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SOUND FIELDS NEAR BUILDING FACADES

by

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ABSTRACT

Measurement of sound transmission through the exterior facade of a building requires a determination of the incident sound power. Direct measurement of the sound field near the relevant surface seems preferable to the use of a 'calibrated source' because of variability in outdoor propagation associated with ground reflections and atmospheric conditions. The interpretation of sound pressure level measurements in this environment is, however, complicated by the interference between incident sound waves and those reflected from building surfaces. This paper presents experimental results and a simple predictive model.

SOMMAIRE

La mesure de la transmission du son à travers l'enveloppe d'un bâtiment exige qu'on détermine la puissance acoustique incidente. La mesure directe du champ acoustique près de l'élément de surface considéré semble préférable à l'utilisation d'une 'source étalonnée' en raison de variations dans la propagation extérieure des ondes associées aux réflexions par le sol et aux conditions atmosphérique. L'interprétation des mesures du niveau de pression du son dans ces conditions est cependant rendue difficile en raison de l'interférence entre les ondes sonores incidentes et celles réfléchies par les surfaces de bâtiments. Cette communication présente les résultats expérimentaux et propose un modèle simplifié de prédiction.

This paper uses experimental data and a simple predictive model to examine systematic effects associated with reflections from a large flat facade and, subsequently, to investigate deviations from this ideal case. For an infinite reflecting plane, sound pressure level (SPL) at the surface should be 6 dB higher than that for the incident wave alone. At some distance from the surface, phase differences between direct and reflected waves range from 0 to 360 deg for a band of noise, and the average SPL approaches 3 dB above the incident wave SPL. The practical problem is to determine the cases where the limits apply or, if possible, to predict (and correct for) interference effects in intermediate cases.

The prediction model uses a plane wave approximation and assumes specular reflection, with no absorption or phase shift at the surface. Direct and reflected waves for a specific frequency and angle of incidence are treated as fully coherent. Contributions from different angles or frequencies are treated as independent, and are combined by adding weighted mean square pressures at the position of interest. Weighting was chosen to correspond to experimental conditions (e.g., 1/3 octave bands of white noise).

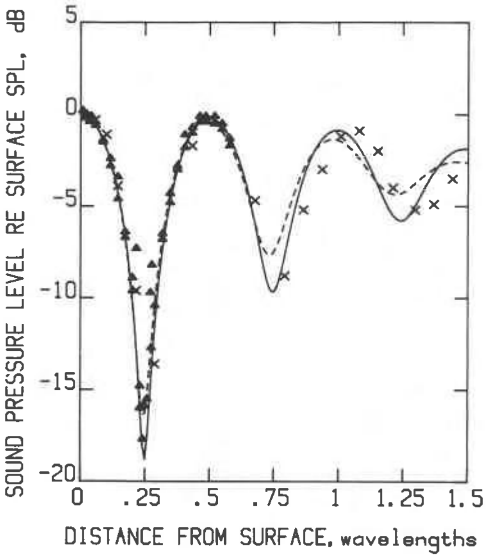

Figure 1

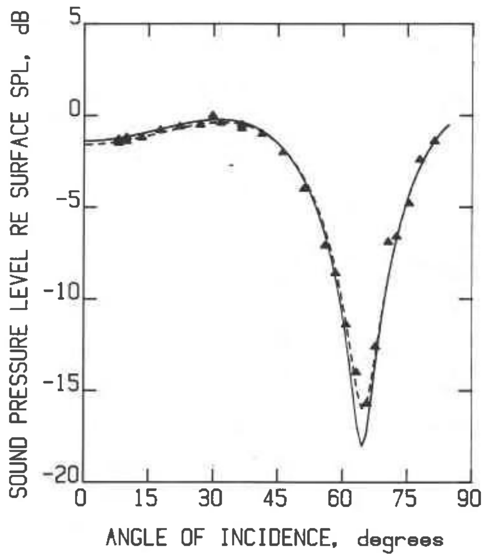

Figure 2

Figures 1 and 2 present 1/3 octave band data for SPL near a reflecting surface in an otherwise anechoic room. The reference microphone was mounted through the wall, its diaphragm flush with the surface. The source was a small loudspeaker 3 m from the reference microphone; white noise was used. Data for 2 kHz (Δ) and 5 kHz (X) bands were obtained using 6 mm condenser microphones with a conventional 1/3 octave measuring system by repeated careful repositioning of microphone or source. The solid line shows the calculated difference in SPL for a perfect 1/3 octave filter, and the dashed line the corresponding calculation for a filter with the minimum attenuation characeristic for an ANSI Class III filter; as expected, data fall between these limits. Figure 1 presents the data for perpendicular incidence, with the second microphone centred from 3 mm (touching surface) to 100 mm from the reflecting plane. The relation between incident sound power and measured SPL changes significantly in the region 0.1 - 1 wavelength from the surface, and quite small changes in microphone position can drastically alter the apparent spectral balance. Figure 2 illustrates the change in SPL at a fixed position (0.57 wavelength from surface) as angle of incidence changes. As the angle moves from 0 deg towards grazing incidence, path length difference between direct and reflected waves decreases; for a fixed microphone position the interference pattern shifts to higher frequencies.

A clear impression of the interference pattern can be obtained more easily by using frequency rather than source or microphone position as the independent variable. Figure 3 shows the difference between measured SPL at two microphones (O), obtained from rms-averaged spectral amplitude measurements with a two-channel FFT analyser. One microphone touched the surface; the other was 2 m from the exterior wall of a building. White noise came from a loudspeaker at an angle of incidence of 60 deg. The dashed line shows the calculated difference in SPL for the filter response associated with an individual frequency line of the FFT. Small discrepancies between experiment and calculation are believed to be due to physical complications (such as sound reflected from the ground surface) not accounted for in the calculation. The solid curve in Fig. 3 is the 1/3 octave response synthesized from the FFT; at high frequencies the results approach 3 dB below the surface SPL, but interference effects are appreciable for the lowest bands.

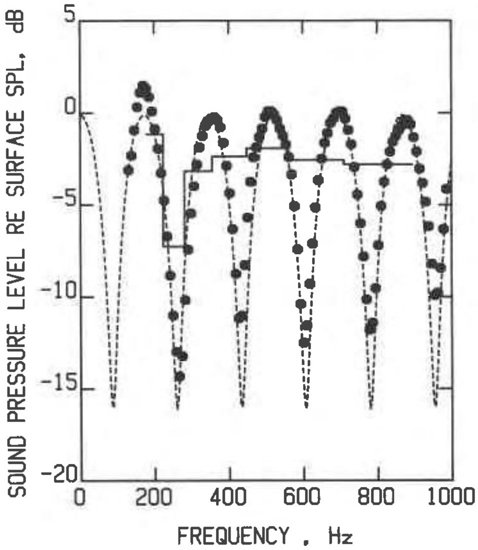

Figure 3

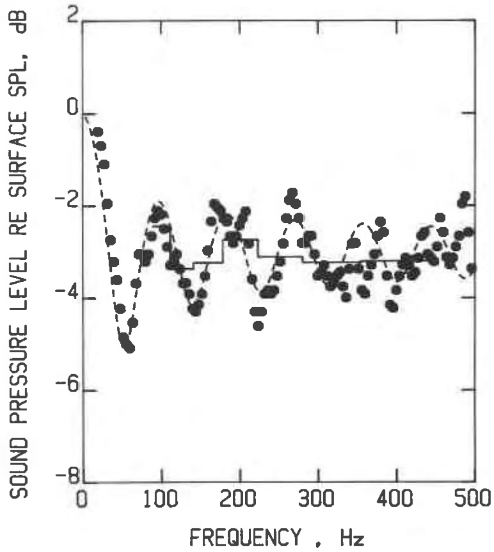

Figure 4

Reduced interference effects were observed with a line source. Figure 4 shows the predicted and measured SPL differences for microphones touching and 2 m from a large flat wall facing a major highway. The different interference patterns for different angles of incidence average out much of the variation in SPL versus frequency or distance from the surface. For the 2 m position the 1/3 octave SPL (solid curve) approaches surface SPL minus 3 dB for the bands above 100 Hz. Measuring closer to the surface would shift interference effects to higher frequencies.

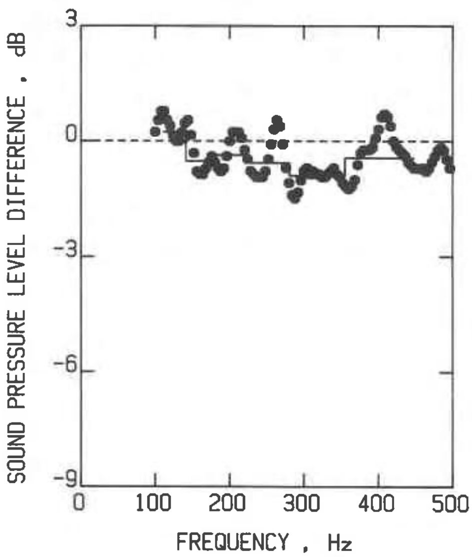

Figure 5

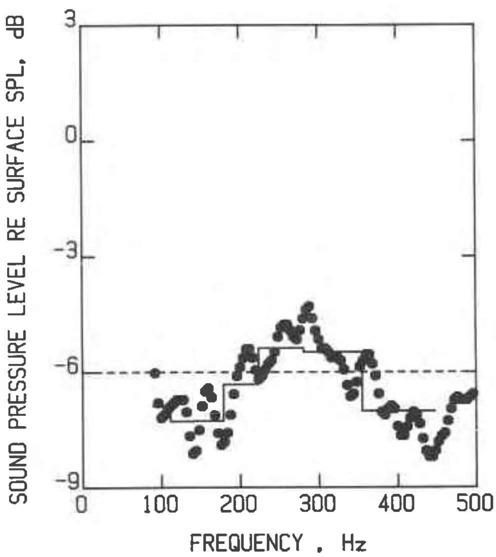

Figure 6

Standards for measuring facade sound transmission commonly assume that SPL at building surfaces is 6 dB higher than the SPL for the incident wave. Scattering, diffraction, and response of surface elements to the sound field could introduce deviations from this. Figures 5 and 6 show the difference in SPL measured with the FFT analyser for two microphones near a house wall (3 m high x 9 m wide). The data in Fig. 5 were obtained with microphones touching the wall at mid-point and 1 m from the corner. Similar results were obtained for other positions. Although systematic variation with frequency is evident, the 1/3 octave SPL (solid curve) is nearly uniform over the surface. The data in Fig. 6 were obtained with one microphone touching the wall surface (1 m from the corner) and the second microphone 2 m beyond the corner. Variations in SPL differences with frequency are consistent with expected diffraction fringes, but detailed calculations to confirm this mechanism are beyond the scope of this work. Variations in reflections from the rather uneven ground surface might also contribute. The average difference in SPL is close to 6 dB; for 1/3 octave bands, assumed pressure doubling at the wall is reasonably accurate.

At high frequencies the pressure doubling assumption fails if microphone diameter is comparable to wavelength. Figure 7 shows the difference, for a point source at normal incidence, between surface SPL (measured with flush-mounted microphone) and that measured with a 25 mm microphone touching the surface. The dashed line shows the calculation (as in Fig. 3) for expected SPL at the microphone mid-point; a sharp minimum is predicted near 7 kHz. The lumped response of the microphone to pressure distribution over the entire diaphragm limits the measured minimum; diffraction and microphone response also affect the results above 6 kHz. Measurements with smaller microphones centred at the same location should approach the calculated result more closely. The preceding analysis is concerned with SPL adjacent to essentially flat surfaces, but actual doors and windows are seldom flush. Because these elements often dominate sound transmission, sound power reaching them is of particular interest. Figure 8 shows the measured difference between SPL at a door surface (recessed 150 mm) and the reference SPL at an adjoining flat surface. Microphone location on the door surface alters the observed maxima and minima, which are apparently due to interference of sound wave components parallel to the surface: the high impedance of the 40 mm solid wood door should ensure negligible panel response. These effects should average out for higher 1/3 octave bands, but as shown by the solid curve in Fig. 8, they may affect the lower bands appreciably.

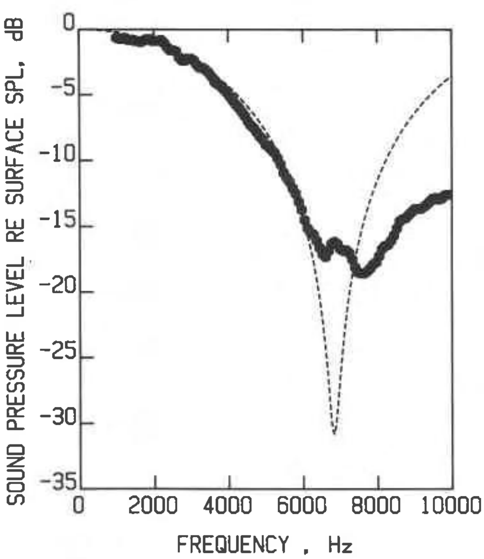

Figure 7

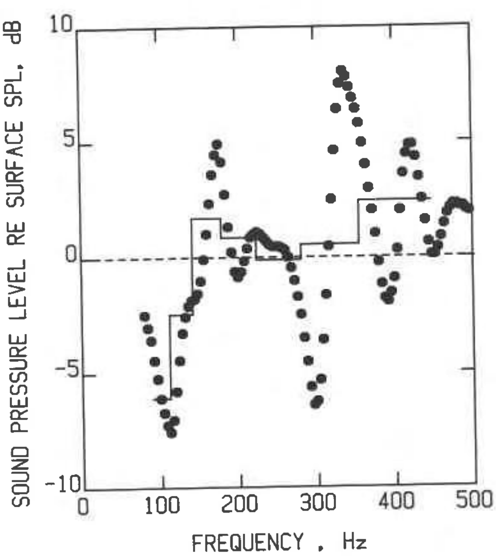

Figure 8