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A Review of the Adoption of International Vibration Standards in New Zealand

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ABSTRACT

The New Zealand Standards authority has no current vibration standards relating to human exposure since withdrawing its adoption of the ISO 2631 series in 2005. Notwithstanding this, ISO 2631-2:1989 continues to be implemented by local government and other requiring authorities. This paper conducts a review of the major environmental vibration standards (i.e. human exposure and building damage) currently in use around the world, with a view to recommending a fresh suite of standards for adoption in New Zealand. The rating systems of a selection of human response standards are compared and used in a practical study of truck vibration.

INTRODUCTION

Environmental vibration assessments generally consider two factors: building damage risk and human response. These two facets are linked as peoples' sensitivity to vibration in buildings can be exacerbated by concern over damage to their building. The most prevalent sources of environmental vibration are associated with construction activities, blasting (for construction or quarrying purposes) and transportation (i.e. road and rail traffic).

This paper has been prompted by the fact that New Zealand has no current environmental vibration standards, and so local government and requiring authorities have been relying on the adoption of international standards.

A number of relevant international vibration standards are reviewed. The criteria and methodologies in these standards have been assessed in order to determine a current and practicable suite of standards recommended for adoption in New Zealand.

In addition, a comparison of human response standards is used in a practical comparison case study of truck vibration, to assess the equivalency between standards.

STANDARDS RELATING TO HUMAN RESPONSE TO VIBRATION

Human response standards specify criteria in terms of comfort, quality of life and working efficiency for human receivers, using adverse comment as a test for limits of acceptability (a similar procedure as used for the determination of acceptable environmental noise limits (e.g. NZS 6802, 2008)).

During construction activities, the level of tolerance, particularly from residents and office tenants tends to relate to concern over possible building damage to their building structure. For this reason, building damage risk is usually the primary focus during construction assessments, but the human response element still needs to be managed.

Human response standards generally utilise a range of calculation methods, weightings and rating curves, therefore it is difficult to directly compare and contrast them based on the criteria alone. In the 'Equivalency Study' section below, a comparison of four Standards is undertaken whereby measured truck drive-by data is processed and rated by each standard, according to its criteria for residential sensitivity.

The standards in the following sections relate to measurement and evaluation of human response to vibration in buildings.

ISO 2631-2:1989

This International Standard ISO 2631-2:1989 "Evaluation of human exposure to whole-body vibration – Part 2: Continuous and shock-induced vibration in buildings (1 to 80 Hz)" was superceded in 2003 (refer next section) and the assessment criteria were removed from the 2003 version due to international criticism.

However, the 1989 version is still referenced (due to its assessment criteria) by a number of legislative and requiring authorities, including:

- Auckland City District Plan: Isthmus Section under sections 8.8.1.6, 8.8.3.9 and 8.8.10.9 Vibration in Buildings (Business Zones)
- Auckland City District Plan: Central Area Section under section 7.6.5.1 Vibration in buildings affecting comfort or amenity.
- Waitakere City District Plan under Living Environment Rules section 14.1, and Working Environment Rules section 10.1

- The New Zealand Transport Authority's Environmental Plan

The criteria contained in the Standard are multiplying factors of a frequency weighted base curve (expressed as both acceleration and velocity) which are designed to represent magnitudes of approximately equal human response with respect to human annoyance and/or complaints about interference with activities. The Standard states that compliance with vibration levels "at these values no adverse comments, sensations or complaints have been reported."

Annex A of the Standard contains a table of multiplying factors which are applied to the base curve to produce "satisfactory magnitudes of building vibration with respect to human response" in different building types, as follows:

Table 1. Ranges of multiplying factors applied to base curves for human response criteria in ISO 2631-2:1989

Place	Time	Continuous or intermittent vibration	Transient vibration with several occurances per day
Critical working areas	Day Night	1	1
Residential	Day Night	2 to 4 1.4	30 to 90 1.4 to 20
Office	Day Night	4	60 to 128
Workshop	Day Night	8	90 to 128

Source: (International Organisation for Standardisation, 1989)

Transient vibration is defined as "a rapid build-up to a peak, followed by a damped decay… it can also consist of several cycles of approximately the same amplitude, providing that the duration is short (i.e. less than 2 seconds)." The continuous and intermittent criteria cover other typical vibration sources including traffic and rail, which the Standard classifies as intermittent.

ISO 2631-2:2003

In April 2003, the 1989 version of ISO 2631-2 was superseded and the revised version was significantly different. It removed the guidance values (Table 1 above) citing international criticism and that the range of values measured in human response tests were too widespread for an International Standard.

Furthermore the New Zealand Standards authority withdrew its vibration standard NZS/ISO 2631 series (which was identical to ISO 2631:1989) in April 2005.

Arguably, this eliminates ISO 2631-2:1989 as a current and valid standard for determining the effects of vibration on building occupants, therefore despite its continued use and reference by local government and requiring authorities in New Zealand, it is considered inappropriate as a standalone reference document.

Note that the methodology in ISO 2631-2:2003 for measurement of building vibration is still valid, but conducting a vibration measurement according to this Standard is questionable if the subsequent assessment must then refer to a different standard for criteria.

AS 2670-2:1990

This Australian Standard is identical to ISO 2631-2:1989, and despite the ISO Standard having been superseded, it still holds a current status, as of June 2010. This may be an oversight by Standards Australia, or it could be an intentional endorsement of the old Standard over the new.

This Standard could potentially be adopted in New Zealand in order to, in essence, retain the ISO 2631-2:1989 criteria. However, this would ignore the deliberate action of the ISO retracting the Standard, and is not recommended.

ANSI S2.71-1983 (R 2006)

The American Standard ANSI S2.71-1983 (R 2006) "Guide to the Evaluation of Human Exposure to Vibration in Buildings" is similar to ISO 2631-2:1989 also. The weighting base-curves match (with very few exceptions) the ISO curves, and the recommended criteria are very similar if slightly more stringent.

Unlike ISO 2631-2:1989, this Standard includes tentative modification factors for frequency of occurrence and event duration, which are used to adjust the criterion curves. However, the application of these factors is not clear. For the frequency of occurrence factor, for instance, there is no indication as to whether it applies to continuous or intermittent vibration and applying them to a vibration source with a large number of discrete events (e.g. traffic) may result in unachievably strict criteria.

The Standard was developed in 1983, but was revised in 2006; the introduction in the revision indicates that it merely contains "provisional recommendations on satisfactory magnitudes" which are a "compromise between the available data and the need for recommendations which are simple and suitable for general application." It would seem therefore to be aligning with ISO 2631-2:2003 in retreating somewhat from the earlier version without, in this case, actually superseding it.

DIN 4150-2:1999

The German Standard DIN 4150-2:1999 "Structural Vibration – Part 2: Human exposure to vibration in buildings" is from the same suite of Standards as DIN 4150-3:1999 which assesses building damage (refer section on DIN 4150-3:1999 below).

The Standard uses unique descriptors for vibration velocity data, which is band limited to 1-80Hz, weighted and normalised according to the specifications in another German Standard (DIN 45669-1, 1995) to produce values in terms of $KB(t)$. This parameter is time-averaged to produce $KB_{\tau}(t)$ values which are then further averaged in 30 second blocks to produce the KB_{FTm} rating value. The maximum KB_{Fmax} signal is also used as a rating value.

The guideline values for human exposure in dwellings (A_u, A_o and A_r) are obtained through the use of a flow-diagram which contains tests for the calculated KB_{FTm} and KB_{Fmax} values. These guideline values are further modified according to whether they are short-term, generated by road traffic, rail traffic or construction work.

In general, the Standard appears to be comprehensive but very complicated, and unfamiliar in the context of New Zealand experience with vibration standards. The calculation of the KB_{FTm} from measured vibration waveform data requires statistical programming as it cannot be calculated using 'standard' tools such as Microsoft Excel.

It is understood that there are special software packages available to undertake the calculations, but these are not available in New Zealand. It is therefore considered that this

Standard is too complex to be easily adopted in New Zealand.

NS 8176E:2005

The Norwegian Standard NS 8176.E:2005 "Vibration and shock – Measurement of vibration in buildings from land-based transport and guidance to evaluation of its effects on human beings" specifically addresses vibration effects from rail and road traffic. It purports to have been developed to fill a requirement for a transport-specific vibration standard, stating in its introduction that the recommended limits in ISO 2631-2 – presumably the 1989 version – "are not adequate for vibration from transport".

It is referenced in the NZTA Environmental Plan and has been successfully adopted in a number of large Auckland roading projects.

The Standard outlines the requirements for measuring equipment, and outlines a measurement procedure which requires a minimum of 15 heavy vehicle 'passings' (i.e. train, tram or heavy road vehicles (gross weight greater than 3500 kg)). The maximum velocity values v_i of each of these passings is recorded with a slow time-weighting in 1/3 octaves between 0.5Hz and 160 Hz. There is provision for acceleration values also, however the application is identical so for the purposes of this description, velocity will be used.

The values for each pass are weighted according to the W_m weighting curve (ISO 2631-2, 2003), and the mean and standard deviation of the 15 passings is calculated. The mean and standard deviation are then combined (assuming a log-normal distribution) to provide a statistical maximum value $v_{w,95}$. Specification of the statistical maximum value implies that there is about 5% probability for a randomly selected passing vehicle to give a higher vibration value. Note that this is of a similar nature to the percentile levels adopted in NZ for noise but would be expressed as an L_5 i.e. the percentile is inverted.

Appendix A of the Standard contains exposure-effect curves for annoyance and disturbance which look at the relationship between measured $v_{w,95}$ levels and percentage of people affected. This is a very useful resource which can assist in predicting and quantifying vibration effects. It is similar to Shultz curves (Shultz, 1978) for noise but may not have been as thoroughly tested to determine the veracity of the curves.

Appendix B of the Standard gives guidance classification of dwellings in relation to their sensitivity to vibration. The four classes of dwelling and corresponding statistical maximum values are as follows:

*"**B.3 Guidance vibration classes***

The statistical maximum value for weighted velocity (or acceleration) shall not exceed the limits specified in Table B.1 [refer Table 2 below]

B.3.1 Class A: Corresponds to very good vibration conditions, where people will only perceive vibration as an exception.
NOTE Persons in Class A dwellings will normally not be expected to notice vibration

B.3.2 Class B: Corresponds to relatively good vibration conditions.
NOTE Persons in Class B dwellings can be expected to be disturbed by vibration to some extent

B.3.3 Class C: Corresponds to the recommended limit value for vibration in new residential buildings and in connection with the planning and building of new transport infrastructures.
NOTE About 15% of the affected persons in Class C dwellings can be expected to be disturbed by vibration.

B.3.4 Class D: Corresponds to vibration conditions that ought to be achieved in existing residential buildings.
NOTE About 25% of persons can be expected to be disturbed by vibration in class D dwellings. An attempt should be made to meet class C requirements, but Class D can be used when the cost-benefit considerations make it unreasonable to require class C.

Table 2. Guidance classification of dwellings with the upper limits for the statistical maximum value for weighted velocity $v_{w,95}$ or acceleration $a_{w,95}$ after NS 8176.E:2005

Type of vibration value	Class A	Class B	Class C	Class D
Statistical maximum value for weighted velocity $v_{w,95}$ (mm/s)	0.1	0.15	0.3	0.6
Statistical maximum value for weighted acceleration $a_{w,95}$ (mm/s^2)	3.6	5.4	11	21

Source: (Norsk Standard, 2005)

Class C relates to about 15% of receivers being disturbed by vibration, and Class D relates to about 25%. These recommendations are based on the large scale exposure-effect studies in Appendix A of the Standard. The studies were conducted in fourteen areas of Norway, with residents' reactions to vibration from road traffic, railways, underground and trams.

Scandinavian countries are generally recognised for maintaining a high living-standard, so it is considered that the survey outcomes may be relatively conservative in terms of residents' responses to environmental vibration effects.

BS 6472-1:2008

The British Standard BS 6472-1:2008 "Guide to evaluation of human exposure to vibration in buildings – Part 1: Vibration sources other than blasting" is not widely adopted in New Zealand, but has advantages in the assessment of operational vibration effects due to its dose-response metric Vibration Dose Value (VDV).

VDV is calculated from the frequency-weighted vibration acceleration (weighted according to the W_b or W_d curves for vertical and horizontal acceleration respectively), which is integrated over the day or night time period. Table 1 of the Standard (refer Table 3 below) contains VDV ranges which may result in adverse comment in residential buildings, as follows:

Table 3. Vibration dose value ranges which might result in various probabilities of adverse comment within residential buildings, after BS 6472-1:2008

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 16 h day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8 h night	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

Source: (British Standards, 2008)

There is however some controversy surrounding the use and usability of VDV. For continuous vibration (such as motorway traffic), the "estimated VDV" metric eVDV is recommended in place of VDV. The correlation between VDV and eVDV for the same data set is variable, and relies heavily on the event period used in the calculation.

The Institute of Acoustics (UK) has undertaken comparison studies of the two parameters (Greer et.al., 2005), and concludes that eVDV is generally a reliable estimate of VDV provided the crest factors for transient signals are calculated correctly, and that the constant 1.4 in the eVDV equation is not necessarily correct and should be derived for a given signal (e.g. a value of 1.11 should be used for a sinusoidal signal).

This Standard is not known to have been adopted in New Zealand.

BS 6472-2:2008

The British Standard BS 6472-2:2008 "Guide to evaluation of human exposure to vibration in buildings – Part 2: Blast-induced vibration" contains PPV criteria for human response to blasting, as well as prediction methods utilising scaled distance. It is not widely adopted in New Zealand.

The recommended criteria are as follows:

Table 4. Maximum satisfactory magnitudes of vibration with respect to human response for up to three blast vibration events per day

Place	Time	Satisfactory magnitude PPV mm/s
Residential	Day	6.0 to 10.0
	Night	2.0
	Other times	4.5
Offices	Anytime	14.0
Workshops	Anytime	14.0

Source: (British Standards, 2008)

When compared with ISO 2631-2:1989 and NS 8176.E:2005, the recommended criteria in both BS 6472 Parts 1 and 2 are very lenient. For instance, it can be seen that a vibration level of 10 mm/s PPV (which is double the DIN 4150-3:1999 standard for residential building damage risk between 1-10Hz) is considered satisfactory in terms of human response. This is possibly due to the limitation of no more than 3 blasting events per day, however the allowable magnitude of each event is considered to be the primary consideration for blasting because of the potential for startle effect and disturbance with each blast.

Similarly, the British Standards criteria for building damage (BS 7385-1, 1990 and BS 7385-2:1993) are significantly less stringent than those in the commonly adopted DIN 4150-3:1999, so it appears that British Standards for environmental vibration in general are comparatively lenient.

This Standard is not known to have been adopted in New Zealand, but is referenced by Australian Standard AS 2187.2:2006 "Explosives – Storage and use, Part 2: Use of explosives".

It is possible that the lenient approach taken by the British Standards is defendable through underlying research, and the other standards commonly applied in NZ are overly stringent. However, immediate adoption of such lenient criteria into a large project, for instance, may be at odds with society's expected control of vibration effects, and the marked relaxation in vibration controls would be difficult to justify.

It is recommended that further research and investigative use of the British Standards are undertaken to gain experience in the methodologies therein. This will allow an informed assessment of their benefits (or otherwise) over the proposed suite of standards.

BS 5228-2:2009

The British Standard BS 5228-2:2009 "Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration" is a comprehensive and voluminous standard covering many aspects of prediction, measurement, assessment and control of vibration from construction works.

In terms of vibration criteria this standard contains references to, and reiterates the criteria from BS 6472 (human response) and BS 7385 (building damage).

However Annex B of the Standard addresses human response to construction vibration and suggests that BS 6472 may not be appropriate. It states:

> *"BS 6472, as stated, provides guidance on human response to vibration in buildings. Whilst the assessment of the response to vibration in BS 6472 is based on the VDV and weighted acceleration, for construction it is considered more appropriate to provide guidance in terms of the PPV, since this parameter is likely to be more routinely measured based on the more usual concern over potential building damage. Furthermore, since many of the empirical vibration predictors yield a result in terms of PPV, it is necessary to understand what the consequences might be of any predicted levels in terms of human perception and disturbance. Some guidance is given in Table B.1* [refer Table 5 below]

Table 5. Guidance on the effects of vibration levels

Vibration level (PPV)	Effect
0.14 mm/s	Vibration might just be perceptible in the most sensitive situations for most vibration frequencies associated with construction. At lower frequencies, people are less sensitive to vibration
0.3 mm/s	Vibration might just be perceptible in residential environments
1.0 mm/s	It is likely that vibration of this level in residential environments will cause complaint, but can be tolerated if prior warning and explanation has been given to residents
10 mm/s	Vibration is likely to be intolerable for any more than a very brief exposure to this level

Source: (British Standards, 2009)

The use of PPV is a pragmatic approach to construction vibration assessment and the criteria in Table B.1 are considered suitable for assessment of human response to construction vibration effects. Furthermore, the criteria have a reasonable correlation with DIN 4150-3:1999 in terms of the level of concern expected with regard to building damage.

It is noted that the primary issue relating to construction vibration is damage to buildings and although people may become concerned at levels above 1 mm/s PPV, in the context of a project this effect can be managed through communication with concerned residents and other mitigation strategies outlined in they project's construction management plan.

DISCUSSION – HUMAN RESPONSE STANDARDS

To summarise the vibration standards for human response, the ISO 2631-2:1989 Standard which is traditionally applied in New Zealand is no longer considered suitable, as it was replaced in 2003 by an informative only standard. The NZ adoption of this Standard (NZS/ISO 2631-2:1989) was therefore withdrawn by Standards New Zealand.

A comprehensive review has been undertaken of relevant international standards from the UK, Europe, United States and Australia. The US and Australian Standards are aligned with the ISO 2631-2:1989 and may therefore be deemed inappropriate by association.

The Norwegian Standard NS 8176.E:2005 is an attractive alternative for use in traffic and rail assessments, as it contains a statistical approach to vibration events and community response relationships, has a history of successful implementation in major roading projects, and is referenced by the NZTA Environmental Plan. Furthermore, no known adverse effects have been reported for vibration on projects for which this Standard was applied.

However because it addresses only transportation vibration, another standard is needed to assess the effects of other vibration sources. Blasting and Construction are considered to be the other relevant vibration-inducing activities relating to environmental works, and it is considered that the human response criteria for both these operations are addressed by the British Standard BS 5228-2:2009, Appendix B.

The British Standard BS 6472-1:2008 contains an attractive methodology involving the use of Vibration Dose Value (VDV), which considers the period of exposure to vibration as well as the vibration level. However, the criteria in this Standard are considered to be too lenient and further investigation would be required to rationalise this before it could be considered for adoption in New Zealand.

EQUIVALENCY STUDY

To compare and contrast the human response standards, a dataset of truck drive-by measurements were assessed against the standards contained in the above section – NS 8176.E:2005, BS 6472-1:2008, ANSI S2.71-1983 (R 2006) and ISO 2631-2:1989. The Australian Standard AS 2670-2:1990 is assessed by proxy because it is identical to the ISO standard. The German Standard DIN 4150-2:1999 is considered too complicated to be easily adopted for use in New Zealand.

The purpose of the comparison is to investigate how each standard rates the same vibration dataset, and shows the equivalency of their criteria with respect to one another.

To ensure a clear vibration signal, the measurement location was selected adjacent to a road with high heavy vehicle numbers and a dilapidated surface – the entrance to a quarry in South Auckland.

The measurements were undertaken on 13th January 2010 using an Instantel Minimate Plus vibration meter with tri-axial geophone. The meter was positioned 25 metres from the closest lane of the two lane road (one lane in each direction). The geophone was fixed to the ground with ground-spikes and weighted with a sandbag.

The general geology of the site was provided by Beca Limited. The ground comprised medium-dense gravel, clayey silt and stiff to very stiff silty clay.

Fifteen truck passes were measured in accordance with the NS 8176.E:2005 Standard, as well as an ambient measurement i.e. with no traffic on the road. The vibration levels of the truck passes were considerably higher than the ambient measurement.

Table 6. Comparison of the assessment outcomes of four human response standards

	NS 8176.E :2005		BS 6472-1 :2008	ISO 2631-2 :1989	ANSI S2.71-1983 (R 2006)
	$v_{w,95}$ mm/s	Class	VDV ($ms^{-1.75}$)	Multiplying factor	Multiplying factor
Vibration Level	0.18	C	0.016	4	4
Assessment	Complies with criterion for existing dwellings. Approx. 12% may be moderately/highly annoyed		Readily complies with residential night-time criterion. Low probability of adverse comment	Complies with residential daytime criterion, but exceeds night-time criterion	

This comparison confirms that the British Standard BS 6472-1:2008 is significantly more lenient than the other three standards i.e. it considers that the measured data readily complies with the night-time residential criterion, whereas the other three standards indicate some annoyance and/or exceedance of their night-time residential criteria.

The subjective impression during the measurements was that vibration from the truck passes were detectable, but would not be considered excessive in any way.

It is noted that the ISO and ANSI standards do not contain an averaging method for multiple vibration events, so the rating is based on the worst truck pass. However, all but two of the 15 truck passes would comply with the daytime criterion but not the night-time, so the assessment in Table 6 above for these standards generally represents the entire dataset.

STANDARDS RELATING TO BUILDING DAMAGE RISK

The following standards relate to measurement and evaluation of the effects of ground-borne vibration on building structures.

DIN 4150-3:1999

The use of German Standard DIN 4150-3 "Structural vibration – Part 3: Effects of vibration on structures" is widespread in New Zealand and it has a history of successful implementation in projects involving construction activities and/or blasting. Two versions of the standard – the current 1991 version, and the earlier 1986 version – are referenced in several local government and other requiring authorities, as follows:

The earlier 1986 version of the standard is referenced in:

- Auckland City District Plan: Isthmus Section under section 8.8.2.7 Noise and Vibration arising from Blasting
- Auckland City District Plan: Central Area Section under section 7.6.5.2 Noise and vibration from explosive blasting of pile driving.

- Waitakere City District Plan under section 13.1(c) regarding blasting in quarry areas
- The NZTA Environmental Plan (see Section 3.4.1 below)

The 1999 version is referenced in:

- Auckland City District Plan: Hauraki Gulf Islands Section (Proposed 2006) under section 4.6.3 Noise and vibration from blasting or pile driving for construction activities.

The Standard adopts the Peak Particle Velocity (PPV) metric and gives guideline values which, "when complied with, will not result in damage that will have an adverse effect on the structure's serviceability."

The guideline values are different depending on the vibration source, and are separated on the basis of short-term and long-term vibration. The standard defines short-term vibration as "vibration which does not occur often enough to cause structural fatigue and which does not produce resonance in the structure being evaluated". Long-term vibration is defined as all other types of vibration not covered by the definition of short-term vibration.

In general, the short-term vibration definition would be applied to activities which follow the form of a single shock followed by a period of rest such as blasting, drop hammer pile-driving (i.e. non-vibratory), dynamic consolidation etc. All other construction activities would be considered long-term. Traffic may be categorised as either, depending on the nature of the vibration i.e. vibration from consistent (but rough) road surface may be long-term, whereas a road with a bump in the pavement may generate a short-term vibration event.

The criteria for short-term and long-term vibration activities, as received by different building types, are summarised in Table 7 below. This table is a combination of Tables 1 and 3 of the Standard:

Table 7. Summary of Building Damage criteria in DIN 4150-3:1999

Type of Structure	Short-term vibration				Long-term vibration
	PPV at the foundation at a frequency of			PPV at horizontal plane of highest floor	PPV at horizontal plane of highest floor
	1 - 10Hz	10 - 50Hz	50 - 100Hz	At any frequency	At any frequency
Commercial, Industrial	20	20-40	40-50	40	10
Residential, School	5	5-15	15-20	15	5
Historic, Sensitive	3	3-8	8-10	8	2.5

Source: (Deutsch Institut für Normung, 1999)

The standard also contains criteria for buried pipework of different materials and the effects of vibration on floor serviceability, as well as guidelines for measurement of vibration in buildings i.e. placement and orientation of the transducers.

It should be noted that these criteria are designed to avoid superficial damage to buildings i.e. cracking in plaster. Significantly greater limits would be applied for damage to structural foundations.

To address this range in the effects on buildings, it is considered appropriate to adopt a statistical analysis methodology for assessing damage risk due to vibration. There is precedence for this approach in Section 8.8.2.7e of the Auckland City District Plan – Isthmus Section for blasting, and Section A10.3.1 of the Whangarei District Plan, although actual criteria of each differ slightly.

The following Table 8 proposes a statistical analysis methodology for short-term and long-term vibration, based on the limits contained in DIN 4150-3:1999.

Table 8. Long-term vibration criteria after DIN 4150-3:1999

Vibration Duration (as defined in DIN 4150-3:1999)	Statistical Analysis Methodology
Short-term (e.g. blasting, drop-hammer piling, dynamic consolidation	Activities shall be conducted so that 95 % of the 20 most recent events, measured on the foundation of any building, shall produce peak particle velocities (PPVs) not exceeding the limits specified in Table 1 of DIN 4150-3:1999 and 100 % of the measured events shall not exceed PPV 10, 20 and 50 mm/s for sensitive/historic, residential and commercial structures respectively, irrespective of frequency content.
Long-term (e.g. most other vibration sources)	Activities shall be conducted so that 95 % of a measured activity on the foundation of any residential building shall produce PPVs not exceeding the limits specified in Table 3 of DIN 4150-3:1999 and 100 % of the measured events shall not exceed twice the limits specified in the same table. For the measurement of long-term activities, PPVs shall be recorded at one second intervals. The total assessment period shall be sufficient to ensure a representative sample of the activity is recorded.

BS 7385-1:1990 – ISO 4866:1990(E)

The British Standard BS 7385-1:1990 "Evaluation and measurement for vibration in buildings – Part 1. Guide for measurement of vibration and evaluation of their effects on buildings" is identical to ISO 4866:1990(E) "Mechanical vibration and shock – Vibration of buildings – Guidelines for the measurement of vibration and evaluation of their effects on buildings", therefore it adopts the ISO standard and reproduces it in full (hence the two standards in the title).

ISO 4866:1990(E) establishes the basic principles for carrying out vibration measurements and processing data. In conjunction with BS 7385-2:1993, its scope is similar to that of DIN 4150-3:1999, but it addresses several aspects in greater detail than the German Standard.

The Standard contains a formula (rather than guidelines) for establishing whether the source is continuous (long-term) or transient (short-term), addresses the influence of soil attenuation, the structural response of different building types for various sources, measurement and reporting procedures, and a comprehensive building classification.

Another useful section contains a description of building damage categories, as follows:

"<u>Cosmetic</u>
The formation of hairline cracks on drywall surfaces, or the growth of existing cracks in plaster or drywall surfaces; in addition, the formation of hairline cracks in mortar joints of brick/concrete block construction

<u>Minor</u>
The formation of large cracks or loosening and falling of plaster or drywall surfaces, or cracks through bricks/concrete blocks

<u>Major</u>
Damage to structural elements of the building, cracks in support columns, loosening of joints, splaying of masonry cracks etc."

This Standard is not known to be adopted in New Zealand.

BS 7385-2:1993

The second part of the BS 7385 series – BS 7385-2:1993 "Evaluation and measurement for vibration in buildings – Part 2. Guide to damage levels from groundborne vibration" sets vibration limits based on an extensive review of international case histories. The introduction states that despite the large number of UK case studies involved in the review, "very few cases of vibration-induced damage were found".

The criteria, also in PPV, are contained in Table 1 of the Standard, refer Table 9 below:

Table 9. Transient vibration guide values for cosmetic damage in BS 7385-2:1993

Line	Type of building	Peak component particle velocity in frequency range of predominant pulse	
		4 – 15Hz	15Hz and above
1	Reinforced or framed structures, Industrial and heavy commercial buildings	50mm/s at 4Hz and above	
2	Unreinforced or light framed structures, Residential or light commercial type buildings	15mm/s at 4Hz increasing to 20mm/s at 5Hz	20mm/s at 15Hz increasing to 50mm/s at 40Hz and above

Source: (British Standards, 1993)

These criteria relate predominantly to transient vibration, and the standard suggests that the criteria "may need to be reduced by up to 50%", especially at low frequencies. Notwithstanding this, the criteria are 3 to 10 times higher (i.e. less stringent) than those in DIN 4150-3:1999.

Note that there is no consideration for historic or sensitive structures in the above table. This is addressed in Section 7.5.2 of the Standard which states:

"7.5.2 Important buildings

Important buildings which are difficult to repair may require special consideration on a case-by-case basis. A building of historical value should not (unless it is structurally unsound) be assumed to be more sensitive."

Note that 'peak component particle velocity' refers to the maximum PPV of the three orthogonal axes (longitudinal, transverse or vertical), also known as peak vector sum (PVS).

This approach to historic structures is quite different to that of the DIN 4150-3:1999 Standard which is less definitive with its definition of such buildings and more stringent in its criteria.

DISCUSSION – BUILDING DAMAGE STANDARDS

To summarise the building damage Standards, the British building damage Standards (BS 7385-1:1990 and BS 7385-2:1993) are more comprehensive and detailed in their scope than DIN 4150-3:1999, and can be considered 'current' (having received endorsement from the recent BS 5228-2:2009 standard.

However, they are significantly less stringent than the German Standard DIN 4150-3:1999 and there is concern that their criteria may be too high, and may allow damage to building structures.

The German Standard has a record of successful implementation in a number of major Auckland projects. Its criteria are more conservative than BS 7385-2:1993, but has not been found to be overly restrictive. It therefore affords adequate protection for building structures, and addresses the concerns of building occupants by setting a reasonable limit.

The adoption of a statistical approach to the implementation of DIN 4150-3:1999 is considered pragmatic, and promotes comprehensive monitoring and assessment of vibration activities such as construction works.

Australia does not have a National Standard for vibration building damage however it is understood that DIN 4150-3:1999 is widely adopted. Similarly, there is no American National Standard addressing building damage from vibration.

The DIN 4150-3:1999 standard is therefore considered most suitable to assess and quantify the risk of building damage from vibration.

SUMMARY OF STANDARDS

A number of international environmental vibration standards have been reviewed with a view to informing the adoption of a relevant suite of standards to address environmental vibration effects relating to building damage and human response.

Due consideration has been given to those standards which have a successful history of implementation in New Zealand, and are recognised by authorities such as Auckland City Council, Auckland Regional Council, Waitakere City Council and NZ Transport Agency.

In lieu of the superceded ISO 2631-2:1989 Standard, traditionally adopted in New Zealand for assessing human response, the following Standards are recommended:

- Norwegian Standard NS 8176.E:2005 for human response to traffic and rail vibration.
- British Standard BS 5228:2009 for human response to construction vibration

NS 8176.E:2005 has been successfully implemented in a number of major Auckland projects, and aligns well with the rating criteria of ISO 2631-2:1989. Furthermore the straightforward calculation procedure and data relating to population annoyance are beneficial. It is more stringent than BS 6472-1:2008 but has shown to be practicable in New Zealand applications.

BS 5228-2:2009 gives guidance values for human response in terms of Peak Particle Velocity (PPV) which is directly applicable to construction and blasting operations.

For the assessment of building damage risk, the following Standard is recommended:

- German Standard DIN 4150-3:1999 for building damage risk relating to all vibration sources

DIN 4150-3:1999 is widely recognised and successfully implemented in New Zealand.

These recommendations provide a robust and, for the most part, familiar approach to assessment of environmental vibration.

It must be said that the suite of British Standards is an attractive option, as it is comprehensive and offers a complete range of vibration assessment tools with robust methodologies. However, in the context of New Zealand's implementation of vibration standards, its criteria are considered too lenient. This is not to say that the criteria are wrong, but an abrupt change from the current standards to less stringent criteria may cause alarm and consternation over the possible effects.

It is recommended that further investigations of the British Standards are undertaken in a New Zealand context, in an attempt to rationalise and qualify the differences between them and other relevant Standards, such as those assessed herein.

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