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DETERMINATION OF LOW-FREQUENCY ROAD TRAFFIC NOISE LEVELS OVER THE SURFACES OF A BUILDING USING A SCALE MODEL

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Summary

The theory of sound transmission into a reverberant enclosure is briefly outlined. The assessment of variation in sound pressure over the surface of a large structure, using a scale model, is described. Some practical difficulties which may occur during such tests are discussed.

1. Introduction

Building work at present in progress at the BBC's Television Centre, London, includes a new Television Theatre. Basically this is a very large studio (floor area about 30 metres by 26 metres) with permanent audience seating. A particular feature is a "fly tower" some 24.5 metres high extending over the whole stage area of the theatre (Fig 1), which will enable scenery changes to be made live and so give artistic continuity to a production. Although the lower part of the theatre is protected from external ambient noise by other structures, the fly tower rises above these and the wall areas shown shaded in Fig. 1 are exposed to this noise. These walls must therefore provide adequate attenuation of ambient noise to satisfy the specified noise criterion at all frequencies. This paper briefly examines the theoretical aspects of sound insulation and describes tests using a scale model which were carried out to estimate ambient noise levels at the exposed wall areas.

2. Brief Account of Theory

In the present case the room under consideration is of irregular shape, more than one wall is involved in the transmission of sound into it, the wall areas exposed to the external ambient sound represent only part of the total wall area, and the ambient sound level differs from place to place on a wall. Under these conditions the relevant relationship between transmission loss (L_T) and sound pressure level (spl) difference ΔL_p) [1] is (in decibel units)

$$L_T = \Delta L_p + C + K \qquad \text{— (1)}$$

In Equation 1 the value of ΔL_p is given by

$$\Delta L_p = L_S - L_R \qquad \text{— (2)}$$

where L_S is the ambient sound level on the exterior of the wall of the building, averaged (as usual) over a time long compared with the period of the sound oscillation, and also averaged on a "power average" basis (not a "decibel-average" basis) over the wall

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surface,

and L_R is the (time-averaged) sound level inside the building, assumed to be uniform spatially.

The factor C allows for the sound pressure level inside the building reaching an equilibrium value, when the rate of sound energy transfer through the wall equals the rate of energy absorption within the building. The value of C is given by

$$C = 10 \log_{10} \frac{S_p}{\bar{\alpha} S} \qquad \text{---(3)}$$

where S_p is the area of wall involved in sound transmission
S is the total surface area of the room
and $\bar{\alpha}$ is the mean absorption coefficient of the room surfaces.

Formulae for relating transmission loss to sound pressure level difference are usually derived with reference to transmission of sound from one room to another [2] and therefore assume the presence of a diffuse (random incidence) sound field on the "source" side of the partition. The data [3] used in the present work to relate partition construction and spl difference was obtained on this basis. In the case of exposure to traffic noise, however, this condition is not satisfied, the sound field at the exterior of the building being "direct" in character. The factor K in Equation 1 is introduced to allow for this difference between the "data-bank" and practical conditions. It can be shown [1] that, for the same measured sound pressure level, the sound power incident onto a surface in the presence of a normally-incident plane wave is four times (6 dB) greater than the value in the presence of a randomly-incident (diffuse) sound field. Thus

$$\left.\begin{array}{ll} & K = 0 \text{ (random incidence)} \\ \text{or} & K = 6 \text{ (normal incidence)} \end{array}\right\} \qquad \text{---(4)}$$

It may be noted that taking K = 6 in Equation 1 represents a "worst case" condition, since if the sound is not normally incident the correction required is less than 6 dB. On the other hand, the above treatment ignores factors such as the "coincidence effect" [4] which can enhance the transmission of sound through a panel at certain frequencies and angles of incidence, and of diffraction effects at the edges of building structures which can modify the angle of incidence of the sound relative to the direct "line of sight" between the source and the wall. Thus it is relevant in the present circumstances to adopt this "worst case" approach.

Equations 1-4 can be used to relate spl difference requirements in the Theatre to those given for different wall constructions in the data bank, and thus to select suitable types of wall construction. For a particular wall construction, the transmission loss does not depend either on room or on source sound field parameters. Using subscripts T and D to

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refer respectively to conditions in the Theatre and the data bank of spl differences, it can be seen from Equation 1 that

$$\Delta L_{pT} + C_T + K_T = \Delta L_{pD} + C_D + K_D$$

or $$\Delta L_{pT} = \Delta L_{pD} + (C_D - C_T) + (K_D - K_T) \quad \text{---(5)}$$

In the case of the Theatre, the total surface area is $4368m^2$, the area of exposed wall is $623m^2$ and the mean absorption coefficient can be taken as 0.5 (reverberation time (RT) of 1 second): thus from Equation 3, $C_T = -5.5$ dB. In the case of the data bank values, corresponding values have been taken as $22.1m^2$, $143.2m^2$ and 0.34 (RT = 0.3 sec), giving $C_D = -3.5$ dB. Furthermore, since the source sound fields in the cases of the Theatre walls and the data bank measurements are respectively direct and reverberant, $K_T = 6$ dB and $K_D = 0$ dB, from Equation 4. Thus from Equation 5

$$L_{pT} = L_{pD} - 4 \quad \text{---(6)}$$

which shows that for a given wall structure, the sound pressure level difference obtained in the Theatre will be 4 dB lower (i.e. 4 dB less insulation) than as indicated in the data bank.

3. Coherence properties of noise

Strictly speaking, the term "noise" implies complete statistical randomness, so that there should be no waveform correlation between two signals from the same source, one of which is delayed relative to the other. In this case the two signals would simply add in a statistical (i.e. power) manner, irrespective of the actual delay between the two. In the case of road traffic noise, however, the term "noise" simply implies that the sound is unwanted, without any implications as to its statistical randomness. Noise from vehicle engines is in fact very coherent, which implies that constructive or destructive interference can occur when two signals from such a source, one delayed with respect to the other, combine: in other words, pronounced directional effects may be present when such a sound source is relatively close to a reflecting surface (a wall of a neighbouring building, or even the road over which the vehicle is passing). Such effects immensely complicate the experimental procedure if the problem of traffic noise is carried into the domain of scale modelling. As a simpler alternative to using sinusoidal signals in the present work, third-octave band-limited noise was used : this still retains considerable properties of coherence [5] but at the same time gives an average of the effects obtained across the frequency range within the band.

The coherence of the ambient noise also gives rise to standing wave patterns in front of reflecting surfaces (Fig 2) which makes the observed sound pressure level dependent on microphone position. To ensure measurement consistency in the modelling work, all readings were taken with the microphone as close to the reflecting surface as possible without actually touching it.

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4. Preliminary Assessment of Sound Pressure Level Difference Requirements

A survey carried out by Sound Research Laboratories Limited in December 1983 showed that particularly high values of sound pressure level, caused by traffic in the road (Wood Lane) adjacent to the site of the Television Centre Theatre, occurred in the one-third octave frequency band centred on 63 Hz. A peak level of 107 dB was recorded on one occasion, but a value of 100 dB can be regarded as representing a more reasonable peak level for practical purposes. The noise criterion for the interior of the studio (BBC Criterion (ii) relaxed by 5 dB) indicates that in the 63 Hz band the noise spl should not exceed 41 dB. On this basis a 59 dB difference in sound pressure level between the exterior and interior of the building is required. From Equation 6 it can be seen that a partition construction which is shown in the data bank to give a spl difference of 63 dB at 63 Hz would be suitable. Inspection of the data bank showed, however, that a partition giving this performance involved the use of a triple-leaf construction. Such a structure, some 25m high, represents a very difficult design problem, particularly as it must be remembered that the three leaves must not be coupled mechanically to each other. The work using a scale model described in the following sections was undertaken to see whether any relaxation of the sound pressure level difference criterion could be permitted, so that a simpler (e.g. two-leaf) and therefore more feasible type of construction could be used. The approach which was adopted compared noise levels measured near ground level, as in the case of the survey, with levels measured adjacent to the exposed Theatre walls.

5. The Modelling Technique

In order to ascertain sound pressure levels, due to traffic noise, that were likely to occur at the exposed walls of the Theatre, use was made of an architects' model (made by Richard McKinder of Finchley, London N.3) which had been constructed in cardboard at a scale of 1:100 and showed with reasonable accuracy the external features of the building. The material used in the construction of the model could not be taken as representative (at the appropriate scale frequency of 6.3 kHz) of the actual wall structure as far as sound transmission was concerned, but its reflective properties at the scale frequency were considered to be sufficiently representative of those of the actual building structure. As well as the Television Centre structure itself, other reflective surfaces (also cardboard) were placed in positions occupied by neighbouring buildings. The road (Wood Lane) layout was drawn on the base-plate of the assembly as a guide to the likely positions of vehicles. Fig. 3 shows a photograph of the complete assembly.

The sound source consisted of a small loudspeaker, (L, Fig. 4) excited with a third-octave band of noise centred on the scale frequency of 6.3 kHz. Initially the loudspeaker itself, provided with a short tube(T) to restrict its aperture to a rectangle 20mm long and 15mm high, was used as the sound source. This had undesirable directional properties, however, and later work was carried out with the sound conveyed through a longer

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tube(P), 6mm in diameter, to the centre of a "ground plane"(G) consisting of a square of cardboard of side 100mm (this can be seen in the left-hand side of Fig. 3). Radiation from this source was uniform to within approximately ± 1.5dB in both horizontal and vertical planes: these residual polar properties have been ignored in conducting the present tests. To minimize the emission of sound from points other than the end of the tube, the loudspeaker unit was covered with a layer (D) of Plasticine.

Sound was received using a small omnidirectional microphone which was mounted on a thin "stalk" (see centre of Fig. 3). As explained in Section 3, all measurements were carried out with the microphone close to the surface at the point of measurement. As a first step, an investigation was made into the location of a sound source position in the "roadway" which maximized the sound pressure level at each of the walls in turn, with the microphone placed at the centre of the exposed section of each wall. The detailed sound pressure level measurements were then conducted with the sound source placed (in turn) in these positions. On each of the two exposed walls, measurements were made at the centres of a number of equal "sub-areas", and a "power average" mean sound pressure level was then calculated.

Sound pressure levels were also measured using a "reference jig" which modelled, on the same 100:1 scale, the conditions used in the survey conducted by Sound Research Laboratories. Here it was assumed that the maxima of sound pressure levels observed during this survey occurred when a vehicle was directly opposite the measuring position in one or other carriageway of the road, and the sound source was positioned accordingly. The difference between the sound pressure level measured at this reference position and the mean sound pressure level measured at the "exposed" wall surfaces gave an estimated of the reduction in traffic noise level, relative to the surveyed value, which would occur in practice.

6. Results of the scale model tests

It was found that the mean reduction in traffic noise level, adjacent to the exposed wall surfaces, was 12 dB relative to the surveyed value. The value obtained was found to depend considerably on the position of the sound source, not only along the roadway but also transversely across it. In this respect the distance of the source from the wall on the opposite side of the road to the Theatre was critical: at the position of maximum level at the wall surfaces it was thought that sound components from the source itself and from its reflection in this wall arrived at the Theatre wall in phase. The noise level at the north-west wall was very considerably enhanced by reflection from a large block of residential flats facing this wall.

Referring to Section 4, it can now be seen that a partition construction which is shown in the data bank to give a spl difference of 63-12 = 51 dB would in fact be suitable. Inspection of the data bank showed that this sound pressure level difference could be achieved using a two-leaf wall construction.

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7. Conclusions

The use of a 100:1 scale model has indicated that road traffic noise at the exposed walls of the proposed Television Centre Theatre will be some 12 dB lower in sound pressure level than as measured at or near ground level. This reduction permits the recommendations of a rather simpler form of wall construction than would be the case if the design was to be based on the ground-level noise measurement itself. It may be noted that the presence of buildings adjacent to the Theatre itself enhances the noise level at the exposed wall surfaces.

8. Acknowledgment

This paper is published with the permission of the Director of Engineering, British Broadcasting Corporation.

9. References

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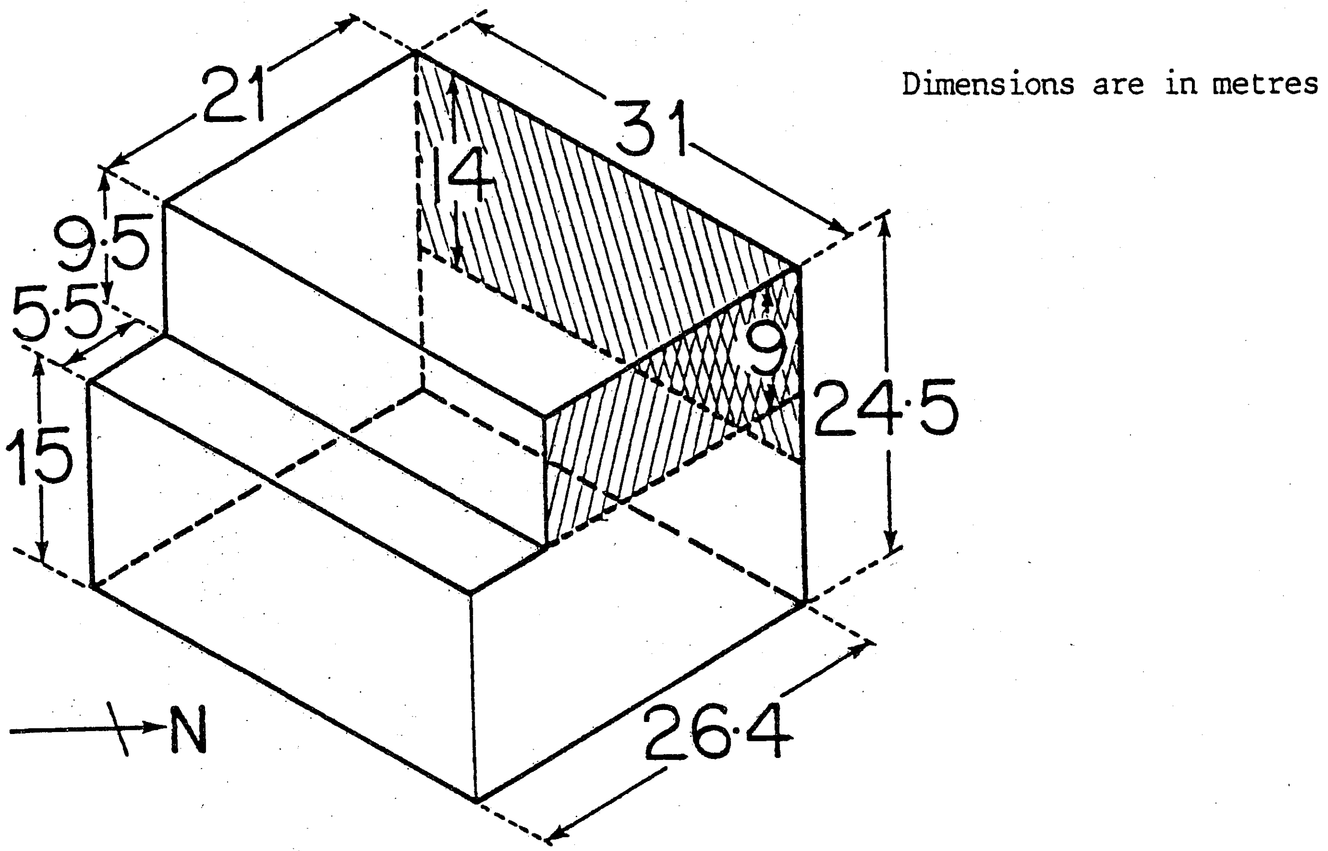

Fig. 1: Outline of proposed Television Centre Theatre.
Areas exposed to traffic noise:-
North-East wall   North-West wall

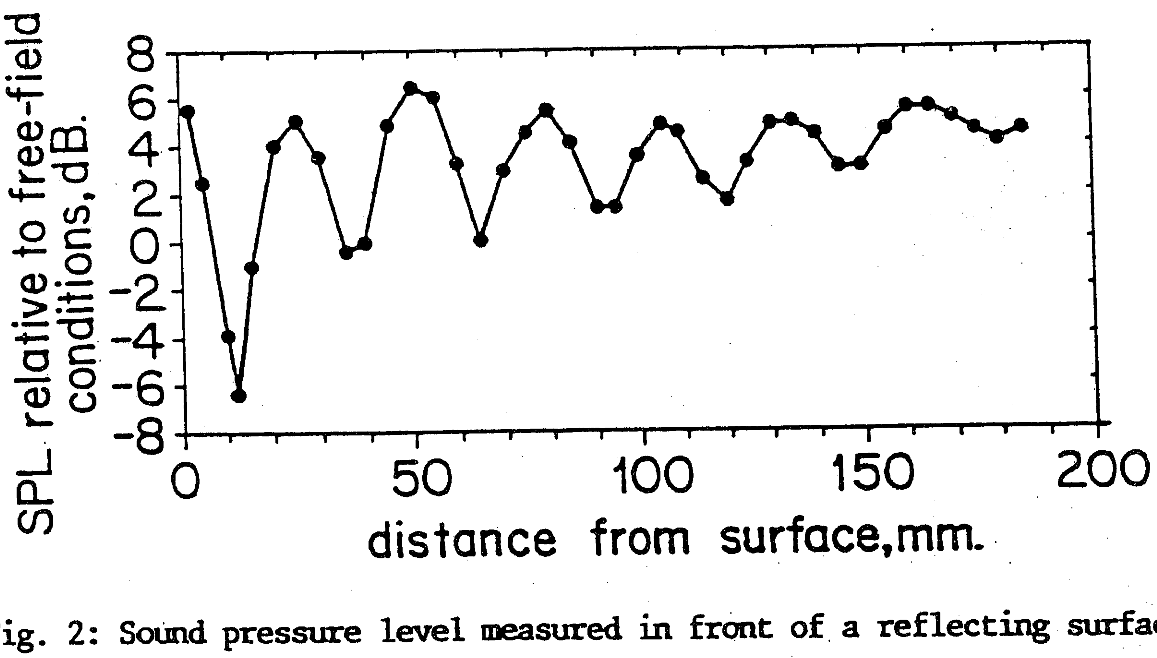

Fig. 2: Sound pressure level measured in front of a reflecting surface.
Incident signal: third-octave band-limited white noise with nominal centre frequency of 6.3 kHz.

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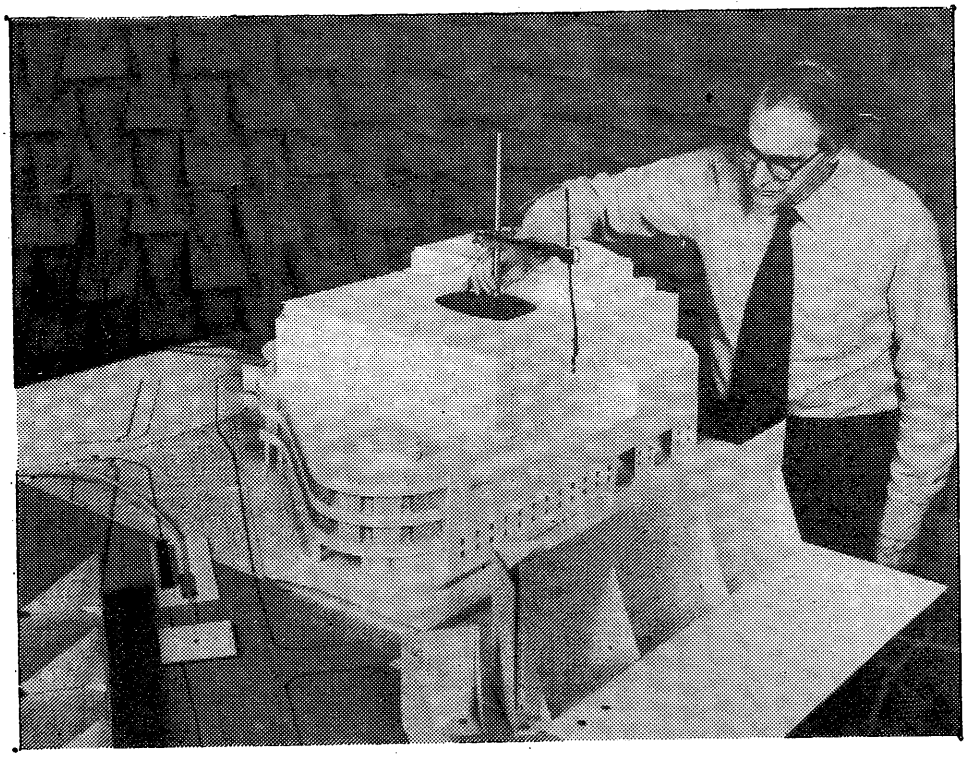

Fig. 3: Model used for tests.

Note sound source (left-hand side), microphone (centre) and reflecting surfaces representing neighbouring buildings (lower left and right).

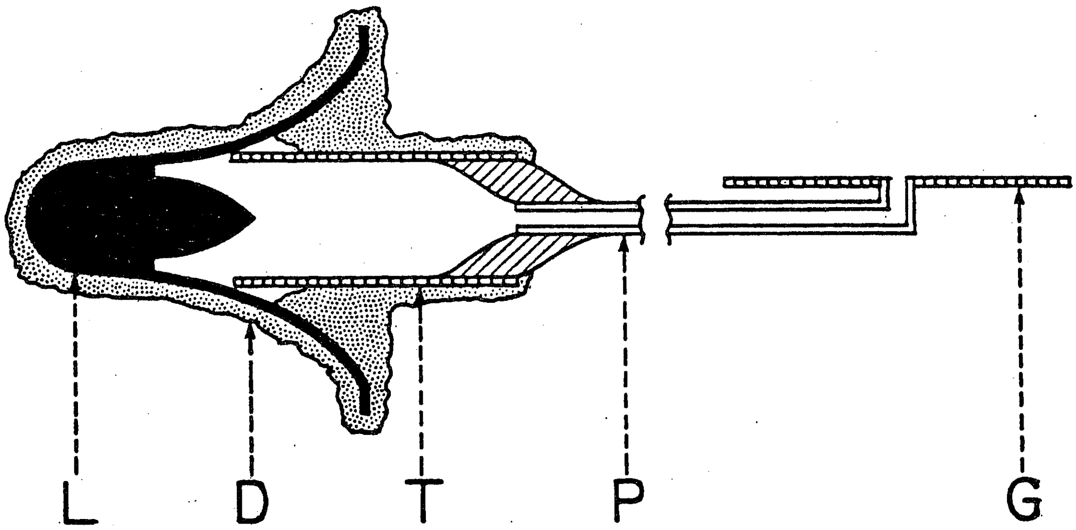

Fig. 4: Sound source used for modelling work.