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SCALE MODEL MEASUREMENTS ON BARRIERS IN FACTORY BUILDINGS

R J Orlowski

Dept of Applied Acoustics, University of Salford, Salford M5 4WT

INTRODUCTION

The aim of this paper is to present results of measurements at model scale on the shielding performance of barriers in a typical factory environment. This exercise was part of a comprehensive project on the acoustic scale modelling of factories whose broad objective was to investigate the feasibility of using models for predicting the efficacy of noise control measures. The reason for adopting acoustic scale modelling to investigate sound fields in factories is that the conventional theory for predicting sound levels in enclosures, namely Sabine's theory, has been found to be inapplicable in flat shaped spaces such as factories and open plan offices.

A NOTE ON SOUND FIELDS IN FACTORIES

In a conventional room with approximately equal dimensions and uniformly distributed sound absorption the sound field is diffuse and the sound energy density is independent of observation point except in the immediate vicinity of the source. The value of the sound energy density, w, is given by the equation:

$$w = \frac{4P}{cA}$$

where P is the sound power of the source, A is the total absorption in the room and c is the speed of sound.

In contrast with this, in a room which has one or two dimensions much larger than the third, for example a single storey factory with an extensive floor area, the sound field is not diffuse and the sound energy density decreases steadily with increasing distance from the source. Furthermore, the machinery, fittings and barriers (if any) act as sound scatterers and absorbers which considerably influence the rate of decrease of the sound energy density with distance.

Thus, in a factory, the decrease of energy density with distance, referred to here as the sound propagation with distance (SP), depends on the shape of the enclosure, the absorption of its surfaces, the density and size of the machinery and other obstacles and their absorption. Depending on the values of these parameters, the rate of sound propagation will occur somewhere in the region between zero and 6dB per distance doubling.

Measurements of sound propagation in 40 factories, both empty and fitted with machinery, resulted in a range of curves falling between these two extreme values.

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In order to design effective noise control measures, the consultant has to be able to predict sound propagation curves accurately. With a knowledge of these and the sound power of the machines he can evaluate the sound pressure level at any point in a factory. Unfortunately, mathematical prediction methods are not yet readily available for use by the noise consultant although a number are under development based mainly on the method of image sources [1][2]. This is the principal reason for resorting to acoustic scale modelling for predicting the effect of noise control measures in factories.

FACTORS INFLUENCING BARRIER PERFORMANCE IN FACTORIES

The shielding performance of barriers in factories has to be considered in the general context of the behaviour of sound in factories as described above. In addition, according to the model proposed by Kurze [2], barrier performance in a factory can be adequately expressed by making the following three assumptions.

First, barrier attenuation due to diffraction is effective only for the direct sound. For reflected sound, the barrier is just another obstacle in the room that causes scattered reflections.

Secondly, reflections from the barrier contribute to the scattered sound field near the barrier proportional to the ratio of barrier height h_b to room height h.

Thirdly, a fraction of the total scattered sound field on the source side of the barrier which is proportional to the ratio of the open area above the barrier and total room cross section $(h-h_b)/h$ is balanced by the scattered sound field behind the barrier. The coupling between the two sides depends on the absorption of the ceiling and the absorption of the barrier.

Thus the total barrier performance results from shielding of the direct sound, enhancement of the local scattered field and insertion loss for the overall scattered field.

THE FACTORY AND ITS SCALE MODEL

The factory selected for the modelling exercise had a characteristic factory shape, namely a flat building with a relatively small height compared to its length and width - the dimensions were 10m x 120m x 45m. Inside the factory were 12 main production lines, ancillary equipment and stockpiles for manufacturing domestic lightbulbs.

A scale factor of 1:16 was chosen for the model on the basis that this was the largest size practicable for testing in the laboratory environment. Using this scale factor, measurements could be made up to the equivalent of the 4kHz octave full scale which is a reasonable upper limit for measurements in dB(A).

The model was built of timber and perspex and a special construction was developed for the roof consisting of distributed Helmholtz resonators to scale the low frequency absorption and transmission of the full-scale roof.

Appropriately sized wooden blocks and metal cylinders were used to represent the machinery and fittings.

ACCURACY OF THE SCALE MODEL

The sound field in the factory was characterised by measuring Reverberation Time (RT) and Sound Propagation with distance from an omnidirectional source (SP). These two parameters were also measured in the 1:16 scale model.

Figure 1 shows a comparison of the RT in the factory with the scaled up RT in the 1:16 model. It is evident that the agreement is good: the two curves are within 10% of each other at all except the lowest frequencies.

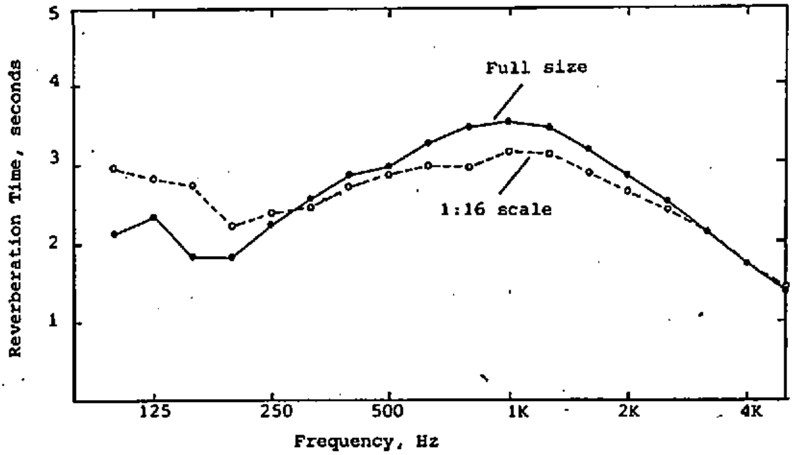

Fig 1 Comparison of Reverberation Time in the factory with the scaled up Reverberation Time in the 1:16 scale model.

In the case of SP, the sound power of the full scale and model scale omnidirectional sources was measured so that SP curves could be plotted in absolute terms, namely Sound Pressure Level minus Sound Power Level (L_p-L_w). This enabled a comparison of SP in absolute terms between the factory and its model. Figure 2 shows the full scale and model scale SP curves expressed in dB(A). Again the agreement between the factory and its model is good: the two curves are typically within about 1dB.

The accuracy of the 1:16 scale model, based on the comparisons of RT and SP, was deemed sufficiently high to consider that noise control experiments in the model would also be accurate with respect to full scale.

MODEL MEASUREMENTS ON BARRIERS

The objective of the measurements on barriers was to evaluate the insertion loss (IL) of various types in a typical factory environment by using the

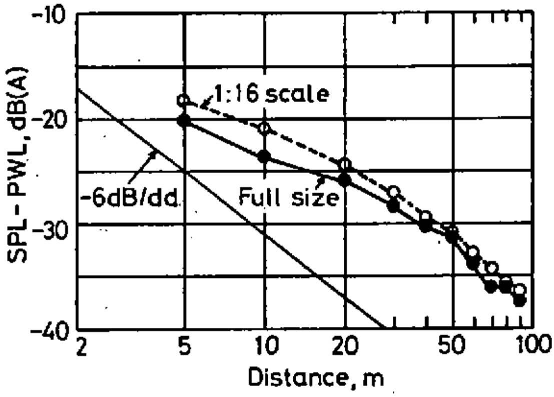

Fig 2 Sound Propagation in dB(A) measured in the full-size factory and its 1:16 scale model.

scale model. The experimental arrangement in the model is shown in Figure 3, the barrier extended across the whole width of the production lines, i.e. 30m. The method involved measuring the SP with distance from an omnidirectional source with and without the barrier in position. The difference between the two SP curves gave the variation of IL with distance from the source. Measurements were made in six octaves corresponding with the 125Hz to 2kHz octaves FS (FS = full scale).

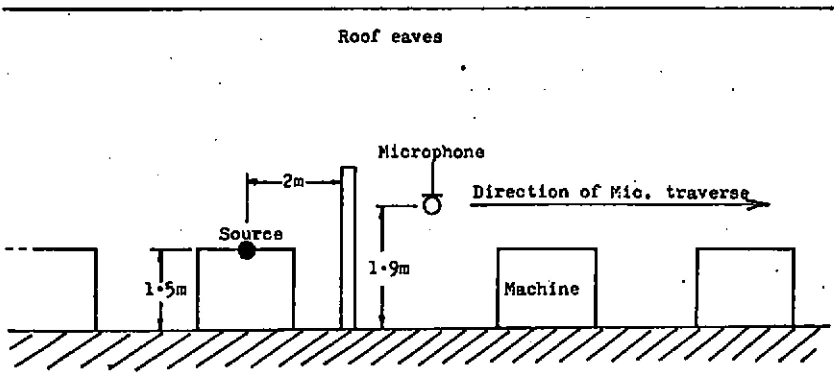

Fig 3 Experimental configuration for measuring the Insertion Loss of barriers and its 1:16 scale model.

RESULTS

The first experiment investigated the effect of barrier height on IL. The results for the 1kHz octave FS are shown in Figure 4. As expected, IL increases with increase in barrier height. The largest value of IL occurs immediately on the opposite side of the barrier from the source and then decreases with increasing distance up to 10m. In this region the shielding of the direct sound is the dominant factor. At distances greater than 10m the IL remains constant; this represents the IL for scattered sound. It is noteworthy that even with a barrier height of 5m, equivalent to half the roof height, the IL does not exceed 10dB, for the scattered sound it is 4dB. With a barrier height of 1m where line of sight is preserved between source and receiver, the IL is less than 1dB.

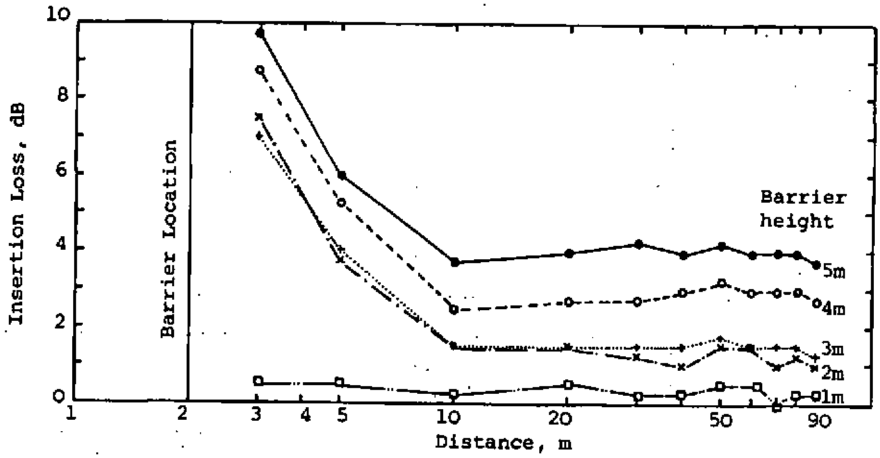

Fig 4 Insertion Loss of barriers in model factory (1kHz octave full-scale).

Figure 5 shows the variation of IL with frequency for a single barrier with different heights. From these curves no systematic increase with frequency is evident. This is in contrast with the free-field performance of a barrier where an increase of 3dB per doubling of frequency is predicted by theory if the barrier exceeds half the wavelength of sound. This lack of frequency dependence occurring in a factory environment can be explained in terms of the strong acoustic coupling between the two sides of the barrier resulting from the scattering of sound energy by the roof, machinery and fittings.

In practice, when barriers are installed for noise control in factories, the side of the barrier facing the source is made absorbent to prevent an increase of noise level near the source. This arrangement was tested in the factory model by treating the source side of the barrier with a porous absorbent which represented 50mm of mineral wool. With a 2m high barrier, the increase in IL was negligible throughout the frequency range. However, with a 4m high barrier, a consistent 1dB increase in IL was observed independent of distance at frequencies up to the 1kHz octave FS. This increased to 2dB at the 2 and 4kHz octaves FS.

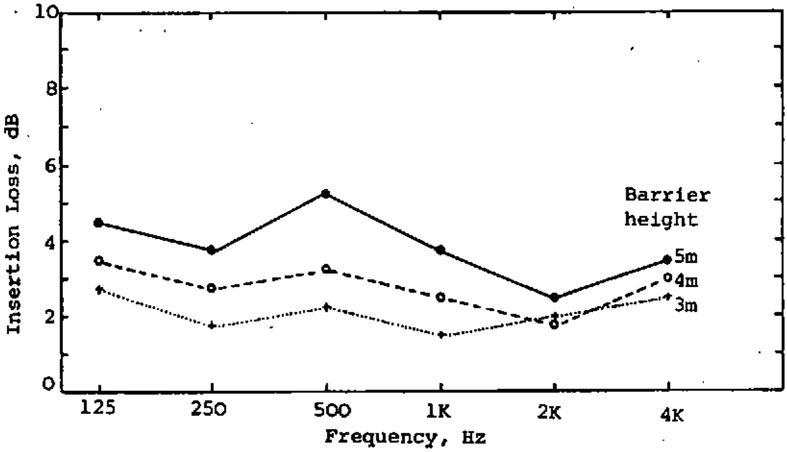

Fig 5 Variation of the Insertion Loss of barriers with frequency in model factory (Source-Receiver distance 10m full-scale)

As the IL of a barrier in a factory is influenced by reflections from the ceiling which tend to acoustically couple the two sides of the barrier, it should be possible to increase the IL by making the ceiling absorbent. The effect of this arrangement was tested by hanging 700 suspended absorbers (equivalent to 0.2 absorbers/m^2 of floor area) in the factory model with a semi-absorbent barrier in position. Figure 6 shows the increase in IL of a barrier in the presence of suspended absorbers. The results indicate that the IL is approximately doubled at distances around 10m from the source and continues to increase with increasing distance. Thus, at 90m from the source the IL is approximately quadrupled. Thus the combination of a barrier with suspended absorbers appears to be an effective method of reducing noise levels.

A further experiment was carried out in the model to examine the effect of a possible practical noise reduction treatment that could be installed in this factory, namely the installation of absorbent barriers between machine lines in combination with suspended absorbers. First, 12 barriers, absorbent on both sides and with an equivalent height of 2m, were positioned between the machine lines in the model. Subsequently, 700 suspended absorbers were added. The overall levels of noise reduction were determined from sound propagation measurements in the model with these arrangements and the results are given in Table 1.

	Frequency, Hz						
	dB(A)	125	250	500	1K	2K	4K
Reduction in Lp with 12 absorbent 2m barriers	6	3	6	5.5	5.5	6	7.5
Reduction in L_p with 12 absorbent 2m barriers + 700 suspended absorbers	8	3.5	7.5	7	8	8.5	10

Table 1 Model Prediction of the Reduction in Sound Pressure Level in a factory resulting from the installation of absorbent barriers and suspended absorbers.

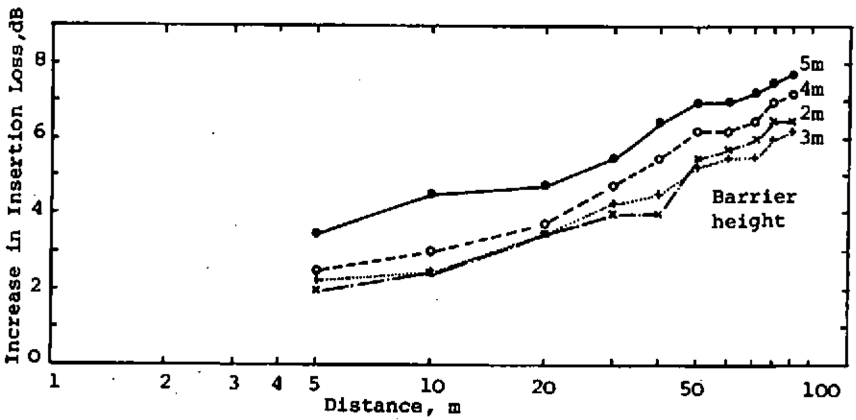

Fig 6 Increase in Insertion Loss of barriers with suspended absorbers above (density 0.2/m²), (1kHz octave full-scale)

It is apparent from the figures in Table 1 that the sound level reduction in the individual octave bands increases with increasing frequency. This is due to the typical absorption characteristics of the porous absorber used for the suspended absorbers and on the barriers. This happens to be fortuitous in this particular factory since the noise spectrum also increases with frequency. Thus the maximum reduction in sound level occurs where the noise levels are highest. Expressed in dB(A), the reduction in sound pressure level of 6dB(A) with 12 absorbent 2m barriers which increases to 8dB(A) with the addition of suspended absorbers is a substantial reduction in noise level. Thus, a combination of barriers and absorbers appears to be an effective noise control treatment in factories with this type of machine layout.

SUMMARY OF RESULTS AND COMPARISON WITH OTHER DATA

The results of the experiments on a single reflective barrier, shown in Figure 4, are summarised in Table 2.

Barrier height/ room height m	Source-receiver distance/room height m		
	0.3	0.5	1 to 10
0.1	0.5dB	0.5dB	0.5dB
0.2	7.5dB	4 dB	1.5dB
0.3	7 dB	4 dB	1.5dB
0.4	9 dB	5 dB	3 dB
0.5	10 dB	6 dB	4 dB

Table 2 Insertion loss of a reflective barrier measured in a 1:16 scale model factory in the octave band equivalent to 1kHz at full scale

The barrier height and the distance from source to receiver have been normalised in terms of the room height. Furthermore, the normalised distance from source to receiver has been split into three ranges. This facilitates comparisons with other data in particular that published by Kurze [2], [3] which is shown in Table 3. This data gives a summary of the results of measurements on the performance of barriers in 54 flat-shaped rooms, partly factories and partly open-plan offices.

Barrier height/ room height m	Source-receiver distance/room height m		
	0.3	0.3 to 1	1 to 3
0.3	7.4 ± 1.4dB	3.6 ± 2.1dB	-
0.3 to 0.5	10dB	7.1 ± 1.8dB	4.5 ± 1.8dB
0.5	-	8.6 ± 1.7dB	6.3 ± 1.5dB

Table 3 Insertion loss of barriers in workrooms. Mean Values and standard deviations of data measured in octave-band centred at 1000Hz (after Kurze).

A comparison of Table 2 with Table 3 shows that the model results fall within the range of the full-scale results or are within 1dB of them. This agreement between model-scale and full-scale results supports the validity of the model tests on barriers. Moreover it is considered that this model data can be added to the full-scale data for making empirical predictions of barrier performance.

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CONCLUSIONS

The shielding performance of barriers in factories must be considered in the general context of the behaviour of sound in flat-shaped enclosures containing scattering elements. As yet the theory for predicting sound levels in these enclosures is not fully developed. Until it is, noise consultants will have to resort to empirical methods such as acoustic scale modelling which appears to provide accurate results. However, it is appreciated that modelling may not always be convenient because of the time and cost involved. As an alternative approach, the published data on the IL of barriers in factories, to which the model results presented here can be added, can be used by noise consultants to make reasonably good estimates.

ACKNOWLEDGEMENT

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