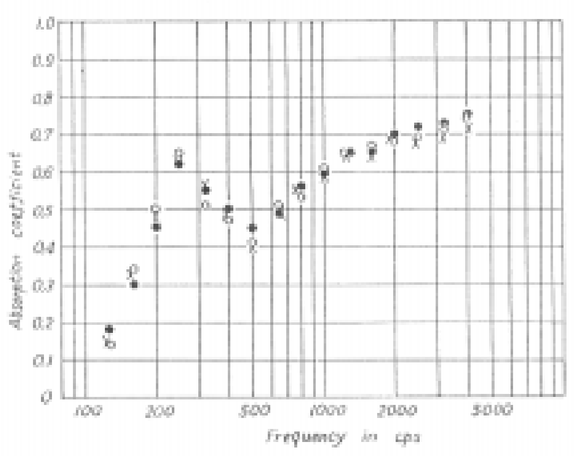

FIG.6. Effect of the position of test specimens on the absorption coefficient. ○ floor center, ● floor edge, × floor and two walls.

Table II. Relative variation of the sound pressure level in decibels for chambers No.3 and No.5.

Chamber No.3

Frequency cps	Position 1	2	3	4	5	6	"near wall" 7	8	9	10
125	0	−2	+1	−1	0	+2	+1	+4	+1	+4
250	0	−3	−2	−2	−2	−2	0	−3	0	−2
500	0	0	−1	0	+1	−1	0	0	+1	+1
1000	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	−1	−1	−1	0	−1
4000	0	0	0	0	0	0	−1	0	0	0

Chamber No.5

Frequency cps	Position 1	2	3	4	"near wall" 5	6	7	8
125	0	−2	+1	+1	+3	+3	+3	+3
250	0	−3	−1	−1	−1	0	+2	0
500	0	0	+1	+1	0	0	−2	+1
1000	0	0	+1	+1	0	0	0	+1
2000	0	0	0	0	0	−1	0	0
4000	0	0	0	0	−1	−1	0	0

decibel in all cases. Thus, it would be possible to measure the sound transmission loss from the data obtained at only a small number of points for each chmaber, in the same way as the absorption coefficient measurements.

CONCLUSION

For the measurements of the sound absorption coefficient and the transmission loss, five reverberation chambers were constructed in our institute. In this paper, the outline and the characteristics of these chambers were presented.

Reverberation chamber No.1, which is used for the absorption coefficient measurements, has a volume of 513 m^3 and its reverberation time is above 20 sec at 500 cps. Chambers No.3 and No.4 are used for measurements of airborne sound transmission loss. These are constructed with a shape similar to that of chamber No.1 and have a volume of 164 m^3 , respectively. These three chambers are surrounded by nonparallel plane walls and were designed using model room experiments. Besides these three chambers, there are two chambers: chamber No.2 with air-conditioning apparatus which is used for the absorption coefficient measurements and chamber No.5, which is built under chamber No.4, and is used for measurements of impact sound transmission loss.

The results of fundamental experiments on these chambers have shown that in chamber No.1 the position of the microphone and the test specimens do not affect the measured absorption coefficient and that the sound pressure levels in chambers No.3, No.4 and No.5 are nearly constant except at positions near the walls. Thus, it was confirmed that the characteristics of these chambers would satisfy the requirements for the measurements of the sound absorption coefficient and the transmission loss.

5 R.V.Waterhouse, J.Acoust.Soc.Am. **27**, 247-258(1955).