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LOW FREQUENCY AIRBORNE SOUND TRANSMISSION IN BUILDINGS: SINGLE PLANE WALLS

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1. INTRODUCTION

The problem of sound transmission in buildings at low frequencies is becoming of increasing practical [1] and theoretical interest [2] due to the spectra of indoor and outdoor noise sources [3]. This paper is aimed at improving the understanding of this problem.

2. CALCULATION MODELS

The analysis is restricted to airborne sound transmission through plane, rectangular, single-leaf walls. The walls are assumed to be homogeneous, isotropic and thin compared to the bending wavelength. Harmonic pure bending wave motion according to Kirchoff's theory is assumed.

Infinite plate theory. This approach is based on plane wave transmission through an infinitely extended plate [4]. Sound transmission at normal incidence is governed by the mass law. For oblique incidence there is increased sound transmission at the critical frequency, which depends on the mass and the stiffness of the wall. Random incidence sound transmission loss (TL) is expressed as

$TL = 10\lg\left(\int_{0^0}^{78^0} \tau_\alpha \sin 2\alpha d\alpha\right)^{-1}$ (1), where α is the angle of incident, τ_α is the transmission coefficient.

Modal approach: baffled plate model. A plane wave of unit amplitude is incident on a plate mounted in an infinitely extended, rigid baffle. The sound pressure radiated by the plate is expressed in terms of the Huygens integral [5]:

$P(x_1,y_1,z_1) = -\frac{i\omega\rho}{2\pi}\iint_s v(x',y')\frac{\exp(ikR)}{R}ds$ (2), where v is the particle velocity, R is the distance from the surface element ds to the observation point and s is the area of the plate.

The difference between the total sound pressures on both sides of the plate is substituted into the bending wave equation of the plate. The transverse velocity of the plate is expanded as a modal summation over the plate's egenfunctions. The radiation impedances for the bending modes of the plate are calculated numerically. Finally, the transmission coefficient is calculated as ratio of the acoustic power incident on the plate to the power radiated at the receiving side. Numerical results for the finite sized plate show a complex sound transmission function, with violent peaks and dips due to plate modal behavior.

Modal approach: room-plate-room model. In this model, full coupling between the bending modes of the plate and the modes in the emitting and receiving room is taken into account [6]. The analysis is restricted to a rectangular geometry. The sound pressure in the rooms fulfills the Helmholtz equation and is expressed as a summation of traveling waves:

$P(x,y,z)=\sum_m\sum_n[exp(-ik_{zmn}z)A_{mn}+exp(ik_{zmn}z)B_{mn}]\phi_{mn}(x,y)$ (3), where A_{mn} and B_{mn} are the unknown pressure amplitudes. The room boundaries normal to the separating wall are assumed to be rigid. The transverse velocity of the plate is expanded as a modal summation over the plate's eigenfunctions. The unknown plate and pressure amplitudes are solved from the plate equation of motion and the continuity conditions between the sound fields and the plate surface.

3. RESULTS

Measured and predicted results (Fig. 1.). As a validation of the calculation models, measurements were carried out in the transmission rooms of university laboratory. Both rooms are identical with a volume of 85 m^3 each. The partitions were a calciumsilicate brick wall (3x3.3x0.1m) and a thick glass plate (1.48x1.25x0.019m). Additional experiments were performed in a scale model (1:5) of two adjacent rooms (2 m^3) separated by a glass plate (1.285 x1.21x0.019m). The rooms are exited by a corner source or a source suspended close to the back wall. Sound pressure levels were measured in narrow band (FFT mode, 800 lines, 1-400Hz band) and in 1/3 octave bands in 33 fixed microphone positions. Experimental results show that the rooms and the partition (plate) respond in a resonant manner with room modes dominating in the emitting room (Fig. 1.A.) and by room/plate modes dominating in the receiving room (Fig. 1.B.). The plate also has a nonresonant response enforced by the emitting room modes. The calculation results indicate that the room-plate-room model provides better agreement with measurement results, compared to the infinite or baffled plate models (Fig. 1. C. - H.).

Parametric study (Fig. 2.). Numerical experiments were carried out to examine the influence of room/partition dimensions on the sound transmission. In setup A. the width of the partition is varied: this affects selected modes of the emitting and receiving room and all modes of the partition. In setup B. the back wall of the receiving room is moved: this affects selected modes of the receiving room only. In both experiments emitting and receiving rooms have a reverberation time of 2.5 s and 1.0 s, respectively. The sound pressure is calculated as the integration over the whole room volume and averaged over 1/3 octave bands and full octave bands for setup A. The sound reduction index (SRI) is calculated according ISO 140. The standard deviation in 1/3 octave bands is up to 15 dB. In full octave bands the standard deviation ranges from 2 to 6 dB.

Parametric study shows that in the low frequency range it is very difficult to extrapolate laboratory results to situations with different geometry and dimensions for the rooms or the partition. However, analysing the low frequency transmission in full octave bands (Fig. 2. G., H.) minimises the influence of the rooms/wall dimensions.

4. CONCLUSION

The results show that the sound transmission at low frequencies depends not only on the properties of the test wall, but also of the geometry of the room-wall-room system. For rigid, stiff walls both resonant and nonresonant transmission significantly affect the sound insulation. In general, variation in low - frequency sound insulation compromises the accuracy of a prediction of the sound insulation in situ. In our further research we will focus on the validation of the results of the parameter study, by comparing measurements and predictions of low-frequency sound transmission between size-varying rooms separated by the stiffness (bending)-varying walls.

ACKNOWLEDGMENT

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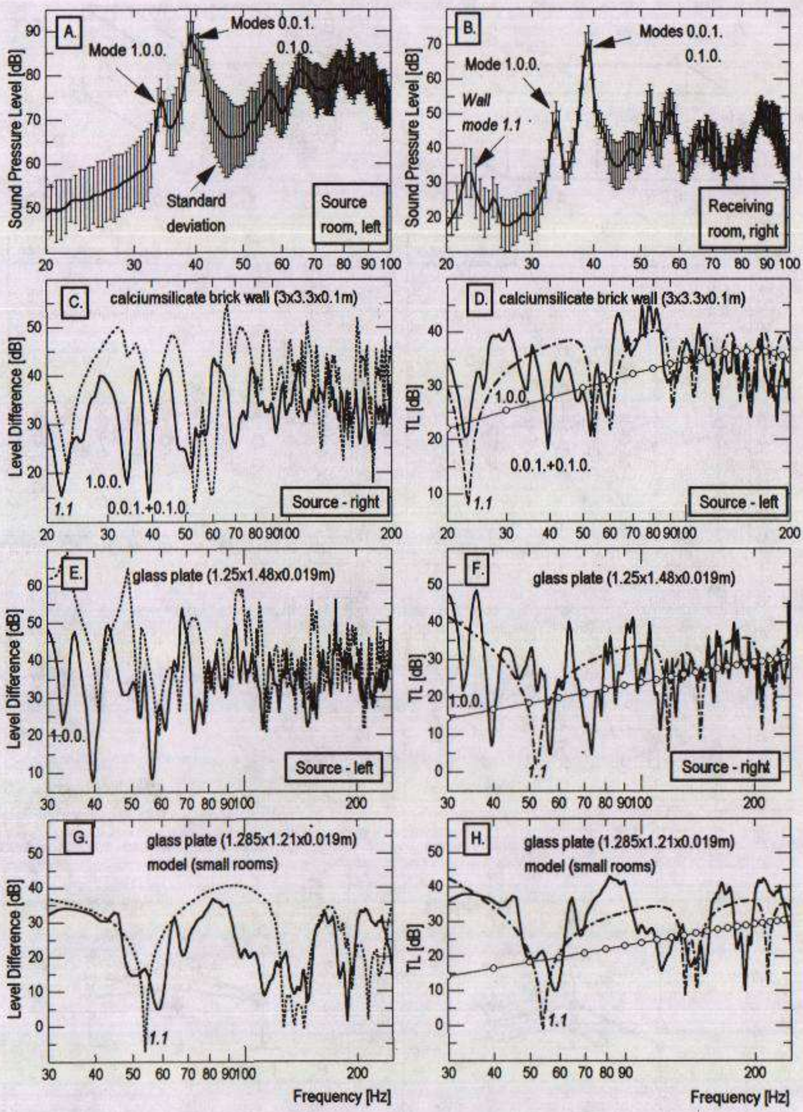

Fig.1 Graphs A. - F. - laboratory, real scale transmission rooms. Graphs G. and H. - model (small rooms). Graphs A. and B. - measured sound pressure levels, source in the left room. Graphs C. and H. - measured and predicted sound pressure level difference and transmission loss (TL). ——— - measurements, —o— - infinite plate theory, -·-·-·- - baffled plate model, ·········· - room-plate-room model.

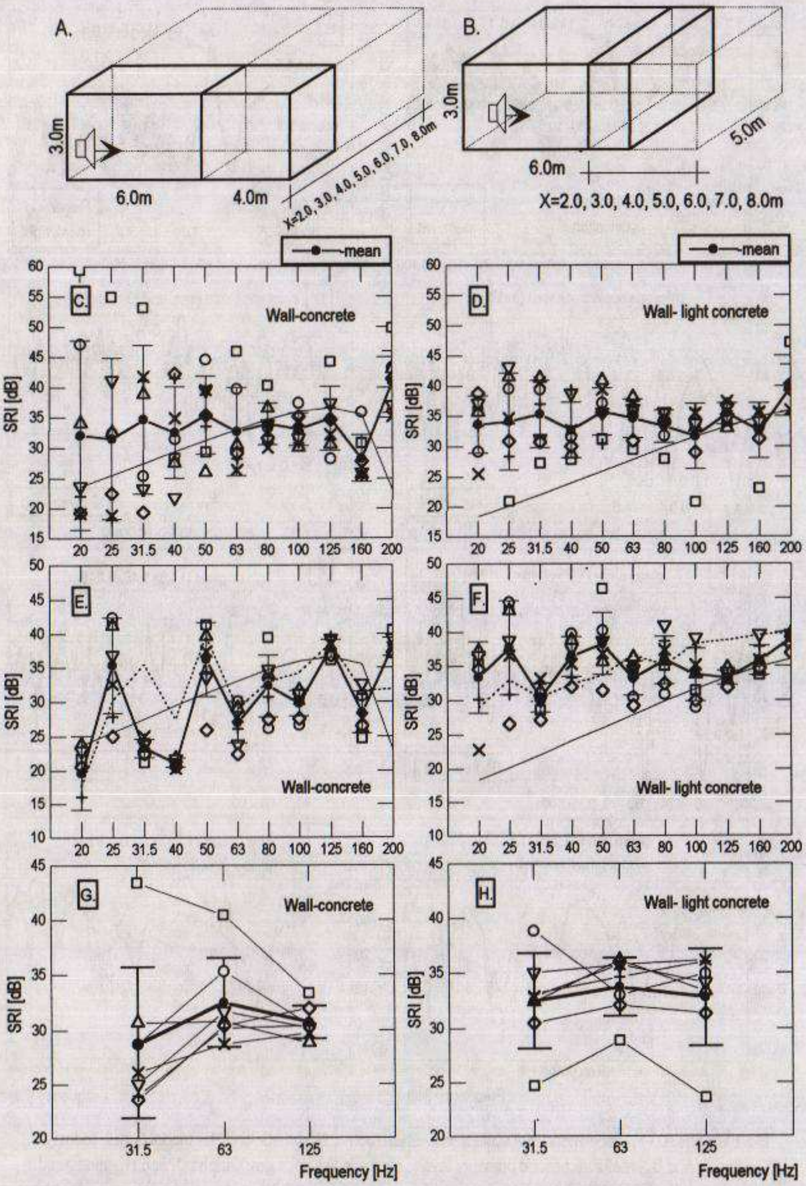

Fig. 2 Predicted SRI. Setup A. - graphs C., D., G., and H. Setup B. - graphs E. and F.
X=2.0 □ , 3.0 ○ , 4.0 △ , 5.0 ▽ , 6.0 ◇ , 7.0 + , 8.0m × . Wall thickness - 10 cm.
(———) - infinite plate theory. (··········) - baffled plate model. Symbols - room-plate-room model.