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COMPARISON OF REVERBERATION - ROOM AND IMPEDANCE - TUBE ABSORPTION MEASUREMENTS

BY

D. OLYNYK AND T. D. NORTHWOOD

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SOMMAIRE

Des mesures d'absorption du son ont été effectuées dans une chambre de réverbération pour une cinquantaine d'échantillons de matériaux acoustiques commerciaux et des comparaisons ont été faites avec les valeurs prévues par des mesures faites en tube d'impédance sur les mêmes matériaux. Les prédictions ont impliqué le calcul d'une absorption d'incidence aléatoire pour un panneau standard de 9 x 8 pieds. Aux fréquences de 125, 250, 500, 1000 et 2000 cycles par seconde divers degrés de corrélation ont été trouvés entre les données du tube d'impédance et les résultats de la chambre de réverbération impliquant des montages 1, 2 et 4 (type adhésif, baguette et soutien rigide respectivement). Des résultats particulièrement intéressants ont été obtenus à 250 cps lorsque l'absorption était sensible au type de montage. Pour les montages facilitant la vibration du diaphragme du matériau les résultats de la chambre de réverbération étaient beaucoup plus élevés que les valeurs prévues fondées sur des échantillons à support rigide. Un comportement de ce genre s'est manifesté à 500 cps pour les matériaux minces mais par ailleurs la corrélation était bonne à cette fréquence et aux fréquences plus élevées. Les matériaux très absorbants étaient en meilleure corrélation que ceux ayant une faible absorption lesquels ont donné dans la chambre de réverbération des résultats ayant tendance à être plus élevés que ceux prédis.

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Comparison of Reverberation-Room and Impedance-Tube Absorption Measurements*

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Reverberation-room absorption measurements on some 50 samples of commercial acoustical materials were compared with values predicted from impedance-tube measurements on the same materials. The predictions involved calculating the random-incidence absorption for the standard 9×8-ft patch of material. At frequencies of 125, 250, 500, 1000, and 2000 cps, various degrees of correlation were found between impedance-tube data and reverberation-room results involving mountings 1, 2, and 4 (adhesive, furring strips, and rigid backing, respectively). Of special interest were results at 250 cps in which the absorption was sensitive to type of mounting. For mountings that permitted diaphragm vibration of the material, the reverberation-room results were substantially higher than predicted values based on rigidly backed samples. Remnants of this behavior appeared at 500 cps for the thin materials, but otherwise correlation was good at this and higher frequencies. Highly absorptive materials correlated better than those with low absorption, for which reverberation-room results still tended to be somewhat higher than was predicted.

IN the *American Standard Acoustical Terminology*, the sound-absorption coefficient of a surface is defined as the fraction of incident sound energy absorbed or otherwise not reflected from the surface. Unless otherwise stated, a diffuse sound field is assumed. Although this definition is clear and concise, it leaves unresolved the question of how to measure the sound-absorption coefficient. It is the object of this study to compare the results of two quite different methods of measurement employing the reverberation room and the impedance tube. Several similar studies have been made since the impedance tube was first developed, but generally they involved only a few isolated comparisons and led to no consensus regarding the degree of correspondence between methods.¹⁻³ The chief feature of the present work is that a large number of test specimens and test conditions have been examined.

The reverberation-room method requires a knowledge of the relation between the reverberation time in a room and the total sound absorption of the room sur-

faces. Various relations have been derived, of which the most important are the Sabine and Norris-Eyring formulas. For reverberation rooms where the average absorption coefficient of the surfaces is always less than 0.10, the two formulas become substantially the same, and the simpler Sabine formula is customarily used. The key hypothesis in reverberation theory is that the sound field is diffuse and that the room surface is therefore exposed to an assembly of waves from all angles of incidence.

Briefly, the testing procedure⁴ is to measure the reverberation time in an empty reverberant room and then repeat the process after introducing a sample of the test material. From the two reverberation times, the total absorptions in the two cases are determined, the difference being attributed to the absorption added by the sample. Dividing the sample absorption by sample area gives the absorption per square foot, which is taken to be the absorption coefficient.

The assumption that the absorption due to a surface is simply the product of its area and absorption coefficient is valid only when the dimensions of the surface are large as compared to a wavelength. The standard reverberation method employs a 9×8-ft specimen.

* This paper is a contribution from the Division of Building Research, National Research Council, Canada, and is published with the approval of the Director of the Division.

¹ F. G. Tyzzer and H. A. Leedy, *J. Acoust. Soc. Am.* **26**, 651-656 (1954).

² P. M. Morse and R. H. Bolt, *Rev. Mod. Phys.* **16**, 69-150 (1944); see p. 141.

³ L. L. Beranek, *Acoustical Measurements* (John Wiley & Sons, Inc., New York, 1949), p. 861.

⁴ "Tentative Method of Test for Sound Absorption of Acoustical Material in Reverberation Rooms," *Am. Soc. Testing Mater. ASTM* 423-60 T (1960).

FIG. 1. Mounting conditions selected for study. (Designations follow practice of Acoustical Materials Association.)

When a patch of absorbing material as small as this forms part of a highly reflecting plane surface, it absorbs extra energy because of diffraction near the edges. Thus, dividing sample absorption by sample area may be expected to give coefficients higher than the infinite-area values. With very efficient absorbers, the effective coefficient obtained with a standard test area can quite legitimately exceed unity. This is demonstrated in some instances in the present study. An obvious way to reduce the importance of this factor would be to use a much larger sample area, but then it becomes difficult to maintain the required diffuse sound field in the room.

Another point to observe is that the absorption of most acoustical materials depends on the method of mounting them. The Acoustical Materials Association has established a set of standard test mountings, of which three were selected for the present study.

The impedance-tube method is based on a measure-

FIG. 2. Calculated and observed values of absorption coefficient at 2000 cps.

ment of the normal-incidence acoustic impedance.⁵ With suitable equipment, the measurement is simple and fairly precise. If the material is "locally reacting" (i.e., if there is little propagation of sound laterally within the material), it is then possible to calculate the random-incidence absorption coefficient for an infinite area of the material. It is also possible to calculate the effective coefficient for a small patch of material such as that tested in the reverberation room.⁶ As the tube method is necessarily a small-scale one (usually the specimens are 2-3 in. in diameter), the effect of typical large-scale mountings cannot be simulated in the tube.

The present comparison is based on an assortment of some 50 commercial materials on which both kinds of measurements had been made. Most of the materials were in the form of acoustic tiles 1 ft square, but a few

FIG. 3. Calculated and observed values of absorption coefficient at 1000 cps.

other types such as sprayed-on materials are included as well. From the tube results, calculations were made of the effective coefficients for the standard sample area used in the reverberation room. These measurements were made on a routine basis over a period of about 6 years.

I. EXPERIMENTAL DETAILS

The reverberation room used for these tests is 26×21×16 ft high, giving a total volume of 8880 cu ft (252 m³). Diffusion is provided by a 6×8-ft vane

⁵ "Method of Test for Impedance and Absorption of Acoustical Materials by the Tube Method," Am. Soc. Testing Mater. ASTM 384-58 (1958).

⁶ T. D. Northwood, J. Acoust. Soc. Am. 35, 1173-1177 (1963). (More-complete information is given in Building Note 44, Division of Building Research, National Research Council, Ottawa, Canada.)

inclined at 30 deg from the vertical and rotating at 5 rpm. Warbled sound is produced by four loudspeakers at four corners of the room and picked up by four microphones at the other corners. The standard 8×9-ft test specimen is placed on the floor approximately 5 ft from the nearest walls. The reverberation times of the empty room range from 2.6 sec at 4000 cps to 8.9 sec at 125 cps.

Figure 1 gives details of the three sample mountings used in the reverberation-room tests. Mounting 1 involves cementing the sample to a hard backing with four cement patches of about 2 in. in diameter by $\frac{3}{16}$ in. thick. In mounting 2, the sample is nailed to nominal 1×3-in. furring strips. In mounting 4, the sample is laid directly on the laboratory floor.

The impedance tube employed is $2\frac{1}{4}$ in. i.d. by about 3 ft in length. Sound from a horn driver unit is intro-

FIG. 4. Calculated and observed values of absorption at 125 cps.

duced at one end through an annular ring located so as to avoid excitation of the first radial mode. The probe microphone consists of a small piezoelectric transducer mounted on the end of a $\frac{1}{4}$ -in.-diam tube, which is moved along the axis of the impedance tube to explore the interference pattern resulting from incident and reflected sound waves. The upper frequency limit of the tube, dictated by its diameter, is about 3200 cps, so that the highest of the standard frequencies that can be studied is 2000 cps. Associated equipment includes a beat-frequency oscillator whose frequency is monitored by an electronic counter and a narrow-band microphone amplifier. All tube samples were tested with a rigid backing comparable to mounting No. 4 in the reverberation room.

FIG. 5. Calculated and observed values of absorption coefficient at 250 cps for all except $\frac{1}{2}$ -in. tiles.

II. RESULTS

Figures 2 to 7 show all the results as a function of material thickness, mounting, and frequency. It may be seen that on the average the correlation is good at 2000 and 1000 cps (Figs. 2 and 3), even through there is considerable scatter in individual results. This scatter is attributable to three main causes: the different mounting conditions for tube and reverberation-room tests,

FIG. 6. Calculated and observed values of absorption coefficient at 250 cps for $\frac{1}{2}$ -in. tiles.

Fig. 7. Calculated and observed values of absorption coefficient at 500 cps.

Fig. 8. Diaphragm absorption as a function of mounting and frequency for two typical samples.

departures of materials from the locally reacting assumption, and lack of precision in the test methods.

Mountings 1 and 2, which involve an air space behind the material, permit diaphragm vibrations of the material. Materials with low flow resistance also involve the air space since it combines with the flow resistance to form a resonant absorption system. A similar effect occurs when sound can penetrate through cracks between tile elements. All these effects give rise to an additional amount of absorption in reverberation-room tests in addition to that provided by the material proper. The extra absorption caused by the mounting is most evident when the intrinsic absorption of the material is low. The effect is evident in the lower portions of Figs. 2 and 3, and is increasingly important as the frequency decreases, both because mounting absorption is higher in this range and because the material absorption is generally lower. At 125 cps, where the material absorption is very low, there is almost no correlation between calculated and reverberation-room absorption.

The most interesting effects of the mounting system are at 250 and 500 cps (Figs. 5-8). Mounting No. 2, in which tiles are edge-mounted over a space, shows a large extra absorption at 250 cps. A similar effect is evident at 500 cps for mounting No. 1, in which the tile supports are closer together and the back space is smaller. In a few cases, tiles were tested on both mountings, with results as illustrated in Fig. 8. The effects of

the two mountings are clearly shown for two typical samples.

The locally reacting assumption is a reasonable one for materials of high flow resistance, but results for a few of the materials tested may be suspect on this account. The nature of the resulting discrepancy is difficult to predict because of the involvement of the back space, but the most probable effect is to reduce slightly the reverberation-room value relative to the value predicted from the impedance tube.

Finally, the precision of the measuring procedures may be considered. The impedance-tube method is generally very precise; the chief source of possible error is sampling, in the case of nonuniform materials. On the other hand, the discrepancies among measurements from different reverberation rooms are well known.^{1,6,7} Even in the one laboratory where these tests were done, it was found that the results obtained with a very small specimen were dependent on the position of the specimen. Limited experiments indicate that increased diffusion in the room reduces the variation with sample position and also improves the correlation with impedance-tube calculations.

It is concluded that, apart from effects attributable to mounting conditions, the absorption coefficients measured in the reverberation room are generally consistent with the values calculated from the acoustic impedance of the materials.

⁷ C. W. Kosten, *Acustica* 10, 400-411 (1960).