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CASE STUDIES OF NOISE AND VIBRATION IN BUILDINGS

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Introduction

The vibration of building structures, whether caused by mechanical or acoustical excitation, may give rise to complaints of vibration or noise, sometimes accompanied by fears for the integrity of the building. If effective remedial measures are to be devised it will usually be necessary for the acoustics engineer to clarify both the specific cause of complaint and the mechanisms of excitation. Confusion as to the nature of the disturbance usually occurs at low frequencies where clients are often unsure if they are suffering from noise or vibration exposure, but ambiguities in the mechanisms of excitation can be found over a wide frequency range depending on the noise or vibration source. This paper gives outline case histories of noise and vibration disturbance arising from both acoustical and mechanical excitation and in the concluding sections, describes the use of the accelerometer as a diagnostic tool in the study of sound insulation between rooms.

Mechanical Excitation

Data from BAP studies of recent years are shown in Table 1 where the predominant mechanism was mechanical excitation of the building structure.

Source	Receiver	Vibration level	Complaint
piling rig	19 century housing 10m distant	p.p. velocity 10mm/sec ~12 Hz	"vibration unacceptable"
washing machine on timber-joist floor	flat below	p.p. velocity on ceiling 90mm/sec ~10 Hz	noise and "fear of structural damage"
lauderette water pump, pipes fixed to walls	flat above	broadband rms acceleration on walls ~ 5mm/sec^2	noise
underground trains on raised embankment	housing 20m distant	broadband accel., rms peaks 10mm/sec^2 ~31 Hz	"used to it"

Table 1 Vibration measurements in houses subject to mechanical excitation

In the case of the piling rig and the washing machine it was relatively easy to identify this source/receiver transmission path and, on the basis of the measured vibration levels, the possibility that minor architectural damage (plaster cracks etc) might occur, could not be dismissed. In the flat above the launderette, extensive noise and vibration measurements were required to confirm mechanical excitation as the primary cause of noise complaint. The train study was complicated by the high noise levels and unusual vibration spectra produced by the trains passing over a steel bridge adjacent to the site.

Acoustic Excitation

Data from two studies are summarised in Table 2, in which anxiety regarding building vibration was expressed but the picture obtained was of acoustic excitation giving rise to relatively high levels of low frequency noise with barely perceptible levels of vibration. The heavy lorry study was done in an existing building at the request of a local council concerned about noise and vibration in a proposed housing development nearby. The diesel generator noise had given rise to complaints of both noise and vibration with some concern regarding the integrity of the building fabric. In both studies the level of floor vibration was below what we believed to be the threshold of perception but the low frequency noise, in the case of the diesel generators at least, was sufficiently intense to justify complaint when compared with our admittedly ad hoc criterion derived from the principles of BS 4142 extended to narrow band low frequency sounds.

Source	Receiver	Noise SPL	Vibration rms acceleration
heavy lorries	1950's flats 14m from road	peak 75dB 63Hz	floor, 8mm/sec^2 ~16 Hz window, 200mm/sec^2 ~ 63Hz
diesel generator exhaust stack	office block 80m distant	peak 80-90dB 31.5Hz	floor 10mm/sec^2 ~ 32 Hz window 200mm/sec^2 ~ 32 Hz

Table 2 Noise and vibration arising from acoustic excitation.

Noise measured in terms of dB(A) in this case gave only a 1dB increase relative to the background noise level, whereas there was nearly a 20dB difference in the 31.5Hz octave band between the intrusive and background noise levels. Interestingly, the frequency of this noise did not correspond to the fundamental or harmonies of the rotational and firing frequencies of the engines.

Sound Transmission Measurements

Vibration measurements on room surfaces can provide invaluable clues to the identification and relative importance of different sound transmission paths in buildings. The sound power W(watts) radiated on one side by a panel S(m^2) on which the space average mean square velocity $\langle v^2 \rangle$ $(m/sec)^2$ is known can be calculated from,

$$W = \rho c S \langle v^2 \rangle \sigma \quad , \qquad \ldots.(1)$$

where radiation ratio σ (dimensionless) can be taken as unity at frequencies above the critical frequency of the panel. For masonry constructions the critical frequency is usually low (around 100Hz) and the frequency range of interest in sound transmission is therefore above the critical frequency. Airborne sound transmission tests between rooms can therefore be complemented by velocity or acceleration measurements, from which the relative contribution of the different surfaces in the receiving room to the reverberant sound pressure level can be determined through equation (1) and the usual relationship between sound power and reverberant SPL.

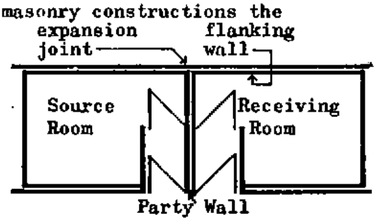

Figure 1.
Music practice rooms, double leaf concrete block construction.

As an example of data obtained obtained by this technique, measurements taken in the room configuration of Figure 1 are shown in Figure 2. Clearly, at all but the lowest frequencies, where the predictions from the vibration measurements are inaccurate in any case because of the proximity to the critical frequency, soundradiation from the walls and ceiling does not account for the relatively poor measured airborne sound insulation between the rooms.

In the absence of significant radiation from the floor which was also checked, we concluded that the predominant sound transmission path was via cracks, holes and poor mortar joints in the wall and perhaps even through the porous, hollow concrete blocks themselves. The measurements proved valuable in the subsequent analysis of the improvement in sound insulation to be expected from different remedial works; for example, after sealing the gaps, a 10dB reduction in party wall and flanking wall sound transmission would give an overall improvement not seriously negated by transmission via the ceiling.

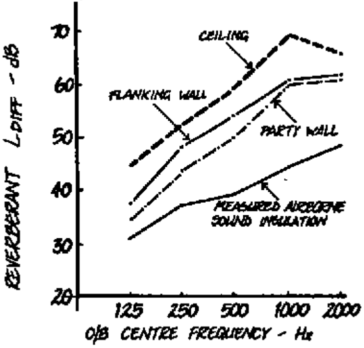

Figure 2. Measured and predicted sound insulation between rooms.

Comment

For mechanical excitation of building structures a simple and approximate model can be derived to give a generalised picture of the likely frequency regions of subjectively significant exposure to noise and vibration. Broadly speaking, as frequency increases from 8Hz, human sensitivity to noise increases and sensitivity to vibration is constant for constant velocity. Taking the perception threshold for whole body vertical vibration as an rms velocity of 0.1mm/sec, the sound power radiated by a surface having this space average rms velocity can be calculated from equation (1) above. Very approximately, in typical housing of heavy masonry construction, this sound power would give rise to sound pressure levels of about 70dB SPL independent of frequency except for variations arising from the frequency dependence of the radiation ratio, room acoustic modes and absorption Comparing this noise level with the Phon curves, B.S. 3383:1961, as shown in Figure 3 we can identify two regions of the frequency domain, the boundary being at about 20Hz. Above this frequency noise is more likely to be perceived than vibration and below 20Hz the reverse would be expected. Since, according to ISO 2631, vibration levels only just above the threshold of perception may be annoying, we expect that as far as complaint situations are concerned the frequency boundary between noise and vibration complaints might be somewhat higher than 20Hz. Thus, in ground-borne noise and vibration from underground trains, the suggestion by Kurzweil (1977) that the structure-borne noise can usually be heard before the vibration levels are high enough to be felt,

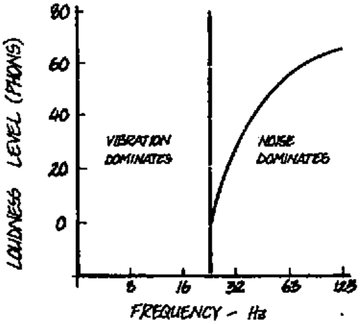

Figure 3. Predicted loudness level of radiated noise from surface with rms velocity of 0.1mm/sec.

is expected to hold only above about 30 Hz. Similarly, ground-borne vibration from trucks if evident at all, would be expected to give rise to disturbing vibration at frequencies below 20Hz. Simultaneous exposure to subjectively significant levels of noise and vibration resulting from mechanical excitation is most likely to occur in the region of 20-30Hz.

With regard to low frequency noise there is, perhaps surprisingly, less guidance available on subjectively acceptable levels than for vibration. As Utley and Heppell (1978) point out, and their comment is supported by the diesel generator study above, dB(A) can be misleading when applied to tonal low-frequency noise problems.

Finally, there are several uncertainties in the use of the accelerometer and equation (1) as diagnostic tools in the analysis of sound transmission problems. For instance, how does the accuracy of SPL predictions based on octave band acceleration measurements compare with the accuracy of direct SPL measurements? How many measurements on a surface are required to achieve a given uncertainty in the space average velocity and what are the limitations on the use of available techniques for the predicting the radiation ratio (eg Beranek 1971)?

References

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