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TOWARDS ACOUSTIC SCALE MODELLING OF FACTORIES

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Introduction

When applying noise reduction measures in excessively noisy factories it is desirable to control the noise at source. However, in many cases this approach is not practical. For instance, industrial processes which require constant manipulation by operators preclude the use of enclosures which hinder accessibility. Consideration must be given in these circumstances to other methods of noise control such as the treatment of walls and ceiling with absorbent material, the re-arrangement of machinery and the use of screens. In order to be able to apply these methods effectively it is necessary to understand the behaviour of sound in factory spaces.

The acoustics of factory spaces are different from auditoria because factories are usually very low compared to their length and width. This tends to give rise to sound fields which are non-diffuse and so cannot be analysed by Sabine's reverberation theory. The sound level from a single sound source drops continuously with increasing distance and does not approach a constant reverberant level. Moreover, there are usually numerous complex sound sources distributed over the whole floor space.

The complexity of analysing the factory situation theoretically is the principal reason for resorting to acoustic modelling. This technique has been used for some time in design and research work on auditoria and has proved very effective. Moreover, many of the methods developed and materials used are directly applicable to modelling factories.

The Prototype Factory and its Model

It was decided to construct a model of a specific factory which is fairly typical of many other factories. This enables results from the model to be compared with the prototype building and so indicate the accuracy of the modelling technique.

The factory chosen houses twelve production lines which manufacture domestic light bulbs. The structure is supported by a portal frame system and is 120m long, 45m wide and 10m high. One wall is almost entirely glazed and the roof construction consists of two skins of asbestos cement, the outer one being corrugated.

A scale factor of 1:16 was chosen for building the model. Initially a scale factor of 1:8 had been considered as substantial experience and data had been accumulated at this scale. However, because of space restrictions and cost the scale was reduced by a factor of two.

The model was constructed using similar techniques to those used in building the prototype factory. The floor consists of blockboard which has been varnished with two coats of gloss varnish. This gives an absorption coefficient of 0.06 at model frequencies and so is suitable for modelling concrete and brickwork. Twenty steel frames were erected on the floor to support the walls and roof. The glazing was modelled by transparent polystyrene sheeting which has an appropriate absorption coefficient at model frequencies.

The most difficult surface to model was the asbestos cement roof which covers the largest single area. In the first instance the absorption coefficient of asbestos cement structures was unknown. In particular, the absorption coefficient of a roof structure was required, namely, one in which the energy transmitted through the roof was taken account of. A full-size asbestos cement roof sample was constructed and sealed into an opening in a reverberation chamber which led to an anechoic chamber. The outside of the sample was thus exposed to free field conditions. The absorption coefficient obtained is shown in Figure 1. There is substantial absorption at low frequencies which drops to a minimum at mid-frequencies.

In order to model the roof material accurately the same measurement technique was adopted using a model reverberation chamber with a sample hole cut in it. Initially materials were tested where the weight of the asbestos cement was approximately scaled. However, these materials, such as cardboard, provided little low frequency absorption. A much lighter material, 250 gauge polythene sheeting, gave an absorption coefficient at 1:16 scale which very closely matched the absorption of asbestos cement at low frequencies. At higher frequencies there is a gradual increase in the absorption of asbestos cement which is presumably due to its porous nature. This was modelled by gluing a fine polyester material with high flow resistance to the underside of the polythene sheeting. The match in absorption coefficients was now close.

However, there are three fundamental reasons why this material proved unsuitable for the model factory roof. Firstly, the absorption depended on the tension of the material and it was difficult to keep this consistent during the construction. Furthermore, the tension varied significantly with the temperature in the laboratory. Secondly, the long term stability of the bond between the polythene and the polyester material was uncertain. Thirdly, some of the sound energy transmitted through the model roof initiated a reverberant field in

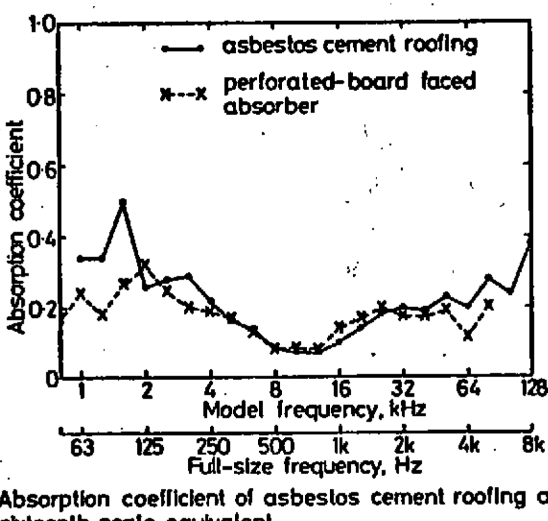

Figure 1. Absorption coefficient of asbestos cement roofing and its sixteenth scale equivalent.

the laboratory which became coupled to the one in the model.

An alternative model roof system was adopted based on the perforated-board faced absorber. The construction consists of 5% perforated hardboard mounted over a half-inch airspace. The absorption of this arrangement is also very similar to the prototype roof although the mechanism by which the absorption occurs is different. The construction can be reproduced accurately, has long term stability and is temperature insensitive. Further, very little sound energy is transmitted through the roof structure so that re-entry of sound energy into the model from the laboratory is minimal.

Modelling of the air absorption is also necessary and this is achieved by reducing the relative humidity inside the model to 2%. The model has been constructed inside a polythene tent which is connected to a silica gel drying plant. A relative humidity of 2% provides fairly accurate modelling of air absorption up to 4kHz equivalent frequency, above this corrections have to be applied.

Adjustment of Reverberation Time

The reverberation time (R.T.) in the prototype factory was measured using theatre maroons as a source. The R.T. curve displays a single hump with a maximum at 1kHz of 3.5 seconds.

The R.T. in the factory model was adjusted by first measuring the model empty and then introducing absorbent until the R.T. was correct. Very little is known about the absorption of machinery and so this was a trial and error procedure. It is important, however, that the correct distribution of absorbent is kept and that the scattering properties of the machinery are also modelled.

Each production line consists of ten machines of approximately equal size together with diverse factory paraphenalia. Part of each production line, which consists of eight machines, has been modelled using a metal basket filled with swarf and steel wool. These baskets provide the required absorption and attempt to model the scattering of the sound by the machinery. Workshops, cupboards and so on have been modelled with varnished timber.

Sound attenuation as a function of distance.

A very significant measurement in the analysis of sound fields in factory buildings is the attenuation of sound as a function of distance. This has been measured in the prototype factory using three types of sound source, namely, a single omnidirectional noise source, single machines running and a whole production line running.

Figure 2 shows the measurements made in dBA of the attenuation with distance for a whole line running. Sound level measurements close to the sources are obviously dominated by individual machines. However at distances greater than 4m sound level values are fairly similar across the building. Between 4m and 20m the rate of decrease is 1.5 dB per doubling of distance, between 20 and 50m - 5dB per doubling. The abrupt break in attenuation is indeed remarkable; the width of a production line is 6m, at 21m there are three production lines between the source and the receiver. This position is not however associated with any particular physical feature and the change is presumably connected to the nature of sound propagation in the space.

In individual octaves with the whole line running, the same characteristic occurs, at least at high frequencies. Results in the 125 Hz octave were rather haphazard.

Measurements for individual machines were not as extensive but also showed this increase in attenuation rate. In general the results for the individual machines showed a tendency to consist of a linear attenuation portion, followed by a region of zero attenuation and then a second linear portion. Attenuation rates were usually higher in the 4KHz than 1KHz octaves, typical values were 3.2dB and 2.6dB / doubling respectively. A typical attenuation rate for dBA was 2.7 dB / doubling.

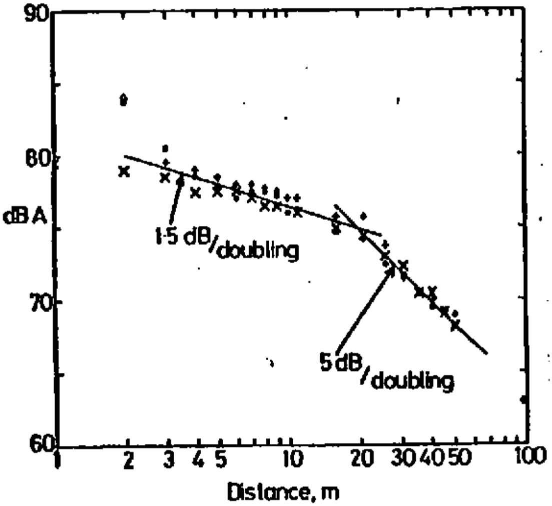

Figure 2. Attenuation with distance in dBA from a whole production line running.

Measurements of sound propagation made with a B & K Sound Power Source (Type 4205) were compared with those from individual machines. The loudspeaker was placed at the centre of the machine being examined and the same microphone positions were used. The agreement between the results for the machines and the corresponding results with the loudspeaker source are fairly good.

The same measurement are now being repeated in the factory model using air-jet sources placed at the individual machine positions. The air-jets have a response which is close to omnidirectionality and operate over the required frequency range. The signal is picked up by a 6mm or 3mm condenser microphone which can be traversed in any direction in the model using a motorised microphone carriage which runs on rails.

These results, when compared with those from the prototype factory, will reveal the accuracy of the modelling technique for factory buildings.

Scope of Factory Modelling

A measurement programme is envisaged which will investigate the effect on sound propagation, and hence sound level reduction, of acoustic treatments on various surfaces. Further, the effectiveness of different types of absorber will be investigated such as vertical noise absorbers and space absorbers as well as screens. The layout of machinery, its density and size will also be studied to see the role it plays.

From the noise aspect, acoustic modelling of factories could clearly provide a useful tool in the design process of industrial spaces. As a research tool, it may enable a clearer picture to be developed of the behaviour of sound in factories.