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THE PREDICTION OF COMMUNITY RESPONSE TO BUILDING VIBRATION

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Introduction

There is no British Standard, code or guide for the evaluation of the disturbance produced by vibration in buildings. However, local authorities are empowered to limit industrially generated vibration in the community. Other countries have produced standards and, with an International Standard in preparation, there are now many alternative objective methods of assessing the acceptability of vibration to the occupants of buildings. This paper outlines some of the more important evaluation procedures and compares their recommendations. Many factors combine to determine the effect of vibration. The frequency, direction, duration, waveform etc. of the vibration have an effect but the experience, attitude and activity of people is also important.

Vibration Evaluation Methods

Several of the methods described below have much in common and while this yields some agreement it also leads to common areas of weakness.

Reiher and Meister (1931) obtained judgements for ten subjects and plotted boundaries between conditions classed as 'not perceptible', 'weakly perceptible', 'easily perceptible', 'strongly perceptible', etc.[1] The lowest boundary (that below 'weakly perceptible') has often been taken as the dividing line between acceptable and unacceptable vibration in dwellings (see Figure).

Deutsches Institut für Normung DIN 4150 (1939)[2] is based on the lines of constant velocity developed by Reiher and Meister. Vibration is evaluated in PAL's:

$$\text{Number of PALs} = 10 \log \left(\frac{v}{v_o}\right)^2 \qquad (1)$$

where v is the peak velocity and v_o is the reference level of 0.45mm/s. A PAL value of 5 is 'just perceptible' and a zero PAL value is the threshold. The latter two lines are shown in the Figure. PAL values are not now in common use.

Dieckmann K Values (1955)[3] and DIN 4025 (1958)[4] employ a scale of K values:

Vertical Vibration:	$K = df^2$	$0.5<f<5$	Horizontal Vibration:	$K = 2df^2$	$0.2<f<2$
	$K = 5df$	$5<f<40$		$K = 4df$	$2<f<25$
	$K = 200d$	$40<f<100$		$K = 100d$	$25<f<100$ (2)

where d is the peak amplitude in millimetres and f is frequency in Hz. These K values are not now often used but they are important in relation to subsequent German Standards. In German Standard DIN 4025[4] a K value of 0.1 corresponds to the threshold and values below 0.3 are described as 'just perceptible, easily bearable, scarcely unpleasant'. These levels are shown in the Figure.

Verein Deutscher Ingenieure VDI 2057 (1963)[5] proposed different K values:

$$K = \frac{12.5a}{\sqrt{1+(f/f_o)^2}} = \frac{0.08vf}{\sqrt{1+(f/f_o)^2}} = \frac{0.5df^2}{\sqrt{1+(f/f_o)^2}} \qquad (3)$$

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where f is frequency, f_o is 10 Hz, d is the peak in millimetres, v is the peak velocity in mm/s and a is the peak acceleration in m/s^2. The threshold is below K = 0.1 and at levels between 0.25 and 0.63 it is "possible to stay in dwelling" with short, or no, pauses. These three K values are shown in the Figure.

DIN 4150 (1970 Draft)(6) employs the formulae for K defined in VDI 2057 but there is more guidance on the levels for buildings.

DIN 4150 (1975)(7) differs from the above draft in defining KB values:

$$KB = \frac{20.2a}{\sqrt{1+(f/f_o)^2}} = \frac{0.13vf}{\sqrt{1+(f/f_o)^2}} = \frac{0.80df^2}{\sqrt{1+(f/f_o)^2}} \qquad (4)$$

where a is the peak acceleration in m/s^2, v is the peak velocity in mm/s and d is the peak displacement in mm. The value of f is now 5.6 Hz. The levels corresponding to KB values of 0.2, 0.4 and 0.6 (day limits for residential, business and industrial areas) are shown in the Figure.

International Standard (ISO 2631 1974)(8) is not intended for assessing disturbances in buildings but defines influencial frequency weightings and two relevant levels - a threshold and a 24 hour reduced comfort boundary (see Figure).

Proposed Addendum to ISO 2631 (1977)(9) There is a proposed International Standard on the evaluation of the acceptability of building vibration. In the current draft, vibration is evaluated with frequency weightings provided in ISO 2631. A new combined weighting is suggested for conditions where it is not clear in which direction the motion will enter the body. Figure 1 shows baseline curves for z-axis (foot to head) and x- and y- axis (fore-and-aft and lateral) vibration applicable to critical working areas. Levels corresponding to 2,4 and 8 times this base are for residences, offices and workplaces respectively. These levels give good environmental conditions. Levels a factor of two higher will give moderate complaint and levels a factor of four higher will give major complaint. Other multipliers are provided for impulsive shock excitation.

Japanese Limits (1976)(10) employ ISO 2631 frequency weightings where:

$$\text{Acceleration level} = 20 \log \frac{a}{a_o} \qquad (5)$$

a is the measured acceleration (in m/s^2 rms) and a_o is a reference level which varies according to the ISO 2631 frequency weightings; from 1 to 4 Hz $a=2\times10^{-5} f^{-\frac{1}{2}}$ m/s^2rms; from 4 to 8 Hz $a=10^{-5}$ m/s^2rms; from 8 to 90 Hz $a_o=0.125\times10^{-5}f$. Levels may be measured with meters incorporating appropriate filters.

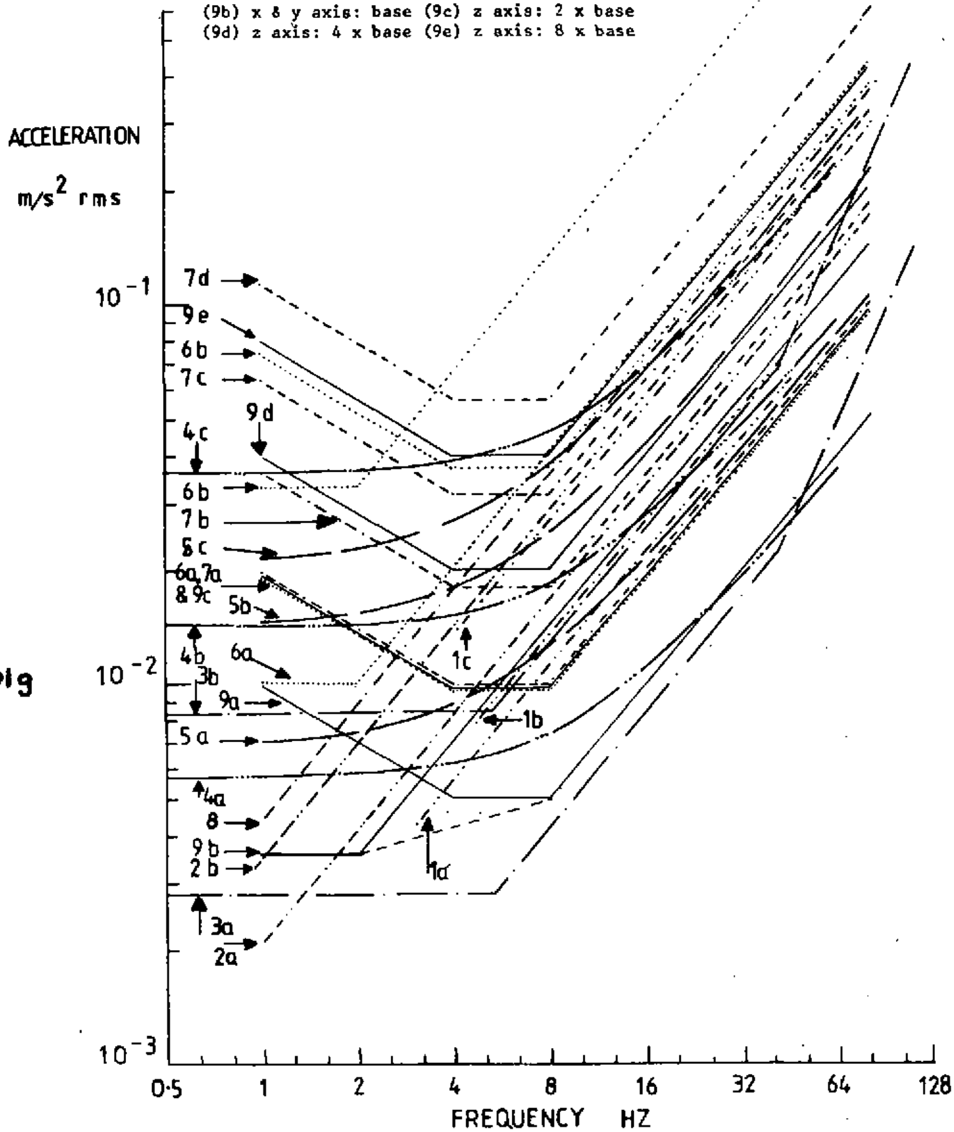
Factory vibration is limited to 60-65 dB in quiet residential areas and 65-70dB in commercial and industrial residential areas, (5 dB lower at night). Limits for construction machinery are 70 or 75 dB. Road traffic limits are 65 or 70 dB. 60, 65, 70 and 75 dB levels are shown in the Figure.

USA Proposal (Von Gierke (1977))(11) refines the proposed ISO addendum. Acceleration should be attenuated by a low pass filter where:

$$\text{Attenuation} = \sqrt{1 + (f/5.6)^2} \qquad (6)$$

(This approximates the combined weighting defined in the proposed ISO addendum and is similar to the KB weighting). Levels are similar to the proposed ISO addendum but a table provides for a gradual reduction in level for increases in the number of shocks up to 100 or the duration of vibration up to 100 seconds.

1. Reiher & Meister (1931) below "weakly perceptible"
   (1a) vertical standing (1b) horizontal (1c) vertical lying
2. DIN 4150 (1939) (2a) PAL=0 (2b) PAL=5
3. DIN 4025 (1958) (3a) K=0.1 (3b) K=0.3
4. VDI 2057 (1963) (4a) K=0.1 (4b) K=0.25 (4c) K=0.63
5. DIN 4150 (1975) (5a) KB=0.2 (5b) KB=0.4 (5c) KB=0.6
6. ISO 2631 (1974) (6a) threshold (6b) 24 hr reduced comfort
7. Japanese (1976) (7a) 60dB (7b) 65dB (7c) 70dB (7d) 75 dB
8. GLC (1976)
9. ISO Addendum (1977) (9a) z axis: Base
   (9b) x & y axis: base (9c) z axis: 2 x base
   (9d) z axis: 4 x base (9e) z axis: 8 x base



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Other vibration evaluation methods are being used to evaluate the acceptability of building vibration within Britain. A simple velocity limit of ± 1 mm/s has been proposed as the limit of acceptability by the Greater London Council (see Figure). Allen and Rainer (12) have provided a means of evaluating motions containing impacts which depend on the damping ratio of the floor and was intended for assessing the acceptability of vibration due to walking.

Discussion and Conclusions

A standard should give a useful assessment of motions of variable level, frequency, duration and axis. It should provide an unambiguous method of evaluating impulsive motions, intermittent vibration, vibrations which vary slowly with time and complex spectra. The method, location and duration of measurement should be specified and there should be guidance on how the limiting levels depend on the use of the building, the type of building, the area and the time of day. Guidance on the degree of complaint likely at various levels should also be provided. None of the standards mentioned in the previous section meet all the above requirements. In part, this is because there has been remarkably little rigorous research on the perception and disturbance produced by low levels of whole-body vibration.

The figure illustrates disagreement between some alternative means of assessing building vibration. However, there is sufficient agreement to be able to identify a range of vibration levels below which there will be no disturbance to occupants of buildings and above which complain is possible. It is concluded that there is a need within Britain for a guide to the disturbance caused to occupants of buildings by vibration. Although several recent standards are of considerable value, it should be possible to improve their usefulness by suitable research and considering the manner in which the guide or standard will be used in Britain.

References

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