SOME PRACTICAL ASPECTS OF VIBRATION ISOLATION

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1. INTRODUCTION

Broadcasters have many reasons for wishing to build studios in city centres, and the problem of isolating buildings from ground vibration is therefore one that especially concerns us.

The obvious way to prevent vibration being transmitted to or from any structure is to place it on devices specially available for the purpose - namely, anti-vibration mountings or AVMs for short. One can discern about three levels at which this approach may be attempted.

(a) To the uninitiated, it is clear that AVMs must reduce or cure vibration, and certainly could in no circumstances increase it. As a safety precaution, they often consider it wise to use two or three times as many AVMs as the manufacturers recommend.

This actually happened in one of our control rooms some years ago. The system resonated at 25 Hz, in sympathy with water pumps in a nearby plant room. Vibration was 17 dB worse in the control room than in the plant room, causing some users to suffer from acute nausea.

(b) To those with a little more experience, the solution is much less obvious (a common feature of acoustics). Now, an AVM is usually some form of spring, whose chief attribute is "give" or compliance. The structure that it supports appears to behave as a mass, so that the system has a predictable frequency of resonance. Since masses on springs do not oscillate for ever, some form of viscous damping is evidently involved.

A tentative model is the three-element mechanical system of Fig. 1, which for most of us is easier to think about in its equivalent electrical form. Indeed, some of our studios have been designed on this principle, and certainly possess a very useful degree of isolation from groundborne vibration. The data supplied by most AVM manufacturers seem to be based on such a model, which is probably adequate for many applications.

(c) Given this three-element model, which works very well for low frequencies (up to, say, ten times fundamental resonance), one can advance possible reasons for its failure at higher frequencies, then set up experiments to test such hypotheses.

Recent work has taken us some way in the direction of this third approach, and its results form the substance of this paper.

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2. ISOLATION REQUIREMENTS

Problems in studios are not usually caused directly by vibration, but rather by the acoustic noise into which some of the vibrational energy is transformed at the boundary surfaces. Based on measurements of surface acceleration averaged over a number of points, Fig. 2 shows the noise level that would be generated in one of our Broadcasting House drama studios by an average surface acceleration of unity (one metre per second per second). Plotted for comparison is the calculated curve, assuming, for simplicity, uniform unit acceleration of all surfaces.

In the BBC, studios are designed to one of three background noise criteria. On a "quiet" site, for a studio built to one of the less stringent criteria, no problem would occur, as is shown, for example, by our music studios at Maida Vale. In contrast, to achieve the criterion appropriate to a drama studio (the most exacting requirement), built on a noisy West End site, isolation of the order shown in Fig. 3 would be needed.

3. EXPERIMENTAL TEST RIG

To investigate further the problems of vibration isolation, we set up the test rig shown diagrammatically in Fig. 4. It consists of a reinforced rectangular concrete slab surrounded on three sides by a reinforced ring beam, with the fourth side almost doubled in thickness over a width of 1m. The structure weighs about 11 tonnes.

Provision has been made to raise the slab to a maximum height of 1m, so that it may be set on any chosen type and arrangement of AVMs. Beneath is a very substantial ground slab, constructed of 600 mm thick reinforced concrete, supported on piles drilled through the floor of the room in which the test rig is accommodated.

The rig occupies part of a London sub-basement, a location chosen for several reasons. Most importantly (apart from the fact that the space was available), underground train tunnels run close by, providing a valuable and predictable source of ground vibration. In addition, the site was at that time being considered for future studio development, and any information obtained could well have directly contributed to studio design data.

4. INITIAL FINDINGS

Isolation measurements were made with the slab supported on a wide variety of anti-vibration mounts, providing fundamental resonant frequencies ranging from 2 to 14 Hz. It rapidly became apparent that only below about 30 Hz did the system behave like the three-element model of Fig. 1, whatever the AVM type used. Later work has confirmed this conclusion for all readily available types of AVM, including airbags, rubber in shear or in compression, helical steel springs with or without "noise stop" pads, glassfibre cubes, and steel "omega" springs.

A typical narrow-band plot of measured isolation is shown in Fig. 5, compared with a prediction based on the simple model. The plot (produced by a Fourier transform analyser) has equal frequency increments on a linear scale, and in logarithmic form therefore appears coarsely quantised at the low-frequency end. Aside from this peculiarity, two main features are evident. Below 30 Hz, the curve accords reasonably well with the model, except for two sharp dips. Above 30 Hz, the isolation appears to become approximately constant with frequency.

5. TESTING OF HYPOTHESES

To explain why the test rig behaved in a much more complex way than a model consisting of three lumped elements, three hypotheses seemed plausible. (The first two are mentioned in all textbooks on the subject.)

(a) The floated structure exhibits one or more series of vibration modes, and therefore behaves as a pure mass only at frequencies below that of its first mode.

(b) The AVMs are also modal in their behaviour, and correspondingly therefore behave as pure compliances only at frequencies below that of their first mode.

(c) Energy is transferred from the ground to the floated structure via the surrounding air, i.e. an acoustic flanking path exists.

To test hypothesis (a), a simple modal analysis of the floated slab was undertaken, with the results shown in Fig. 6. Behaviour is very much as expected, although the actual frequencies and Q factors would clearly be very difficult to estimate. At higher frequencies, the mode shapes increase in complexity, and the modal series presumably continue indefinitely.

The first two dips in isolation evident in Fig. 5 are very likely to be due to the 13.5 Hz and 29.5 Hz modes shown in Fig. 6.

To investigate the behaviour of AVMs, a stack of steel plates weighing about 50kg was bolted together to approximate to an ideal mass. Tests with a small rubber compression-type AVM (which intuitively seemed free of modal mechanisms, at least at low frequencies) confirmed that the "ideal" mass was usable up to about 500 Hz. The limit of 50kg was set to allow convenient handling with reasonable safety.

Fig. 7 shows the isolation provided by a large rubber compression mount, and indicates that the system follows the three-element model very closely indeed. By way of contrast, the behaviour of a helical steel spring, complete with rubber "noise-stop" pad is apparent from Fig. 8. Removal of the pad caused a just-measurable shift in the modal frequencies, but had no other discernible effect. Even the simple (now four-element) equivalent suggests that a rubber mat is too stiff to dissipate much energy, and thereby to provide useful damping.

Apart from these helical steel springs, none of the other AVM types mentioned above showed clearly defined modal behaviour.

What of the third hypothesis, namely, that acoustic flanking of AVMs may be a problem?

The test method used was as follows. Firstly, the slab vibration, ground vibration, and ambient noise due to a train passage were measured. Secondly, in the absence of trains, a sound field was generated using loudspeakers; both the sound level and the resultant slab vibration were measured.

If at any frequency:

At = ground acceleration due to train
As = slab acceleration due to loudspeaker noise
Pt = SPL due to train
Ps = SPL due to loudspeaker

then the acceleration A of the slab due only to train SPL is

$$A = As.(Pt/Ps)$$

and the minimum measurable transmission T via the AVMs is

$$T = A/At = (As/Ps)/(At/Pt)$$

i.e. the isolation limit due to acoustic flanking is

$$1/T = (At/Pt)/(As/Ps)$$

In Fig. 9 this limiting isolation is compared with both the actual isolation and with that predicted from the three-element model. It is very clear that at frequencies above 30 Hz the AVMs are having negligible effect on isolation, which is governed almost entirely by the acoustic transfer of energy from ground to floated slab.

6. CONCLUSIONS

In attempting to isolate building structures from groundborne vibration, the benefits obtainable from the use of antivibration mountings are limited by three factors - namely, modes in the supported structure, modes in some types of AVM, and acoustic flanking of the AVMs.

Let us consider the three problems in turn.

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(a) **Modes in structure**

The only solution appears to be the incorporation of mechanical damping into the structure. Past attempts to introduce lossy materials into a concrete mix have shown, not surprisingly, that structural strength is lost just at the point where some degree of damping is obtained. At the BBC we have had some success with constrained-layer damping of concrete floor slabs by sandwiching a layer of lossy material between two layers of concrete. Whilst applicable to floor and ceiling slabs, the technique cannot be directly applied to walls, for which some other, possibly more complex solution may have to be considered.

(b) **Modal effects in AVMs**

These seem to be a problem only with helical springs, which need much better damping than is obtained by the use of the "noise stop" pads usually provided. Other types of AVM do not appear to suffer from this effect.

(c) **Acoustic flanking**

This is evidently a very serious problem which has to be overcome if isolation figures in excess of 25 dB are to be reliably achieved with simple structures. Brief investigation suggests that up to 10 dB improvement may be obtained by the use of acoustically lossy material, such as mineral wool, to damp acoustic modes which occur in the voids surrounding a floated studio.

Otherwise, it may be necessary to abandon "simple" structures and where critical studios are concerned, use the time-honoured but expensive principle of building a "box within a box".

7. ACKNOWLEDGEMENT

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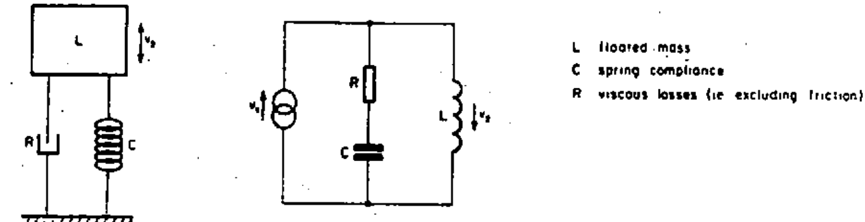


Fig. 1. Representations of simple mass-spring system

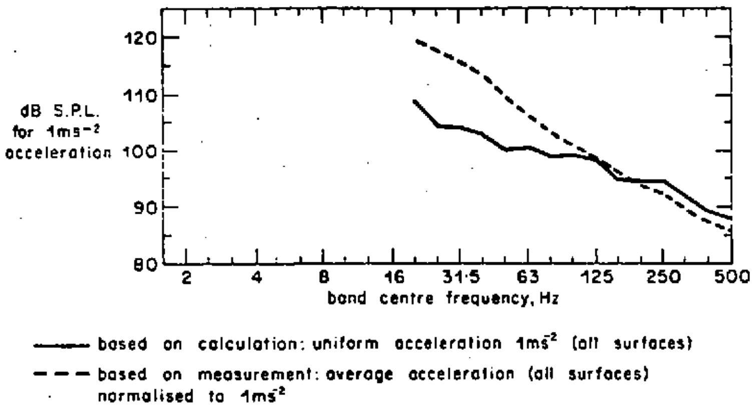


Fig. 2. S.P.L. in a typical drama studio (B11, B.H.) caused by acceleration of internal surfaces

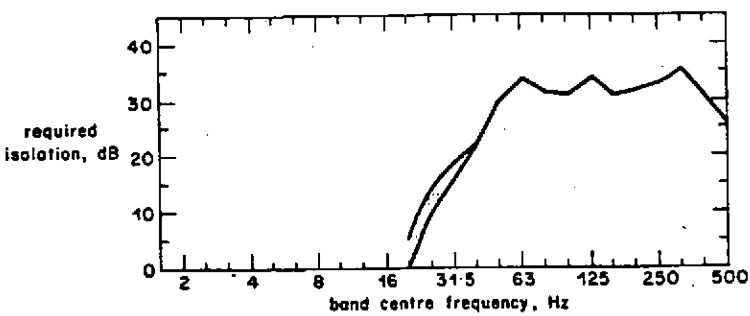
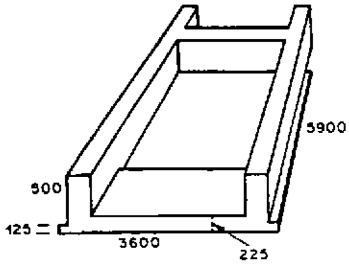


Fig. 3. Mechanical isolation that could be required for a drama studio at a noisy West End location



dimensions in mm

Fig. 4. Experimental reinforced concrete slab

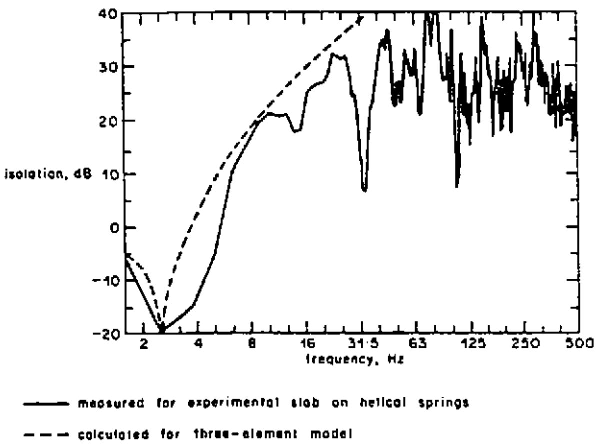


Fig. 5. Calculated and measured isolations: Concrete slab

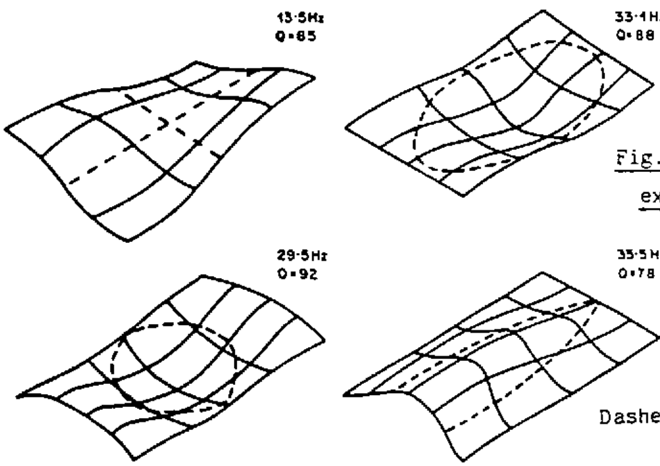
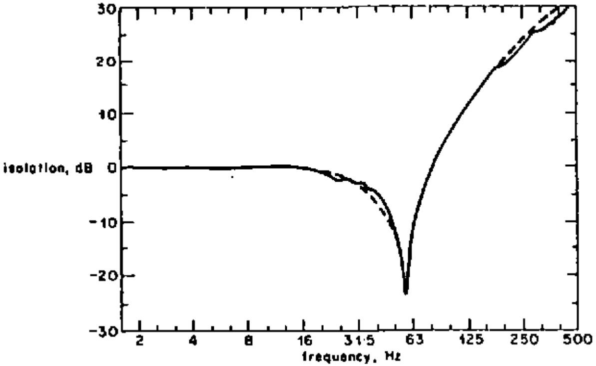


Fig. 6. First four modes of experimental concrete slab

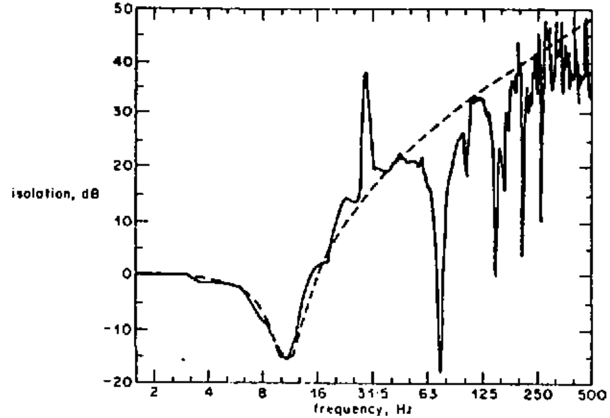
Dashed lines show nodes



—— measured for 50kg "ideal" mass on rubber compression mount

- - - calculated for three-element model

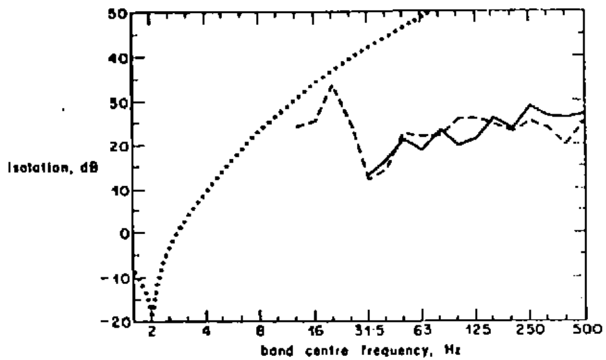
Fig. 7. Calculated and measured isolations: 'Ideal' Mass



—— measured for 50kg "ideal" mass on helical steel spring with "noise stop" pad

- - - calculated for three-element model

Fig. 8. Calculated and measured isolations: 'Ideal' Mass



—— isolation limit due to acoustic flanking, based on measurement (slab on airmounts)

- - - measured isolation

······ predicted isolation (three-element model)

Fig. 9. Acoustic Flanking: Effect on isolation