MEASUREMENT OF THE SOUND ABSORPTION COEFFICIENT OF A FACTORY ROOF AT VARIOUS ANGLES OF INCIDENCE.

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Introduction

Measurements have been made of the acoustical characteristics of a particular factory building. These form part of a project concerned with developing techniques of physical scale modelling of industrial spaces. The overall aim of the project is to determine whether physical modelling will enable noise control measures to be predicted with more accuracy than has been possible to date.

In most factory spaces the roof forms a large proportion of the total surface area. In fact, if the roof is pitched or sawtooth it is likely to form the largest single surface area. The acoustic characteristics of this surface, therefore, can be particularly relevant to the acoustical properties of the whole space.

The factory we have investigated has a pitched roof constructed of two layers of asbestos cement sheeting separated by an airspace, the outer layer being corrugated. The initial measurement of the absorption coefficient of this construction was made by testing a sample, $5m^2$ in area, in a reverberation chamber. To simulate the condition that the outside of the factory roof is exposed to a free field, the sample was sealed into an opening in the reverberation chamber which leads to an anechoic chamber. The results are shown in Figure 1. Two slightly different constructions were measured although the variation had little effect on the results. There is substantial absorption at low frequencies due to panel vibration which drops to a minimum at mid-frequencies. The absorption then begins to rise again at higher frequencies due to surface porosity.

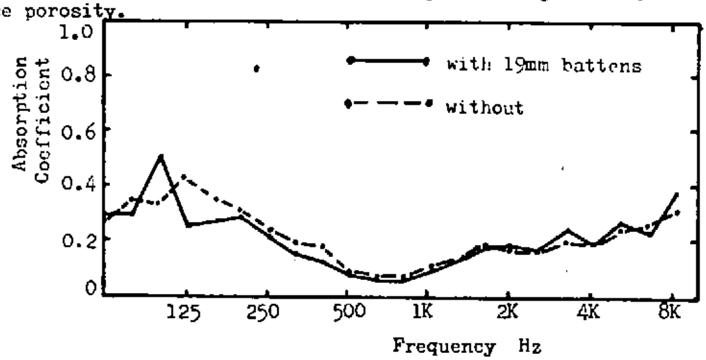

Fig. 1. Absorption coefficient of asbestos cement roofing (random incidence).

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An acoustic model of the roof was constructed at 1:16 scale based on the principle of the perforated-board faced absorber. The construction consists of 5% perforated hardboard mounted on a solid backing with a 12.7mm airspace in-between. Good agreement was obtained between the diffuse-field absorption coefficients of this construction at model scale and of the prototype roof. However, measurements of reverberation time and propagation with distance in the completed factory model showed inadequate absorption at low frequencies compared with the real factory. It was felt that this might be attributable to the roof and that reverberation chamber measurements on a small sample would not reproduce possible large scale panel vibrations of the total roof structure, $5000m^2$ in area. In situ measurements were undertaken therefore of the absorption characteristics of the factory roof. An impulse technique was adopted and the absorption coefficient was measured at various angles of incidence.

Method

The measurement procedure involved radiating a short sound pulse from a loudspeaker in the factory space and monitoring the resultant impulse response with a microphone placed at distances corresponding to different angles of incidence with the roof. The received signal was electronically gated to isolate the reflection from the roof. Subsequent squaring and integration of the reflected pulse gave a measure of its energy content. A similar procedure was adopted for measuring the energy in the direct pulse. The value of the direct pulse energy was corrected to correspond to the distance travelled by the reflected pulse assuming spherical divergence from the loudspeaker. A comparison of the two energy values gave the reflection coefficient, and hence the absorption coefficient, of the roof at a particular angle of incidence.

Precautions had to be taken to ensure that the arrival time of the ceiling reflection was sufficiently well separated from other reflections to enable easy isolation. By analysing the reflections using an image model it was apparent that the reflections arriving nearest the ceiling reflection were a first order floor reflection and a second order floor/ceiling reflection. A microphone height was selected, therefore, to enable the ceiling reflection to arrive roughly mid-way between these two reflections. Since the reflection sequence becomes denser for larger source-receiver distances, the most critical situation for impulse testing is for the larger angles of incidence. Having decided that measurements at angles of incidence up to 60° were feasible, the microphone height was optimised for this condition. If the height of the source is 2m and that of the microphone 4.5m above floor level, the delay differences are 9 and 6.5ms before and after the ceiling reflection. However, by using a highly directional 3.3m column loudspeaker the floor/ceiling reflection is suppressed. For an angle of incidence of 60° the "ray" reflected off the floor is suppressed 20dB at 125Hz due to the column directionality.

Thus for this situation the effective delay differences are 9 and 11.5ms, which implies that an impulse signal with a duration less than 9ms is required. Effective delay differences for smaller angles of incidence are larger for the same microphone and loudspeaker heights.

The impulsive signal chosen was ½ cycle of sine wave. At an equivalent frequency of 200Hz this signal produces a pulse from the column loudspeaker which

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is approximately 6ms in duration and therefore suitable for the experiment. Measurements were made in $\frac{1}{3}$ octaves using a 200Hz pulse for low frequencies and a 1kHz pulse for high frequencies.

Results

The results can be split into two parts: namely those at low frequencies and those at high frequencies. This is convenient because a systematic error became evident at high frequencies which resulted in many of the absorption coefficients in this band being evaluated as negative!

The cause of this error had not been anticipated and sheds some new light on sound propagation from column loudspeakers. It had been presumed for the purposes of calculation that the radiation from the column loudspeaker was spherically divergent. The drop off of direct energy measured showed that this was more or less true at low frequencies up to 400Hz. At higher frequencies, however, the propagation curves began to exhibit a discontinuity in the form of a peak at distances around 10m from the loudspeaker; the peak increased in magnitude with increasing frequency. This meant that the energy in the direct sound pulse, corrected for distance by spherical divergence, was too low and hence resulted in low or negative absorption coefficients. The direct pulse energy was then corrected according to the new propagation curves measured but the values of absorption coefficient remained low.

A separate experiment was performed to confirm the propagation characteristics of the column loudspeaker in anechoic conditions using both impulsive and noise signals. The high frequency curves again showed a discontinuity whose peak increased in magnitude, and distance from the loudspeaker, with increasing frequency. The effect is due to interference between the different units in the column loudspeakers. In the frequency range of interest, up to 1.25kHz, the discontinuity occurred in a range from 6m to 12m from the loudspeaker. This also happened to be the same distance range at which the pulse from the loudspeaker was incident on the roof. An irregularly divergent incident wave will presumably give rise to an irregularly divergent reflected wave whose propagation characteristics are difficult to predict. The absorption coefficients measured under these conditions must be subject to very high errors. The was borne out by the low or negative values obtained even after corrections for irregular propagation had been applied. It became necessary, therefore, to discard the high frequency results which, luckily, were of less intermediate concern.

The results at low frequencies are shown in Figure 2. Here the propagation from the column loudspeaker is close to spherical divergence. The values at the various angles of incidence can be intergrated to give a value at random incidence using Paris' equation:

$$\bar{\alpha} = \int_0^{\pi/2} \alpha(\theta) . \sin(2\theta) \, d\theta$$

Where $\bar{\alpha}$ is the absorption coefficient at random incidence and $\alpha(\theta)$ is the coefficient at an angle of incidence, θ.

The values of $\alpha(\theta)$ at very low and very high angles of incidence had not been measured and values were approximated, partly from other measurements and partly from theoretical predictions.

The results obtained by this method do not show a marked difference from the results obtained by measuring a sample in the reverberation chamber. At 125Hz, for example, there is only about a 25% increase in the absorption coefficient. At 100Hz there is a slight decrease.

Conclusions

Measurement of the absorption coefficient of a factory roof in situ involves solving numerous problems. However, it appears from the results that the total roof structure shows absorption characteristics which are similar to those of a small sample measured in a reverberation chamber. Finally, the use of a column loudspeaker indicated that sound propagation from columns cannot be assumed to be spherically divergent.

Acknowledgement

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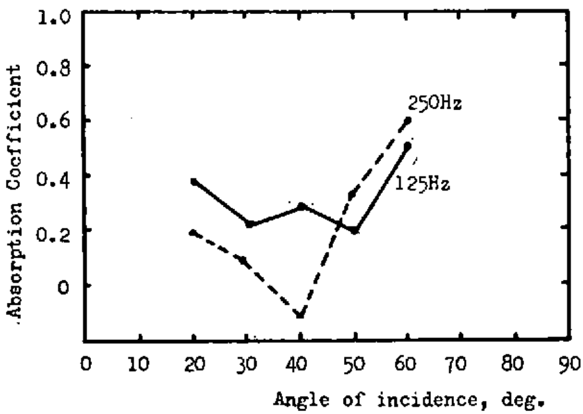

Fig. 2. Absorption coefficient of asbestos cement roofing at various angles of incidence.