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ASSESSING ANNOYANCE FROM VIBRATION USING VIBRATION DOSE VALUES

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1 INTRODUCTION

Due to an increase in environmental awareness, the exposure to vibration in the home and at work has become a much greater cause for complaint than in previous years. To help meet this concern the British Standard BS6472 (1984) [1] is soon to be updated. The new version is currently in draft form and the intention of this paper is to provide a practical summary of the new Standard.

2 THE CURRENT BS6472

The current BS6472 : 1984 - Guide to Evaluation of human exposure to vibration in buildings gives the preferred measurement units, frequency weighting and a standardised system of directions for mechanical vibrations influencing humans. It also gives multiplying factors to account for different types of buildings (ie critical working areas, residential, office or workshop) and for the time of the day (ie day or night). The rms acceleration (ms^{-2}) is the preferred measurement in the Standard. While this is adequate for continuous vibration, it is less so for intermittent vibration assessments.

Intermittent vibration assessments

Other than for blasting, the only reference to the assessment of vibration which has an intermittent time history (ie a string of vibration incidents, each of short duration, separated by intervals of much lower vibration magnitudes) is shown in appendix 1, note 6, of table 3 in the Standard (page 7). This refers to the root-mean-quad (rmq) of the weighted acceleration which may be used as a method of assessment for intermittent and impulsive events. This has not been used very often in practice, perhaps because it may seem complicated, and unlike the root-mean square (rms), it has not been readily available in standard instrumentation.

The root-mean-quad

To obtain the rmq the vibration signal, each value (in ms^{-2}) is:

raised to the power of 4 (ie squared twice)
averaged, and finally
the fourth root is found (ie square root twice)

To explain the rmq principle it is useful to look at a simple calculation in comparison to the more familiar root mean square rms.

The addition of events
BS6472 shows an example of an application is in Appendix A, note 3 of the Standard (page 6). However, this example is only applicable to one type of vibration time history and it does not allow for the addition of various time history events.

3 THE NEW DRAFT BS6472

The main difference between the old Standard and the new draft is the introduction of the Vibration Dose Value (VDV) (which is also included in BS6841:1987 [4]) and the estimated Vibration Dose Value (eVDV). These permit assessments of human response to vibration to be carried out, regardless of the temporal structure (ie continuous, impulsive or intermittent).

Vibration Dose Values
The VDV are based on the root-mean-quad principle, (fourth power time-dependency). However it is a summation (dose) rather than an average. In the example shown above, the fourth root of sum (0.00221) is found (ie the VDV over a 16 hr time period is $[0.00221 \times 16 \times 3600]^{\frac{1}{4}} = 3.36\ ms^{-1.75}$.

The VDV, fourth power time-dependency means that a doubling of vibration magnitude would require a sixteen-fold reduction in duration to result in an equivalent dose.

Estimated Vibration Dose Values
Both rmq and VDV can be measured directly when using the correct instrumentation. However, where this is not available, an estimation of the vibration dose value can be used to give a valid approximation, provided the crest factor (peak/rms ratio) is low (ie does not exceed about 6).

The total vibration dose value for the day is approximately given by:

$$eVDV = 1.4\ a_w\ (nd)^{\frac{1}{4}}$$

where :
eVDV is the estimated vibration dose value (in $ms^{-1.75}$),
a_w is the weighted (see BS6472) rms value (in ms^{-2}),
n is the number of events in a day
d is the duration of the events at the 20 dB down points (in secs).

The correction factor, 1.4, is the ratio of rmq to rms and is empirically formulated from typical vibration environments having low crest factors (mainly trains and other traffic). This procedure will greatly underestimate the true vibration dose values when crest factors exceed about 6. The error will tend to increase with increasing crest factors. Where there is an element of doubt, the true VDV should be used.

Example
If, as a simple example we take three weighted acceleration values from a time history, say 0.1, -0.15 and 0.2, the rms and rmq would be as shown in table 1.

TABLE 1 - A simple example of rms and rmq calculations

VALUE (ms^{-2})	SQUARED	SQUARED TWICE
0.1	0.01	0.00010
-0.15	0.0225	0.00051
0.2	0.04	0.0016
sum	0.0725	0.00221
average	0.0242	0.00073
rms (square root of average)	0.155	
rmq (square root of average twice)		0.165

The simple average of these three values is 0.15 and the rms is 0.155. Experimental work [2] has shown that the average and rms underestimate the human response to vibration, whereas the rmq gives a much better correlation.

If the calculation shown above is computed over complete cycles a graphical comparison can be made. Figure 1 shows a simple sine wave where the average value is zero and hence not very useful.

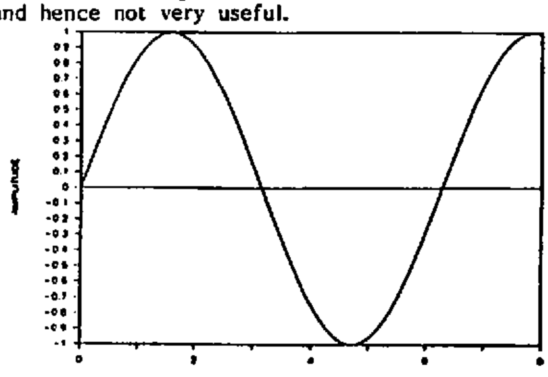

Figure 1 A Sine Wave

Figure 2 compares the sine wave squared (a) with the sine wave to the power four (squared twice) (b) and in figure 3 the square root (0.707), quad root (approx 0.7825) and average values (0.5 for the sine squared curve and 0.375 for the sine quad curve) are added. The ratio of the rmq and the rms for a sine wave is not large (approximately 1.1) because the crest factor (peak/rms ratio) is small (approx 1.4). Sine waves, however, are not often found outside of the laboratory, and it is useful to compare the rmq and rms to more practical vibration signals.

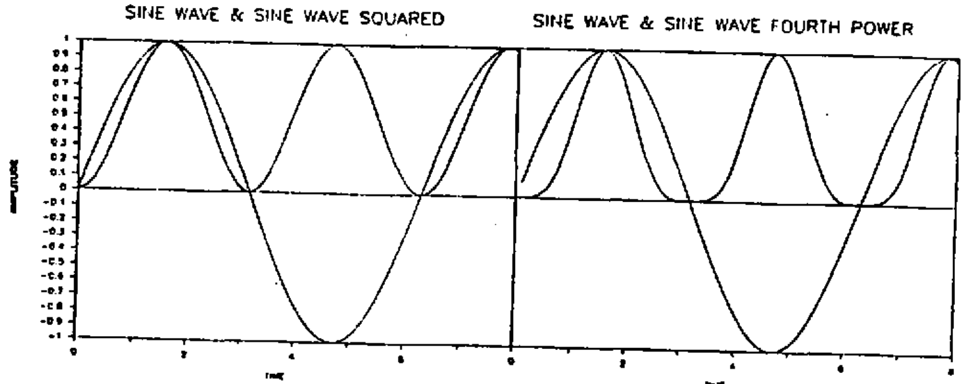

Figure 2 The Sine Wave compared to (a) the Sine Wave Squared and (b) the Sine Wave to the Fourth Power.

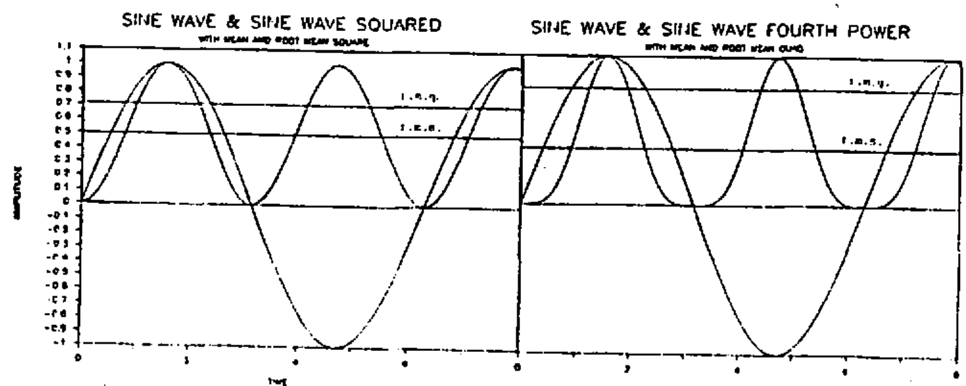

Figure 3 The Sine Wave compared to (a) the Sine Wave squared and (b) the Sine Wave to the Fourth Power. The rms and rmq values are also shown.

Practical sources of vibration

In practice, many sources of vibration fall into the 'intermittent' category, for example, vibration generated from pile drivers, forging presses, concrete breakers, ball demolition, compaction, railway trains and other traffic. A more practical example is the weighted acceleration time history of vertical floor vibration from a pile driver which has a crest factor of 4.6 as shown in figure 4. Here the rmq is almost twice the value of the rms (ie a ratio of 2).

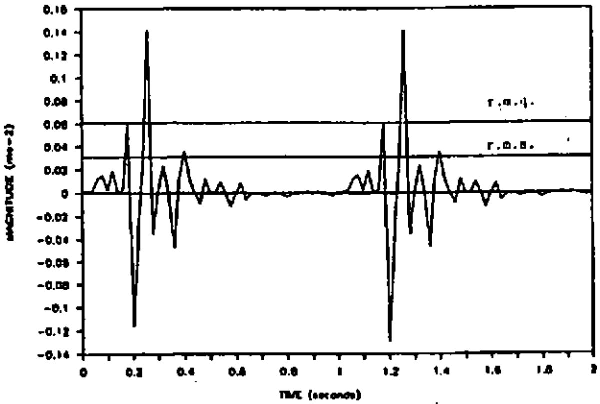

Figure 4 The acceleration time history of vertical vibration from piling at 25m

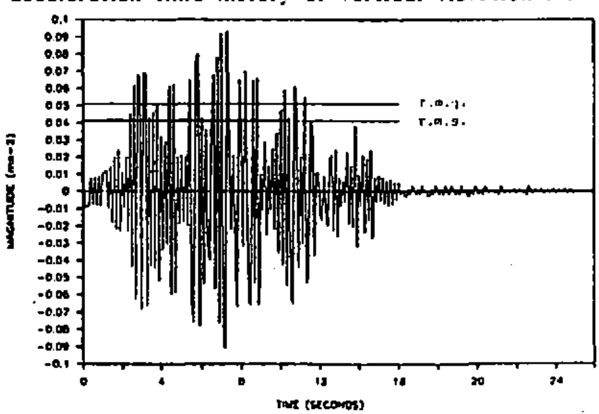

Figure 5 The acceleration time history of vertical vibration from a passing train at 30m

In Figure 5 the weighted acceleration time history of vertical floor vibration caused by a passing train is shown. This gives an rmq/rms ratio of approximately 1.4.

Summation of events
Where events from different vibration sources are required to be summed the following formula can be used:

$$eVDV = [\ (1.4\ a_{w1})^4\ n_1 d_1 \ + \ (1.4\ a_{w2})^4\ n_2 d_2 \ + \ldots \ (1.4\ a_{wi})^4 n_i d_i \ ]^{\frac{1}{4}}$$

where a_{w1}, a_{w2}, a_{wi} are the first, second and 'i'th weighted rms acclerations
n_1, n_2, n_i are the number of similar events
d_1, d_2, d_i are the durations

The measured VDV or the calculated eVDV can then be compared to table 2 (below) which gives Vibration Dose Values at which various degrees of adverse comments may be expected in buildings.

TABLE 2 Vibration Dose Values at which various degrees of adverse comment may be expected in buildings ($ms^{-1.75}$)

Place	Low probability of adverse comment	Adverse comment possible	Adverse comment probable
Critical area	0.1	0.2	0.4
Residential (day)	0.2 - 0.4	0.4 - 0.8	0.8 - 1.6
Residential (night)*	0.13	0.26	0.52
Office	0.4	0.8	1.6
Workshop	0.8	1.6	3.2

These values are derived from the guidance for continuous vibration in BS6472 : 1984 and ISO 2631/2 (International Organisation for Standardization, 1989), [5] but applicable to intermittent vibration and shock of any duration. However, values for shock in workshops may be unacceptable for other reasons.

* Night time values are calculated for an eight hour night, the Standard does not state a time period for night and gives no guidance on start or stop times for a night period.

4 CASE STUDIES USING eVDV

1 Low frequency vibration affecting a six storey commercial building
Lateral vibration on the top floor was caused by the demolition of the neighbouring building. The building was swaying at its natural frequency (2.19 Hz) with a weighted rms acceleration (a_{yw}) of 0.013 ms^{-2}). The expected number

of events, lasting approximately 20 seconds (t) per day was 168 (n).

The calculated eVDV is :

$$eVDV = 1.4\ a_{yw}\ (nt)^{\frac{1}{4}}$$
$$= 1.4 \times 0.013 \times (20 \times 168)^{\frac{1}{4}}$$
$$= 1.4\ ms^{-1.75}$$

Comparing this result with the 0.4 $ms^{-1.75}$ given in Table 2, it would seem unlikely to give reasonable cause for complaint for office workers. As the vibratory signal had low crest factors the estimated result is very close to the true VDV.

2 Piling affecting residential dwellings

Piles were being sunk within 25m of residential buildings causing vertical floor rms acceleration (a_{zw}) of 0.027m^{-2} (weighted). The work was carried out over a three day period using an average of 1800 hammer drops per pile and sinking 14 piles per day, giving a total of 25200 blows per day (n). The duration (t) of the vibration was approximately 0.7 seconds per hammer drop.

$$eVDV = 1.4\ a_{zw}(nt)^{\frac{1}{4}}$$
$$= 1.4 \times 0.027 \times (25200 \times 0.7)^{\frac{1}{4}}$$
$$= 0.44\ ms^{-1.75}$$

Comparing this result with Table 2, adverse comment is possible. The relatively high crest factor of the signal (see figure 4) indicates that the calculated result is an underestimate (the true VDV was 0.61 $ms^{-1.75}$) and hence control measures were taken to reduce the magnitude of the vibration.

3 Compaction affecting residential dwellings

A development site was to be compacted prior to the start of a development. The work was to be carried out over a 10 day period using an 8 tonne flat plate as the compactor. The weight was dropped from a crane at three different heights (13m, 9m and 5m). The closest drops were within 70m of the residential dwellings.

The results are shown below :

	Drop Height (m)		
	13	9	5
Weighted rms acceleration a_{zw}(ms^{-2})	0.055	0.03	0.02
Duration (s)	3	0.5	0.25
Number of events	49	49	117

The eVDV is calculated as follows:

$$eVDV = [(0.055 \times 1.4)^4 \times 3 \times 49 + (0.03 \times 1.4)^4 \times .5 \times 49 + (0.02 \times 1.4)^4 \times .25 \times 117]^{\frac{1}{4}}$$

$$eVDV = 0.27 ms^{-1.75}$$

Comparing this result to the figures shown in table 2 it can be seen that this magnitude of vibration would be unacceptable for critical working areas and for residential dwellings at night. However there is a low probability of adverse comment for day time operation in residential areas even allowing for crest factor underestimates.

5 CONCLUSIONS

The new draft Standard BS6472 gives a method of assessment for annoyance from vibration, including intermittent events, using vibration dose values (VDV). These can be measured directly with the correct instrumentation or an estimate (eVDV) can be obtained using the correction factor of 1.4. Good correlation is found between the VDV and eVDV for vibration time histories, such as passing trains. However where higher crest factors (4 to 5) can occur, as from piling vibration, compaction, etc, the eVDV underestimates the true value of the VDV. For crest factors over 6 or where there is an element of doubt, only the true VDV should be used.

6 REFERENCES

[1] BS6472 : 1984 British Standard Guide to evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)

[2] Griffin, M J, 'Handbook of Human Vibration', Academic Press, 1990

[3] BS6472 : 1989 Draft Revision

[4] BS6841 : 1987 British Standard Guide to Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock

[5] ISO 2631/2 : 1989 Evaluation of human exposure to whole-body vibration. Part 2 : Continuous and shock-induced vibration in buildings

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