Preliminary Results Of A Systematic Study Of Sound Transmission Through A Cavity Wall Assembly

T.R.T. Nightingale and J. D. Quirt
Institute for Research in Construction, National Research Council, Ottawa, Ontario, Canada K1A OR6

INTRODUCTION

This paper examines trends from a parametric study that examined the transmission loss (TL) of simple cavity walls without framing. This paper is restricted to examining the effect associated with doubling the depth of a simple wall constructed from two sheets of 3 mm thick LEXAN (1.2 x 2.4 m, density 1183 kg/m^3, and modulus of elasticity 4.8×10^9 Pa). The LEXAN wall specimen was placed in a filler wall that had a very much greater TL so no correction to the measured data was necessary. Fibrous material, when installed, was placed vertically (i.e., parallel to the LEXAN leaves) and was supported by thin wires to prevent the material from touching the leaves. The LEXAN was supported only at the perimeter; there was no framing interior to the cavity. Measured trends are compared to predictions from a lumped-impedance (T-Matrix) model to provide insight into the transmission mechanism(s).

Simple cavity walls like the one described above can be modelled using the T-Matrix method if each element (LEXAN sheets, and the cavity) can be considered to be semi-infinite. LEXAN sheets and the cavity approximate these conditions reasonably well, since the cavity perimeter is hard and reflective and the LEXAN has a very high critical frequency.

Lumped impedance models show that the TL of a cavity wall will exhibit different trends in three frequency regions: below the mass-spring-mass (MSM) resonance, between the MSM resonance and the first cavity cross-mode, and above first cross-mode.

The MSM resonance is caused by the air in the cavity coupling the wall leaves. The air acts like a spring and the resonance frequency, F_{MSM}, is given by,

$$F_{MSM} = \frac{1}{2\pi}\left[\left(\frac{\rho c_c^2}{d}\right)\left(\frac{\rho s_1 + \rho s_2}{\rho s_1 \rho s_2}\right)\right]^{\frac{1}{2}} \qquad (1)$$

where ρ is the density of air, C_c is the speed of sound in the cavity, d is the cavity depth and ρs is the surface density of the leaf indicated by the subscript. The frequency of the first cross-mode is given when n=1 by,

$$F_{CM} = \frac{n\,c}{2d\,\cos(\theta)} \qquad (2)$$

where θ is the angle of incidence.

The formulation of the T-Matrix model for a cavity wall has already been given[2] and will not be repeated here. Recently, it has been shown that accuracy of T-Matrix predictions can be greatly improved if a Gaussian weighting function[3] is used when computing the angular average TL. This was incorporated in this work.

EMPTY CAVITY RESULTS

Figure 1 shows the measured TL for the wall with an empty cavity of varying depth. Shown for comparison are the data for a single sheet of LEXAN. From the figure is easy to see the detrimental effect of the MSM resonance. The 25-mm cavity shows this very well, since the TL is higher for the single sheet in the frequency range 250 Hz to 1000 Hz than for two sheets spaced by 25 mm. Increasing the air space reduces the MSM frequency and shifts the frequency at which the single sheet out-performs the cavity wall to lower frequencies. It is for this reason that separating impermeable materials in walls or floors by a small air space should be avoided, where possible.

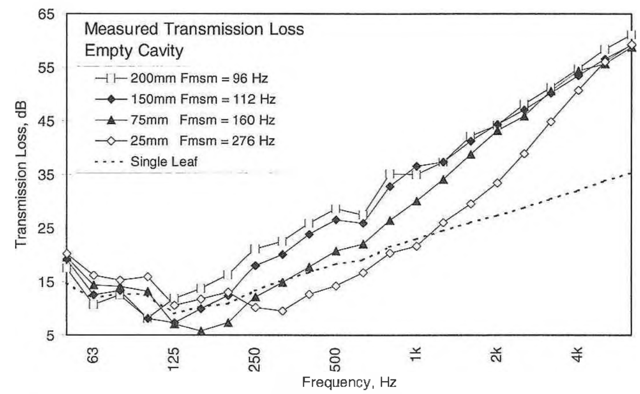

Figure 1: TL for the LEXAN wall with an empty cavity of varying depth measured in accordance with ASTM E90. Shown for comparison are the TL data for a single LEXAN sheet.

Figure 2 shows the measured and predicted change in the TL for doubling the cavity depth. From the figure it is evident that the below F_{MSM} there is no improvement. This should be expected since, for both the larger and smaller cavity depths, the air appears to be a very stiff spring that couples the two leaves. For frequencies well below F_{MSM}, the resulting TL is the same as if the leaves were glued together, without a cavity.

Both the measured and predicted results indicate that increasing the cavity depth causes a very significant change in the TL near F_{MSM}. There will be a reduction in the TL at F_{MSM} for the deeper cavity and then there will be a rapid improvement with increasing frequency to a maximum at F_{MSM} for the original cavity depth before doubling. Above F_{MSM} for the smaller of the two cavities, the benefit of depth doubling is diminished with increasing frequency. The predictions show that the TL will tend to converge to a limiting value and increasing the cavity depth will have only a very marginal improvement. The measured data exhibit this trend too, although not as clearly. Inspection of Figure 1 suggests that the once the cavity depth is greater than approximately 1-1/2 wavelengths there is little benefit to increasing the depth.

The trend of diminishing TL improvement with increasing frequency shown in Figure 2 can be explained by noting that above F_{MSM}, the transmission loss increases rapidly with increasing frequency (18 dB/octave for normal incidence) to the point at which the cavity depth is equal to one-half wavelength, F_{CM}. At this frequency, and all multiples of it, (e.g., n=2, 3, 4... in equation 2) the TL will take an abrupt drop because of efficient coupling across the cavity. Since, the sound field is incident at all angles, there will be at least one angle for which this half-wavelength condition is satisfied at each frequency. Thus, in a given frequency range, there should be a minimum cavity depth above which the number of cross-mode conditions (equation 2) remains nearly constant with increasing frequency. This explains the presence of an upper limit for the transmission loss for an empty cavity and the strong dependence of the TL on the angular distribution of the incident sound field[3].

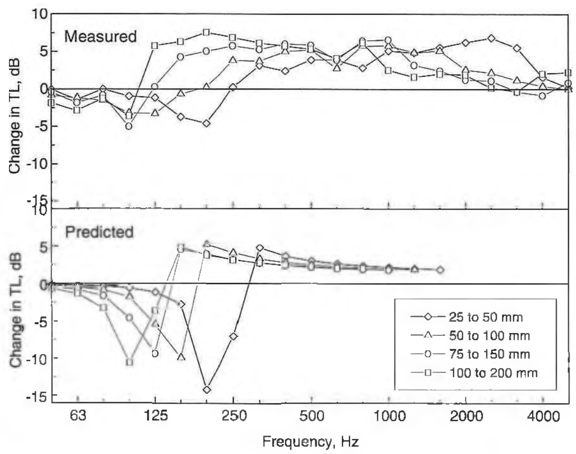

Figure 2: Measured and predicted change in the TL due to doubling of the cavity depth of the LEXAN wall without absorption. Predictions above 1600 Hz are not shown due to difficulties in obtaining solution convergence.

FILLED CAVITY RESULTS

The same series of measurements were conducted with the cavity filled with a rigid fibrous board material having an airflow resistivity of 7800 mks rayls/m. Both the measured and predicted results of Figure 3 show that F_{MSM} shifts to lower frequencies when cavity is completely filled with absorption. This is because the speed of sound in the fibrous material is slower than in air, and can be approximated by,

$$C_c = \frac{C_o}{1+0.0978\left(\rho\frac{f}{R}\right)^{-0.700}} \qquad (3)$$

where C_0 is the speed of sound in air, and R is the airflow resistivity of the fibrous material filling the cavity.

For frequencies well below F_{MSM}, the effect of doubling the depth of a completely filled cavity is the same as if the cavity were empty; there is no improvement.

In the frequency region near F_{MSM} the measured and predicted results are in reasonable agreement as shown in Figure 3.

Just as in the empty cavity case, for frequencies above F_{MSM} of the original cavity, the improvement due to doubling the cavity depth diminishes with increasing frequency. However, unlike the empty cavity, the data to not converge to a limiting value. There is a frequency at which there is a very pronounced TL improvement with increasing depth. From Figure 3 and using equation 3 it can be shown that if the depth of the original cavity is at least 1/5 of a wavelength then there will be a very significant increase in the TL due to doubling the cavity depth.

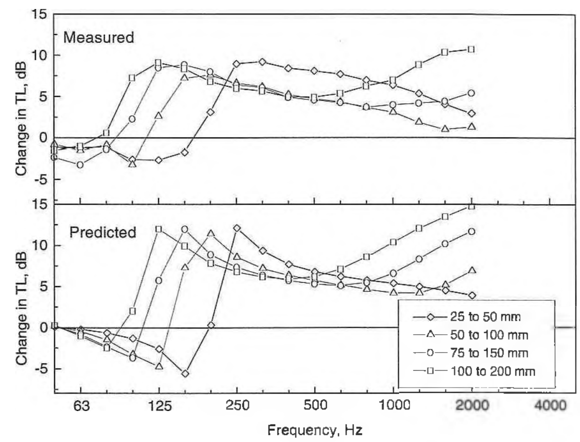

Figure 3: Measured and predicted change in the TL due to doubling of the cavity depth of the LEXAN wall that was completely filled with fibrous material having an airflow resistivity of 7800 mks rayls/m. Measured data are not shown above 2000 Hz since the measured results proved to be very sensitive to edge conditions and unreliable.

CONCLUSIONS

Cavity depth is an important factor in determining the sound insulation of double leaf walls. The trends due to doubling the cavity depth are similar for cavities with and without fibrous material. Measured and predicted results show that there is no improvement for frequencies well below F_{MSM} even if the cavity has absorption. Absorption tends to shift the F_{MSM} to lower frequencies and, in this sense, it can be thought of as effectively increasing the cavity depth. Increasing the cavity depth should not be relied upon as a method to improve the high frequency TL of a wall with an empty cavity. However, if the cavity is completely filled with fibrous material and the wavelength is less than 5 times the depth of the cavity, doubling the cavity depth will offer significant TL improvement.

REFERENCES

Quirt J.D., Warnock A.C.C. "Influence of sound absorbing material, stud type and spacing, and screw spacing on sound transmission through a double-panel wall specimen", Proceedings of InterNoise'93, pp. 971-974. 1993

Ookura, K., Saito,Y., "Transmission loss of multiple panels containing sound absorbing materials in a random incidence field," Proceedings of InterNoise'78, pp. 637-642. 1978.

Kang, H.J., Ih., J.G., Kim, J.S., Kim, H.S., Kim, S.R., "Directional dependence of the incident energy in measuring and predicting the sound transmission loss through partitions," Proceedings Sixth International Congress on Sound and Vibration, Copenhagen, Denmark, July, pp. 305-312, 1999.