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Models for sound transmission through buildings

Robert J.M. Craik and Aganaden Thancanamootoo

Department of Building Engineering and Surveying, Heriot-Watt University, Riccarton, Edinburgh, Scotland (Great Britain)

INTRODUCTION

When using Statistical Energy Analysis (SEA) to model sound transmission through buildings there are a number of decisions to be made. Some of these involve how the building is to be modelled and the overall complexity required. Others affect the assumptions that are made when that actual data is not known.

In this paper two aspects of modelling are considered both of which affect transmission over long distances in large buildings. The first is whether or not it is necessary to consider longitudinal and transverse waves in addition to the bending waves in the structure. The second concerns the sensitivity of the model to small changes in the internal losses assumed for the structural elements.

LONGITUDINAL AND TRANSVERSE WAVES

The first aspect of transmission considered in this paper is whether or not longitudinal and transverse waves need to be included in an SEA model of a building. From a practical point of view it is desirable to have the model as simple as possible and not include these other waves types. However, if the omission of these waves results in large errors then they must be included.

When modelling a structural joint a wave is assumed to be incident on the joint. Using the methods of classical mechanics and equating the motion of the plates, their slopes, the balance of the forces and moments, the magnitude of the waves leaving the joint can be computed [1]. From this the CLFs can be found.

In the simplest model the joint is assumed to be pinned so that it can rotate but does not move. With this set of boundary conditions only bending waves are produced and the transmission coefficients are independent of frequency. This can be carried out on a small computer in a few seconds.

This model is accurate at low frequencies but at higher frequencies the motion of the joint produces longitudinal and transverse waves. These waves in turn propagate throughout the building. Since the energy associated with longitudinal and transverse waves is different from bending wave energy they have to be considered as separate subsystems. Thus each wall or floor becomes three subsystems instead of one. This considerably increases the complexity of the model. In addition the calculation of the transmission coefficients takes longer because there are more variables and there are more wave types to consider. There is an increase in computation time of several hundred times.

The CLF is computed from the equation

$$\eta = \frac{Cg\ L\ \tau}{S\ \ \pi\ \omega} \quad (1)$$

where τ is the classical measure of performance of a joint (power transmitted divided by power incident), L is the boundary length, S is the source plate area and Cg is the group velocity of the incoming wave. The thin plate bending wave equation was used for all calculations of τ but for the more complex model the thick plate bending wave equation was used to give the value of the group velocity [2]. For thin plates the group velocity is twice the phase velocity for bending waves and is equal to the phase velocity for longitudinal and transverse waves.

INTERNAL LOSS FACTOR

The damping of an element or subsystem that is measured is the total loss factor and is the sum of all mechanisms of loss including transmission to other parts of the structure (coupling losses) and losses as heat (internal losses). For building structures most of the damping is attributed to structural coupling and the internal loss factor is relatively unimportant. Measurements of damping (total loss factor) therefore give little information about the internal losses. It is therefore common to use a single value of between 0.01 and 0.02 [3] for the internal loss factor of structural elements.

For the building as a whole the power in must equal the power out and so the power balance of the building can be given as

$$W_{in} = \Sigma\ E_i \omega\, \eta_{id} \quad (2)$$

Thus the power input is equal to the sum of the energy in each subsystem times ω times the internal loss factor. If the internal loss factor is changed there will be a change in total energy in the building. Close to the source a little extra energy makes no difference but far from the source a little extra may make a large difference.

RESULTS

In order to investigate the effects of the factors discussed an SEA model of a building was set up. This is a building that has been used for previous studies [4]. The building has three floors and on each floor has rooms on either side of a long corridor. In all there are about 80 rooms and 400 walls and floors.

The simplest SEA model is one in which only bending waves are produced at the joints. This model is relatively simple to produce. A section of one side of the building can be seen in Figure 1 which shows the energy level difference predicted for this model for each of the walls and floors at 500 Hz (relative to the source level). It can be seen that the level difference increases as the distance increases and that the level difference is considerable.

Figure 2 shows the same building and this time shows the difference between the measured and predicted performance using the same model and again at 500 Hz. It can be seen that close to the noise source the errors are small but that as the distance from the source increases so the error tends to become large and positive. This corresponds to a predicted level difference that is too high.

Figure 3 shows what happens when the longitudinal and transverse waves are included in the model. This figure shows the predicted energy level difference for the simple model (bending waves only) minus that of the complete model (bending, longitudinal and transverse waves). It can be seen that close to the source the numbers are negative whereas further away they are positive. This corresponds to a reduction in the noise level close to the source and an increase in the noise level further away. For the building as a whole the extra transmission paths give rise to a redistribution of the energy. There is relatively less near the source and more further away.

Close to the source the difference between the models is small but further from the source the error is larger. A comparison with Figure 2 shows that the difference between the models is close to the difference between the measured and predicted results so that a comparison of the measured results with the more complex prediction would give better agreement.

An alternative method of increasing the sound transmitted to distant parts of the building (as suggested by the large positive errors in Figure 2) is by reducing the internal loss factor of the walls and floors. This would result in more energy in the building.

Figure 4 shows the difference for the simpler model between having an internal loss factor of 0.015 (used for Figures 1 to 3) and a value of 0.01. It can be seen that the difference in the internal loss factor (less than 2dB) has resulted in large differences in the level difference at some distance from the source.

CONCLUSIONS

From the results it is concluded that even at the mid frequency range the omission of longitudinal and transverse waves will give a large difference in the prediction at some distance from the source but that close to the source the errors are small.

A redistribution of the energy can also be obtained by changing the internal loss factor.

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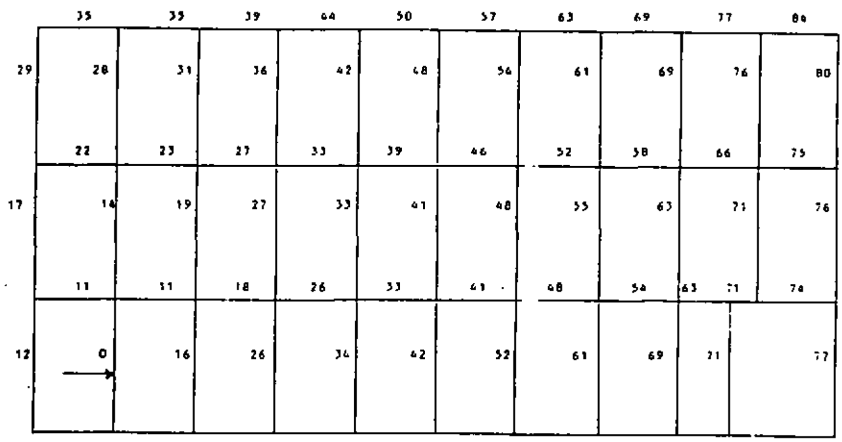

Figure 1 Predicted Energy Level Difference for simple model (⟶ ,source)

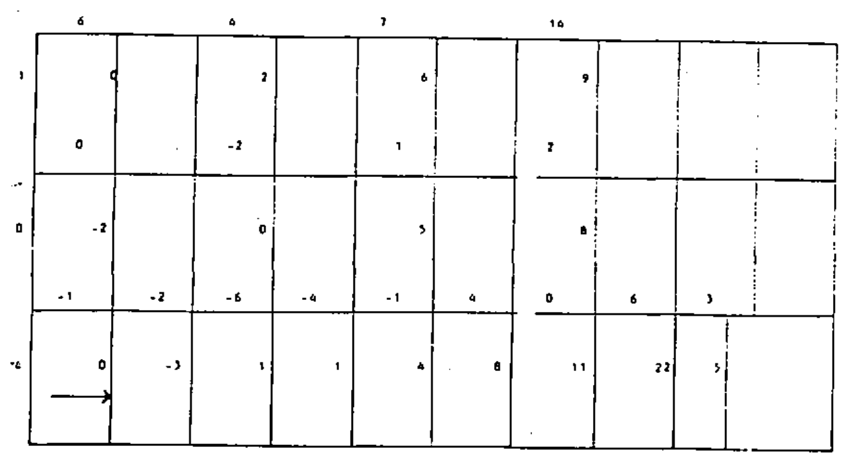

Figure 2 Difference between predicted and measured response for simple model (⟶ , source)

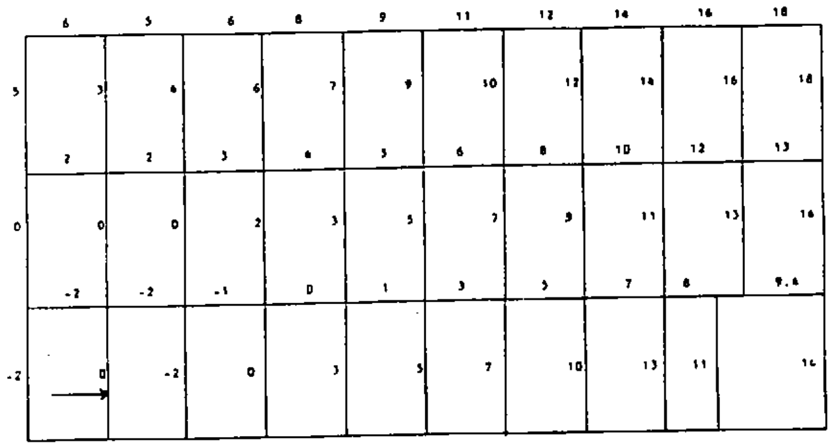

Figure 3 Difference between simple and complete model predictions (⟶, source)

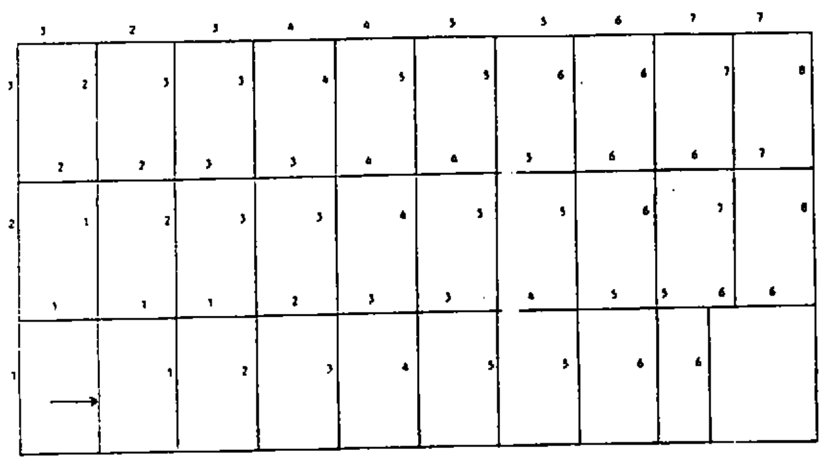

Figure 4 Variations in predicted response for 2 different internal loss factors. (⟶, source)

