SOUND ABSORPTION IN ROOMS AT LOW FREQUENCIES: ROOM CONTENTS AS OBSTACLES AND ABSORBERS

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ABSTRACT
This paper reports on a study of low frequency room absorption due to contents such as furniture. A model of absorption appropriate for a modal description of contained sound fields at low frequencies is presented. It is shown that when a large solid item is introduced into a room there is little effect on the room frequency response for frequencies below 50 Hz. In the frequency range 50 to 200 Hz the effect is more pronounced and the influence of location becomes apparent. In a further study, solid objects with absorbent coverings and wholly absorbing objects were considered. A real item of furniture also was measured and modelled for inclusion in the room model. Eigenfrequency shifts and selective modal damping were observed throughout the frequency range of interest and the numerical model indicated these effects, showing overall good agreement with measurements. It is shown that when an absorbing item is introduced into a room there is again little effect on the room frequency response for frequencies below 50 Hz. In the range 50 to 200 Hz, contents placed along a wall or in room corners produce a greater change in room response, when compared with a central location.

INTRODUCTION
In extending procedures for field measurement of the sound insulation of walls and floors to frequencies below 100 Hz, consideration is required of the sound absorption of room contents at such frequencies [1, 2]. In particular, the effect of introducing contents on the steady-state sound pressure level in rooms requires investigation.

At low frequencies, the inclusion of furniture in a room may generate additional eigenmodes, mode shifts and selective damping of modes [3]. In a study of the influence of room contents (e.g., furniture) on room frequency responses, a solid obstacle was first considered.

Figure 1.-Plan view of obstacle locations within a test chamber: a) central, b) centre wall c) corner position
The obstacle, of size 1.53 m x 0.88 m x 0.75 m, was constructed from lightweight concrete blocks. The obstacle was positioned in three locations in a small reverberant chamber (see Figure 1). The size was chosen in order to approximate a large item of furniture such as a sofa. The experimental set-up consisted of a sound source and microphones in room corners, in order to excite and register all room modes. The microphone positions were unaltered to allow comparisons between results for the empty room and room with content. A FE model of the empty reference room previously had been successfully developed [4]. The model was modified to include the solid obstacle with a constant surface absorption coefficient of 0.02 assigned to the box surfaces.

RESULTS FOR SOLID OBJECT
Figure 2 shows results for the obstacle at a corner position. Independent of location, the introduction of the obstacle did not generate any additional acoustic modes in the measured room frequency responses. However, eigenfrequency shifts are observed throughout the frequency range and some of the modes became significantly damped.

![Figure 2](image_url)

Figure 2. -Room frequency response for obstacle at a corner, in frequency range 20-200Hz: a) Measurement (---) empty room, (- - -) obstructed room; b) prediction (---) empty room, (- - -) obstructed room; c) level difference between measured values, (- - -) between predicted values.
The predicted frequency response presented similar characteristics, showing eigenfrequency shifts and selective modal damping but again with no new eigenmodes. The measured and predicted level differences are shown in Figures 2c and indicate the change in the room response after the introduction of the obstacle, with the empty room response as a reference. There is little change in the frequency range 20-50Hz. Above 50 Hz, the eigenfrequency shifts and the (small) additional sound absorption generate the level difference fluctuations. For the corner location, the level difference is of the order of +12 dB to -8 dB, with significant changes for individual modes. Predictions are in agreement with experimental results.

This effect is represented in Figure 3, which shows the predicted change in pressure distribution at 77 Hz as a result of including the solid object [5].

![Figure 3.-Change in pressure distribution for the ninth room mode (1, 1, 1) at 77 Hz.](image)

**SOLID OBJECT COVERED WITH ABSORBANT**

The solid core, measured previously, was covered with an open cell porous absorber, consisting of 150 mm of polyurethane flexible foam with a density of approximately 30 kg/m3. The acoustic impedance of the material was obtained by means of the impedance tube method [6]. The input parameter for the finite element model was the normal acoustic admittance, An, which is the inverse of Zn.

It was not possible to measure absorption coefficients at frequencies below 90 Hz and therefore a linear extrapolation was applied, assuming a zero value of absorption coefficient at 0 Hz [7]. Figure 4 shows the predicted and measured level differences in 1/12th octave bands for the central location. Figures 5 and 6 show the corresponding results for the location at a wall and at the corner, respectively.

The corner position was observed to be the least influential. This may be explained by the fact that for the centre location five absorbing surfaces contribute whereas three surfaces contribute in a corner.
REAL FURNITURE
A single item of furniture, a large armchair, was introduced into the chamber and also was modelled. The chair was constructed of a timber frame, with steel spring seat supports. The frame and springs were covered with dense fibrous material, which in turn, was covered with low density fibre padding and cushions. The covering was a thick-woven textile. The overall dimensions were 0.85 m x 0.85 m x 0.85 m.
Preliminary measurements indicated a small change in room response on introducing the chair, particularly below 100 Hz. This has practical significance. If furniture does not have a significant effect in this frequency region then it need not be included as a correction to the measured sound level difference between rooms. Alternatively, a refined model of content absorption is not required. Figures 7, 8 and 9 present the level difference, between measurement and prediction, in 1/12th octave bands for the armchair at the floor centre, centre wall, and corner, respectively.

![Figure 7](image1.png)
Figure 7.-Level difference between room responses for empty room and with armchair at the floor centre: ■ measured, ○ predicted

![Figure 8](image2.png)
Figure 8.-Level difference between room responses for empty room and with armchair at the wall centre: ■ measured, ○ predicted

![Figure 9](image3.png)
Figure 9.-Level difference between room responses for empty room and with armchair in corner: ■ measured, ○ predicted
At the floor centre, both measured and predicted levels indicate that below 90 Hz the armchair has no significant effect on the room frequency response. Above 90 Hz, the measured level difference is approximately 2 dB with a variation 0 dB to +5 dB. For the centre wall position, the measured average level difference is 0 dB ±1 dB below 65 Hz. Above this frequency, the measured level difference is 3 dB with a variation 0 dB to +8 dB. For the corner position, the room response is altered above 50 Hz by an average value of 2 dB with a variation 0 dB to +6 dB. In general, the predicted level differences agree with measured values.

CONCLUSIONS
It has been shown that when a large solid item is introduced into a room there is little effect on the room frequency response for frequencies below 50 Hz. This is despite the fact that the first three normal room modes occur in this frequency range for the case considered. However, this might be expected, since the major obstacle dimension is less than one quarter of the sound wavelength at 50 Hz. This was regardless of the obstacle position and, therefore, it is possible to conclude that the room frequency response is insensitive to location below 50 Hz, considering the present obstacle dimensions.

Above 50 Hz, the effect of a solid item within the room is more pronounced. In addition, the influence of location becomes apparent. Obstacles placed along a wall or in room corners will produce a greater change in room response, when compared with a central location. The generated eigenfrequency shifts are the principal reason for the observed changes in the room response.

Results confirm the greater influence on room frequency response of a solid obstacle with absorbent cover, compared with an uncovered obstacle.

Results indicate that the introduction of an armchair does not significantly alter the room frequency response. Thus, a detailed modelling of an absorptive element of furniture within an enclosure is not justified.

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REFERENCES
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