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IMPLICATIONS OF UPDATING THE VIBRATION ASSESSMENT METHODOLOGY OF BS6472 FROM THE 1992 TO THE REVISED 2008 VERSION

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INTRODUCTION

In New South Wales, human comfort from tactile vibration is usually assessed against The New South Wales Department of Environment, Climate Change and Water (DECCW) guideline “Assessing Vibration: a technical guideline”, dated February 2006. The methodology contained in this document is based upon the guidelines contained in British Standard 6472:1992, “Evaluation of human exposure to vibration in buildings (1-80 Hz)”. This British Standard was superseded in 2008 with BS 6472-1:2008 “Guide to evaluation of human exposure to vibration in buildings – Part 1: Vibration sources other than blasting” and the 1992 version of the Standard was withdrawn. The new Standard contains some significant differences to the older Standard including a change of the vertical frequency weighting function. Vibration assessed according to the older Standard will therefore differ from assessments made in accordance with the new Standard.

This technical note highlights how assessing vibration in accordance with the 2008 Standard (rather than the 1992 Standard) will result in a 1.5 to 2-fold increase in the Vibration Dose Values (VDVs) of common vibration sources assessed in building vibration such as plantrooms and other indoor vibration sources (gyms, escalators, etc.), road and rail traffic and construction activities. In particular for the latter, these changes will directly impact on safe working distances which may in some cases result in reduced working hours/increased respite periods.

Although a new version of BS 6472 has been published, the DECCW still requires vibration to be assessed in accordance with the 1992 version of the Standard at this point in time.

SUMMARY OF BS 6472-1:2008 ASSESSMENT PROCEDURE

In this section a brief overview of BS 6472-1:2008 is given with a focus on highlighting the differences between this version and its predecessor, BS 6472:1992.

The Vibration Dose Value

BS 6472-1:2008 assesses the probability of adverse comment from vibration by means of VDVs. Unlike its predecessor, BS 6472:1992, the new Standard allows for assessing continuous, intermittent and impulsive vibration events with a unified procedure. This represents a considerable simplification from the 1992 Standard which used different procedures for continuous, intermittent and impulsive vibration events and blasting. In particular the use of weighted summed acceleration and weighted root mean square (rms) acceleration added complexity at no or little benefit as did providing criteria in both the acceleration and velocity domain.

The VDV is given by the fourth root of the time integral of the fourth power of the acceleration level after it has been frequency weighted (effects of frequency weighting are discussed in the following section). This is expressed mathematically as:

$$VDV = \left(\int_0^T a_w^4(t)\,dt \right)^{0.25} \qquad (1)$$

The VDV is much more strongly influenced by vibration magnitude than by duration. A doubling (or halving) in the vibration magnitude results in a sixteen fold decrease (or increase) in the exposure duration for a VDV with the same magnitude.

The VDV is a cumulative measure and increases as the exposure duration increases. It is not an averaging procedure. An X% increase in VDV can be directly related to an X% increase in vibration discomfort (Griffin 1986).

In the case that vibration conditions are constant or repeated regularly, only one representative sample VDV needs to be measured to determine the overall VDV of the assessment period. Similarly, VDVs of different events can easily be added. Corresponding formulas are provided in BS 6472, Griffin (1986) and the ANC guideline (2001).

Principal Difference: Weighting Functions

The frequency weighting used for vertical vibration has changed from W_g, used in BS 6472:1992, to W_b in BS 6472-1:2008. The frequency weighting functions are defined in BS 6841:1987 and are plotted in Figure 1. The thin and thick lines show the asymptotic approximation and the actual modulus of the transfer function, respectively. The 12 dB per octave roll-offs of the band-limits (below 0.5 & 1 Hz and above 80 Hz), which filters one-third of an octave outside the nominal frequency limits, are not plotted. Formulas for the modulus are provided in BS 6841:1987 and Griffin (1986). Griffin (1986) also provides formulas for the asymptotic approximation.

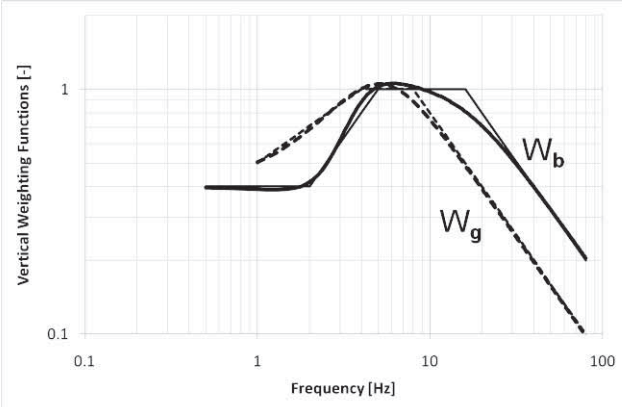

Figure 1 - BS 6841:1987 weighting function in vertical direction - W_g (dashed) and W_b (solid).

The use of the W_b-weighting function improves the consistency between BS 6472 and BS 6841 (W_g-weighting is the preferred weighting for the assessment of hand control and vision in BS 6841:1987). Furthermore, while the W_g weighting was related to activity interference, the W_b weighting was related to comfort which intuitively would suggest the W_b weighting would be more stringent.

The difference in these two weighting functions is frequency dependent as can be seen in Figure 1. In between 4 Hz and 10 Hz the differences arising from the change in weighting functions are small. The weighted acceleration will increase by a factor of up to two at high frequencies, i.e. $W_b > W_g$, while at low frequencies the weighted acceleration is reduced by a factor of up to 1.4, i.e. $W_b < W_g$. The 2008 version of the Standard also assesses vibration down to 0.5 Hz whereas the 1992 version of the Standard has a higher frequency limit of 1 Hz.

The frequency shift in weighting functions means that the revised 2008 Standard is more sensitive to vibration levels above 10 Hz whilst the 1992 standard is more sensitive to vibration below 4 Hz.

Estimated Vibration Dose Values

Actual VDVs may be estimated by eVDVs for continuous vibration that is not time-varying in magnitude and has a crest factor between three and six. The new Standard has distanced itself from the eVDV procedure by discouraging the use of eVDVs for vibration with time-varying characteristics or shocks.

eVDVs can be calculated from the following equation:

$$eVDV = 1.4 \times a_w \times t^{0.25} \qquad (2)$$

where a_w is the frequency weighted rms acceleration in m/s^2 and t is the period over which a_w has been evaluated in seconds.

Historical data

BS 6472-1:2008 provides information on how to appropriately use historical data in situations where it is desirable to examine results derived in the past in light of the revisions introduced with the new Standard.

Considerable care must be taken when only historical spectra (W_g-weighted or unweighted, one-third octave or narrowband) are available. In particular, if the data has been 1-80 Hz band-limited (i.e. information between 0.5 Hz and 1 Hz has been filtered out), this data can only be analysed if there are no low-frequency contributions in the signal.

Recommended Levels

The probability of adverse comment from occupants exposed to a particular level of vibration is given in Table 1. The daytime results in Table 1 do not represent a change to the old version, however for the night-time period a range is now presented as compared to discrete values.

Table 1 – Vibration dose value ranges which might result in various probabilities of adverse comment within residential buildings

Place and time	Low probability of adverse comment (ms-$^{1.75}$)	Adverse comment possible (ms-$^{1.75}$)	Adverse comment probable (ms-$^{1.75}$)
Residential buildings, 16hr day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings, 8hr night	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

Note: For offices and workshops, multiplying factors of 2 and 4 respectively should be applied to the above vibration dose value ranges for a 16 hr day.

The new Standard acknowledges that there is widely differing susceptibility to vibration in the community and accordingly, ranges rather than discrete values are provided.

Coordinate System

In addition to the changes outlined above, the 2008 version of the Standard no longer uses a co ordinate system that is referenced to the human body (i.e. foot-to-head) but uses a Standard geocentric earth based coordinate system.

IMPLICATIONS – WORKED EXAMPLES

Table 2 presents results for some typical construction activities in addition to train pass-by vibration spectra on different track forms. It is important to keep in mind that these changes are indicative and will vary depending on the particular plant used and to some extent on the local geotechnical conditions.

In some cases the historical data was available as one-third octave data band-limited between 1 Hz and 80 Hz. The historical eVDVs were multiplied by $\sqrt{20/23}$ to ensure consistency in the comparison of eVDVs[1]. For all considered cases, there was no low frequency energy contribution and the crest factors were acceptable.

The increases were calculated by dividing a W_b-weighted eVDV by a W_g-weighted eVDV. Almost identical results would

[1]If the W_g-weighted rms acceleration is based on 20 one-third octave bands (i.e. 1 Hz to 80 Hz) then post-multiplication by $\sqrt{20/23}$ is deemed appropriate since W_b-weighted rms acceleration is based on 23 one-third octave bands.

have been obtained had VDVs been compared. Accordingly, the term VDVs in the subsequent discussion and sections relates to both VDVs and eVDVs.

For the considered cases, the shift from the W_g to the W_b frequency weighting implies a 1.6- to 2-fold increase in VDV magnitudes.

In the special case of a tonal vibration source, the change in VDVs can be approximated simply by scaling the historical VDV according to the W_b/W_g ratio at the dominant frequency. For the case that the vibration is of broadband character, a calculation is required to determine the impact of a change from the old to the new Standard.

Table 2 – Expected typical VDV increases associated with a move from W_g to W_b frequency weighting.

Vibration	Typical Increase
Trains at grade, ballasted track	1.75 to 1.9
Trains in tunnels, direct fixation (very stiff pads)	1.9 to 2.0
Vibratory piling	2.0
Hammer piling	1.8
Jackhammer	1.6
Vibratory Roller	1.9
Rockbreaking	1.9
Tunnel Boring	1.9

The data presented in Table 2 is based on ground measurements. It is reasonable to expect that the typical increase in VDV inside buildings on suspended long-span floors will be somewhat less than predicted in Table 2. This is because a floor's fundamental frequency will put more weight to the no-change regime between 4 Hz and 10 Hz and may attenuate vibration at higher frequencies. Similarly, the use of highly resilient rail pads may reduce the 'impact' of W_b-weightings compared to W_g-weightings.

Some typical vibration spectra are presented in Figure 2, Figure 3 and Figure 4. The weighted overall rms acceleration is indicated by the symbols on the right hand side.

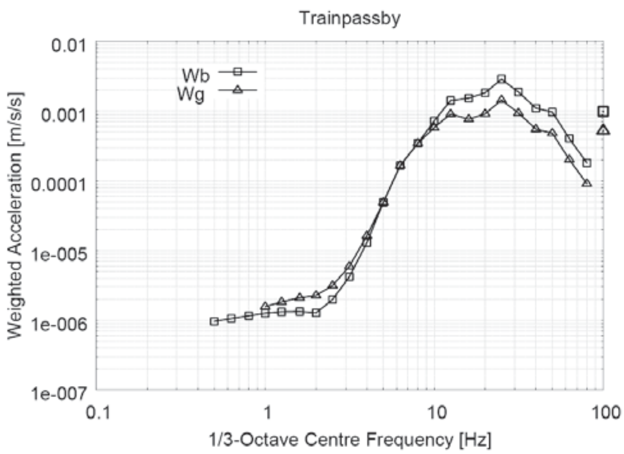

Figure 2 – Train pass-by on ballasted track.

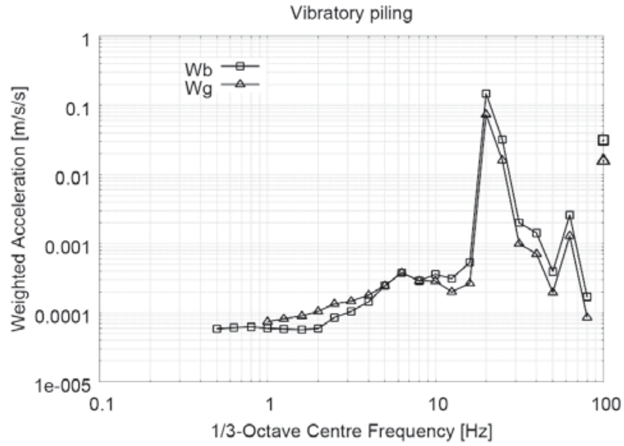

Figure 3 – Vibratory piling (ICE 416L vibratory hammer).

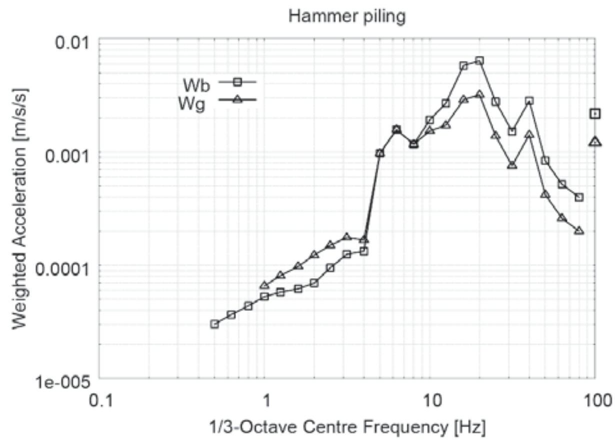

Figure 4 – Hammer piling (BSP 357 hydraulic hammer).

DISCUSSION

Due to the change in frequency weightings the impact of vibration assessed in accordance with the 1992 Standard will be different to assessments in accordance with the 2008 Standard. For most building vibrations the VDVs will increase. In many cases the VDVs may increase by up to a factor of 2.

As a consequence, required offset distances for construction works will increase with the 2008 version of the Standard. We expect that generally accepted minimum offset distances, such as those presented in the Transport Infrastructure Development Corporation's (TIDC) publication entitled "Construction Noise Strategy (Rail Projects)" (CNS) would increase by a factor of approximately 1.2-1.6. Minimum offset distances for human response given in the TIDC's CNS are shown in brackets in the right hand column of Table 3 underneath the safe working distances for human response based on BS6472:2008. These distances are based on continuous vibration, are indicative and will vary depending on the particular item of plant and local geotechnical conditions.

Table 3 TIDC Recommended Safe Working Distances for Human Response.

Plant/Item	Rating/Description	Safe Working Distances 2008 / (1992)
Vibratory Roller	< 50 kN (Typically 1-2 Tonnes)	20m to 25m (15m to 20m)
	< 100 kN (Typically 2-4 Tonnes)	25m (20m)
	< 200 kN (Typically 4-6 Tonnes)	50m (40m)
	< 300 kN (Typically 7-13 Tonnes)	130m - 150m (100m)
	> 300 kN (Typically 13-18 Tonnes)	130m - 150m (100m)
	> 300 kN (> 18 Tonnes)	130m - 150m (100m)
Small Hydraulic Hammer	(300 kg – 5 to 12t excavator)	10m (7m)
Medium Hydraulic Hammer	(900 kg – 12 to 18t excavator)	30m (23m)
Large Hydraulic Hammer	(1600 kg – 18 to 34t excavator)	90m (73m)
Vibratory Pile Driver	Sheet piles	30m (20m)

Similarly, the exposure duration (or the number of vibration events) will be decreased. For instance, one W_b-weighted train pass-by (2008 Standard) induces the same vibration dose as 16 of the same pass-bys using the W_g-weighting (1992 Standard)[2].

CONCLUSION

In comparison to BS 6472:1992, the 2008 version of the Standard represents a simplification of the assessment methodology since a unified VDV procedure is used to assess the impact of vibration in relation to human comfort.

The shift away from the W_g to the W_b vertical frequency weighting function is based on the latest knowledge and experience and is believed to better correlate with human comfort response to vibration, rather than activity disturbance. The change in weightings results in appreciably higher VDVs than those predicted with the old Standard for common sources of vibration.

If the DECCW was to incorporate the 2008 revisions into their Assessing Vibration guideline, this would result in the prediction of higher VDV levels for most building vibration events assessed for human comfort. Greater safe working distances than those currently recommended in TIDC's Construction Noise Strategy would also follow.

REFERENCES

[1] BS 6472:1992, "Evaluation of human exposure to vibration in buildings (1-80 Hz)", 1992.

[2] BS 6472-1:2008 "Guide to evaluation of human exposure to vibration in buildings – Part 1: Vibration sources other than blasting", 2008.

[3] BS 6841:1987 "Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock", 1987.

[4] M. J. Griffin "Evaluation of Vibration with Respect to human Response", SAE paper no. 860047, 1986.

[5] Association of Noise Consultants "Measurement & Assessment of Groundborne Noise & Vibration", ANC guidelines, 2001.

[6] Department of Environment and Climate Change "Assessing Vibration: A Technical Guideline", 2006.

[7] Transport Infrastructure Development Corporation "Construction Noise Strategy (Rail Projects)", 2007.

[2]Based on a 2-fold increase in VDV.

Letter to the Editor

What is Offensive Noise? A Case Study in NSW

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I refer to my paper "What is Offensive Noise? A Case Study in NSW" published in Acoustics Australia Vol. 38 No. 1, April 2010, and wish to clarify a statement made on page 32 that *"Private schools (unlike public schools) are subject to the POEO Act"*. This should have read *"Private schools (unlike public schools) are subject to Noise Abatement Orders"*. Public schools are subject to other provisions of the POEO Act, notably a Noise Control Notice issued by the regulatory authority (DECCW in the case of public schools) and a Noise Abatement Direction (given by an authorised officer appointed by DECCW).