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SOUND INSULATION BETWEEN DWELLINGS AT LOW FREQUENCIES USING A FINITE ELEMENT METHOD.

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1. INTRODUCTION

Noise from adjoining dwellings is increasingly recognised to occur below 100Hz due to powerful modern hi-fi and home cinema systems with enhanced bass response[1,2]. Laboratory and field measurements at these frequencies are known to be unreliable and do not produce acceptable repeatability and reproducibility, because of the non diffuse sound fields[3,4]. Rooms in dwellings are much smaller than the standard volumes in laboratories and the modal character of the sound field is influential. The introduction of an annex ISO 140 Part IV[5] for low frequency measurements in dwellings still has not improve the reproducibility of the measurements; and it is only recently that it has been found that repeatability and reproducibility in laboratories can be improved by placing special absorption panels at positions, which damp peaks and dips in the room frequency response [6,7].

In previous studies, sound insulation between rooms have been investigated using analytical[8-14] and Finite Element Methods (FEM)[15-17] in simulated test and field conditions. The effect of room dimensions on the sound level difference has been considered and in both studies, it has been shown that the sound level difference between rooms is not only a characteristic of the party wall, but also of the room configuration. However, the party walls were modelled as simply supported or as mass controlled.

The work reported here is of an investigation using FEM of the effect of wall edge conditions on the sound insulation of party walls between rooms of volume less than 50m^3, at low frequencies. The selected mesh model was validated by comparing the predicted frequency response of a single room and then the sound pressure level difference with the measured frequency response and sound pressure level difference respectively of a ¼ scale model. The agreement allowed an investigation of the effect of edge conditions and room configurations on the sound pressure level difference across masonry walls.

2. FEM SOUND TRANSMISSION MODEL

The principle of FEM is to solve a system by discretising a set of governing differential equations. The elements are characterised by a number of nodes, which fulfil continuity conditions between elements. The choice of the number of elements is defined by wavelength and thus the upper frequency of the range of interest[18]. It is used to model structural and acoustic systems. The structural model describes the wall vibration in terms of mass, stiffness and sometimes damping matrices and the nodal variable is displacement. The acoustic model describes the enclosed field in terms of mass, stiffness, and damping matrices, and the nodal variable is pressure. The sound transmission between two rooms was modelled by linking the structural model with the acoustic model i.e. add the acoustic matrices and structural matrices[19,20].

FEM allows the effect of varying edge conditions of the separating wall to be studied and the enclosure can have any shape. Powerful computers are required to speed data acquisition, which depends on the size of the defined system and on the number of elements which increases with frequency[20]. The more complicated the model, the more elements are required. When coupling the acoustic FE and the structural FE, the acoustic meshes need to match the structural meshes, which can lead to an underestimation of the panel radiation[12].

The FEM model was validated by comparing the predicted frequency response with the measured frequency response of a ¼ scale model with the dimensions presented in Figure 1. The results are shown in Figure 2 of one of the model rooms, with peaks and dips corresponding to the room modes. The predicted and measured frequency responses display the same signature. At high frequencies, the agreement between prediction and measurement is less good because of the limited number of elements used to describe the frequency response.

The sound pressure level difference was then predicted and measured in the ¼ scale model using a 5 mm and 10mm perspex panels as partition. The difference between the measured and predicted sound pressure level difference are presented in Figure 3 with a 1/3 octave band resolution. The FEM prediction underestimates the sound pressure level difference by 5dB between 200Hz and 400Hz, but with increasing frequency difference above this range. This can be explained in part by the fact that the simply supported edge condition was physically modelled with a non-zero rotation stiffness. The real edge conditions are stiffer, giving a measured sound pressure level difference greater than predicted

The initial investigation did not include damping in the acoustic model. However, subsequently, the frequency response was measured inside a full - scale room and results compared with the predicted sound pressure level with no damping and where a surface absorption coefficient of 0.02 was assumed. Figure 4 shows that the surface absorption has little effect below 100Hz and therefore could be ignored in the FEM model.

3. EFFECTS OF EDGE CONDITIONS ON THE STIFFNESS OF THE WALL

The effects of varying party wall edge condition were investigated by modelling a fixed room configuration of 40m^3 and 35m^3 [21]. The party wall model was assumed to be of brick with dimensions 4x2.5m^2. Two wall thickness were considered; as 0.05m and 0.2m. The frequency response in each room was calculated to a frequency resolution of 1Hz. A field mesh box in each room was defined with 152 points which were then averaged and the narrow band values recalculated to give the 1/3 octave band level difference. The sound pressure level difference was calculated from 31.5Hz to 160Hz.

The results are presented in Figures 5 and 6 for the wall of 0.05m and 0.2m, respectively. The sound pressure level difference displays alternative maxima and minima due to room and wall resonances[13]. A part from a strong coupling between two room resonnances at 40Hz, the sound level difference of the 0.05m wall generally increases with increasing frequency, with a gradient of about 6dB/octave. The sound insulation can be assumed to be mass controlled.

The sound level difference of a simply supported (SSSS) 0.2m wall decreases with increasing frequency at about -6dB/ octave. The sound insulation can be assumed to be stiffness controlled and this supports the findings of Parkin[22], Bergassoli[23], Gargliadini[10], Gibbs[24] and Osipov[13]. Since it is stiffness controlled, the clamped condition (CCCC) gives the highest value.

The positions of the first excited structural mode of the two edge conditions explain the different trends. In the case of the simply supported 0.05m wall, the first structural mode is excited below the first acoustic mode and the sound transmission can be assumed mass law controlled. In the cases of the clamped 0.2m wall, the first structural mode is excited above the first acoustic modes and the sound transmission can be assumed stiffness controlled.

The effects of the mixed edge conditions (SCSC) present less strong dips than the simply supported cases and change with the wall thickness. The sound pressure level difference of the 0.05m wall tends to be greater than that of the simply supported and of the clamped. The sound pressure level difference of the 0.2m wall lies between simply supported and clamped.

It has been demonstrated that edge conditions control sound insulation at low frequencies and their effect depends on wall stiffness and therefore thickness. The classic monotonic decrease and increase with frequency for the stiffness controlled and mass controlled regions, respectively, are observed as trends about which values fluctuate according to modal matching.

4. EFFECTS OF EDGE CONDITIONS ON THE ROOM CONFIGURATION

Room configurations, representative of dwellings in U.K.[26] were considered to examine their effects on the sound level difference of a 0.2m wall with different edge conditions. A small sample of 10 room configurations, varying from $20m^3$ to $40m^3$ was modeled using FEM. The volume of the two rooms was modified by changing the room length only. Figures 7-8 show the spread of data for a simply supported and clamped 0.2m brick wall when placed in equal and unequal room configurations. It can be observed that the sound pressure level difference decreases with increasing frequency but with gradients ranging from –6dB to –15dB/octave.

The spread of data varies with edge conditions and is greatest for the simply supported edge condition. The different acoustic-acoustic couplings and acoustic-structural couplings and structural resonances are the reasons of those differences. Strong couplings take place when the acoustic modes have the same distribution, as in equal rooms. So, if data for equal rooms are removed, the spread of data is reduced. The spread of data also is small when no structural modes are present, recalling the work of Kropp[11] and Pietrzyk[12] on limp walls[27].

Figure 9 displays the averaged sound pressure level difference for each edge condition for seven uneven rooms. Again, the simply supported wall is found to insulate less than the clamped wall. Values for the mixed edge condition lie between those for the simply supported and clamped. The effects of edge conditions on the sound insulation are not affected by the modification of the room length.

5. CONCLUDING REMARKS

A FEM software package has been used to investigate the sound transmission at low frequencies between dwellings.

For small room volumes, the party wall response is strongly influenced by the modal characteristics of rooms, as well as of the party wall, producing a large spread in data.

The wall edge conditions affect the sound pressure level difference since they also change the structural modal density, a phenomenon already observed by other workers[25,29-31]. The level difference of the thin clamped lightweight wall is lower than the simply supported case, since as the rigidity of the wall increases[25,29,32] structural modes increase in frequency.

The sound level difference is lower when the volumes of the two rooms are equal whatever the edge conditions of the party walls. Unfortunately, such a situation is often the case for attached dwellings. Therefore, the sound pressure level difference could be improved by uncoupling the acoustic modes e.g by creating staggered rooms. The number of acoustic couplings would decrease and therefore the sound insulation would improve.

6. REFERENCES

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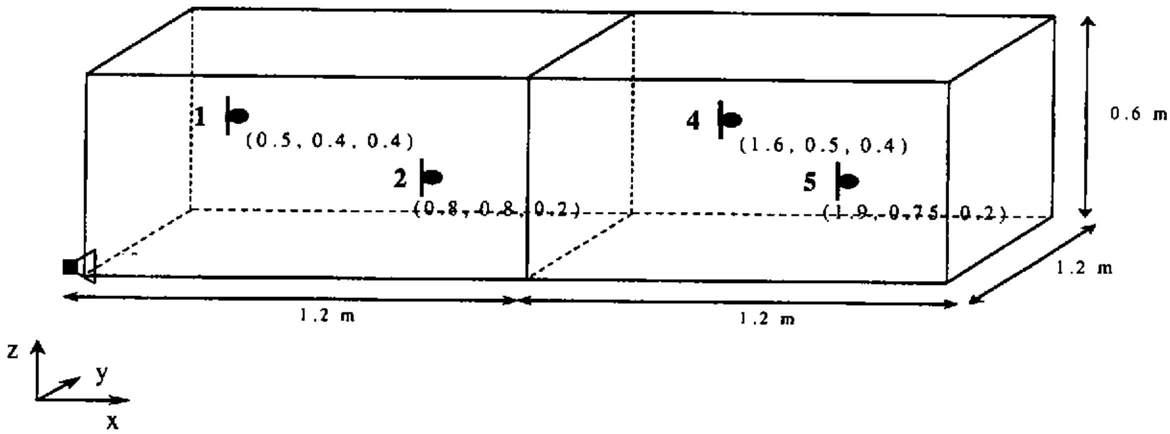

Figure 1. Room dimensions of the ¼ scale model with microphone positions

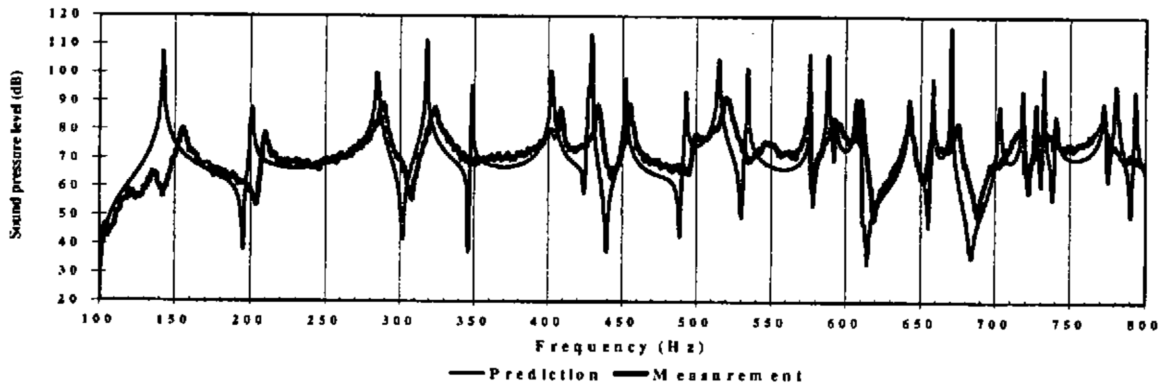

Figure 2. Frequency response at position 1

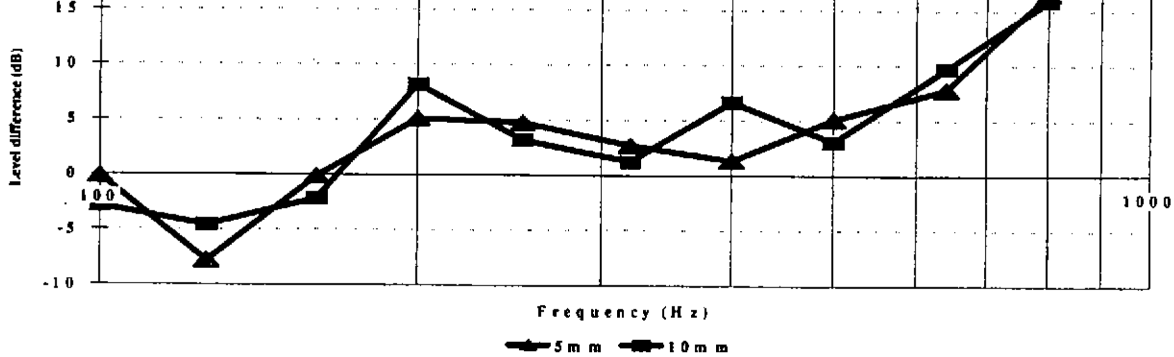

Figure 3. Level difference for the 5mm and 10mm perspex panel

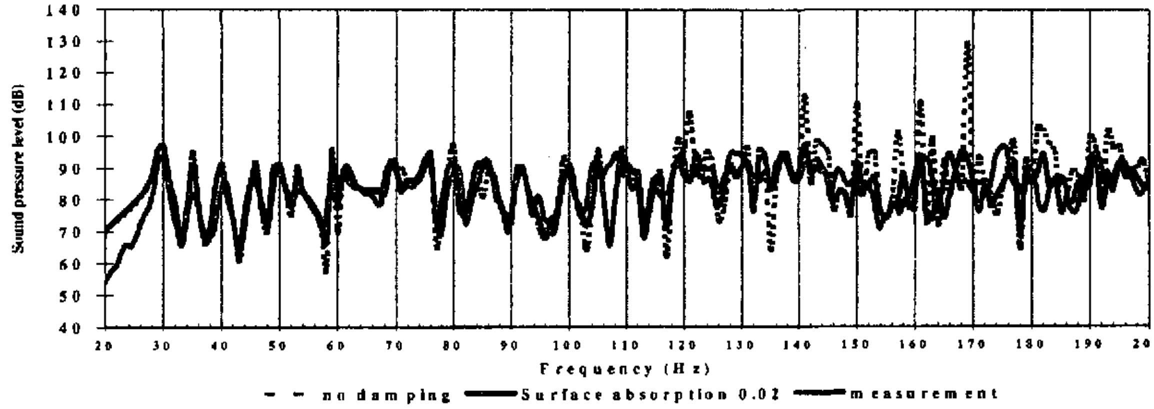

Figure 4. Effect of the introduction of surface absorption 0.02 in the numerical model.

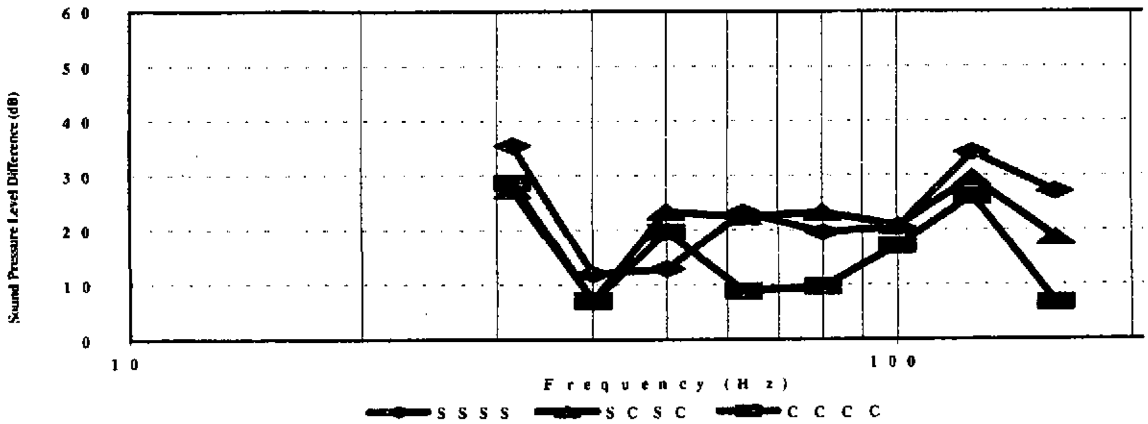

Figure 5. Effects of edge conditions on a 0.05m brick wall

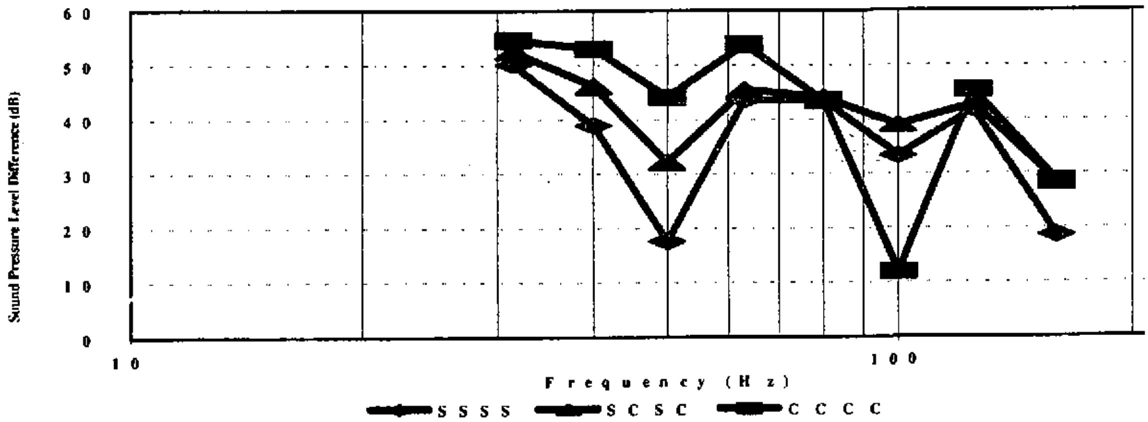

Figure 6. Effects of edge conditions on a 0.2m brick wall

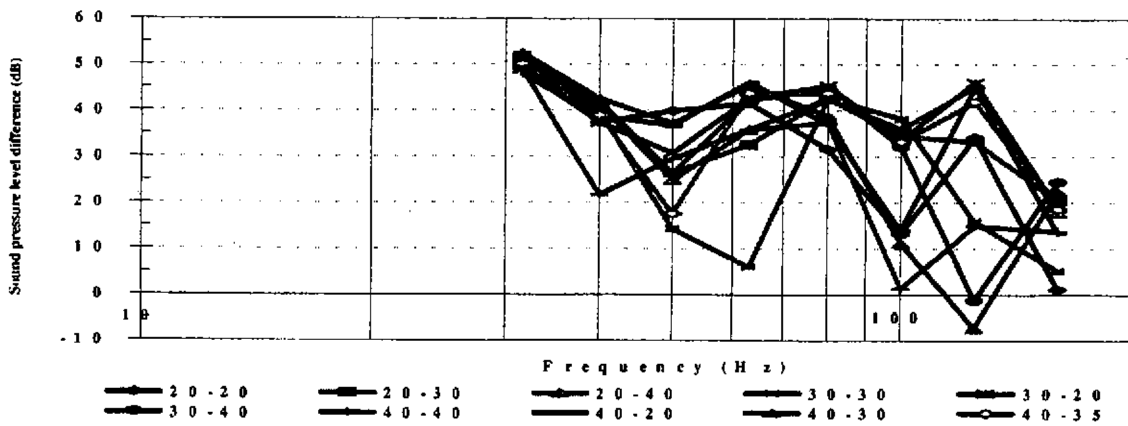

Figure 7. Effect of different room configuration on a 0.2m simply supported brick wall

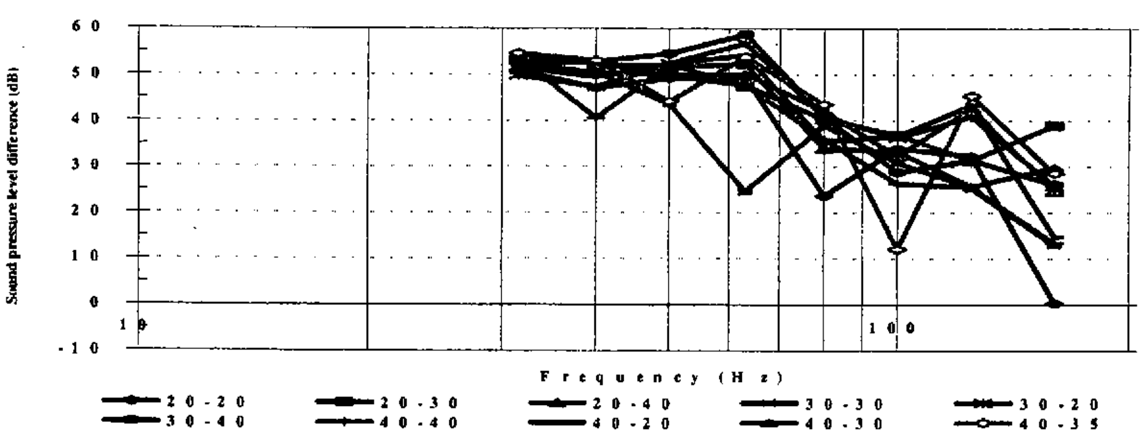

Figure 8. Effect of different room configuration on a 0.2m clamped brick wall

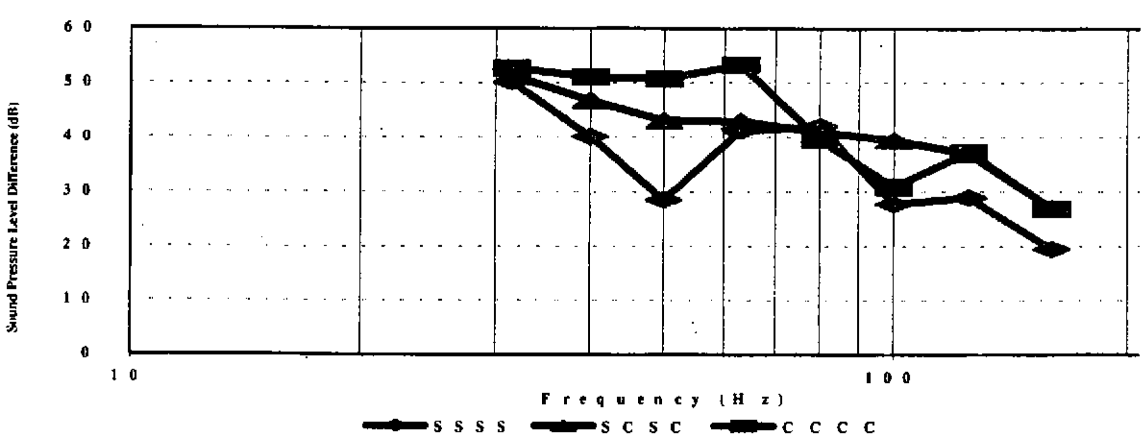

Figure 9. Effect of unequal room configurations on a 0.2m brick wall with different edge conditions