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SOUND TRANSMISSION THROUGH TIMBER FLOORS

Robert J. M. Craik, R. Sean Smith and Robin Wilson

Department of Building Engineering and Surveying, Heriot-Watt University, Riccarton, Edinburgh, UK

INTRODUCTION

Timber floors are widely used both as internal floors in houses and as party floors separating multi-occupancy dwellings. Their overall design has been one of gradual development leading to the traditional party floor with its resilient walking surface and internal pugging (mass). These floors give good sound insulation when properly designed. By comparison the internal floor is generally light lacks a resilient layer and provides poor sound insulation.

Sound transmission through a timber floor is complicated due to the interaction of the many components. Therefore basic design and attempts at improving their performance have been largely based on experimental trials. There are, at present, no reliable theoretical models that can be used to predict the performance of such floors.

This paper looks at the development of a statistical energy analysis model that can be used to predict the performance of basic timber floors. The model discussed in this paper is limited to simple floors comprising timber joists with a walking surface and ceiling as shown in Figure 1. However, it can be developed to include more complex forms of construction. The model is sufficiently complex to enable small changes in design, such as the addition of a resilient quilt laid between the joists, to be evaluated.

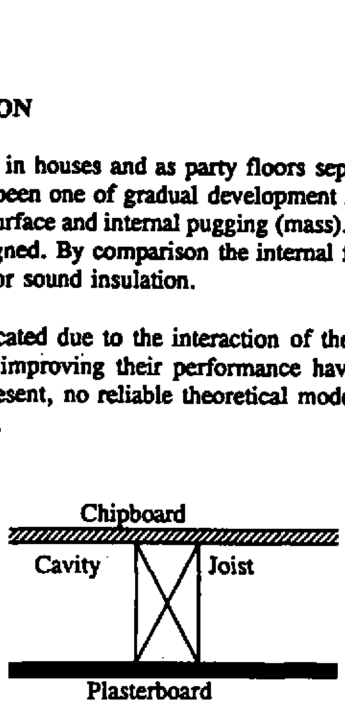

Figure 1. Section through a simple timber floor

THEORETICAL MODEL

The statistical energy analysis model for a floor is more complex than for a single homogeneous wall except at low frequencies. At low frequencies, where the wavelength is large compared with the spacing between the joists, the floor behaves as a single plate and theories that have been developed for homogeneous walls and floors can be used. The floor is not homogeneous as the joists make the floor stiffer in one direction but this can be taken into account if necessary.

At higher frequencies where the joist spacing is greater than half a wavelength for waves travelling on the chipboard (walking surface) and the plasterboard (the ceiling) the floor stops behaving as a single subsystem and has to be modelled by several interconnected subsystems. This typically occurs at around 160 Hz.

The basic model for transmission between two rooms through a timber floor can be seen in Figure 2. Each of the two rooms is a separate subsystem as is the chipboard, the plasterboard, the joists and the cavity between the joists.

The coupling between the rooms and the panels is the same as for single leaf walls [1].

Measurements have shown that when the chipboard (or plasterboard) is nailed to the floor it acts as a single plate connected to the joists by point connections. The coupling loss factor for this connection can be found from the junction impedances and is similar to transmission across cavity walls connected by wall ties [2] except that the impedance of the joist (acting as a beam) is used instead of the impedance of one of the walls (which acts as a plate). This gives the coupling from the panel to joist as

$$\eta_{12} = \frac{r\,Re(Y_2)}{m\omega\left|Y_1 + Y_2\right|^2} \qquad (1)$$

where Y_1 is the mobility of the panel (or joist) [3], Y_2 is the mobility of the joist (or panel) [3], r is the number of nails and m is the total mass of the panel. Coupling from the joist to the panel can be found using the consistency relationship [4]

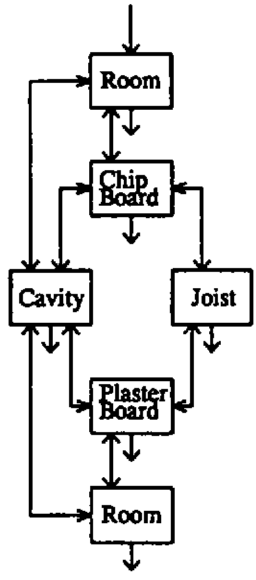

Figure 2. SEA model of a timber floor.

$$n_1\eta_{12} = n_2\eta_{21} \qquad (2)$$

here n is the modal density [3] or by reversing the indices.

Coupling into the cavity either due to radiation from the light weight panels or non-resonant transmission from the rooms must also be included. When modelling double walls Price and Crocker [5] assumed that transmission *into* a cavity was the same as transmission *into* a room and used the same equations. Transmission in the opposite direction out of the cavity was found using the consistency relationship, equation (2).

However, measurements made on the timber floors suggest that transmission *out of* the cavity is the same as transmission *out of* a room. Transmission into the cavity can then be found using the consistency relationship. This would be consistent with other measurements that have shown that transmission is determined by where the sound is *going* but not where it *came from* [6]. This revised theory does not work as well for transmission into and out of narrow cavities in dry lined walls [7].

This revised theory gives the coupling from a panel into a cavity as

$$\eta_{panel-cavity} = \frac{n_c}{n_r}\eta_{panel-room} = \frac{\rho_o c_o \sigma}{\omega \rho_s} \frac{\lambda}{2d} \tag{3}$$

where n_c is the modal density of the cavity calculated using the theory given by Price and Crocker [5] and n_r is the modal density of the cavity calculated using the room equation [8]. The correction to the standard equation for radiation is very simple, where d is the cavity depth and λ is the wavelength in air and applies where λ is greater that $2d$.

The coupling from a room to a cavity by non-resonant transmission becomes

$$\eta_{room-cavity} = \frac{n_c}{n_r}\eta_{cavity-room} \tag{4}$$

where $\eta_{cavity-room}$ is calculated using the standard expression for mass-law transmission [9], the modal density of the cavity is obtained using Price and Crocker's expressions and the modal density of the room radiating into the cavity is given by the standard equation [8].

Together these transmission paths account for most of the behaviour of the floor. In certain circumstances other mechanisms can be important and included as necessary. Nearfield radiation from the connection points between the joist and the plasterboard can be important though was not for the floors that were tested. This radiation occurs from the bending nearfield generated on the plasterboard and is proportional to the velocity of the nailhead. If it is assumed that the joist is stiff compared with the plasterboard then the nail velocity will be approximately the same as that of the joist and so the power radiated can be shown as a non-resonant transmission path direct from the joist to the receiving (or source) room [7].

At frequencies below the first cross resonance, where no resonances are possible in the cavity that have particle motion normal to the panels, the air is stiff. This stiff air can introduce an additional transmission path between the two panels. This can be modelled as an equivalent point stiffness as used in cavity walls [2]. However, for panels with high critical frequencies (as is the case here) this overestimates transmission and so this mechanism was omitted from the predictions.

Another possible path couples the source room directly to the receiving room with the floor behaving non-resonantly. This would only be important at very low frequencies and no evidence was found for this path though it may be important for some systems.

TEST FLOOR AND RESULTS

The test floor was built vertically in a sound transmission suite designed for walls so that access could be gained without the need for walking on the surface. The test floor was 3 x 4 m and was made from 150 x 50 mm joists at 450 mm centres with 18 mm chipboard on one side and 13 mm plasterboard on the other. The walls separated two rooms. The source room has a volume of 120 m^3 and the receiving room a volume of 210 m^3.

The reverberation times of the rooms and the cavity were measured for inclusion in the SEA model. The total loss factor of the structural members was obtained by summing the predicted coupling and measured internal losses.

The measured reverberation time in the cavity can be seen in Figure 3. There was no added damping in the cavity.

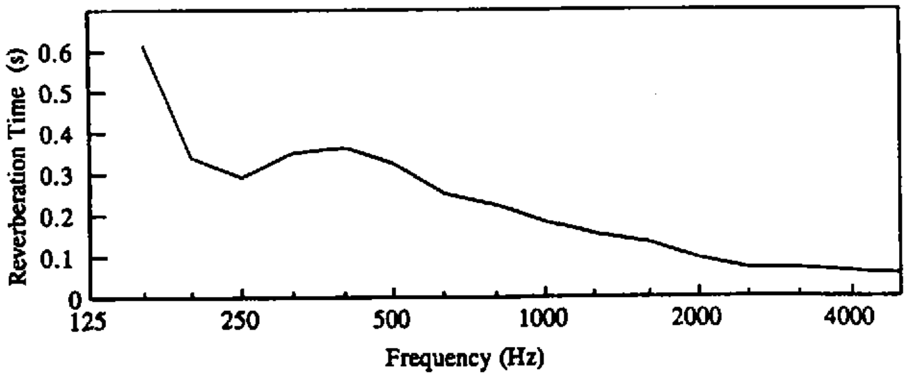

Figure 3. Measured reverberation time in the cavity between the joists of a timber floor.

The measured and predicted airborne level difference for transmission between the two rooms can be seen in Figure 4. The measured data is compared with three theoretical curves. At low frequencies the floor behaves as a single panel and is predicted using conventional theories. These theories apply up to 160 Hz and give good agreement with the measured data.

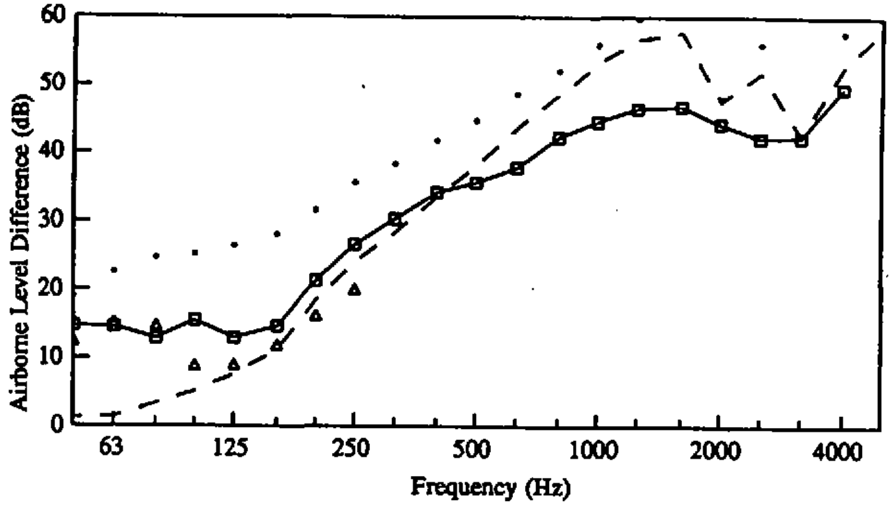

Figure 4. Measured and predicted airborne sound transmission through a timber floor. ——□——, Measured data; ▵, Predicted results modelling the floor as a single subsystem;······, Predicted using Price and Crocker's theory; - - - -, Predicted using the modified theory.

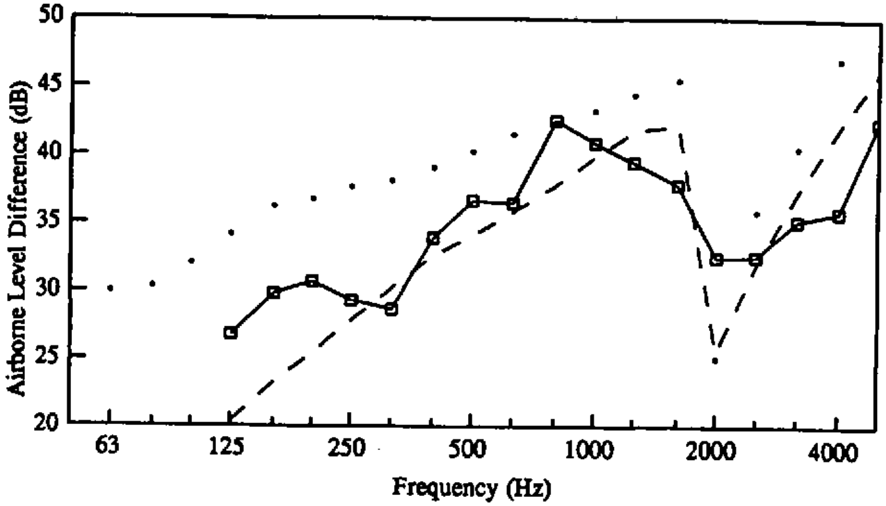

Figure 5. Measured and predicted airborne sound transmission for transmission from a cavity to a room. ——□——, Measured data;······, Predicted using Price and Crocker's theory; - - - -, Predicted using the modified theory.

Above this frequency the floor has to be modelled by several interconnected subsystems as shown in Figure 2. Two different theories are shown. The dotted curve shows the prediction made using the theory for transmission into and out of the cavity given by Price and Crocker [5]. The dashed line uses the modified theory. It can be seen that the modified theory gives better agreement with the measured data. As would be expected both theories give the same answer when the cavity depth is larger than half a wavelength and is therefore modelled as a room. It is thought that the difference between the measurements and the theories at 1000 Hz may be due to small air leaks.

The effect of changing the theory for transmission into and out of the cavity can be seen in Figure 5 which shows the level difference from inside the cavity to a room when there is a noise source in the cavity. The difference between the two theories can be seen and again the modified theory gives better agreement with the measured data.

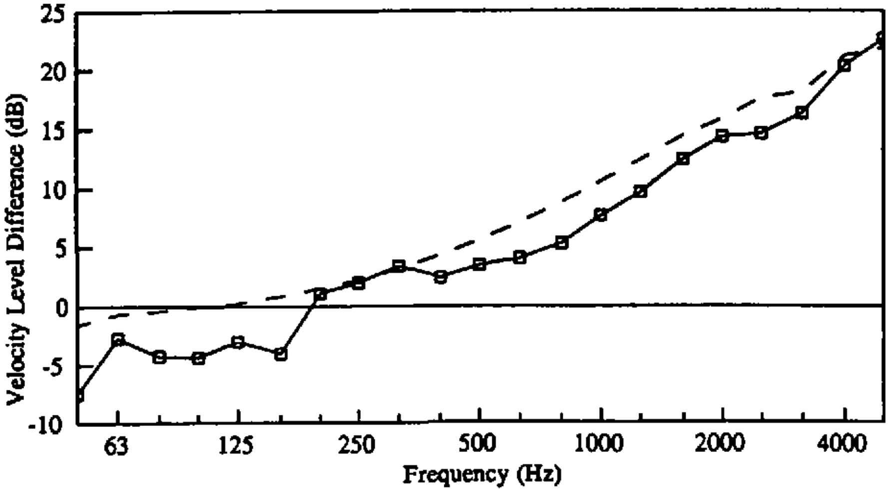

Figure 6. Measured and predicted velocity level difference from chipboard to plasterboard. ——□——, Measured; - - - -, Predicted.

The velocity level difference between the chipboard and the plasterboard when the chipboard is excited can be seen in Figure 6. There is good agreement between the measured and predicted results and this shows that the theory for transmission from the chipboard through the joists to the plasterboard works well. Although this path is not important in the floor that was tested it can be important depending on the design. It will be important for impact sound transmission.

The relative importance of some of the transmission paths for transmission from the source room to the receiving room can be seen in Figure 7 together with the sum of all paths added together.

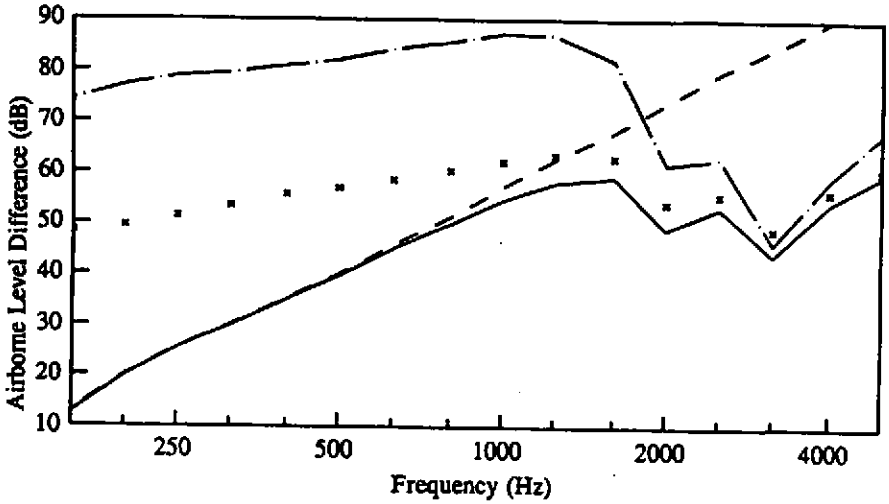

Figure 7. Airborne level difference for transmission paths through a timber floor. ————, Sum of all paths; - - - -, Room-cavity-room path; -·-·-·-, Room-chipboard-cavity-plasterboard-room path; ×, Room-chipboard-joist-plasterboard-room path.

Below about 1000 Hz the dominant transmission path is from the source room into the cavity by non-resonant transmission then into the receiving room by non-resonant transmission. Resonant transmission into and out of the cavity is only important above the critical frequency of the chipboard and plasterboard.

Transmission through the joists is not important in this floor below 1000 Hz though it is important at higher frequencies.

If an absorbent quilt was placed in the cavity then this would have no effect at low frequencies as the floor is behaving as a single plate and adding a quilt adds no significant mass. Above 160 Hz adding a quilt would improve transmission except where transmission is determined by transmission through the joist. Transmission through the joist is increased by increasing the number of nails in the floor.

CONCLUSIONS

These results have shown that statistical energy analysis can be used for complex structures such as timber floors. It has the advantage over many classical theories in that it can include all transmission mechanisms as well as flanking transmission if necessary.

The measured results suggest that the theories for transmission into and out of the cavity used by Price and Crocker do not work in this case but that a simple modification can be made to improve the agreement with measured data.

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