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SOUND TRANSMISSION THROUGH LIGHTWEIGHT DOUBLE WALLS USING STATISTICAL ENERGY ANALYSIS

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INTRODUCTION

Lightweight partitions are widely used both for internal partitions and for party walls. In many cases there is no special requirement for good sound insulation but where the wall is a party wall separating two dwellings then good sound insulation is essential.

A typical construction can be seen in Figure 1. The figure shows the simplest case of two layers of plasterboard attached to a timber frame. This would be appropriate for an internal partition. If better sound insulation is required then absorption may be placed in the cavity. In addition special fixings may be used to isolate the plate from the frame or separate frames may be used so that there is no physical contact between the two leaves of the wall except through the air.

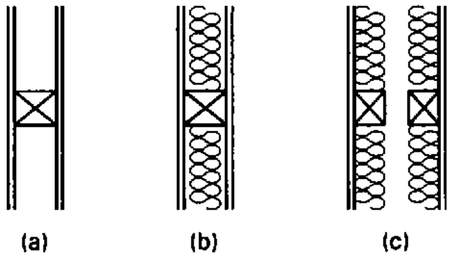

Fig 1. Section through (a) a simple lightweight wall, (b) a simple wall with absorption and (c) a wall with each leaf attached to a separate frame.

Theoretical models for predicting sound insulation are well developed for single leaf walls but have been much less successful for double wall constructions due to their complexity. The classical approach to this type of wall has been to idealise the structure, perhaps by ignoring the frame or considering only normal incidence, and then find a solution for this simpler problem. As a result there are several classical theories that predict parts of the problem.

The main difficulty lies in the complexity of the construction and the way in which subtle changes in the construction (such as the number of nails used to attach the plasterboard to the frame) can affect the basic physics of transmission.

In this paper statistical energy analysis (SEA) is used to model sound transmission through this type of wall. It shows the SEA models that would be appropriate for different situations and some of their properties. Some examples for different walls are given.

SEA MODEL

The first step in setting up any SEA model is to define the subsystems. A subsystem is usually a physical element (though this is not a rigorous definition). This leads to different models depending on the construction and frequency range.

Low frequency model

At low frequencies (below the mass-spring-mass resonance) the two leaves of the wall vibrate together in phase and with the same amplitude and so the wall acts as a single subsystem. The SEA model for this frequency range is therefore the same as for a single wall and would be as given in Fig 2(a). The mass and stiffness will be that of the entire wall.

The mass-spring-mass resonance can be given by

$$f_n = \frac{1}{2\pi}\sqrt{\frac{\rho_0 c_0}{d}\left(\frac{1}{\rho_{s1}} + \frac{1}{\rho_{s2}}\right)} \qquad (1)$$

where d is the depth of the cavity. The other symbols are defined in Table 1.

The coupling loss factors for this SEA model and the others given in this paper are listed in Table 1.

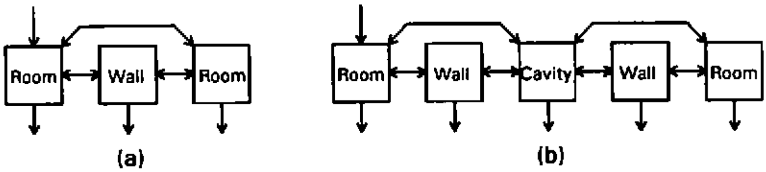

Fig 2 (a) SEA model of a single leaf wall, (b) SEA model of a double leaf wall with no physical connection between the leaves.

High frequency models

At higher frequencies the panels have different vibration levels and so must be modelled as separate subsystems. In addition, the energy in the cavity must be considered. If there is no physical connection between the two leaves of the wall as would occur if the two leaves were attached to separate frames (see Fig 1(c)) then the SEA model would be as shown in Fig 2(b).

Although there can be some difficulty in obtaining the reverberation time for the cavity in this type of construction particularly, if the cavity is fully filled with absorption, the model works well at predicting transmission as can be seen in Fig 3 which shows results for a double leaf wall constructed from 2 leaves each with 2 layers of plasterboard on a 38 x 235 mm frame and filled with sound absorbing material [1].

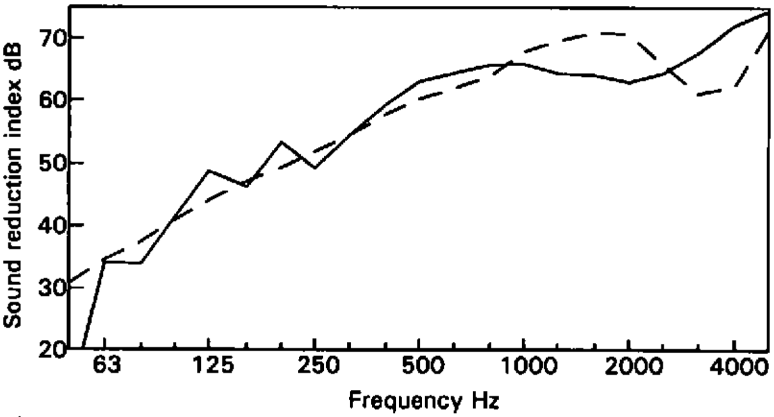

Fig 3 Measured and predicted transmission through a double leaf wall where each leaf is attached to a separate frame. _______, measured; - - - - -, predicted.

Point connections

If the two leaves are attached to the same frame then additional coupling has to be included. There are two ways in which this can be modelled. If the plasterboard is attached to the frame at only a few points (such as by nails) then one method of modelling is to model the frame as a subsystem (a beam) and to couple the plates to the frame by a number of point connections. This would give the SEA model that is shown in Fig 4(a).

Assuming that the number of connections is not too large and that they are randomly spaced than they can be assumed to be independent and the coupling due to each nail will be given by equation (6) in Table 1.

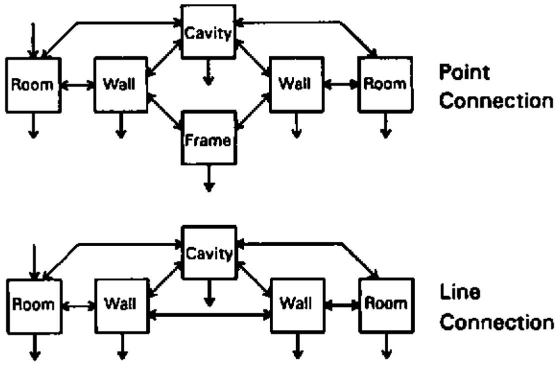

Fig 4 (a) SEA model of a double leaf wall where the frame is modelled as a subsystem connected at points to the sheet material, (d) SEA model where the frame is not modelled as a subsystem but forms a line connection between the sheets.

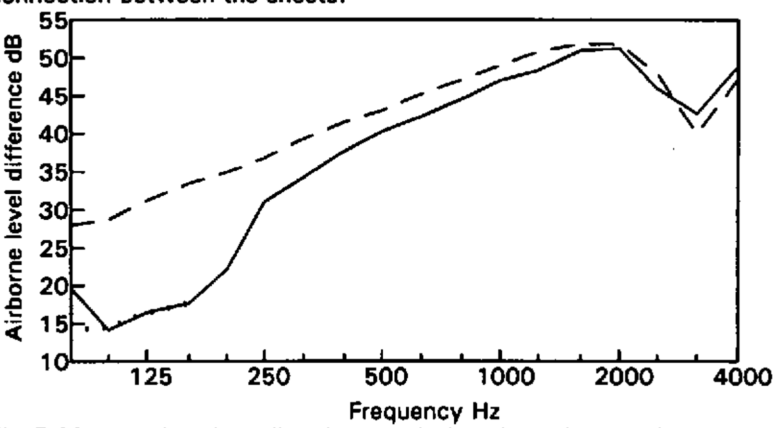

Fig 5 Measured and predicted transmission through a partition (with point connections). ______, measured; - - - -, predicted for a double wall; ...., predicted for a single leaf.

One of the implications of this model is that the coupling will be proportional to the number of point connections and therefore the number of nails in the wall. Doubling the number of nails (on either side) should double the coupling and therefore decrease the overall transmission by 3 dB. Experiments confirm this for situations where transmission by the nails is dominant.

The results for transmission through a test wall where transmission is dominated by nails can be seen in Fig 5. At low frequencies the wall should be modelled as a single leaf (f_n is predicted as 125 Hz) and the measured results agree well with this theory. At higher frequencies the measured results show a sudden increase to the theory for the double wall.

(1) Room(1) to wall (2)	$\eta_{12} = (\rho_0 c_0^2 S f_{c2} \sigma_2)/(8\pi V_1 \rho_{s2} f^3)$
(2) Wall (1) to room (2)	$\eta_{12} = (\rho_0 c_0 \sigma_1)/(2\pi f \rho_{s1})$
(3) Room (1) to room (2)	$\eta_{12} = (c_0 S \tau_{12})/(8\pi f V_1)$
(4) Cavity (1) to wall (2)	$\eta_{12} = (\rho_0 c_0 f_{c2} \sigma_2)/(4\pi f^2 \rho_{s2})$
(5) Cavity (1) to room (2)	$\eta_{12} = \tau_{12}/(4\pi)$
(6) Plate (1) to frame (2) (point)	$\eta_{12} = (Re(Y_2))/(2\pi f m_1 \lvert Y_1 + Y_2 \rvert^2)$
(7) Plate (1) to plate (2) (line)	$\eta_{12} = 0.1365\sqrt{(h_1 c_{L1}/f)}(L_{12}/S_1)\tau_{12}$

c = wavespeed, ρ = density, η = CLF, σ = radiation efficiency, f_c = critical frequency, τ = transmission coefficient, Y = point mobility, m = subsystem mass, c_L = longitudinal wavespeed, L = boundary length, S = surface area, V = volume

Table 1 Equations for the calculation of coupling loss factors [2].

Line connections

As the number of point connections increases so transmission will increase until the point is reached where the points are so close together that the connection behaves like a line. A reasonable estimate of the transition point seems to be where a half bending wavelength can fit between the nails. If the spacing between the nails is more than half a wavelength then the nails act as independent point connections and if the spacing is less than half a wavelength the connections behave line a line connection.

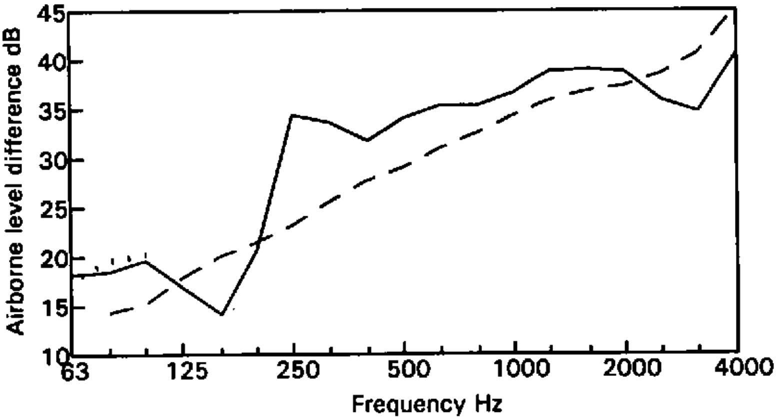

Fig 6 Measured and predicted transmission through a wall with a line connection between the two leaves. ______, measured; - - - - -, predicted; ...., predicted for a single leaf

The standard methods for coupling across a line can then be used [3] where the performance of the joint is described by the transmission coefficient and the coupling is given by the last equation in Table 1.

In these cases it is normal for the beam to be considered as a coupling element and not as a separate subsystem and so the SEA model would be as shown in Fig 4(b). This method of coupling is discussed further in reference [4].

An example of transmission through a wall where there were so many nails in that wall that it is appropriate to model the connection as a line can be seen in Fig 6. Although the wall is thicker the level difference is lower than the wall shown in Fig 5 as a result of the increased number of nails so that at low frequencies there is little difference between the single wall and double wall models. As with the point connection wall there is generally good agreement between the measured and predicted results.

DISCUSSION

The wide range of possible designs of wall make it unlikely that a single model or equation will work in all cases. Even when using SEA there is more than one possible model that can be used. Only experience will show which of the models are the best and which transmission mechanisms need to be included.

The results presented in this paper have shown possible SEA models that can be used in the most common forms of construction. In each model there may be other mechanisms associated with various non-resonant transmission or response mechanisms that are not included for clarity.

ACKNOWLEDGEMENTS

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