From Acoustics Week in Canada 2001/De l'acte semaine candienne d'acoustique 2001

PREDICTION OF SOUND LEVELS IN ROOMS WITH LOCAL- AND EXTENDED-REACTION SURFACES

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A new wave-based model which predicts steady-state sound-pressure levels in rooms bounded by extended-reaction surfaces has been developed and used to study the effect of modeling room surfaces as of extended or of local reaction.

1. MODEL DEVELOPMENT

The new model combined two approaches – a triangular beam-tracing model with phase for the room, and a transfer-matrix model for the surfaces. The model works in the frequency domain.

Room model - A spherical wave was approximated by a point source surrounded by an icosahedron with subdivided faces. Each beam was propagated through the room by tracing its central ray up to a specified reflection order in an attempt to find a valid source-receiver path. The beam face represents a portion of the spherical sound wave-front as a complex pressure (with magnitude and phase). With each surface reflection, the associated complex pressure reflection coefficient was multiplied by the incident beam's complex pressure to find the pressure at the reflected beam front. The sum of the complex pressures at the beam face for each occurrence of a valid source-receiver path is that beam's contribution to the sound pressure at the receiver. The sum of the pressure contributions from all beams yields the steady-state sound-pressure level at the receiver point.

Surface model - A transfer-matrix approach was adopted to predict the acoustical properties of extended- or local-reaction surfaces. This model calculates the surface impedance and pressure reflection coefficient of multi-layered surfaces. These surfaces consist of a series of isotropic layers with finite thickness and infinite lateral extent, and materials classified as either fluid, elastic-solid or elastic-porous. Biot theory is used in the transfer-matrix formulation of the porous layer. The complete model comprised the assembly of the boundary conditions at each layer interface; this involved interface matrices and the transfer matrix of each layer. The surface impedance and pressure reflection coefficient of the multi-layered surface, modeled as of extended- or local-reaction, were obtained from the assembled transfer matrix.

The two models were integrated to form the new room-prediction model. The transfer-matrix model output the complex reflection coefficient and surface impedance. The inputs were frequency, incident angle and the material properties of the layers. It was called in the beam-tracing program at each occurrence of a surface reflection from a multi-layered surface, to calculate the reflection coefficient.

2. VALIDATION

The beam-tracing and transfer-matrix models were validated separately. Predictions by the beam-tracing model were compared with those by a method-of-images model which included phase, for several room/surface configurations (described below). This involved studying the number of beams, and of reflections, required to obtain reliable predictions. Good agreement was obtained using 2500 beams and 25 reflections. Predictions by the transfer-matrix model were compared with theory or published experimental results in the case of surfaces commonly found in rooms, with excellent agreement.

3. PREDICTIONS AND RESULTS

The new model was used to study three rooms: a small office (3 ´ 3 ´ 3 m3); a corridor (10 ´ 3 ´ 3 m3); a small industrial workroom (10 ´ 10 ´ 3 m3). In each case, one wall comprised one of five test surfaces - a single glass plate, double drywall panels, double steel panels, carpet on concrete, or a suspended acoustical ceiling - which were modeled as of either local or extended reaction. Other room surfaces had frequency and angle invariant absorption coefficients of 0.1.

Figure 1 shows the case with the greatest difference between the two results – the corridor with a suspended acoustical ceiling. The study results can be summarized as follows, in terms of the difference between the extended- and local-reaction levels:

- All rooms with a single glass plate showed no difference;
- With double drywall panels on the walls of the office and corridor, there were differences at low frequency, with extended reaction giving 1-9 dB higher levels;
- With double steel plates on the walls of the workshop, the extended-reaction level was higher by 2 dB in the 63 Hz octave band. The local-reaction level was higher by 3 dB and 2 dB in the 125 Hz and 250 Hz octave bands, respectively.

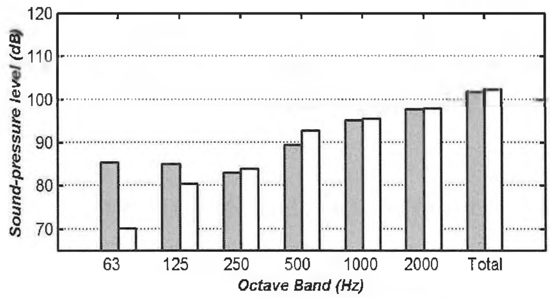

Fig. 1. Octave-band sound-pressure levels predicted in the corridor with a suspended acoustical-tile ceiling. Extended reaction - grey bar; local reaction - white bar.

In the above cases, levels were similar at high frequency.

- With a carpeted floor in the office and corridor, local-reaction levels were 1–3 dB higher in the 500–2000 Hz octave bands;
- In the office and corridor with a suspended acoustical ceiling, the extended-reaction levels were up to 15 dB higher at low frequency, and the local-reaction levels were slightly higher at high frequency;
- In the workshop with a double steel-panel ceiling, the local-reaction level was higher by 2–3 dB in the 63 Hz, 125 Hz and 500–2000 Hz octave bands. The extended-reaction level was slightly higher in the 250 Hz octave band;
- In the workshop with a fibre-glass-lined concrete ceiling, the two levels were similar in all bands.

The results can be partially explained by an analysis of the reflection coefficients of the test surfaces in the two cases, and of the dominant wave-incidence angles on the test surface. For example, Figure 2 shows the real and imaginary parts of the two reflection coefficients relevant to Figure 1 at 63 Hz; values are generally higher with extended reaction, explaining the higher levels. The first-order reflection on the ceiling was incident at 76°. Generally, these results correlated well with the differences between the angular variations of the extended- and local-reaction surface reflection coefficients.

4. CONCLUSION

Following are the main conclusions of the study regarding the difference in modeling a surface as of extended or local reaction on steady-state levels:

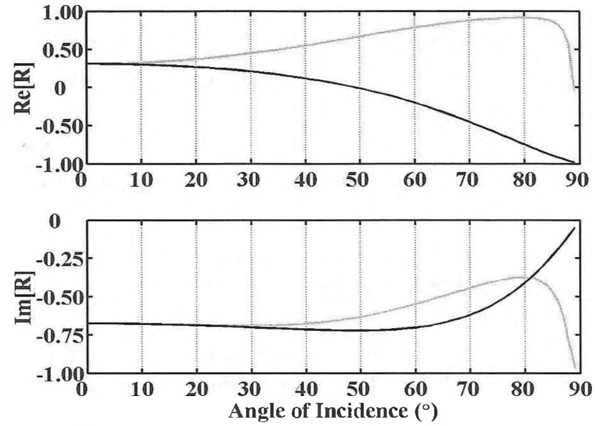

Fig. 2. Angle dependence of the real and imaginary parts of the reflection coefficient R of a suspended acoustical ceiling, at 63 Hz: Extended reaction - grey line; Local reaction – black line.

- It is not significant when the surface is a single plate or a single layer of material (solid or porous) with a rigid backing;
- It is significant when the surface consists of multi-layers of solid or porous material and includes a layer of fluid with a large thickness relative to the other layers;
- For surfaces for which the reflection coefficient is different when obtained with an extended- or local-reaction surface impedance, the extended- and local-reaction assumption may be significant, depending on the source and receiver positions. This may be significant when the positions are such that near-grazing incidence occurs in a source-receiver path that includes a strong reflection.