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A PRACTICAL STUDY OF VIBRATION ISOLATED ROOMS

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1. INTRODUCTION

Studios and similar rooms are often constructed as a box which is linked to the main building structure only through resilient supports. The purpose of this is to isolate the room from structure-borne sound.

Tests in rooms built like this show that the resonant frequency is often indistinct and if it can be measured it is usually significantly higher than the design figure. It is also usually difficult to measure any isolation between the structure and the floated room.

At the BBC Engineering Research Department the Source Room of the newly built Transmission Suite is supported on rubber pads and has exhibited these problems. It was therefore decided that this room would be the subject of a detailed study.

2. THEORY OF VIBRATION ISOLATION

At its simplest, the floated room can be modelled as a mass on a spring with some damping. Above the resonant frequency the mass is increasingly isolated from its support.

For many materials the stiffness measured under dynamic conditions differs from that measured by static loading. The dynamic stiffness is generally higher. It is, of course, appropriate to use the dynamic value in the above model.

Various deviations from the ideal model will reduce the isolation achieved in practice. The room will not behave as a simple mass. There will be modes within its structure involving flexing of the walls, floor and ceiling, and rocking modes will be possible because the system has degrees of freedom other than vertical translation. The AVMs will not be perfect compliances. (Rubber pads have been found to be much more satisfactory as AVMs than steel springs.[1]) In addition there may be unintentional bridges between the main structure and the floated room.

3. THE SUPPORT SYSTEM FOR THE TRANSMISSION SUITE SOURCE ROOM

The Transmission Suite comprises two test rooms: Source and Receive. They are linked by an aperture in which test partitions can be built. Both rooms are independently floated so that during transmission measurements the flanking path through the structure is not significant.

The Source Room has a mass of 56100 kg. The internal dimensions are 6.2 m by 4.6 m by 3.7 m. The AVM system was designed to achieve a resonant frequency of around 7 Hz.

The AVMs consist of three layers of studded carpet. The AVMs are spaced around the perimeter of

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the room and under a central steel beam.

The static stiffness of the rubber carpet was listed as 1.5×10^8 $Nm^{-1}m^{-2}$.

An allowance of 1.5 for the ratio of dynamic to static stiffness was made.

Therefore the dynamic stiffness per unit area of the three layer pad is $1/3 \times 1.5 \times 1.53 \times 10^8$ $Nm^{-1}m^2$

$= 7.65 \times 10^7$ $Nm^{-1}m^2$

The load per unit area of AVM is 42529 kg m^{-2}

This gives a theoretical resonant frequency of 6.7 Hz.

4. INITIAL TESTS IN THE SOURCE ROOM

It soon became apparent that the Source Room did not have a clear resonant frequency. Figure 1 shows a transfer function measured from the over-site concrete (accessible through holes in the source room floor) to the floor. Hammer blows on the carpet floor of the adjacent room provided the excitation. Note that the resonant peak is not clear. The set of peaks which resembles a fundamental resonance extends from 10 to 24 Hz. There is some evidence of isolation but this is questionable.

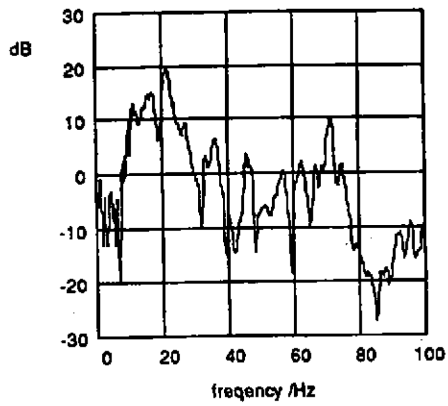

Fig. 1. An early transfer function measured in the Source Room

5. SMALL SCALE EXPERIMENTS

5.1 Static loading

Paving slabs were progressively stacked up on four rubber studs (one under each corner). Dial gauges were positioned to measure the deflection at each corner and the four readings were used to calculate an average deflection.

When the loading curve was plotted it was observed that the stiffness decreased slightly as the load was first applied and then remained constant. In this linear portion the stiffness per unit pad area was 2.4×10^8 $Nm^{-1}m^{-2}$.

The stiffness used in the design of the Source Room AVMs was calculated by dividing the manufacturer's figures for maximum load and maximum effective deflection. This figure was 1.5×10^8 $Nm^{-1}m^{-2}$.

The manufacturing tolerance is quoted as ± 20 %. Different experimental techniques would be expected to give different results but nevertheless the above result does differ significantly from the specification.

5.2 Dynamic stiffness

A stack of paving slabs was again supported by one rubber stud under each corner. A noise signal was fed to an electromagnetic shaker on top of the slabs and an accelerometer on the slabs was connected to a spectrum analyser which showed a clear peak at the resonant frequency.

The dynamic stiffness increased with load. The ratio of dynamic to static stiffness varied from 1.8 at 15 % of maximum load to 2.6 at 83 % of maximum load.

5.3 Vibration isolation

Figure 2 shows the transfer function measured from floor vibration to slab vibration. Note the clear resonant peak and approximately 10 dB of isolation above 40 Hz. The peak at 100 Hz was a resonance of the top paving slab.

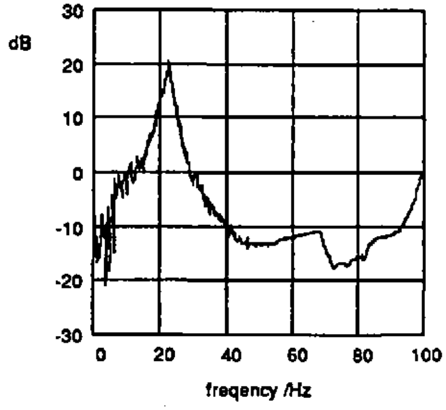

Fig. 2. Transfer function for the paving slabs

6. STATIC LOADING OF THE SOURCE ROOM

An experiment was performed in which the room was gradually loaded by filling five interconnected 60 gallon water tanks. The room deflection was measured at four points. The objectives of the experiment were first to see if the static stiffness of the room was as it should be and secondly to see if any sticking was evident during the downward motion.

The loading curves at the four test points initially showed varying amounts of sticking. After this they all followed straight lines with similar gradients. The average gradient corresponded to a static stiffness per unit area of a single layer of rubber carpet of 3.7×10^8 $Nm^{-1}m^{-2}$; significantly greater than the paving slab result of 2.4×10^8 $Nm^{-1}m^{-2}$.

The displacements at the extreme corners of the room were calculated on the assumption that the floor was rigid. During the initial friction controlled motion one corner rose at first. This indicated that the floor was initially pivoting about a point midway along the test aperture. There was also evidence of resistance to movement in the door wall. Friction can be significant for AVMs. It increases the resonant frequency and reduces the isolation. The effect is most significant for low vibration amplitudes (see again reference 1).

Two conclusions were drawn. Firstly the apparent static stiffness of the mountings was rather higher than expected but was of the correct order. Secondly there was considerable friction to initial movement; in particular there was evidence of pinning around the centre of the test aperture wall.

7. MEASUREMENT OF ROOM MOBILITY AT VERY LOW FREQUENCY

Following the water tanks experiment a further test of the freeness of the room in different places was made. This time the room was subjected to a dynamic force but at such a low frequency that it was effectively the static response of the room that was being tested.

A shaker operating at 5 Hz was placed on the Source Room roof and the amplitude of vibration at a grid of points across the floor was measured. A reference accelerometer close to the centre of the floor was used so that the phase of vibration could be checked. It was clear that the room was moving as a whole. The phase differences measured were at most one or two degrees.

Figure 3 shows a contour plot of the vibration amplitude across the floor. The top edge is the test aperture boundary and the left edge is the door wall. Again there is a lack of mobility along the test aperture boundary, particularly in the middle. Also the door side moves less than the opposite side. This confirms the findings of the water tanks experiment.

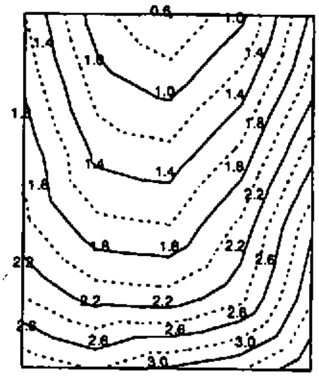

Fig. 3. Vibration amplitude over floor at 5 Hz

8. REMEDIAL WORK

The lack of mobility along the test aperture boundary was significant and so the cause was investigated. The test partition support consists of a steel beam resting on a concrete base. The beam is adjacent to but not in contact with the floor slab. Part of the concrete base is also adjacent to the floor slab. A sheet of fibreboard was placed against the floor slab when the base was cast. Concrete soaked into this fibreboard and it formed quite a firm bridge to the floated floor. It was decided that this was unsatisfactory so the edges of the base were removed and recast using removable shuttering so that a clear gap was left.

9. TESTS AFTER THE REMEDIAL WORK

Figure 4 shows the mobility at 5 Hz following this operation. The room motion is now much more uniform although the test aperture side and the door side still move less than the others.

It is possible that the reduced motion of the floor by the test aperture is due to the fact that it does not have a wall on it to transmit the force from the ceiling. A lack of symmetry between this side and that opposite is to be expected.

Figure 5. shows a transfer function which can be compared with figure 1. Note the clearer resonance. Its frequency is 15 Hz.

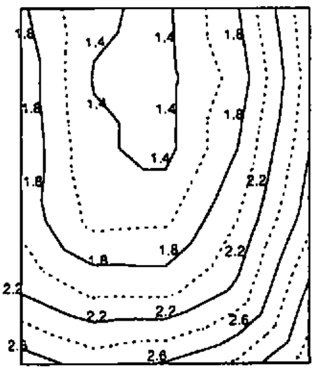

Fig 4. Vibration amplitude over floor at 5 Hz after remedial work to test aperture boundary

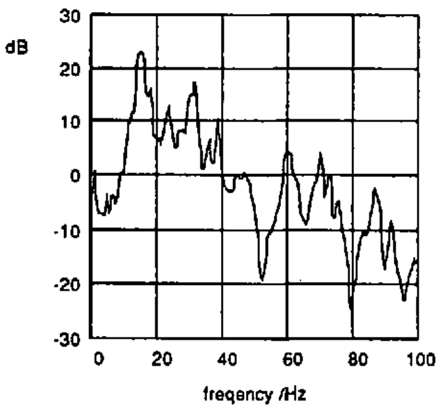

Fig. 5. Transfer function after remedial work

10. SHEAR STIFFNESS OF THE MINERAL WOOL USED IN THE WALL CAVITIES

The door wall and the stub walls around the test aperture have cavities which were filled with mineral wool mainly to prevent building materials falling down and forming a bridge. This mineral wool was under slight compression and it was suspected that its shear stiffness might be significant.

The dynamic shear stiffness of a sample of the mineral wool was measured and from this an estimate was made of the total shear stiffness of the installed mineral wool. The result was $5.8 \times 10^7 Nm^{-1}$. The total dynamic stiffness of the AVMs predicted from paving slab measurements was $2.8 \times 10^8 Nm^{-1}$ so the mineral wool would account for an increase in stiffness of 20 %.

11. REVISED EXPECTATIONS FOR THE SOURCE ROOM

Using the dynamic stiffness measured with the paving slabs and taking into account the additional stiffness of the mineral wool in the wall cavities the expected resonant frequency of the room is 12.5 Hz. Recall that following the remedial work the measured resonant frequency was 15 Hz.

12. WHAT ABOUT VIBRATION ISOLATION?

This paper has concentrated on AVM stiffness and resonant frequency. These are relevant to isolation but it must be stressed that a clear resonance at the correct frequency does not guarantee that useful isolation will be achieved. It is important that isolation is measured directly.

Isolation measurements in the Transmission Suite were made between 0 and 1 kHz. One accelerometer was attached to the main building structure and the other to the Source Room floor. Different positions and different excitations were tried.

At each position the two accelerometers were physically close. This is because if the floor were connected rigidly to the surrounding structure then nearby points would have similar vibration levels. Therefore any isolation measured is a real effect of floating the room.

The coherence obtained with hammer blows is much better than that obtained with white noise. The difference can be attributed to the slow decay of structural vibration. With a noise signal the receive accelerometer has a constant background of vibration unrelated to the present excitation.

Narrow band transfer functions (from structure to floated room) for different cases are compared in figure 6. There is very little similarity. In most cases there is no strong trend with frequency. However, the measurements with hammer blows do generally show a significant isolation.

It appears that vibration isolation cannot be reliably measured. However, the validity of the results cannot be denied. If the site slab is vibrating with a certain amplitude and the floor above is vibrating 10 dB less then this is an improvement over what would happen if the floor were rigidly connected to the site slab. (Assuming, of course, that the effective mass of the foundation is much greater than that of the floated room.)

A vibration isolation measurement is only valid for the particular positions and excitation used. Results cannot sensibly be compared from one building to another. The most meaningful measurements are those made with natural site vibration. Accelerometers at the top and bottom of an AVM will produce the most sensible looking results but these are not necessarily the most valid. For example, the vibration in the middle of a floor is very significant even though this may be the furthest point from an AVM.

13. CONCLUSIONS

In the case studied a cement-soaked fibreboard joint along the test aperture boundary formed a significant bridge. After this was removed, tests on the freeness of the room indicated that all parts of it move freely although with more resistance at those walls with mineral wool filled cavities.

Following the removal of structural bridging the resonant frequency is about 15 Hz. This is more than twice the design figure. The result is almost explained by the facts that (a) the dynamic stiffness of the AVMs is nearly three times the figure used by the designers and (b) the mineral wool used in wall cavities adds 20 % more stiffness. The resonant frequency predicted on this basis is 12.5 Hz. Minor structural bridging may account for the discrepancy.

The fact that the foundation slab and the floated room do not behave as ideal masses accounts for the erratic nature of vibration isolation measurements. Nevertheless, floating the room does seem to have provided a significant degree of isolation from structure-borne sound, particularly impacts. In the case of impacts the isolation achieved is of the order of 20 dB.

14. ACKNOWLEDGEMENT

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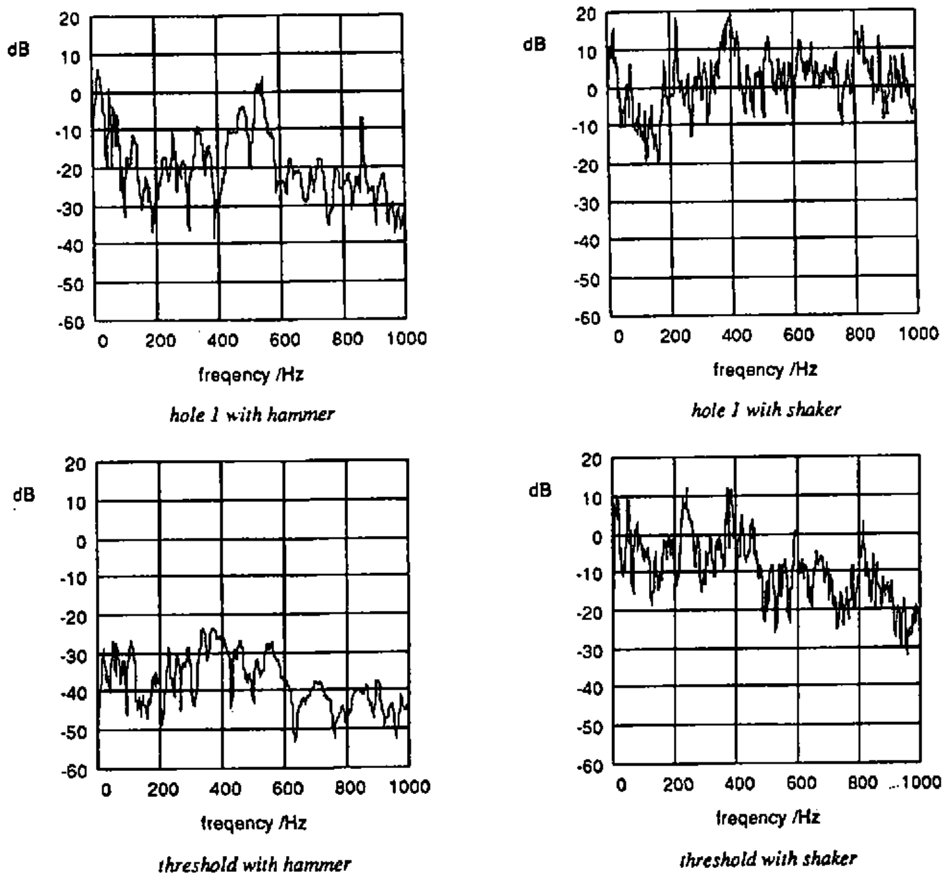

Fig. 6. Transfer functions from main building structure to Source Room

15. REFERENCES

[1] C.D. MATHERS & R. WALKER, 'Some properties of antivibration mounts used in building isolation' BBC Research Department Report No. 1989/3 (1989)