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SOUND TRANSMISSION THROUGH CAVITY WALLS

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INTRODUCTION

Cavity walls consist of two masonry walls separated by a small air gap or cavity. To increase the strength it is normal to join the two walls together using wall ties. These are rod like components which are built into the mortar beds and result in point connections being formed over the surface of the two walls. Normally cavity walls have about 2.5 ties per square metre. Cavity construction is common both in party walls and in the external envelope of dwellings.

Theoretical models to predict the performance of these walls are more complex than models for single walls and have been generally less successful. Crocker *et al* [1] proposed a statistical energy analysis (SEA) model which could be used as the basis of a theory. They modeled the tie as a subsystem where transmission is assumed to be due to bending waves. Cremer *et al* [2] however, showed that for bridges of this type transmission is dominated by longitudinal motion of the tie rather than bending. A typical wall tie exhibits its first longitudinal mode at around 30 KHz and so modelling the tie as a subsystem is inappropriate for use in building acoustics.

In this paper a SEA model is proposed for cavity walls which treats the tie as a coupling mechanism and not as a subsystem.

THEORY

Metal ties

Cremer *et al* [2] has shown that, if there is a short tie connecting two parallel plates, then, the power flow between them is related to the mobility of the plates. Adding in terms for the stiffness of the tie gives the power flow across a single wall tie as

$$W_{12} = v_1^2 \frac{Y_2}{(Y_1+Y_2)^2 + \left(\frac{\omega L}{SE}\right)^2} \tag{1}$$

where W_{12} is the power flow from plate 1 to plate 2, v_1 is the RMS velocity of plate 1, Y is the plate mobility, L is the length of the tie, S is the cross sectional area of the tie and E is the Youngs modulus for the tie. For a homogeneous plate the mobility is given by,

$$Y = \frac{1}{2.3\rho_s C_l h} \tag{2}$$

where ρ_s is the surface density of the plate, C_l is its longitudinal wavespeed and h is the thickness. If all the ties act independently then the total power can be obtained by multiplying the power for one tie by the number of ties.

In SEA the power transmitted between two subsystems is, by definition,

$$W_{12} = E_1 \omega \eta_{12} \tag{3}$$

where E_1 is the energy in subsystem 1 (and is mass, m_1, times velocity squared, v_1^2) and η_{12} is the coupling loss factor (CLF) from subsystem 1 to subsystem 2. Equating the two expressions for power gives the CLF for transmission across the ties as

$$\eta_{12} = \frac{r\ Y_2}{\omega \rho_{s1}\left((Y_1+Y_2)^2 + \left(\frac{\omega L}{SE}\right)^2\right)} \tag{4}$$

where r is the number of ties per square metre.

<u>Air Coupling</u>

In addition to power flow across the metal ties there is power flow between the two plates due to the air in the cavity. A reasonable assumption (which agrees with measured data) is to model the air as a single point connection with the same stiffness as the air. The total stiffness k_a of the air in a cavity of width d is given by,

$$k_a = \frac{K\,A}{L} \tag{5}$$

where K is the bulk modulus of air equal to $1.4\text{x}10^5$ N/m^2 and A is the area of the wall. Normally the effect of the air is insignificant compared with that of most wall ties, however at high frequencies cross cavity modes occur and this results in an increased air stiffness. A more exact expression that accounts for the resonances that occur in the cavity at the higher frequencies is [2]

$$k_a = S\left(\frac{-i\omega\rho c\,(1+(1-\alpha)^2 e^{-2i\omega L/c})}{(1-e^{-i\omega L/c})\,(1+(1-\alpha)\,e^{-i\omega L/c})}\right) \tag{6}$$

where c is the wavespeed in air and α is the absorption of the wall.

The coupling due to the air is then found by inserting the air stiffness into the equation in place of the tie stiffness to give the CLF as

$$\eta_{12} = \frac{Y_2}{\omega \rho_{s1} S \left(\left(Y_1 + Y_2 + Re\left(\frac{\omega}{k_a} \right) \right)^2 + Im\left(\frac{\omega}{k_a} \right)^2 \right)} \quad (7)$$

The two CLFs (one for ties and one for the air) are summed to give a single CLF for transmission across the cavity.

SEA Model

For a system consisting of two rooms separated by a cavity wall, the simplest SEA representation is a four subsystem model like the one shown in Fig 1.

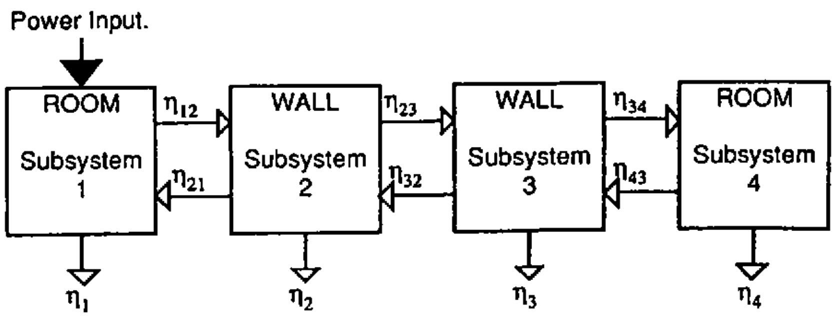

Fig 1. SEA model of two rooms separated by a cavity wall.

The CLF's between the rooms and the walls are the same as for a single wall and may be found in reference [3]. The solution of the model may be performed in the normal manner.

At low frequencies, below the mass spring mass resonance, the two walls are strongly coupled and equipartition of energy occurs. Modelling the cavity wall as two subsystems is then no longer strictly valid. It would be more correct to model the wall as a single subsystem with a surface density and bending stiffness equal to twice the single wall values. The results from this "single subsystem" model are then 3 dB higher than the results of the two subsystem model in this frequency region.

RESULTS

Measured and predicted results from two test walls are shown in Figs. 2 to 5. Both walls were nominally identical except for the wall ties. The first wall had twenty-five twisted bar ties (20 x 3 mm) which are very stiff and the second wall had the same number of butterfly ties (3 mm diameter wire) which are quite flexible. The walls measured 4 x 3 m and were made of 100 mm thick dense concrete blockwork. They were built in a horizontal transmission suite where the two rooms were structurally isolated from each other and shared a common opening. The two leaves of the test wall were built in the opening, one in each room so that the only structural connection between the two leaves was via the ties. Airborne level difference measurements between the two rooms and structural level difference measurements between the two leaves of the test wall were made.

The stiffness of the ties was measured by casting the tie into two blocks of concrete and measuring the mass spring mass resonance. This enabled the tie stiffness to be determined despite the kinks and twists that are an integral part of the tie.

The SEA model used in the predictions included the walls and the floor of the test chambers as it was found that below the critical frequency of the test wall the airborne sound transmission was dominated by radiation from the floor of the receiving room. Above critical frequency transmission was dominated by radiation from the test wall.

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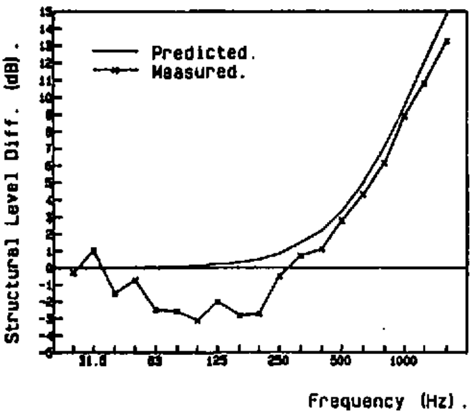

Fig 2. Structural level difference for twisted bar ties.

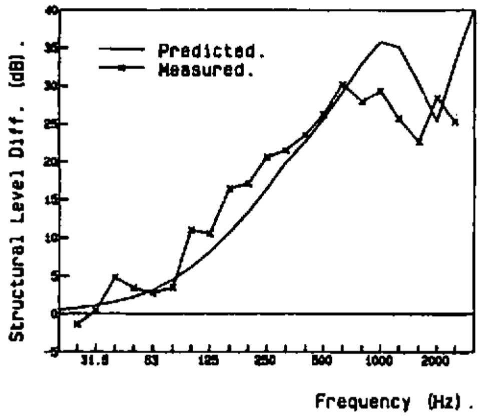

Fig 3. Structural level difference for butterfly ties.

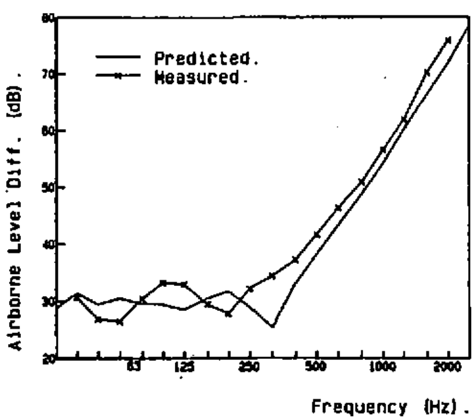

Fig 4. Airborne level difference for twisted bar ties.

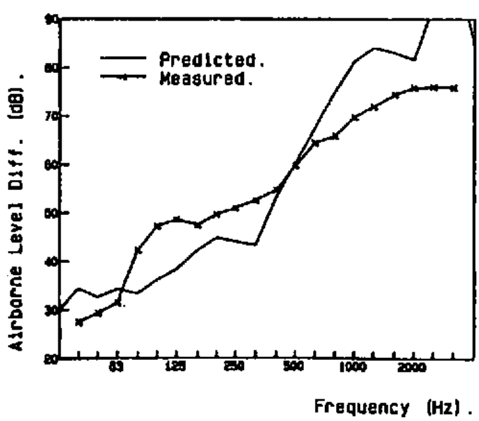

Fig 5. Airborne level difference for butterfly ties.

The agreement between the measured and predicted structural level differences is good for both walls. For these ties the poor agreement below 315 Hz is due to the mass spring mass resonance of the wall (177 Hz), which is not accounted for in the model. The butterfly ties are much more flexible than the bar ties and so the resonance frequency for this wall, at 23 Hz, was much lower and did not affect the data. The levelling off in the predicted curve above 800 Hz is due to resonances in the air in the cavity. The same levelling off occurred in the measured data except starting at a lower frequency. This may have been due to the effective cavity depth being wider than the distance between the faces of the two walls. If the air penetrated into the open textured blockwork the cross cavity resonances would occur at lower frequencies.

The predicted airborne level difference for the bar ties shows good agreement with the measured data over the whole frequency range. For the butterfly ties the poor agreement is due to flanking transmission which occurred due to drying shrinkage, a problem which was identified on a subsequent test wall. This problem affected the data above 500 Hz causing a drop in the level difference which increased with frequency to about 10 dB at 2000 Hz.

DISCUSSION

The model used to predict the performance of the wall gave reasonable agreement with the measured data. The region where poor agreement was encountered was around the frequency of the mass spring mass resonance, a phenomenon not accounted for in the expression for the coupling loss factor.

As would be expected more sound is transmitted across stiff ties than across flexible ties. It is therefore possible to improve the sound insulation of a cavity wall by using flexible ties. There is however a limit to the usefulness of this strategy. Sound is transmitted across the cavity along two paths, one via the ties and one via the air. If the tie stiffness is reduced sufficiently transmission via the air begins to dominate and further improvements in sound insulation do not occur. This effect is more pronounced at high frequencies where cross cavity modes increase the air stiffness.

ACKNOWLEDGEMENTS

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