APPENDIX B: REVIEW OF VIBRATION STANDARDS

Human Response Standards

1. The principal physiological effect standard that has historically been successfully applied in New Zealand is NZS/ISO 2631-2:1989 "*Evaluation of human response exposure to whole body vibration – Part 2: Continuous and Shock Induced Vibrations in Buildings (1 to 80 H_z)*" ("**1989 Standard**"). The 1989 Standard provides factored curves for vibration limits for activities based on time of day and duration, as well as the level of potential impact on receivers. The 1989 Standard recommends a ppV limit of about 0.3 mm/s for continuous vibrations during the day, which is at perception levels, while a ppV limit of 5-10 mm/s is recommended for transient (short time frame) events. A considerably lower limit of 0.14 mm/s is recommended at night. These recommended limits are provided to ensure that receivers (people in buildings) are not subject to significant discomfort, while also enabling construction work to progress without incurring unnecessary additional delay and cost. It also assists in reducing effects by completing work faster. The limits are likely to be above perception levels for many receivers, particularly the higher limits recommended for daytime activities, but are less than 10% of the levels likely to cause fatigue or affect health. They should not result in unacceptable disturbance when people are kept well informed of timing and duration.

2. The 1989 Standard is included in the Auckland Council District Plans, although it was superseded in 2003 by an informative standard which contains no vibration limits. While the 1989 Standard was subsequently withdrawn by Standards NZ, it has continued to be referenced by Councils as it provides definitive guidelines which are easily applied and provide clear guidelines for a range of conditions. My review of the international standards is that, while there is general agreement on the levels of recommended vibrations which will result in adverse comment by receivers, most do not provide clear recommendations for construction limits. Nor do they consider whether the permitted levels of vibration may be increased if the work is undertaken in accordance with a well developed management plan that recognises some minor discomfort may be acceptable by receivers, provided close controls are implemented. While there is no direction on this matter in the Standard, it is my experience that this type of provision promotes good communication and notification and encourages implementation of mitigation measures to assure receivers they are not at risk. This Standard has been used for The Waterview Connection Project, and previously applied to the Vector tunnel and Project Hobson.

3. The British BS6472-2:2008 *Guide to Evaluation of Human Exposure to Vibration in Buildings, Blast Induced Vibration* ("**BS6472-2:2008**") includes similar vibration limits as the 1989 Standard, but its application is limited to blasting works only.

4. No works are proposed outside normal construction hours. However, if any such works were to occur then for ease of application, consistency with the existing District Plans, ability to apply to a range of activities, and ease for the public to readily understand the criteria, I recommend the application of the 1989 Standard for any works outside normal working hours for at least the construction phase of the Project. The DIN 4150-3:1999 (discussed below) provides adequate protection for humans during normal (daytime) working hours. However, at night-time or for continuous works, with high-frequency vibration components, the 1989 Standard provides better protection for humans. As stated above, this is not an issue where (as here) no works are proposed outside normal construction hours. Nor was it seen as an issue in Waterview, where I proposed a similar multi-standard approach but it was considered unnecessary and overly complicated. I am, however, simply raising it for completeness and to act in accordance with the Code of Conduct for Expert Witnesses.

Building Damage Standards

5. Standards addressing susceptibility of damage to buildings invariably reference work undertaken by Siskind et al (1980) as the basis for setting vibration limits. This applies probabilistic methods to damage threshold from blasting. Examples of damage thresholds are provided in Table 1.

Table 1: Vibration Damage Threshold (mm/s) after Siskind et al (1980)

Damage Type	**Probability %**			
	5	**10**	**50**	**100**
Threshold for cosmetic damage e.g. cracking of untaped plaster joints	13	18	64	228
Minor Damage: loosening of plaster and hairline cracks in plaster, and in masonry around openings	46	56	127	406
Onset of structural damage affecting load support elements	64	76	152	430

6. This table shows that there is a low probability of surficial or cosmetic damage to structures at ppV < 13 mm/s. Vibration standards that limit ppVs to less than the cosmetic damage thresholds (ppV < 13 mm/s) provide a large margin before any significant risk of structural damage. Similar thresholds can be applied to other construction activities. Some of these are included in **Appendix D** to my evidence.

7. Vibration standards apply factors to these thresholds to limit the potential for damage to acceptable levels. A commonly used Standard for structural damage in New Zealand is the German standard DIN 4150-3:1999 "*Structural Vibration – Part 3: Effects of Vibration on Structures*". The DIN 4150-3:1999 guidelines for vibration limits are summarised in Table 2 and shown in Figure 1 below. They include 3 categories of building with increasing levels

of protection for commercial, residential and sensitive structures. The lines in Figure 1 below reflect these 3 categories.

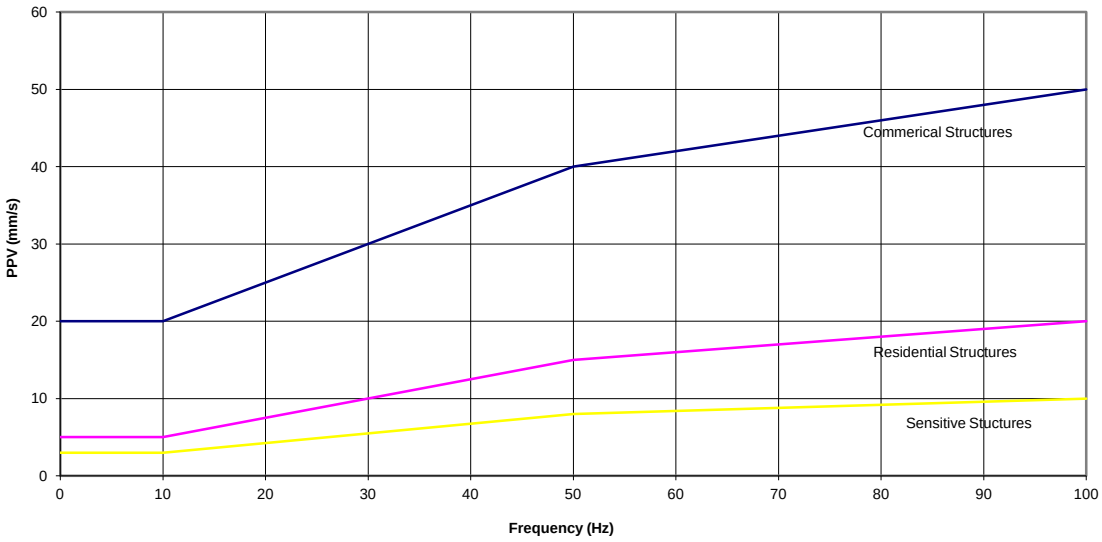
8. DIN 4150-3:1999 includes guidelines for residential buildings together with criteria for both commercial/ industrial buildings and high sensitivity structures. The guidelines provide for increased levels of vibration (ie higher ppV) as the wave frequency increases, recognising that structures will generally have an increased response close to their natural frequency (frequency at which resonance and amplification occurs) which will typically be in the low (1 to 10Hz) range. Conversely, the human body has increased sensitivity at increased frequency which tends to cap the level of vibration able to be tolerated for construction activities.

Table 2: Guideline values of vibration velocity, for evaluating the effects of short-term vibration, DIN4150-3:1999

Line	Type of Structure	Vibration peak particle Velocity (mm/s)			
		Foundation Frequency			Plane of Floor of Uppermost Storey
		Less than 10 Hz	10 to 50 Hz	50 to 100* Hz	Frequency Mixture
1	Buildings used for commercial purposes, industrial buildings and buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and/or use	5	5 to 15	15 to 20	15
3	Structures that, because of their sensitivity to vibration, do not correspond to those listed in lines 1 and 2 and are of great intrinsic value (eg buildings that are under a preservation order)	3	3 to 8	8 to 10	8

* For frequencies above 100Hz, at least the values specified in this column shall be applied

Figure 1 Baseline Curves Representing Short-Term Vibration Effects on Structures in Relation to Recorded Data



9. The significant margins shown in Table 2 and Figure 1 reflect the higher level of protection provided by this standard to residential structures (category 2), compared to commercial structures (category 1). A higher level of protection again is provided to sensitive structures (category 3). With the possible exception of the two research institutes at Haverstock Road, there are no known category 3 buildings along the alignments of the main tunnel and link sewers.

10. In addition, DIN 4150-3:1999 also includes a limit for continuous (steady state) vibration. DIN 4150-3:1999 recommends a constant limit of 5mm/s (as measured in the plane of the uppermost storey) be applied to all category 1 and 2 buildings.

11. The Construction Industry Research and Information Association of the United Kingdom ("**CIRIA**") has published guidelines providing a detailed assessment of the issues related to effects of vibrations in the urban environment, specifically acceptance levels and options for mitigation. The CIRIA (2011) guidelines recommend that extrapolation of the vibration monitoring data be undertaken to reduce the probability of damage (due to transient events) with a confidence limit greater than 95%.

12. This recommended statistical design approach is being increasingly used in the management of vibration effects for construction works. There are clear benefits in applying best practice methods to blasting and other activities which generate significant levels of vibrations that may impact on adjacent properties. It is my experience that where works are undertaken by experienced staff in accordance with a well developed methodology and management plan, and outcomes are monitored and results analysed to assess statistical

parameters (eg 95% and 99% confidence limits), then the detailed design and construction methodology can be best targeted relative to the limits. This rewards good practice by reducing cost, controlling risk and generally achieving a better outcome for both the Project and receivers.

Current Operative District Plans

13. There are two relevant Operative District Plans as the Project alignment spans both the former Manukau City and Auckland City and their District Plans include controls on vibration.

Manukau

14. The Auckland Council District Plan (Manukau Section) includes a rule for vibration, Rule 5.18.4.1, to ensure vibration from a business activity does not cause significant nuisance. This rule requires that "at or within the boundary of any adjacent site zoned for residential, Papakainga or Maori Purpose" no activity shall create vibration exceeding the following average levels.

Table 3: Auckland Council District Plan (Manukau Section) Vibration Performance Standards

Vibration Performance Standards (Residential)		
Time	Maximum Weighted Vibration Levels (W_b or W_d)	Maximum Instantaneous Weighted Vibration level (W_b or W_d)
Monday to Saturday 7.00 am to 6.00 pm	0.045 m/s^2	1.0 m/s^2
At all other times	0.015 m/s^2	0.05 m/s^2

15. The Auckland Council District Plan (Manukau Section) specifies that the weighted vibration levels W_b and W_d are to be measured according to BS6841:1987 and measurements are to be obtained:

(a) at any point where it is likely to affect the comfort or amenity of persons occupying an adjacent site; or

(b) where damage is the primary concern measurement is to be undertaken on the ground near the building.

16. The Auckland Council District Plan (Manukau Section) also references the NZS/ISO 2631-2 2003 Standard (which is the update to the 1989 Standard) but considers it is not suitable as it was a draft Standard at the time the Plan was prepared.

Auckland Isthmus

17. The Auckland Council District Plan (Auckland City Isthmus Section) addresses vibrations arising from blasting in Section 8.8.2.7. These are the Development Controls for Business 7, 7A and 7B Zones. There are no other references to blasting in the Auckland Council District Plan other than in this section. Clause 8.8.2.7(a) says "the Peak Particle Velocity should not exceed the limits set out in Table 1 of DIN 4150 Part 3:1986." (The limits in the 1986 DIN standard are the same as in DIN 4150-3:1999 referred to above when introducing building damage standards and included in Table 1 of my evidence). The District Plan qualifies the above requirement in Section 8.8.2.7(e) as follows:

> "Notwithstanding 8.8.2.7(b) above, blasting activities undertaken at Mt Wellington Quarry and Three Kings Quarry and any extensions of these quarries shall be conducted so that 95% of the blasts undertaken (measured over any 20 blasts on the foundation of any building in the Business 7 Zone) shall produce peak particle velocities not exceeding 5 mm/s and 100% of the blasts undertaken shall not exceed 10mm/s irrespective of the frequency of the blast measured." This recognises the utilisation of best practice methods by these quarries.

18. Section 8.8.3.9 of the Auckland Council District Plan (Auckland City Isthmus Section) also references the 1989 Standard (referred to above when introducing human response standards) for vibrations in buildings where it states in 8.8.3.9(a):

> Activities shall not generate vibrations which may cause discomfort or adversely affect the health and well being of the occupants of adjacent premises. Vibrations which do not exceed the limits, referred to below as set out in the provisions of the International Standard ISO 2631-2:1989 Evaluation of Human Exposure to whole body vibration – Part 2 Continuous and Shock Induced Vibrations in Buildings (1 to 80 H_z), will be deemed to meet this requirement.

Waterview Project

19. Also of potential relevance to the setting of Project Vibration Standards is the recent decision of the Board of Inquiry for the Western Ring Route (Waterview) Project. That project involves tunnelling and extra works involving blasting of rock in an Auckland urban environment similar to that proposed for this Project.

20. The Standard referenced for limiting construction vibrations was DIN 4150-3:1999. The Conditions of Consent required that a Construction Noise and Vibration Management plan (CNVMP) be prepared to describe the measures adopted to meet the Project Vibration Standards set out in the Conditions, or to otherwise mitigate the effects.

21. Of particular relevance was the Board's decision to permit the use of statistical methods to monitor blasting and other construction activities such as piling, excavation, compaction and drilling. An upper limit ppV of 10 mm/s was not to be exceeded for dwellings, irrespective of the frequency of the activity measured.

22. Also of note is the advice note to Condition CNV 13 which reads:

> It is accepted that the Criteria for CNVZ (Noise) and CNV.4 (Vibration) may not be met at all times, but that the NZTA will take all practical steps to achieve compliance, taking into account the hierarchy of mitigation options outlined in Condition CNV.1 (ix).