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PREDICTING FACTORY SOUND FIELDS USING 1:50 SCALE MODELS

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Introduction

Two years ago the Institute held a meeting on noise control in factory buildings which discussed the issues of predicting sound fields in factories and evaluating the effect of noise control measures [1]. One point that emerged clearly from this meeting, and confirms the observations of many researchers in the recent past, is that in large factories fitted with machinery neither the reverberation time nor the sound propagation with distance can be predicted correctly using Sabine's theory. New theories have been proposed based on mathematical models and, at present, these are being refined for application to practical situations (see [2]). In parallel with this work on theoretical models, physical scale models have two important roles to play. First they can be used to create a sound field similar to that proposed in a theoretical model so that the physical scale model provides a test bed for the theoretical model. Secondly, a physical scale model has the potential for recreating in miniature the sound field in an actual factory so that noise levels can be predicted for new factories and noise control measures evaluated in existing ones. The latter role, which is the subject of this paper, hopes to fill a gap in current prediction methods and is likely to remain relevant in the future for factories which are of unusual shape or have an uneven distribution of machines. Following a brief outline of recent developments in factory modelling, the main issue is discussed, namely, whether relatively small models at 1:50 scale are a useful design aid for predicting sound fields in factories. Three examples are given which compare the sound fields in existing factories with their 1:50 scale models.

Recent Developments in Factory Modelling

Acoustic scale modelling of auditoria at 1/8 or 1/10 scale is now a well established technique for predicting the quality of sound fields in these spaces. It was hoped, therefore, that a similar technique would be suitable for predicting noise levels in factories. To test this hypothesis a scale model of an actual working factory was built and tested and the model scale and full scale results were compared. A scale factor of 1:16 was chosen for the model on the basis that this was the largest size practicable for testing in a laboratory environment. Since air absorption and transducer capabilities limit acoustic scale modelling to about 100kHz, measurements in the 1:16 scale model could be made up to the 64kHz octave which is equivalent to the 4kHz octave full scale - a reasonable upper limit for measurements in dBA. (This upper frequency limit applies when tests are carried out in a dehumidified atmosphere of around 2% relative humidity.)

It was not necessary to reproduce in the scale model the actual sound field in the factory with all the machines running since the acoustics of a factory enclosure are adequately characterised by the Reverberation Time (RT) and Sound

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Propagation with distance from an omnidirectional source (SP). With a knowledge of the SP and the sound power of the machines, the sound pressure level at any point in a factory can be evaluated.

Sound Propagation measurements in the model were made using a crossing air-jet source in combination with a 1/4or1/8"condenser microphone. The sound power of the air-jet at model frequencies was determined so that propagation curves could be expressed in absolute terms, namely sound pressure level minus sound power level.

The process of matching the model to the real factory gave considerable insight into the acoustical behaviour of a factory enclosure. By far the most dominant feature is the low frequency absorption and transmission of sound by the lightweight roof, in this case a double panelled structure of asbestos cement. The roof absorption coupled with the scattering effect of the machines dominates the RT and SP.

A detailed investigation was carried out into the acoustical behaviour of double panel factory roof constructions by Bolton and Baines at ISVR [3,4]. This investigation indicated that in long, low height factories the statistical absorption coefficient of the roof may not be relevant (particularly in the case of RT rather than steady state level) since the sound incidence on the roof may not be uniform with angle and, furthermore, the absorption may be strongly variable with angle. They suggested that it may be necessary to reproduce these roof characteristics when building acoustic scale models of factories. Although measuring the variation of absorption with angle of incidence was attempted both at full scale and model scale, the measurements proved cumbersome and inaccurate. A simplified solution for the roof absorption was adopted whereby an array of Helmholz resonators was tuned to the frequency at which maximum absorption occurred in the full-scale factory. It was assumed that the maximum absorption occurred at the same frequency as the minimum RT. In practice the model roof construction consisted of a perforated sheet backed by an airspace.

With this roof construction together with metal cylinders and solid blocks to represent the machines and other factory fittings, a fairly good match was obtained with the actual factory in terms of RT and SP results. Figure 1 shows a comparison of SP results.

The model was subsequently used to investigate the usefulness of various noise reduction treatments such as suspended absorbers and barriers. These measurements, which have been reported elsewhere [1], produced sensible results although it was not possible to verify them at full scale.

The conclusion of modelling a factory sound field at 1:16 scale was that a reasonably accurate match can be obtained between model and factory and the model appears capable of predicting the effect of noise control measures. However, constructing and testing a model at this scale is expensive in terms of both finance and labour and does not lend itself readily for use as a design aid.

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1:50 Scale Modelling of Factories

A useful scale factor for factory modelling as a design aid would be 1:50. The benefit of using small models in addition to reduced costs is that they can be easily modified or rearranged so that several alternative noise control measures could be readily evaluated. The main limitation is that measurements are accurate only to the 1kHz octave full scale. However, this restricted frequency range may be justifiable in terms of the flexibility and low cost of 1:50 scale models.

To test the feasiblity of factory modelling at 1:50 scale, a model was built at this scale of the same factory used for the 1:16 exercise. This permitted the accuracy of 1:50 scale modelling to be compared with 1:16 scale. The main problem in building the new model was again concerned with scaling the roof absorption. Following an unsuccessful experiment with a lightweight foil material, the same construction was adopted as for the larger model, namely a Helmholz resonator arrangement with the resonant frequency increased according to the new scale factor.

Figure 1 shows the results of sound propagation measurements in the 1:50 scale and the 1:16 scale models together with the full-scale results. It is evident that results from the 1:50 scale model are as good as those from the 1:16 scale model and in some cases, in the 125Hz octave for example, they are closer to the full scale curve. The RT, on the other hand, in the 1:50 scale model is a poorer match with full-scale than the 1:16 scale case.

The sound propagation curves for both models have been used to predict the sound pressure level at the centre of the factory assuming that all 120 machines are running. Table 1 compares the predictions from the two models together with the values actually measured in the factory.

	Frequency, Hz						
	dB(A)	125	250	500	1K	2K	4K
Lp in factory, dB	86	73	74	78	79	80	81
Lp in 1:50 model (predicted from SP)	-	73	76	78	78	-	-
Lp in 1:16 model (predicted from SP)	86	70	77	80	80	81	79

Table 1. Sound Pressure level measured at the centre of full-scale factory compared with scale model predictions

Results from the 1:50 scale model are remarkably close to the measured full scale values, typically within about 1dB, and slightly better than the 1:16 scale results.

One problem, however, remained unsolved by this exercise. In a factory with a lightweight roof which is fitted with machinery the total effective absorption appears to be largely governed by an interaction between the roof absorption and the scattering of sound by the machines. In fact, it is possible, at least in models, to counterbalance a change in roof absorption with an opposite change in scattering whilst maintaining the same RT or SP. Therefore, the model studies at 1:16 and 1:50 scale only confirmed that it is possible to get the combined effect of roof absorption and machine scattering reasonably accurate without providing any information on whether the individual components were scaled correctly. An attempt to resolve this was made by modelling at 1:50 scale an empty factory which was subsequently fitted with machinery so that the roof absorption could be observed independently of scattering by machines. The results of this exercise will be presented in the spoken version.

The third factory modelled at 1:50 scale was selected because of its non-absorbent ceiling to hopefully permit the scaling of scattering effects of machinery to be investigated independently. During the scaling process of this factory it became evident that the solid timber floor was substantially more absorbent than expected with the result that only matching a combination of scattering and floor absorption could be achieved. Although similar to the first exercise, it showed that the low frequency floor absorption could be scaled with a similar construction to roof absorption. It is worth mentioning that of the 40 factories visited during this research programme, nearly all of them had substantial amounts of low frequency absorption present as a result of either lightweight cladding, floor construction or glazing or combination of all three.

Conclusions

Three factories have been modelled at 1:50 scale to see if the sound field can be reproduced sufficiently accurately to permit noise control measures to be evaluated. Comparisons of RT and SP between model and factory have shown that SP can be reproduced reasonably well and RT slightly less so.

The main factor limiting the accuracy of factory modelling is scaling the absorption of lightweight roof structures which is often complicated by the interrelation between roof absorption and the scattering of sound by machines. This limitation is not simply a shortcoming of modelling techniques; it is concerned with a lack of data about the absorption characteristics of lightweight roof structures. More laboratory and field measurements are required on these structures to improve confidence in scaling their characteristics, this in turn will increase the feasibility of using 1:50 scale models as a design aid for evaluating noise control measures in factories.

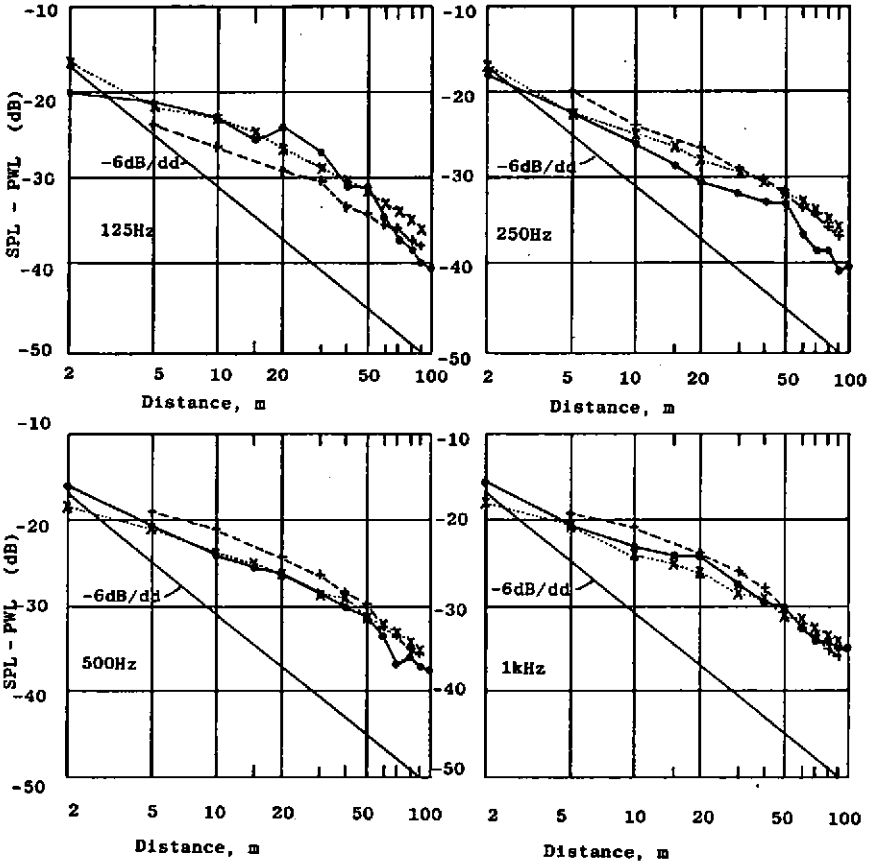

FIGURE 1 Sound propagation measured in octave bands in a factory fitted with machinery (•—•) compared with its 1:16 scale model (+-- +) and 1:50 model (x···x).

<u>Factory Details</u>

Dimensions: 119m x 44m x 9m. Volume 46,000m³.

Construction: Single pitch portal frame supporting double skin asbestos cement roof panels, masonry or glazed walls, concrete floor.

Contents: 12 long and 5 short production lines containing mainly cylindrically shaped machines. Workshops, ancillary machines and equipment, stockpiles.

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