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TOWARDS VIBRATION DOSE STANDARDS - A DISCUSSION PAPER

D Trevor-Jones (1), and R J Peters (2)

(1) London Scientific Services, Great Guildford House, 30 Great Guildford Street, London SE1 0ES
(2) Department of Construction Studies, NESCOT, Reigate Road, Ewell, KT17 3DS

Existing British Standard guidance on the assessment of nuisance vibration (1) appears to be reasonably effective with regard to continuous vibration such as might arise from an industrial process, but ambiguous and inadequate when it comes to the assessment of intermittent vibration events. Partly in recognition of this shortcoming, Griffin has developed the concept of vibration dose value (VDV) (2), a quantity which may be thought of as analogous with noise SEL, based on the root mean quad magnitude and duration of a vibration episode.

The dose concept has itself been adopted in a subsequent British Standard (3) which provides a clear framework for further work on the human response to vibration stimuli but which stops short of defining limiting values to quantify nuisance. The use of the VDV and estimated VDV (eVDV) to evaluate intermittently occurring nuisance vibrations in dwellings has been explored elsewhere (2), (4), (5) and needs no further exposition here.

These new assessment parameters have been found by the authors and others (6) to represent effectively the intermittent, irregular vibrations which probably give rise to the majority of complaints from the public about vibration nuisance. As direct measuring vibration dose meters are about to become generally available the means to make the measurements either directly, or indirectly by estimation, will become more widespread so that the need for assessment criteria with which to compare the measured values becomes pressing. Our purpose here is to advance the debate over criteria and, in so doing, to shed some light on the use of eVDV.

The 'satisfactory' magnitudes for continuous vibration given in BS 6472 are an obvious starting point. It seems reasonable to take these as the basis for derivation of dose equivalents of the steady magnitudes assuming that they occur over the day, night or some other period of interest. There are, however, a number of problems which make this simple proposition more complicated than it at first appears. The complications become apparent when each component of the eVDV algorithm is considered more carefully. The definition given in (3) for eVDV is

$$\text{eVDV} = [(a \times 1.4)^4 \times b]^{\frac{1}{4}}$$

where

a = weighted rms acceleration value (ms^{-2})
b = event duration (s)

and the eVDV is calculated in units of $ms^{-1.75}$ because dimensionally it is composed as follows:

$$\left\{\left(\frac{m}{s^2}\right)^4 \times s\right\}^{1/4} = \left(\frac{m^4}{s^7}\right)^{1/4} = \frac{m}{s^{1.75}}$$

For steady, constant vibration the rmq and rms magnitudes are approximately equal but for 'peaky' events with crest factors of up to 6 the rmq may be approximated from the rms by use of the empirical factor 1.4.

The weighting of acceleration value 'a' is crucial. The actual VDV should (and, indeed, can only) be obtained from the weighted root mean quad acceleration signal; the weighting curves (which may be thought of as being precisely analogous with the A-weighting curve familiar from noise measurement) are themselves defined in British Standard 6841 (3). In contrast with BS 6472 (1) which effectively makes use of only two weighting curves (implicit in the base curves, both for acceleration and velocity, for the z and the x/y axes), BS 6841 defines six curves, each of which has a quite specific role. Those particularly relevant in the assessment of nuisance, classified in the Standard as 'discomfort' and 'perception', are w_b which is principally applicable to z axis measurements and w_d which is the corresponding weighting for x/y axis measurements. A further curve, w_g, is defined for the assessment of vibration affecting manual and visual tasks. For the sake of clarity and simplicity the rest of this discussion will be concentrated on the assessment of z - axis vibration; the principles and problems raised are on the whole equally applicable to the x/y axis case.

The base curve for z axis vibration given in BS 6472 approximates most closely to the w_g weighting curve given in BS 6841. If we take the curve in BS 6472 as the basis for the new dose standard, therefore, it will be wrongly weighted according to BS 6841. Perhaps the solution would be to take the lowest value in BS 6472 curve and to apply the BS 6841 w_b weighting factor for each third-octave band to that value to derive a new base curve. Alternatively we could simply assume that the most sensitive part of the base curve represents the key to the perception of nuisance and that we might insert that value into the eVDV equation, as if it represented the weighted value.

The next problem is that of whether it is more legitimate to include or to exclude the constant factor for approximating rmq from rms. Since the BS 6472 base curves are assumed to represent continuous vibrations it could be argued that this empirical factor should be excluded in the setting of an equivalent standard (though not, of course, in the estimation of the VDV from the rms value for an event).

Lastly, the period of measurement, b, presents a problem. BS 6472 is opaque when it comes to periods of assessment; the base curve values are intended to represent tolerable levels of continuous vibration over a period of sixteen hours, which does not correspond with any of the 'standard' day or night periods used in the assessment of noise impact. The question arises then as to whether it should be assumed that the 'day' and 'night' time values given in BS 6472 each refer to a notional 16 hour period so that this should be the value substituted for 'b', or whether the day and night sub-periods are implicitly dealt with in the base curve multiplication factors so that other periods such as 15 hours (day; 07.00-22.00) and 9 hours (night; 22.00-07.00) could be inserted.

In estimating vibration dose values, use can be made of the fact that the w_b weighting factors equate with constant velocity values at $f \geq 16$Hz. Consequently it is possible to measure a vibration rms velocity magnitude and substitute this directly for 'a', using only a constant multiplier to achieve numerical identity. The error introduced if a significant proportion of the energy in the measured signal is in frequency bands centred below 16Hz is such that the eVDV will be over estimated rather than underestimated. Furthermore, in the frequency bands centred at 16Hz and above the modulus of the w_b weighting factor is twice the modulus of the w_g weighting factor so that if the BS 6472 base curve values are adopted an extra factor of 2 must be included to approximate w_b weighting.

In summary, then, a true vibration dose value (VDV) cannot be obtained other than by processing the input signal from an accelerometer through a true rmq integrator and appropriate weighting circuitry. It is not possible, therefore, to derive notional VDV criteria with any degree of certainty from the BS 6472 reference curves and when VDV measuring equipment becomes widely available it will become necessary to attempt to identify new vibration nuisance criteria through field study and social survey. In the mean time estimated VDVs based on rms values may be obtained from existing direct measuring equipment. Velocity values may be used as well as acceleration values and might in fact represent better estimates of weighted rmq acceleration than do rms acceleration values. Standards for the assessment of eVDVs may be derived from the BS 6472 base curves, though a number of assumptions must be made.

The authors propose that the following assumptions are reasonable:

a) that the most sensitive part of the BS 6472 base curve, the minimum threshold of perception level, $0.005 ms^{-2}$, should be taken to represent 'a'

b) that the x 1.4 factor for conversion of rms to rmq should be omitted

c) that the criterion values should be based upon 'standard' evaluation periods of 15 hours (07.00-22.00) for 'day' and 9 hours (07.00-22.00) for 'night'.

Thus, for w_g weighting, in dwellings by day for which 2 x the base curve is taken as the 'satisfactory' level

$$eVDV_{LIM} = [(0.005 \times 2)^4 \times 15 \times 60 \times 60]^{\frac{1}{4}}$$
$$= 0.15 \ ms^{-1.75}$$

and the corresponding night-time value, for which 1.4 x the base curve is taken as the 'satisfactory' level would be

$$eVDV_{LIM} = [(0.005 \times 1.4)^4 \times 9 \times 60 \times 60]^{\frac{1}{4}}$$
$$= 0.09 \ ms^{-1.75}$$

These implicitly 'g-weighted' values would be multiplied by 2 to obtain approximate 'b-weighted' values, as recommended in BS 6841 for perception/discomfort determination. The equivalent 'w_b' criteria are therefore

daytime : $0.30 \ ms^{-1.75}$
night-time : $0.19 \ ms^{-1.75}$

These apply only to dwellings; the factors given in (1) for multiplication of the base curve values to derive 'satisfactory' levels in other types of building must be taken into consideration where necessary, as must the BS 6472 recommendation that 'adverse comment' may be expected at twice these values. Furthermore, different criteria should be derived, along similar lines but using appropriate base values and weighting, for vibration in the x and y axes. It is important to distinguish between the two different weightings implied in the proposed criteria and that the report of a site investigation must clearly state which has been used in the assessment of field results.

While these criteria would be directly applicable when investigating vibration in existing buildings the further question of coupling and amplification factors arises when ground vibration is being assessed on an undeveloped site as part of the pre-development planning process. This problem has been investigated and the result of pre- and post-construction surveys suggests that a source spectrum -dependent analysis of green field ground vibration provides the most accurate prediction of vibration in proposed buildings (7). More simply, for conventionally constructed dwellings a coupling factor of x 1.2 for the ground floor and x 2.4 to 2.7 for first and second floors seems to provide a reasonable estimate.

Consequently, z-axis criteria for ground vibration evaluation on green field sites could be determined as

day, for ground floors:	$0.25 ms^{-1.75}$
night, for first floors:	$0.08 ms^{-1.75}$

with the latter based for the sake of simplicity on a coupling factor of 2.5.

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