THE INTER-RELATION BETWEEN THE MODAL CHARACTERISTICS OF THE ROOMS AND THE SEPARATING WALL, IN THE SOUND INSULATION BETWEEN DWELLINGS AT LOW FREQUENCIES.

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ABSTRACT

The sound insulation between dwellings at low frequencies is a function not only of the performance of the separating wall, but also of room size and geometry. This is because the pressure fields in the adjoining rooms and the vibrational field on the separating wall are modal and the standard measurement methods, which assume diffuse field conditions, cannot apply. A finite element model was used to study sound insulation of solid heavyweight walls and lightweight cavity walls, for varying room volumes, shape and construction materials. The sound pressure level difference of lightweight walls was observed to vary little with the room volume. That of heavyweight walls varied more. The structural modal density of heavyweight walls is small and the acoustic-acoustic and acoustic-structural couplings are emphasized at low frequencies. The relatively high modal density of lightweight cavity walls reduces the effect of those couplings. The factors that influence sound level difference therefore include not only the material and construction of the separating wall, but also the size, shape and construction material of the separating rooms.

INTRODUCTION

It is recognised that low frequency sound transmission into and between dwellings is an increasing contribution to nuisance. Sources of low frequency noise include hi-fi and home movie systems of high power and enhanced bass response, domestic appliances and road traffic. If heavyweight walls and floors and lightweight cavity partitions fail insulation standards, they tend to do so at low frequencies. Current standards [1,2] deal only with the frequency range 100-3150 Hz and generally there is poor reproducibility between laboratories below this frequency range and a method of measurement of insulation below 100 Hz has yet to be agreed [3]. A fundamental question remains on how laboratory measurements can be related to field performance of the party wall, floor or partition when installed. Diffuse or neutral field conditions in test chambers do not correspond to the highly modal characteristics at low frequencies and for small room volumes associated with dwellings [4].

A finite element method was used to investigate the sound insulation between dwellings. The source room and the receiving room, as well as the cavity of the double wall, when required, were modelled as rectangular volumes discretised into elements the number of which depends on room dimension and governing wavelength [5]. The acoustic FE model is linked to a structural FE model, representing a single or double wall, to recreate the sound transmission from one room to the other. The sound insulation of the party wall was obtained from predicted average pressures in the source room and in the receiver room to calculate the average sound pressure level difference.

In preliminary investigations, it had been demonstrated that both modally and locally reactive damping could be simply modelled as an equivalent frequency invariant absorption coefficient [6,7]. For the frequency range of interest, 40-200Hz, heavyweight rooms were assigned an equivalent absorption coefficient of 0.02; lightweight timber-frame rooms were assigned an absorption coefficient of 0.15. All separating walls were assumed to be simply supported.

In this paper, a description is given of an investigation of the effect of the acoustic and structural modes on the sound insulation performance of single and cavity walls. The first part of the paper is a validation of the FE models by comparison with field measurements. The second part is an investigation of the effect of room length and wall area on the sound pressure level difference of typical party walls found in dwellings.

FINITE ELEMENT MODELS

Lightweight cavity wall

To validate the FE model, the sound pressure level difference of a cavity wall of lightweight construction between two equal rooms of length 4.23m was predicted and measured. Figure 1 shows the spatial average sound pressure level difference for a source in a corner position. Results are shown as narrow-band and third-octave band values. Also shown are the predicted eigenfrequencies for the wall and rooms.

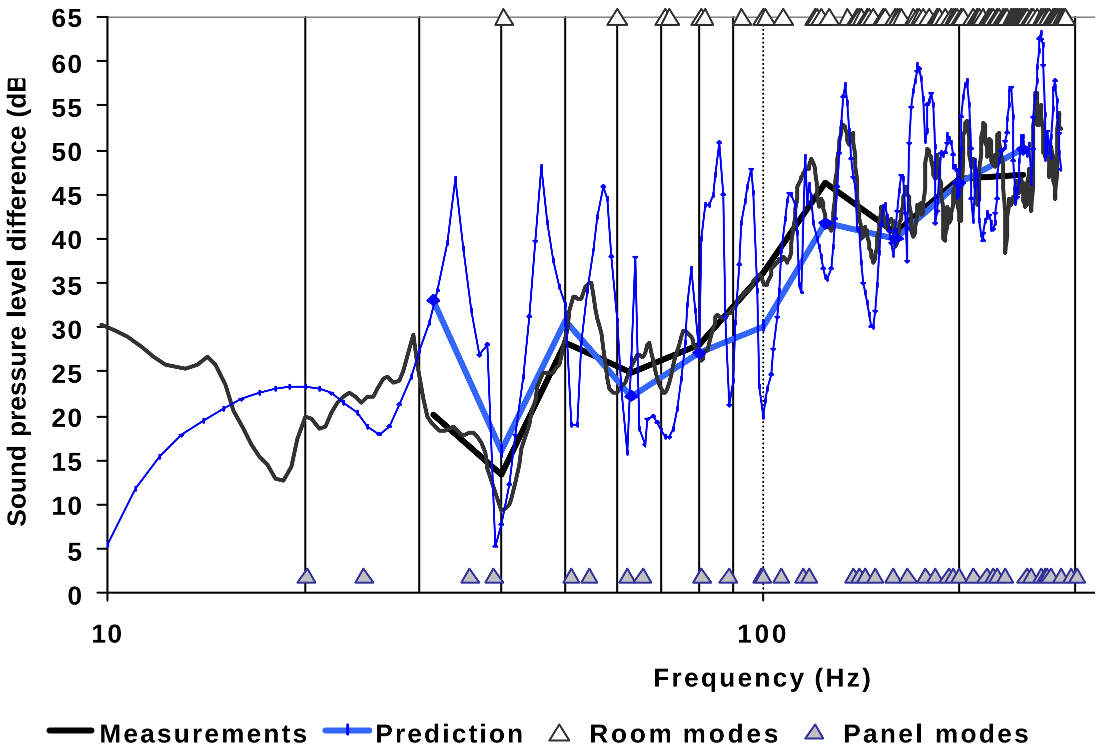

Fig.1 Predicted and measured sound level difference between identical room volumes (4.23x2.84x2.4m), separated by a lightweight cavity wall.

Both prediction and measurement indicate minima in level difference caused by acoustic–acoustic coupling, e.g. at 40Hz and 60Hz. The dip at 40Hz corresponds to the (100) room mode normal to the wall surface. The wall resonances in the 40 Hz band also emphasise the dip. The agreement between predicted and measured third-octave values is within 5 dB, and the FE model for lightweight constructions, is experimentally validated.

Heavyweight cavity wall

The sound pressure level difference of a 140/50/140 mm heavyweight cavity wall between two equal rooms of length 2.7m also was predicted and measured. The two leaves of the cavity wall were strongly linked by steel ties and therefore the wall was modelled as a single wall of equivalent mass. Figure 2 shows the measured and predicted sound pressure level difference. The source was at a corner and the sound levels were recorded at corner position opposite to the party wall.

Again, a strong dip within the 63 Hz band results from a room eigenmode (100) normal to the wall surface and a wall eigenmode (11) within the same band. The influential room mode is not the lowest in frequency. The lowest mode (010) is across the width of the rooms and has little effect. Again, predicted and measured third-octave values are within 5 dB.

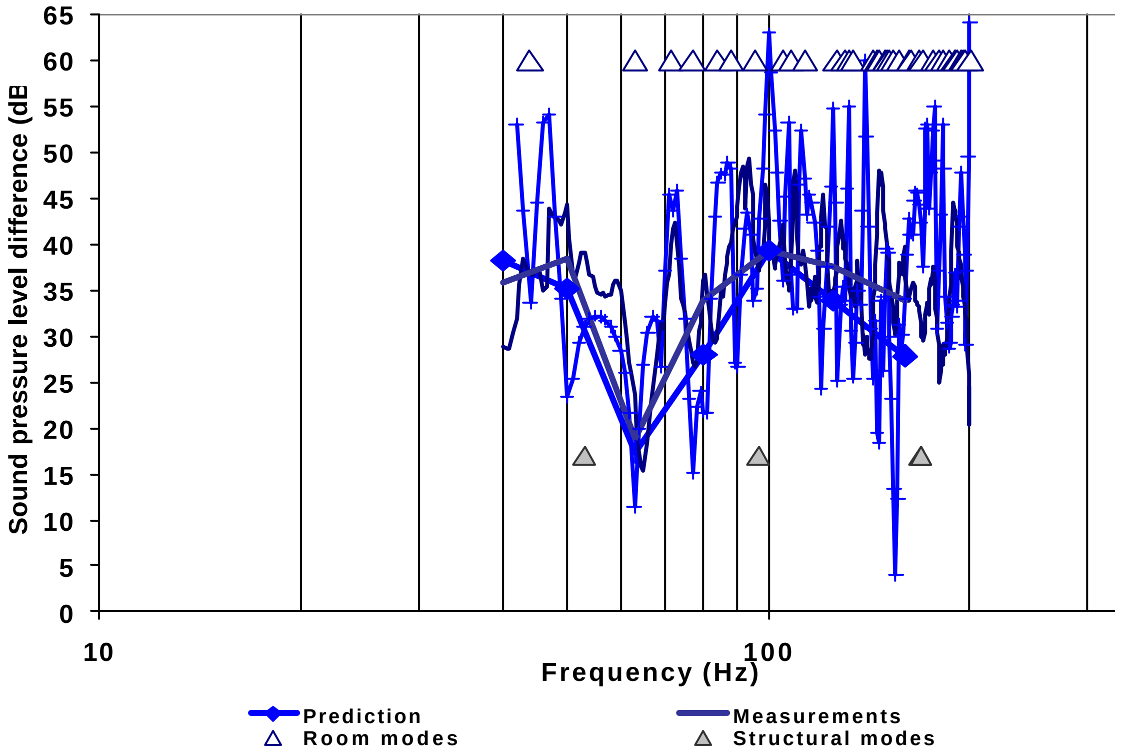

Fig. 2 Predicted and measured sound level difference between identical room volumes (2.7x3.9x2.4m), separated by a heavyweight cavity wall.

Despite simplifications in the FE model, the models for lightweight and heavyweight separating walls predicted important modal characteristics also observed in measurement. The two models therefore were used in a parametric survey of wall and room resonance effects at low frequencies.

EFFECT OF ROOM LENGTH AND WALL AREA

In Figure 3 is shown the predicted sound level difference between identical rooms of lengths 2m, 3m and 4m. Results are for a single heavyweight wall of thickness 215mm and area 3.5 x 2.5 m. Dips are observed at 45, 85, 128 and 171Hz for the room length of 4m caused by the acoustic-acoustic coupling of the axial modes (100), (200), (300) and (400). Dips at 57, 114, 171Hz for the room length of 3m are caused by the acoustic-acoustic coupling modes (100), (200), and (300). The dip at 57Hz is emphasised by the first resonance of the party wall at 58Hz. That explains why the dip is stronger for the room length of 3m than for the other room lengths.

Not only the axial modes normal to the party wall control the sound insulation properties of the wall, but some tangential modes also are observed to produce strong acoustic-acoustic couplings. Dips at 98, 177Hz for the room length of 2m are caused by the tangential modes (110) and (210). Dips at 75, 124, 177Hz for the room length of 3m by the tangential modes (110), (210) and (310). Dips at 65, 98, 137, 177Hz are caused by the modes (110), (210), (310) and (410) for the 4m room length. These modes have a stronger influence than any other tangential modes, because they have components normal to the party wall.

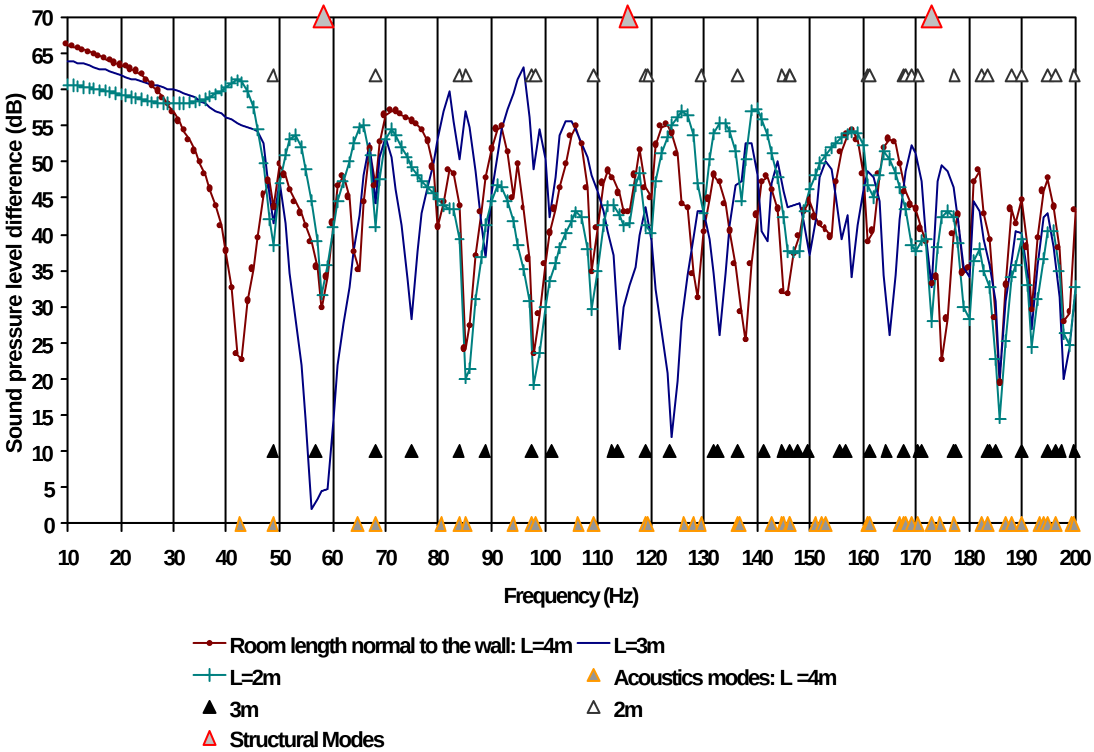

Fig.3 Predicted sound level difference between identical rooms of lengths 2m, 3m and 4m. 215mm heavyweight wall of area 3.5 x 2.5 m.

Figure4 shows the sound level difference of the same wall with a 1/3-octave band resolution. The three curves show different signatures caused by the different acoustic-acoustic couplings and structural resonances. Above 50 Hz, the sound level difference of the wall placed between rooms of length 4m present less peaks and dips because of the increasing number of excited acoustic modes.

Fig. 4 Predicted sound level difference between identical rooms of lengths 2m, 3m and 4m with a 1/3 octave band resolution. 215mm heavyweight wall of area 3.5 x 2.5 m.

The sound level difference between identical rooms of length in the range 2 to 4m was predicted for single heavyweight wall of thickness 215mm and a lightweight cavity wall of thickness 200mm. The wall area was constant at 4 x 2.5 m^2. In Figure 5 the level differences are presented as averages of 7 and 9 room configurations for heavyweight and lightweight walls, respectively.

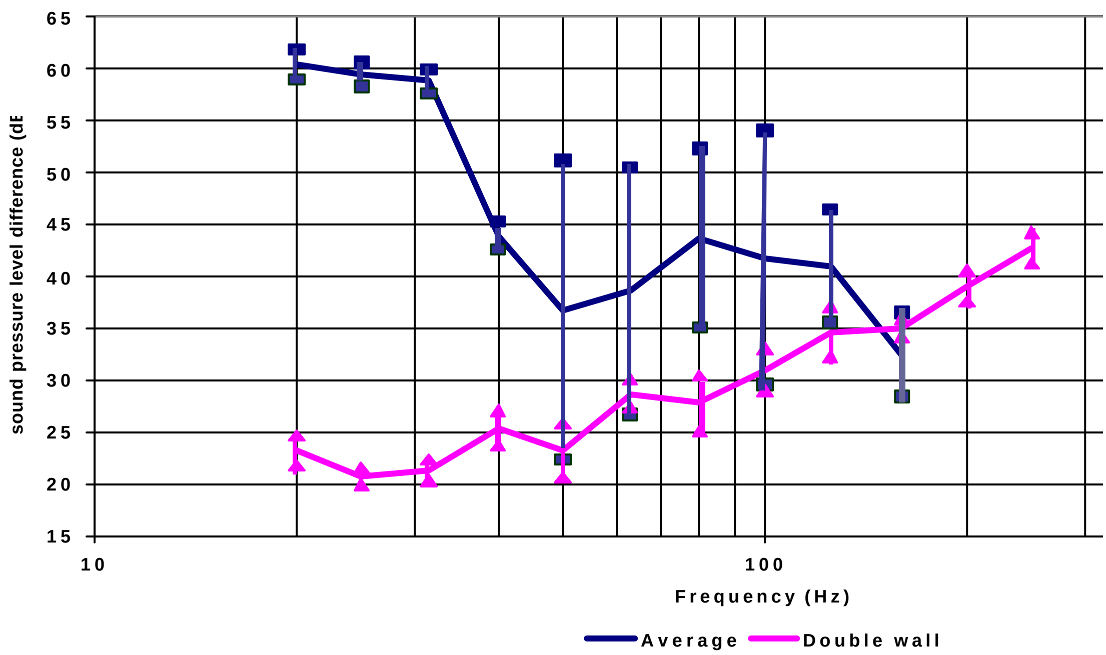

Fig.5 Predicted sound level difference for lightweight and heavyweight walls, averaged with respect to room length.

Also shown is the standard deviation. For the heavyweight wall, the average value shows dips at 50 Hz and 180 Hz which correspond to structural modes (11) and (21), respectively. The standard deviations are large in the frequency range 50 Hz to 125 Hz and are the result of dips in level difference which vary with frequency according to the occurrence of room modes normal to the wall [8]. For the case of the lightweight cavity wall, the vibrational modal density is relatively high and the insulation displays mass-law behaviour. Room length resonances are less influential, as indicated by the small standard deviations.

CONCLUDING REMARKS

An experimentally validated FE model of sound transmission between identical rooms has been used to investigate the inter-action between structural and pressure modes.

It has been demonstrated that room modes normal to the surface of the separating wall give rise to significant dips in level difference which are accentuated if a structural mode occurs in the same measurement band. This occurs in the case of heavyweight wall constructions where structural modes onset above the first room modes and are well separated in frequency.

For lightweight cavity walls, the structural modes onset before the room modes and the structural modal density is relatively high. Although dips in insulation are evident at frequencies corresponding to the room-length modes, they are not so pronounced and the insulation can be assumed invariant both with respect to room and wall dimension.

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