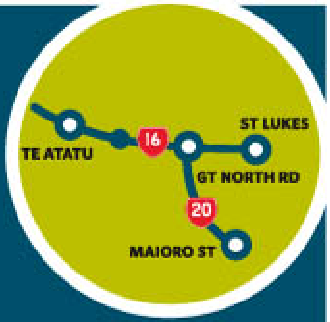
NZ TRANSPORT AGENCY
WAKA KOTAHI

Roads of national significance

16 20

Western Ring Route – Waterview Connection



Assessment of Vibration Effects

MARSHALL DAY Acoustics

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Quality Assurance Statement

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1.0 Introduction

1.1 The Western Ring Route

In 2009, the government identified 'roads of national significance' (RoNS)[1], and set priority for investment in these as New Zealand's most important transport routes. The RoNS are critical to ensuring that users have access to significant markets and areas of employment and economic growth.

The Western Ring Route (WRR) is identified as a RoNS. The WRR comprises the SH20, SH16 and SH18 motorway corridors and, once completed, will consist of 48km of motorway linking Manukau, Auckland, Waitakere and the North Shore.

The strategic importance of the WRR is to provide an alternative route through the region to reduce dependency on SH1, particularly through the Auckland Central Business District (CBD) and across the Auckland Harbour Bridge. The WRR will also provide for economic growth, unlocking potential for development along its

[1] A Glossary of Terms is attached in **Appendix A**

length by improving trip reliability and access from the west to the south of the region, and from the CBD to the southern Auckland isthmus and airport.

1.2 The Waterview Connection (The Project)

The Waterview Connection Project is the key project to complete the WRR, providing for works on both State Highway 16 (SH16) and State Highway 20 (SH20) to establish a high-quality motorway link that will deliver the WRR as a RoNS.

Completion of the Manukau and Mount Roskill Extension Projects on SH20 mean that this highway will extend from Manukau in the south to New Windsor in the north, terminating at an interchange with Maioro Street and Sandringham Road. Through the Waterview Connection Project (the Project), the NZTA proposes to designate land and obtain resource consents in order to construct, operate and maintain the motorway extension of SH20 from Maioro Street (New Windsor) to connect with SH16 at the Great North Road Interchange (Waterview).

In addition, the Project provides for work on SH16. This includes works to improve the resilience of the WRR; raising the causeway on SH16 between the Great North Road and Rosebank Interchanges, which will respond to historic subsidence of the causeway and "future proof" it against sea level rise. In addition, the Project provides for increased capacity on the SH16 corridor; with additional lanes provided on the State Highway between the St Lukes and Te Atatu Interchanges, and works to improve the functioning and capacity of the Te Atatu Interchange.

The Project will be the largest roading project ever undertaken in New Zealand. The Project includes construction of new surface motorway, tunnelling and works on the existing SH16 (Northwestern Motorway) as well as a cycleway that will connect between the Northwestern and SH20 Cycleways.

1.3 Description of Alignment (by Sector)

The Project Sector Diagram (attached in **Appendix B**) provides an overview of the extent and works for the Project. Each Sector is summarised in the sections below.

1.3.1 Sector 1 – Te Atatu Interchange

Sector 1 includes significant improvements to the Te Atatu Interchange including the enlargement and re-configuring of off-ramps and on-ramps to accommodate additional lanes and to provide for bus shoulder and priority for buses and other High Occupancy Vehicles.

The Project involves the realignment of the eastbound on-ramp and the westbound off-ramp, which will require the removal of several dwellings. In addition, the new ramps will result in traffic moving closer to sensitive receivers.

1.3.2 Sector 2 – Whau River

Sector 2 includes the enlargement of the existing Whau River Bridge to accommodate additional lanes. A separate dedicated cycle/pedestrian bridge is also to be constructed alongside the enlarged Whau River Bridge.

1.3.3 Sector 3 – Rosebank - Terrestrial

Sector 3 of the Project involves works around the Rosebank Road Interchange.

1.3.4 Sector 4 – Reclamation

Sector 4 involves the provision of two additional westbound lanes from the Great North Road Interchange to the Rosebank Road Interchange and one additional eastbound lane from the Rosebank Road Interchange to the Great North Road Interchange.

1.3.5 Sector 5 – Great North Road Interchange

Sector 5 of the Project extends from the Waterview Park area, and includes the ramps and alignment associated with the connection of SH20 to SH16 (the Great North Road Interchange). Sector 5 provides motorway-to-motorway connections for SH16 east of the Great North Road Interchange and SH20, while maintaining the existing connections between Great North Road and SH16.

The SH20 alignment exits the tunnel in Waterview Park before splitting to the elevated ramp structures above and connecting to/from the existing SH16.

The Project will require the removal of a number of dwellings on Waterbank Crescent, Cowley Street, Herdman Street, Great North Road between Cowley Street and Oakley Avenue.

1.3.6 Sector 6 – Great North Road Interchange to St Lukes

One additional lane will be provided between the Great North Road Interchange and the St Lukes Interchange (in the east). Works will be beneath the existing Carrington Road overbridge, which is not altered by the project.

1.3.7 Sector 7 – Great North Road Underpass

From the Great North Road Interchange, the Project will comprise two cut-and-cover tunnels beneath Great North Road to connect to the northern portal of the Avondale Heights deep tunnel. Great North Road traffic will be rerouted slightly for a period of time.

1.3.8 Sector 8 – Avondale Heights Tunnel

Sector 8 is in two 'deep tunnels' (one in each direction) from the cut-and-cover tunnel beneath Great North Road through to the Alan Wood Reserve (adjacent to the Avondale Motor Park). The tunnel passes beneath suburbs of Avondale Heights and Springleigh, including the North Auckland Rail Line and New North Road.

The depth of the tunnel crown will vary from approximately 7 metres below existing ground level at the northern portal, through 45 metres at the mid-point to around 14 metres at the southern portal.

1.3.9 Sector 9 – Alan Wood Reserve

The alignment in Sector 9, south of the Avondale Heights Tunnel, is at-grade alongside and overlapping the existing land designated for rail (the Avondale Southdown Line Designation), for a length of around 900m. Richardson Road will be bridged across the State Highway and north-facing ramps will be built at the Maioro Street Interchange to provide local traffic access to SH20 northbound. An integrated road/rail corridor is proposed to retain opportunity for the existing rail designation (albeit realigned) from the Maioro Street Interchange to the southern tunnel portal in Alan Wood Reserve.

The Project will also require the removal of a number of dwellings on Hendon Avenue and Valonia Street, due to the new SH20 alignment and/or proposed rail corridor.

1.4 Overview of Vibration Assessment

This vibration assessment addresses, as part of the AEE, the vibration effects of the two phases of the Project - construction and operation. Each phase of the Project will involve different vibration sources, different work durations, different sensitivities and different effects.

1.4.1 Key Vibration Issues: Construction

The construction phase is the more crucial of the Project's two phases in terms of effects, as vibration levels produced by construction activities are typically higher, and therefore more likely to be detected by local receivers (especially residential), which may result in complaint. Construction vibration will generally however be of limited duration for any one receiver and there may be higher tolerance because the effects may be balanced with the overall benefits the completed Project.

The human perception limit for vibration is at least an order of magnitude below the limit for building damage risk (refer Section 3.3 Project Criteria). This means that adverse human reaction to construction vibration – borne out of residents' concerns over building damage – can often be expressed for activities generating vibration levels which readily comply with the building damage thresholds.

For this reason, the focus of the construction vibration assessment is building damage and site-measurements during the construction phase should focus on building damage. Notwithstanding this, the human response aspect must be carefully managed through the use of management tools such as the Construction Noise and Vibration Management Plan (CNVMP), a draft of which is attached in **Appendix K**.

The key vibration sources for the construction phase are anticipated to be:

- Blasting
- Vibratory rollers for base course and road surfacing
- Piling for bridge abutments, diaphragm wall construction, portal construction and retaining
- Rockbreaking
- Tunnelling equipment 'open face excavation'
- Drilling

Construction activities are expected to affect buildings and building occupants in all Sectors except Sector 4, where the distances from vibration source to receiver are sufficiently large to effectively mitigate the effects.

The Sectors in which vibration effects are most likely are those where operations are undertaken in close proximity to sensitive receivers and/or involve high-vibration activities (vibratory rollers, piling and blasting) e.g. Sectors 1, 6, 8 and 9.

1.4.2 Key Vibration Issues: Operation

The Project's operation phase contains less risk of adverse effects than the construction phase because the vibration levels generated by traffic are significantly less than those generated by construction activities. During the operation phase, more focus is given to human perception because any vibration effects will be ongoing and will continue indefinitely, as opposed to construction, which has a limited timeframe.

The existing ambient vibration survey (refer Section 4.1) involved measurements of existing (i.e. prior to Project commencement) vibration levels in a number of dwellings. Two of these dwellings are directly adjacent to SH16 and, when asked, the occupants of these dwellings expressed no concern about current traffic vibration.

2.0 Methodology

The methodology for assessing the effects of vibration in relation to this Project can be divided into eight broad steps:

- Reviewing the applicability of vibration standards (if any) currently applied by Auckland City Council, Waitakere City Council and Auckland Regional Council, and standards used in similar projects. A review of vibration standards was commissioned by NZTA as a separate body of work (refer **Appendix C**) which has, in turn, been referenced by this Project assessment
- Adopting relevant vibration standards to develop Project Criteria for vibration

- Establishing, through measurement, the current ambient vibration conditions for receivers who may in future be affected by vibration from the Project
- Identifying those Project construction activities likely to generate significant vibration levels
- Sourcing vibration data from historical measurements of sources relevant to the Project
- Analysing the collected vibration data and using prediction models to calculate the 'ground attenuation' between each construction source and 'sensitive receivers' (refer Appendix A for definitions)
- Assessing predicted vibration levels against the Project Criteria and identifying any sensitive receivers that are at risk of criteria exceedance
- Outlining mitigation options should any vibration levels be found to exceed the Project Criteria

3.0 Vibration Criteria

The scale and significance of this Project demands the adoption of widely accepted vibration criteria to assess environmental vibration effects.

Two aspects of vibration effects are considered: the potential for damage to buildings, and the human response to vibration. Both of these effects must be considered for each of the construction and operation phases of the Project, however the risk of each effect differs by phase.

The risk of building damage exists primarily during the Project's construction phase, because operation vibration from motorway traffic is expected to be well below damage thresholds (refer Section 4). The risk of human perception issues (e.g. discomfort, sleep disturbance, loss of amenity) is most significant in the operation phase because of the ongoing nature of vibration from the completed motorway.

Whilst vibration levels produced by construction may be higher than those produced by operation, construction effects have a finite timeframe and, with effective management (through the implementation of management plans etc), the effects can be mitigated. Moreover, the primary concern of receivers during construction is generally of damage to their buildings, which is addressed by building damage standards, rather than human response standards.

3.1 Review of Vibration Standards

There are no current New Zealand standards specifically relating to construction or traffic vibration.

The New Zealand Standards authority did have a human response standard (NZS/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)") until it was withdrawn in April 2005. This Standard was identical to the International Standard ISO

2631-2:1989, which was superseded in 2003 by an informative-only standard (i.e. it contained no vibration criteria). Consequently, Standards New Zealand withdrew NZS/ISO 2631-2:1989 and all related vibration standards in the NZS/ISO 2631 series.

Since this time, however, the ISO 2631-2:1989 Standard has continued to be implemented in New Zealand. For example, the District Plans of both Auckland City and Waitakere City, as well as the NZTA Environmental Plan reference it. However, for the purposes of this Project, to ensure the assessment of effects is robust and fit-for-purpose, the adoption of a superseded (ISO 2631-2:1989) or withdrawn (NZS/ISO 2631-2:1989) standard is not considered appropriate.

Accordingly, a comprehensive review of international vibration standards, and their adoption for use in New Zealand has been conducted by the author of this assessment. This review is contained in the research paper by J. Whitlock entitled "A Review of the Adoption of International Vibration Standards in New Zealand" (2010), which has been commissioned by NZTA to inform future policy on vibration. The paper is attached in Appendix C.

In the research paper, a number of international standards are identified and assessed in detail. The paper's primary focus is on human response standards due to the situation with ISO 2631-2:1999. However, a range of building damage standards are also reviewed and discussed.

The outcomes of the Whitlock study have been used to inform the vibration criteria adopted for use in the Project. Accordingly, three vibration standards have been adopted for use in the Project Criteria, as follows:

- German Standard DIN 4150-3:1999 "Structural Vibration - Part 3: Effects of Vibration on Structures"
- Norwegian Standard NS 8176.E:2005 "Vibration and Shock – Measurement of vibration in buildings from landbased transport and guidance to evaluation of its effects on human beings"
- British Standard BS 5228-2:2009 "Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration" – Appendix B.

Validation of the selection of each standard and details and discussion of criteria contained therein are covered in Whitlock, 2010 (see Appendix C).

To summarise, DIN 4150-3:1999 has been selected because it is the status quo for building damage risk assessments from any vibration source and there is no known reason to replace it. NS 8176.E:2005 specifically addresses transportation vibration and has been successfully used in New Zealand in the past, so has been selected to replace the defunct ISO 2631-2:1989. Appendix B of BS 5228-2:2009 contains human response criteria for construction activities and, unlike other human response standards, utilises the most practical unit of measurement – peak particle velocity (PPV). Refer Appendix A for a Glossary of Terms.

The Project Criteria are discussed in greater detail in Section 3.3 below.

3.2 Other Reference Documents

In addition to the standards discussed in Section 3.1 above, a number of other references were reviewed for this assessment, including authority recommendations, case studies and calculation methods. The most salient references are outlined in the following sections. A complete list of references is given in **Appendix D**.

3.2.1 Auckland City and Waitakere City District Plans

The Auckland City and Waitakere City District Plans reference ISO 2631-2:1989 and DIN 4150-3 (both the older 1986, and the current 1999 versions). Further details of these standards are addressed in Whitlock, 2010 (Appendix C), but to summarise:

ISO 2631-2:1989 is referenced in:

- Auckland City District Plan – Isthmus Section, sections 8.8.1.6, 8.8.3.9 and 8.8.10.9
- Auckland City District Plan – Central Area Section, sections 7.6.5.1
- Waitakere City District Plan, rules 14.1 (Living Environment) and 10.1 (Working Environment)

The earlier 1986 version of DIN 4150-3 is referenced in:

- Auckland City District Plan – Isthmus Section, section 8.8.2.7 Noise and Vibration arising from Blasting
- Auckland City District Plan – Central Area Section, section 7.6.5.2 Noise and Vibration arising from explosive blasting or pile driving
- Waitakere City District Plan – rule 13(c) Blasting in quarry areas

The current 1999 version in referenced in:

- Auckland City District Plan – Hauraki Gulf Islands Section (Proposed 2006), section 4.6.3 Noise and vibration from blasting or pile driving for construction activities (1999 version)

Whilst not all the above District Plan sections are directly applicable to the Project, the list serves to establish the existing usage of the DIN and ISO Standards.

3.2.2 NZTA Environmental Plan

Section 2.12 of the NZTA Environmental Plan addresses vibration effects of State Highways, and the construction and maintenance thereof. It recommends methods for assessing and addressing vibration effects, with references to NZTA Planning Policy Manual (SP/M/001) and State Highway Control Manual (SM012).

Of particular note are the Environmental Plan's references to the following vibration standards in the 'toolkit':

- NZ/ISO 2631-2:1989
- AS 2670-2:1990
- DIN 4150-3:1999, and
- NS 8176.E:2005.

3.2.3 National Environmental Standards

Whilst there is no National Environmental Standard (NES) to control noise and vibration from construction works or traffic operation, it is noted that the NES for Electricity Transmission Activities contains reference to DIN 4150-3:1999 in clause 37.3, in relation to vibration control of construction activities relating to existing transmission lines.

3.2.4 Australian and New Zealand Environment Council (ANZEC)

In September 1990 the Australian and New Zealand Environment Council (ANZEC) issued a document titled "Technical Basis for Guidelines to Minimise Annoyance due to Blasting Overpressure and Ground Vibration". The document is a succinct paper that outlines vibration level, timing and blast frequency criteria to "minimise annoyance and discomfort to persons at noise sensitive sites (e.g. residences, hospitals, schools etc) caused by blasting." It is understood to be widely referenced for roading projects in Australia.

The ANZEC vibration criteria are in line with the statistical application of DIN 4150-3:1999 (refer Section 3.3.3.1 below) i.e. PPV 5 mm/s for 95% of blasts in 12 months, with an absolute limit of 10 mm/s. It states that PPV values less than 1 mm/s are generally achieved (at quarry sites) and recommends a PPV of 2 mm/s as the 'long term regulatory goal'. This recommendation is based on achieving 95% compliance with 5 mm/s.

3.2.5 Resource Management Act 1991

Section 2 "Interpretation" of The Resource Management Act 1991 states that "noise includes vibration", therefore the following sections are directly applicable to vibration:

*"**16 Duty to avoid unreasonable noise***

(1) Every occupier of land (including any premises and any coastal marine area), and every person carrying out an activity in, on, or under a water body or the coastal marine area, shall adopt the best practicable option to ensure that the emission of noise from that land or water does not exceed a reasonable level.

(2) A national environmental standard, plan, or resource consent made or granted for the purposes of any of sections 9, 12, 13, 14, 15, 15A, and 15B may prescribe noise emission standards, and is not limited in its ability to do so by subsection (1).

17 Duty to avoid, remedy, or mitigate adverse effects

(1) Every person has a duty to avoid, remedy, or mitigate any adverse effect on the environment arising from an activity carried on by or on behalf of the person, whether or not the activity is carried on in accordance with—

(a) any of sections 10, 10A, 10B, and 20A; or

(b) a national environmental standard, a rule, a resource consent, or a designation.

(2) The duty referred to in subsection (1) is not of itself enforceable against any person, and no person is liable to any other person for a breach of that duty.

(3) Notwithstanding subsection (2), an enforcement order or abatement notice may be made or served under Part 12 to—

(a) require a person to cease, or prohibit a person from commencing, anything that, in the opinion of the Environment Court or an enforcement officer, is or is likely

to be noxious, dangerous, offensive, or objectionable to such an extent that it has or is likely to have an adverse effect on the environment; or

(b) require a person to do something that, in the opinion of the Environment Court or an enforcement officer, is necessary in order to avoid, remedy, or mitigate any actual or likely adverse effect on the environment caused by, or on behalf of, that person.

(4) Subsection (3) is subject to section 319(2) (which specifies when an Environment Court shall not make an enforcement order)."

It is considered that adoption, prediction and assessment of vibration effects according to the Project Criteria satisfy the requirements of the RMA in relation to the assessment of such effects.

3.3 Project Criteria

The recommended Project Criteria are as follows:

3.3.1 Construction Vibration – Building Damage Risk: DIN 4150-3:1999

The German Standard DIN 4150-3:1999 is widely applied in New Zealand and is referenced in the Auckland City and Waitakere City District Plans in relation to blasting. It should be noted that its criteria (expressed as peak particle velocities (PPV) – refer Appendix A) are intended to avoid superficial damage to buildings. The criteria are well below the level at which damage to building foundations could occur, for which significantly greater limits would be applied. A summary of the criteria are given in Table 3.1 below.

Table 3.1: 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 (mm/s)	PPV at horizontal plane of highest floor (mm/s)
	1 - 10Hz (mm/s)	1 - 50 Hz (mm/s)	50 - 100 Hz (mm/s)		
Commercial/Industrial	20	20 – 40	40 – 50	40	10
Residential/School	5	5 – 15	15 – 20	15	5
Historic or sensitive structures	3	3 – 8	8 – 10	8	2.5

The most relevant criterion in this Standard is the long-term vibration limit for residences/schools of PPV 5 mm/s, as the majority of the Project's construction vibration activities would be classed as long-term (according to the definition given in the Standard).

3.3.1.1 Practical application of DIN 4150-3:1999

The DIN 4150-3:1999 Standard is somewhat conservative, as it has to take account of a vast range of building structure types in different conditions and at varying degrees of dilapidation, and quantify their vibration tolerances. For a given structure, a vibration level in excess of the DIN criterion does not necessarily result in damage, as indicated by clause 5.1 of the Standard which states:

> *"Exceeding the values in table 1 does not necessarily lead to damage, should they be significantly exceeded, however, further investigations are necessary."*

It is considered pragmatic, therefore, to take account of this during the construction phase and address any measured exceedance of the Standard by implementing a suitable management procedure. Such a procedure would include steps such as cessation of the offending activity until a building condition survey can be undertaken, and appropriate measures moving forward depending on the outcome of the survey. This procedure should be fully outlined in the CNVMP (refer draft CNVMP attached in Appendix K).

For blasting activities, Section 8.8.2.7e of the Auckland City District Plan – Isthmus Section contains a precedent for the adoption of a statistical methodology whereby 5% of measured vibration events would be allowed to exceed the criteria in the Standard whilst having to comply with an absolute upper limit of twice the DIN criteria. This approach is considered suitable for adoption in the Project construction phase. Details of the statistical method are contained in the draft CNVMP (Appendix K) and the standards review paper (Appendix C).

3.3.2 Construction Vibration – Human Response: BS 5228-2:2009

As noted previously, the risk of building damage is the primary effect during the construction phase of this (and any other) Project. However Appendix B.2 of British Standard BS 5228-2:2009 provides valuable guidance for people's expectations and responses to construction vibration. The criteria are shown in Table 3.2 below:

Table 3.2: Criteria for human response to construction vibration in BS 5228-2:2009, Annex B

Vibration level (PPV)	Effect
0.14 mm/s	Vibration might be just 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 be just 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."

Comparing these criteria with those of DIN 4150-3:1999, it can be seen that people are likely to complain at vibration levels significantly below those which may cause building damage. It is anticipated that the effects of construction activities which cause concern but not damage will be managed by the CNVMP, in particular through community liaison and education.

Additionally, people are generally most sensitive to vibration at frequencies higher than those which cause building damage. Construction activities generate vibration at a wide range of frequencies, and peoples' sensitivity to the higher frequencies in this range exacerbates their perception of the potential for building damage.

3.3.3 Operation Vibration – Building Damage Risk: DIN 4150-3:1999

The Project Criteria for building damage risk during the operation phase of the Project are the same as those for the construction phase (see Section 3.3.2 above). There is not expected to be any effect relating to this aspect of the Project.

3.3.4 Operation Vibration – Human Response: NS 8176.E:2005

The Norwegian Standard NS8176.E:2005 "Vibration and Shock – Measurement of vibration in buildings from landbased transport and guidance to evaluation of its effects on human beings" specifically addresses the effects of vibration induced by transport, including road traffic. This Standard has been applied in a number of projects in Auckland.[2] The performance criteria are given in Table 3.3 below.

Table 3.3: Human response criteria for transport sources in NS 8176.E:2005

Type of vibration value	**Dwelling classification (and % likelihood of moderate to high annoyance)**			
	Class A (8%)	**Class B (10%)**	**Class C (15%)**	**Class D (25%)**
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

The majority of residences along the Project alignment will be categorised as Class C receivers, according to the Standard's classification. 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" (NS 8176.E:2005). About 15% of the affected persons in Class C dwellings can be expected to be disturbed by vibration, but fewer than 15% will experience discomfort.

Whilst the two human response standards listed above are selected for the Project Criteria, Section 6.3.3 below compares NS 8176.E:2005 with ISO 2631-2:1989, given the wide-spread adoption of the ISO Standard in New Zealand (albeit now withdrawn).

It is noted that these human response standards do not address the effects of reradiated noise – i.e. vibration energy in the house structure that manifests itself as a 'rattle or hum' and is heard rather than felt. It is often difficult for a listener to distinguish this effect from felt vibration, and complaints of vibration can be made when in fact the cause of disturbance is reradiated noise. This effect varies considerably from structure to structure due to the complexity of building junctions and variance in building materials, and it is anticipated that this effect would be handled on a case-by-case basis through the complaint management procedures in the CNVMP.

4.0 Existing Environment

In order to assess the vibration effects of the operation of the Project on residential and other receivers along the Project alignment, site vibration surveys have been undertaken to establish the existing ambient vibration

[2] SH1 Waiouru Peninsula Connection, SH1 North Shore Busway, Esmonde Rd Interchange and widening, Taharota Rd widening

environment. The Project runs through a range of environments, some of which are close to existing vibration sources (i.e. SH16, Great North Road) and others of which are more remote (i.e. Alan Wood Reserve).

Survey locations were selected so as to encompass the range of existing environments i.e. dwellings near existing motorways, dwellings in quiet areas (including above the proposed tunnel section) and schools.

The measured levels provide an existing baseline of vibration levels generated by vehicle traffic. Also, because the surveys at each location were undertaken by measuring the vibration of the building structure, data on occupant-generated vibration was measured. This data provides anecdotal information on the vibration magnitudes that occupants subject themselves to in the course of their daily activities, and therefore their tolerances (presuming they are not disturbed by the vibration levels they generate).

4.1 Ambient Vibration Survey

The ambient vibration survey involved eight locations along the proposed Project alignment.

The following locations were selected for the ambient vibration survey. The corresponding Project sector is indicated in brackets.

1. 20 Titoki Street, Te Atatu [Sector 1]
2. 702 Rosebank Road, Avondale [Sector 3]
3. 77 Herdman Street, Waterview [Sector 5]
4. 1102g Great North Road, Point Chevalier [Sector 6]
5. Waterview Primary School, Waterview [Sector 7]
6. 58 Blockhouse Bay Road, Avondale [Sector 8]
7. 204 Methuen Road, New Windsor [Sector 9]
8. Christ the King School, New Windsor [Sector 9]

These locations are shown on the Plan in **Appendix E**, and a survey sheet for each property with a time trace graph of the measured vibration is included in **Appendix F**.

4.1.1 Survey Details

The measurement programme was undertaken using two Nomis Mini Supergraph vibration loggers with triaxial geophone transducers (Serial Nos. 10046 and 10086). Both loggers carried current calibration certification at the time of measurement. One logger was installed at each location.

The survey period was between 3rd December 2009 and 28th January 2010. At each location, the vibration loggers measured continuously for 3 to 4 days.

The Nomis loggers only measure peak vector sum (PVS) data (see Appendix A for Glossary of Terms), and whilst not the ideal parameter, it is sufficient for the intended purpose. The PVS is the vector sum of the PPV in each of the three orthogonal axes (transverse, vertical and longitudinal), given by the equation:

$$PVS = \mathrm{sqrt}(PPV_{trans}^2 + PPV_{vert}^2 + PPV_{long}^2)$$

Typically, vibration events have one dominant axis (i.e. higher PPV levels compared to the other two axes) so for a given measurement the PVS may not be much greater than the PPV in the dominant axis. In any case, the PVS may be considered to be a conservative (i.e. worst-cast) representation of PPV for any given measurement.

In every case the geophone was firmly clamped to the building structure or foundations, as recommended in DIN 4150-3:1999, and the placement details are contained in photos and the "setup comment" of each monitoring report in Appendix F. Clamping the geophone to the building structure or foundations gives the benefit of acquiring both the ambient baseline vibration (after data filtering – see Section 4.1.2 below) and the occupant generated vibration, which allows comparison with external vibrations. For those locations where the geophone was clamped at mid-span of a bearer, some amplification due to the beam deflection may be expected, however the effect is not considered to be significant.

Location 2 (702 Rosebank Road) is a commercial premises. This location was selected because offices can be considered vibration sensitive environments also (i.e. complaints may arise if work is interrupted). At this location the transducer was placed on the external patio of the office area and weighted with a sandbag.

The measurements were undertaken generally in accordance with DIN 4150-3:1999 (which is primarily used for assessment of damage to structures) because the memory capacity of the vibration loggers used in the surveys restricted the measurement parameter to PVS and PPV. Waveform recording, which would be required for assessments according to the Norwegian Standard NS 8176.E:2005 for human response requires significantly more data acquisition, and suitably practical and robust long-term monitoring machinery with sufficient memory capacity could not be sourced in New Zealand. Notwithstanding this, the measured levels can be assessed against the other human response Standard in the Project Criteria – BS 5228-2:2009, Appendix B which contains PPV criteria.

While the vibration loggers were not ideal for assessing human response to existing traffic vibration, the primary goal for the ambient survey was to establish a 'pre-Project baseline'. Provided any post-Project surveys measure the same parameters, the integrity of the before and after surveys will be maintained.

It is important that (as noted in Section 1.4.2 above) when asked, the residents who live adjacent to SH16 expressed no concern about the current level of traffic vibration. This indicates that, by virtue of either the insufficient vibration levels or acclimatisation, the current traffic vibration is not perceived by those residents as causing any adverse effects.

4.1.2 Identifying ambient vibration level

At all survey locations the buildings were occupied during the measurement period. Frequent vibration peaks were measured – often at high levels. These peaks are generally inconsistent and occur sporadically, which does not align with expected traffic vibration, which would typically be smoother with less variation between peaks and troughs.

The vibration peaks recorded were most likely caused by the building occupants walking, jumping, moving or dropping objects. This hypothesis is supported by the following observations:

1. The peaks in the vibration traces (refer Appendix F) generally stop during the night-time period, i.e. when the occupants are asleep.
2. If the daytime peaks were due to heavy traffic movements, the lack of peaks at night time would infer there were no heavy vehicle movements whatsoever during the night-time period. This is not a credible assumption, particularly for residences adjacent to SH16.
3. If the peak levels were extrapolated over the distance to between receiver and source, to indicate the vibration level at the source, the source vibration level would be much too high to be generated by traffic. An example of this is discussed in Section 6.3.4.2 where, for a measured 6.4 mm/s PVS peak, the source traffic vibration would have to exceed 250 mm/s, which is inconceivable.

Occupant-generated vibration data has been visually filtered from these records, as shown by the 'shadowed' areas in Figure 4.1 below, and in the Appendix F plots. The filtered data (i.e. once the shadow area data has been removed) has been averaged to give the 'mean ambient PVS' over the entire measurement period. This is not an established vibration descriptor, however it has been used here as a quick and simple method of assessing the large datasets and indicating the average vibration level at each site.

Figure 4.1 below is an example time trace from the measurements at Location 3 (77 Herdman Street, Waterview). The raw vibration data has been blocked into 15 minute intervals, and the peaks of each 15 minute block plotted on the graph. This same method has been used to generate the graphs at the other locations in Appendix F.

It can be clearly seen that occupant activity ceased each night between approximately 9 – 11 pm and began again at approximately 6 – 8 am. In this case, the mean ambient PVS was 0.13 mm/s, whereas the maximum PVS (i.e. highest recorded vibration level, regardless of source) was 2.7 mm/s. For all traces, the y-axis scale has been fixed with a maximum level of 2 mm/s.

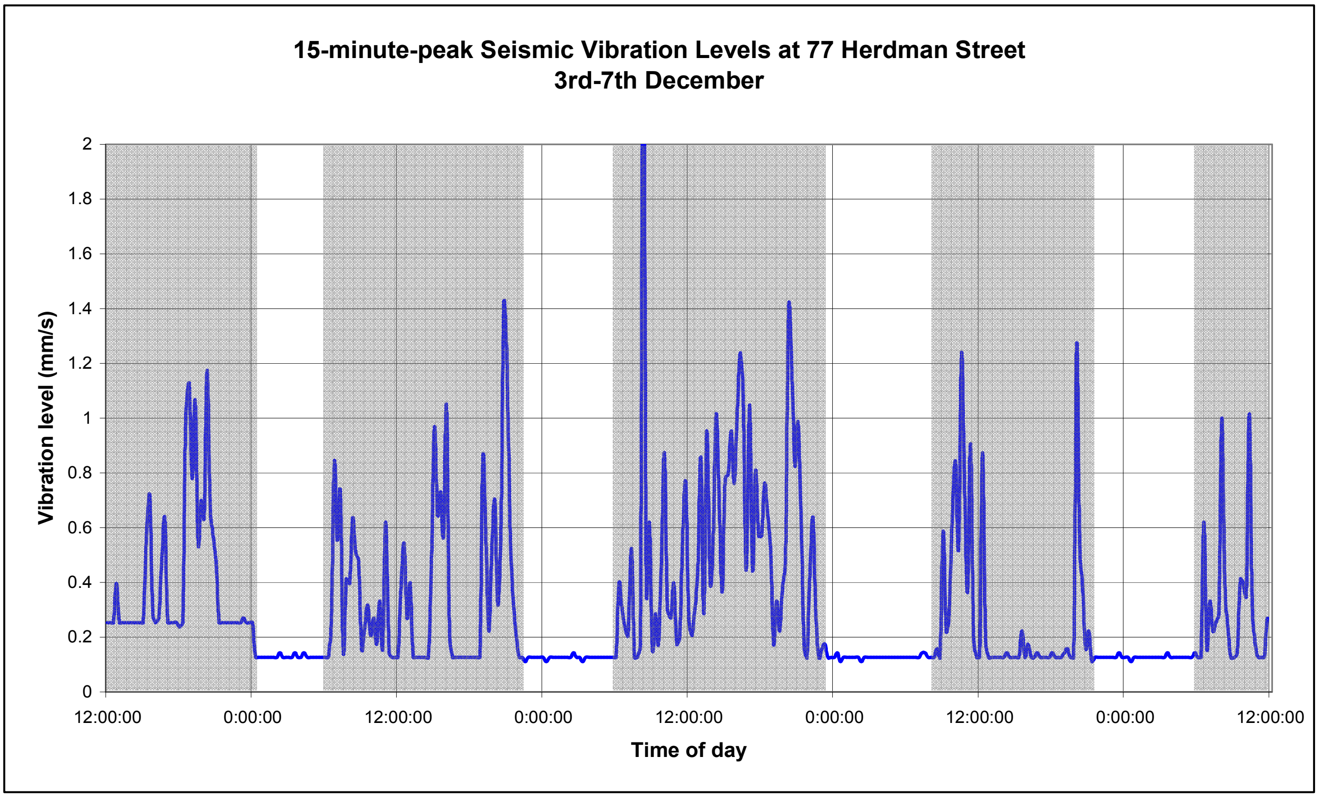

Figure 4.1 - Example of measured time trace, with occupant-based regions highlighted

The noise-floor of the equipment may have some bearing on the lower-bound accuracy of the mean ambient PVS values. This is discussed in the supplementary information on prediction methodologies in **Appendix G**. Notwithstanding this, the measured data is still useful as, regardless of the apparatus noise-floor, the actual ambient vibration levels must be equal to, or less than the mean ambient PVS values.

4.2 Survey Results

The ambient vibration monitoring reports attached in Appendix F contain comments on the equipment setup and results of each survey.

The measured data indicate that the typical mean ambient PVS value for buildings whose properties are adjacent to the motorway (SH16) is around PVS 0.3 mm/s, whereas other buildings not adjacent to a major road were 0.13 mm/s or below (see Section G.1 in Appendix G regarding the equipment noise-floor). The results are summarised in Table 4.1 below:

Table 4.1: Ambient vibration results

Location No.	Address	Distance to nearest major road (m)	Project Sector	Mean Ambient PVS (mm/s)	Maximum PVS (mm/s)
1	20 Titoki Sreet, Te Atatu	33m to SH16	1	0.28	1.5
2	702 Rosebank Road, Avondale	36m to SH16	3	0.33	0.95
3	77 Herdman Street, Waterview	140m to SH16	5	0.13	2.7
4	1102g Great North Road, Pt Chevalier	18m to SH16	6	0.34	7.4
5	Waterview Primary School, Waterview	87m to Great North Road	7	0.27	8
6	58 Blockhouse Bay Road, Avondale	90m to Blockhouse Bay Road	8	0.12	2.6
7	204 Methuen Road, New Windsor	630m to Blockhouse Bay Road	9	0.13	0.9
8	Christ the King School, New Windsor	22m to Maioro Road	9	0.13	0.6

The criteria in Appendix B.2 of BS 5228-2:2009 has been adopted in the Project Criteria for human response to construction vibration. Its criteria are expressed in PPV (which is related to PVS, refer Section 4.1.1) so it allows some context to be given to the measured PVS ambient levels, even though the source is not construction activities.

Notwithstanding the potential for a slight reduction in vibration level from the correction of PVS to PPV (refer Section 4.1.1), the mean ambient PVS levels at dwellings near SH16 may currently marginally exceed the BS 5228-2:2009 criterion of 0.3 mm/s PPV for perceptibility which states that "vibration might just be perceptible at this level".

Furthermore, the filtered time traces for these properties show vibration events of around 0.5 mm/s PVS (above the threshold of perception), which could be due to heavy vehicle passes. However, none of the residents expressed any concern over existing vibration levels. So, whilst the levels may be just perceptible, they are not resulting in an observed adverse effect or discomfort for the residents interviewed.

It is noted also that none of the measured vibration events attributed to traffic (i.e. post-filtering) exceed the 5 mm/s Project Criterion for building damage in the operation phase. Further, the traffic-induced vibration levels were a fraction of those due to activities of the residents.

The time trace for 702 Rosebank Road, Avondale does not conform to the typical daytime – night-time pattern seen in all other traces, however this may be because it is in a commercial zone.

Ambient levels measured on all other buildings in the survey dwellings are well below the BS 5228-2:2009 threshold for perceptibility in residential environments.

4.3 Summary of Ambient Vibration Survey

An ambient vibration survey has been carried out to establish the existing levels of vibration experienced by receivers along the proposed Project alignment. The measured ambient values along the alignment will be used as part of a baseline assessment with which post-Project operational vibration levels can be compared.

It is noted that at some locations, whilst some vibration events considered to be due to traffic (i.e. after filtering out the occupant-generated effects) were measured at levels above the threshold of perception, no complaints or dissatisfaction were expressed by those building occupants questioned. Further, the traffic levels were often well below the vibration levels induced by activities of the occupants themselves.

5.0 Construction Vibration

This section of the assessment addresses the vibration effects of the construction phase of the Project. Each phase of the Project involves different vibration sources, sensitivities and effects. However, the construction phase is anticipated to generate the highest vibration levels.

The following sections identify the key construction activities, sensitive receivers, prediction of construction vibration levels, and the accuracy of these predictions. This assessment will inform the processes and response management for the works in conjunction with the CNVMP.

5.1 Key Construction Vibration Issues

The Project's construction phase will involve the use of heavy machinery operating for periods in relatively close proximity to some vibration sensitive buildings, such as residences. Night-time construction is expected to be required in certain areas. Throughout the construction phase, vibration effects must be carefully managed through the use and implementation of the CNVMP.

The sources that have been identified as the highest risk for building damage from construction vibration for the Project are outlined in Table 5.1 below:

Table 5.1: Key Construction Vibration Issues

Sector	Vibration source(s)	Location of closest buildings
1	• Vibratory rollers for base course and sealing of SH16 and the Te Atatu Interchange	Marewa Street, Milich Terrace, McCormick Road, Titoki Street, Royal View Road, Flanshawe Road, Paton Avenue, McCormick Road, Te Atatu Road, Royal View Road and Alwyn Avenue residences
2	• Piling for bridge construction	Alwyn Avenue residences
3	• Vibratory rollers for base course and sealing of SH16	Commercial premises in Patiki Road and Rosebank Road
4	• Vibratory rollers for base course and sealing of SH16, and piling for bridge abutments	None in the vicinity
5	• Vibratory rollers for base course and sealing of on-grade ramps	Waterbank Crescent and Montrose Street residences
6	• Piling, blasting and rockbreaking for widening works & retaining walls • Vibratory rollers for base course and sealing of on-grade ramps	Carrington Road residences and shops, Sutherland Road, Nova Place, Great North Road, Parr Road North and Parr Road South residences
7	• Piling for diaphragm wall • Excavation plant • Vibratory rollers for road realignment and resurfacing	Great North Road. Oakley Avenue, Alford Street and Waterbank Crescent residences, Waterview Primary School
8	• Roadheader machine or excavators for tunnelling	Hendon Avenue, Bollard Avenue, Powell Street, Cradock Street, Waterview Downs, Oakley Avenue, Herdman Street and Great North Road residences
9	• Drilling for grout curtain • Blasting for portal construction • Drilling for portal construction • Rock breaking for portal construction • Piling for portal construction • Vibratory rollers for road construction	Hendon Avenue, Barrymore Road, Valonia Street and Methuen Road residences

Other construction machinery and activities such as trucks, excavators, etc. will produce ground vibration also. However, prior experience has shown that adverse effects (particularly adverse human response) are most likely to arise from the activities outlined in Table 5.1.

With careful management and liaison with affected parties, as per the CNVMP, the vibration effects of Project construction activities can generally be controlled and or mitigated, as addressed in the following sections.

5.2 Construction Noise and Vibration Management Plan (CNVMP)

The Construction Noise and Vibration Management Plan (CNVMP) will form part of a comprehensive suite of environmental controls within the Construction Environmental Management Plan (CEMP) for the construction phase of the Project. The CNVMP addresses the potential construction noise and vibration effects associated with the construction of the Project. The CNVMP identifies minimum standards that must be complied with as well as best practicable options for noise and vibration management for the construction of the Project. It is intended as a framework for the development of particular control practices and procedures to minimise affects on health and safety and to reduce the impact on the environment.

A proposed draft CNVMP is attached in Appendix K. It will be updated, with the necessary approval, throughout the course of the Project to reflect material changes associated with changes to construction techniques or the natural environment.

An outline of the recommended CNVMP contents in relation to construction vibration is summarised below:

- The vibration Project Criteria
- Hours of operation, including times and days when vibration inducing construction activities would occur
- Machinery and equipment to be used
- Requirements for vibration testing of equipment to confirm safe distances to buildings prior to construction
- Requirements for building condition surveys of critical dwellings prior to, during and after completion of construction works
- Roles and responsibilities of personnel on site
- Construction operator training procedures
- Construction noise and vibration monitoring and reporting requirements
- Construction vibration mitigation options, including alternative strategies where full compliance with the Project Criteria cannot be achieved
- Management schedules containing site specific information
- Methods for receiving and handling complaints about construction noise and vibration

5.3 Sensitive Receivers

As discussed in Section 1.4.1, the primary consideration relating to construction vibration effects is that of building damage. The vast majority of buildings adjacent to the Project construction footprint are residences, so the assessment focuses primarily on these 'receivers'. Some buildings may themselves be vibration-sensitive due, for instance, to their historical status, or dilapidated condition. The Project Criteria for construction (see Section 3.3) generally take account of these variables by specifying more stringent vibration limits for more sensitive structures.

Notwithstanding this, the effect of vibration on building occupants is also assessed. Receivers that are generally considered to be sensitive to construction vibration effects include residences, schools, offices, churches, rest homes, historic structures, hospitals and buildings which may contain vibration-sensitive equipment such as scientific or medical laboratories.

The Project Criterion for human response to construction (i.e. the level above which adverse comment may be expected) is 1 mm/s PPV. For temporary construction activities, levels exceeding the higher building damage threshold will generally be tolerated – if sensitive receivers are well informed of construction activities and consider that the construction operation is well controlled and managed (i.e. through the CNVMP) – because their concern over potential damage to their building can be mitigated.

The effect of noise and vibration on wildlife is generally a specialist topic, with the effects varying widely between species. For instance a study of sonic boom noise on animals of various species[3] showed that some animals displayed startle reactions whilst other animals showed almost no reaction. After periods of exposure many animals quickly adapt to the changed environment. It is not possible to predict the response of all animals as tolerances and reactions vary widely even within species.

Discussions on this issue have been held with members of the Project Ecology team who indicated that studies are not conclusive and there are currently no standards or regulatory rules for either noise or vibration effects on wildlife areas.

Given the temporary nature of the Project construction period, the existing ambient vibration environment close to the motorway and the ability of fish, birds and other vertebrates to move away from noise and vibration sources, the risk to animals from the vibration effects of this Project is considered low.

5.4 Vibration Prediction

The following sections describe the procedure used for predicting vibration levels from the Project construction activities. The outcomes of these predictions are expressed in Section 5.6 in terms of the risk of each activity exceeding the Project Criteria at identified receivers.

5.4.1 Data Sources

For the assessment of Project construction effects, vibration data for a range of construction activities has been sourced from historical Marshall Day Acoustics (MDA) measurements, BS 5228-2:2009 and Tonkin & Taylor Limited and is contained in **Appendix H**.

The data for those sources with a sample size of more than 6 measurements have been assembled and regression analysis has been undertaken to establish vibration propagation trends in the relevant soil types, and to assess the measurement variance. These sources are vibrated casing piling, vibratory compacting and sheet piling, all of which are proposed in the Project construction methodology.

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[3] Kaseloo, P.A., Tyson, K., "Synthesis of Noise Effects on Wildlife Populations", US Department of Transportation – Federal Highway Administration, 2004.

The data for sheet piling (sourced predominantly from BS 5228-2:2009), in particular, has a huge variance e.g. measurements at 5 metres showed a range from PPV 4.3 to 40 mm/s. The regression curve (attached in Appendix H) appears not to have captured this variance particularly well, in that there are a large number of datapoints above the curve. To ensure conservative estimates of design safe distance, a conservative safety factor of 2 (as recommended by Hunt et al., 2010[4]) has been added to the distance for sheet piling works until on-site testing can be undertaken to refine the prediction model.

Vibration data for other relevant source types such as drop-hammer piling, drilling and rockbreaking have also been sourced, and are listed in Table H.1 of Appendix H, but the sample set is not sufficient for statistical analysis.

All data has been normalised for the worst-case (i.e. hardest) ground-type in each Project Sector for which those works are proposed, using the following methodology.

5.4.2 Prediction Methodology

The basic prediction model for vibration propagation with distance is:

$$PPV = K(D/E^{1/2})^{-n} \qquad \text{--- (1)}$$

Where:
- K = the ground transmission constant (for a given ground type)
- D = Distance from source to receiver
- E = Energy of source
- n = empirical constant based on a number of factors such as the geology, ground profile, frequency of transmitted wave, predominant waveform. The value of n is obtained from regression analysis and generally has a value between 0.5 and 1.5.

For a given vibration source, it may be assumed that the energy delivered into the ground is constant (over a sufficient timescale), therefore the equation reduces to:

$$PPV = K \cdot D^{-n} \qquad \text{--- (2)}$$

This prediction method is elaborated in Hassan (2006)[5] which, unlike many other methods, contains frequency-dependant ground attenuation formulae. This method yields slightly more conservative results than other texts such as Gutowsky & Dym[6] and Nelson[7] so is considered preferable in effects assessments. The method is explained in Appendix G. Table G.1 in Appendix G contains data on Project ground types and their

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[4] Hunt, H., et al. "Groundbourne vibration from underground railways: some commonly made assumptions and their associated accuracies and uncertainties". Proceedings of Institute of Acoustics and Belgian Acoustical Society Conference, Ghent, Belgium, 2010.

[5] Hassan, O., "Train Induced Groundborne Vibration and Noise in Buildings", Multi-Science Publishing Co. Ltd, ISBN 0906522 439, 2006

[6] Gutowsky, T. & Dym, C., "Propagation of Ground Vibration: A Review", Journal of Sound and Vibration, 49(2), 1976, pp 179-193

[7] Nelson, P., "Transportation Noise Reference Book", Butterworth & Co. Ltd, ISBN 0-408-01446-6, 1987

corresponding vibration attenuation properties which allow correction of measured vibration data to predict Project construction vibration levels at receiver locations.

For assessment purposes, vibration data for a given activity has been normalised for the worst-cast (i.e. hardest) ground type in each Project Sector in which that activity is proposed.

5.4.3 Accuracy of Predictions

Vibration prediction is less reliable than noise prediction. The primary difficulty for vibration prediction is being able to accurately model ground conditions that are non-homogeneous and complex in three-dimensions, and consequently difficult to quantify on site.

Without the benefit of site specific testing to refine the effect of ground attenuation, vibration prediction models are purported to only achieve accuracy to within ± 100% at best[4] (i.e. doubling or halving). The application of the models and development of attenuation characteristics to assess the expected magnitude of vibrations from the Project are described in Appendix G. The models identify the principal variables as the distance and magnitude of the energy source.

The historical dataset compiled for this construction assessment shows a significant variation between measurements. For example, the largest dataset (for sheet piling) includes 29 measurements (the majority of which were taken from BS 5228-2:2009), and there is a wide range in vibration levels at distance e.g. measurements at 5 metres showed a range from PPV 4.3 to 40 mm/s.

A prediction model would not calculate such a range of vibration levels from the same source type, not necessarily because of the theory involved, but because of the extensive site variables which cannot be encompassed by these models. Such site variables include, but are not limited to, machine type (and consequently the energy delivered into the ground), operating mode, operator skill, ground type (and the accurate assessment thereof), the presence of submerged solid objects (e.g. boulders), measurement technique and apparatus accuracy.

Notwithstanding these inaccuracies, it is understood that vibration specialists at Tonkin & Taylor Ltd report that when site specific testing is undertaken, a standard deviation of 0.25 (for establishing 95% confidence limits) may be achieved for determining vibration attenuation characteristics.

5.4.4 Site Testing

The emphasis for the assessment and management of construction vibration effects from the Project must be placed on site measurements prior to, and during construction. In this way a site-specific dataset can be obtained which ensures many of the variables are consistent.

Early collection of this data during initial stages of the Project's construction phase will allow a structured pragmatic approach to controlling construction vibration effects. The CNVMP provides for this with a comprehensive monitoring regime and recommendations for test measurements away from sensitive receivers.

Notwithstanding potential inaccuracies, there is value in reviewing historical measurements to predict effects, and to broadly determine the degree of risk of construction vibration. If applied conservatively with large safety margins (as in this assessment), the potential effects and risks of the Project may be identified at the assessment stage, with refinement to the prediction methods planned (through the CNVMP) as site-specific data becomes available.

5.4.5 Transmission of Ground Vibration into Buildings

Transmission from the ground into buildings is dependant on the characteristics of the building foundations. Nelson (1987)[7] notes four basic building foundation types: slab-on-grade, spread footings, piles founded on earth and piles supported by rock.

Slab-on-grade and spread footing (typical for commercial buildings and modern houses) foundations involve a significant mass of concrete in contact with the soil, so the coupling loss (see Glossary in Appendix A) is close to zero, particularly at low frequencies. The vast majority of residential dwellings adjacent to the construction footprint are assumed to be either slab-on-grade, or piles founded on earth.

Nelson states that the coupling loss for slab-on-grade construction is zero and the coupling losses for piles founded on earth (labelled as single family residencies) are as shown in Table 5.2 below:

Table 5.2: Coupling losses for vibration into buildings, from Nelson (1987)

	Frequency (Hz)					
	16	31.5	63	125	250	500
Corresponding multiplication factor for PPV value	0.6	0.6	0.6	0.6	0.7	0.9

For the assessment of effects however, it is pragmatic to note that the coupling loss may be as low as zero (for slab-on-grade foundations), so the predictions below conservatively assume no attenuation due to transmission into buildings.

5.5 Special Construction Activities

The proposed Project construction methodology includes two non-typical construction activities which are highlighted in the following Sections – blasting and tunnelling.

5.5.1 Blasting Activities – Sectors 6 and 9 only

Blasting activities have the potential to emit the highest vibration levels of all the Project's expected construction methods. It is understood that up to three blasts per day for a year may be required during the construction of the approach to the southern tunnel portal in Sector 9. The number of blasts in Sector 6 would be significantly less than this.

Both the noise and vibration effects may be mitigated by use of best practice blasting methods i.e. limiting the number of blasts per day, decked charges, frequency control, pre-splitting the rock, blasting at fixed times targeted at least disturbance, pre-warning of sensitive receivers, careful selection of charge weight and effective use of detonator time delays, which can significantly mitigate both vibration and noise effects.

The Explosive Technologies International (ETI) “Blaster’s Handbook”, contains typical prediction models for blasting vibration (see Equation 1 in Section 5.3.2). The key inputs to these models are distance (D), ground conditions (K and n) and explosive charge weight (E). The charge weight is expressed as Maximum Instantaneous Charge weight (MIC), in kg.

Measurement data has been obtained from Tonkin & Taylor Ltd for blasting in basalt. Regression analysis of the measured MIC vs distance plots show indicative ground condition values for basalt to be K = 206 and n = 1.19 i.e. a relationship of:

$PPV_{mean} = 206(D/E^{1/2})^{-1.19}$, and an upper 97.5% confidence limit of:

$PPV_{97.5\%} = 345(D/E^{1/2})^{-1.03}$, as per the statistical approach (Section 3.1.1 above) to achieve 95% confidence either side of the mean.

Table 5.3 below shows the relationship between MIC and safe distance to achieve the Project Criterion of PPV 5 mm/s, with 95% confidence:

Table 5.3: Approximate MIC and safe distance relationships for blasting in basalt, based on 95% confidence limit for measured data (Tonkin & Taylor)

Maximum Instantaneous Charge (MIC) in kg	Design Safe Distance in metres
1	61
2	86
3	106
5	136
10	193

It is understood from discussions with blasting professionals that the minimum MIC for blasting in basalt would be 2 – 3 kg for a standard (machine-drilled) hole. Smaller charge weights can be used, but this would require a change in methodology to hand-drilling, which can protract the blasting schedule and incur additional expense. An alternative to explosive charges is the Penetrating Cone Fracture (PCF) method which utilises a high-pressure gas pulse.

Based on Table 5.3 above, the use of these low-impact (or other) methods may be required for blasts within approximately 90 metres of residential dwellings. For risk assessment purposes, 90 metres is used to represent the minimum safe distance (see Section 5.6 below).

It is recommended that trial blasts in Sectors 6 and 9 are undertaken by the Blasting Contractor prior to commencement of Project blasting works, to assess the vibration effects of blasting and refine the MIC vs distance relationships referred to above. The trial process should be developed by the blasting contractor but where practicable it is recommended that they should be conducted away from sensitive receivers, but in areas of similar geology to the subject sites.

Noise from blasting must also be considered as the airblast pressure wave is often high amplitude. There is often sub-audible low-frequency noise associated with blasting which can result in the rattling of structures even when the blast is not clearly audible outdoors. This may be perceived by building occupants as being due to ground vibration. These effects would be managed using the complaints procedures of the CNVMP.

Blast noise levels will depend on local conditions, proximity of blasting to the receiver and blasting conditions (charge weight, method of blasting, weather etc.). Section 3.1.4 of the Project's Assessment of Construction Noise Effects (Technical Report G.5) refers to the Australian Standard AS 2187.2 Appendix J, and includes further details on the assessment and control of airblast.

Notwithstanding the issue of building damage, the combined noise and vibration effects of blasting can lead to adverse response from receivers in the vicinity i.e. startle reactions etc. The protocols for prior warning and consultation in the CNVMP can mitigate these effects, but generally only if the blasting occurs at a reasonable time of day. It is therefore recommended that blasting activities occur only between 0900 – 1700 hrs, Monday to Saturday.

5.5.2 Tunnel Construction – Sector 8 only

As noted above, the activities associated with tunnelling are assessed differently to other construction activities. Currently the proposed method for tunnel construction is open face excavation, which may include (but is not limited to) the use of machinery such as roadheader tunnelling machines, excavators etc. This assessment predicts and addresses vibration levels from both these two methods below. Note that tunnelling construction activities will only occur in Sector 8.

Vibration data from roadheader operation (from the Vector Tunnel project under Auckland CBD) has been obtained from Tonkin & Taylor Ltd. Excavator data has been sourced from historical measurements by MDA. These measurements were of excavators working on the ground surface, rather than underground, but this has been allowed for in the calculation methodology to predict excavator tunnelling operations (refer Section G.3 in Appendix G).

The geology of the tunnel, for its full length, comprises East Coast Bays Formation (ECBF) Siltstone and Sandstone. Accordingly, the geology is broadly categorised as Class III ground type in Table G.2 in Appendix G. Parts of the tunnel will also cut through Parnell Grit which is a weak rock derived from ancient volcanic debris flows and would be at the high end of the Class III category. The geology above this is a combination of weathered ECBF, Tauranga Group (TG) sediments, Basalt, Weathered Parnell Grit and Fill. For calculation purposes, the ground is taken to be Class III soil type.

5.5.2.1 Roadheader Tunnelling Machine

Measurements of roadheader vibration levels were undertaken at St Matthew's church in Auckland City during construction of the Vector Tunnel project. Details of these measurements are contained in Section G.5 in Appendix G.

The roadheader used for the task was a Voest Alpine AM50 model (28 tonnes). It is understood that a larger machine would be required for the Waterview Tunnel, therefore some increase in source vibration may be expected.

The vibration level measured on the church floor was no greater than PPV 0.2 mm/s whilst the roadheader was operating at a depth of approximately 46 metres.

The calculation method in Appendix G has been used to predict the minimum safe distance (that is distance underground) for the roadheader operation, taking into account the need for a larger machine. The prediction results are shown in Table 5.10 below.

5.5.2.2 Excavator Tunnelling Operations

It is understood that the Waterview Tunnel could also be constructed using appropriately configured excavators. It is anticipated that the excavators could use a bucket or pick attachment to 'dig' the soil, but if the soil type becomes too hard, an excavator mounted hydraulic rockbreaker attachment might be required.

As discussed in Section 5.4.2 above, no measurements of excavator tunnelling operations were available as source data, therefore the data for surface excavator-mounted rockbreaker and general excavator operations from Table H.1 in Appendix H has been used and modified using Equation 1 in Appendix G. The results are shown in Table 5.10 below.

5.6 Risk of Vibration Effects by Sector

The following Sections 5.6.1 – 5.6.9 outline the proposed construction activities for each Project Sector.

Each section contains a table with a list of 'design safe distances', which indicate the distance at which each vibration source is expected to comply with the DIN 4150-3:1999 Project Criterion for a residential receiver (see Section 3.3). The residential criterion has been applied because the vast majority of receivers are residences.

The vibration calculations are based on the worst-case (i.e. hardest) ground type in each Project Sector for which those works are proposed.

The closest receivers to each vibration source have been identified and categorised as high, medium or low risk of exceeding the Project Criteria, according to the following definitions:

- High Risk – Dwellings fall within the design safe distance where vibration levels are likely to exceed Project Criteria. This does not necessarily imply damage to the building structure, but these are the receivers subject to the highest vibration levels.
- Medium Risk – Dwellings are close to the design safe distance and some construction activities may approach the Project Criteria, with possible intermittent exceedances.
- Low Risk – Dwellings are sufficiently distant from construction activities so that exceedance of Project Criteria is unlikely.
- Others – No significant risk.

These risk levels also inform the community liaison process, as outlined in the draft CNVMP in Appendix K.

As discussed in Section 5.5.1 above, blasting activities have the highest potential risk of exceeding the project criteria. There are standard mitigation techniques (such as reducing MIC, electronic timing, hand drilling etc) which can be applied to reduce this risk, however these must be balanced against associated time and cost implications.

For this risk assessment, the vibration calculations have been based on the practical minimum MIC for a standard machine-drilled hole in basalt of 2 kg, which corresponds to a 'safe distance' of 90 metres from the blast location. Receivers within 90 metres are deemed high risk, with receivers between 90 and 140 metres deemed moderate risk. These receivers are shown in the aerial photographs attached in Appendix J.

The distances from the construction footprint to receivers were scaled off aerial photographs provided by Beca Ltd. A visual judgement was made on which buildings were residences (as opposed to garages, carports etc). The houses that are proposed to be removed as part of the Project are not listed in the tables below.

As discussed previously, these predictions are not sufficiently accurate to establish control lines and the tables below are primarily intended to inform the construction contractor of 'hotspots' where particular care is required. As recommended in the CNVMP, data from on-site vibration measurements should be used to refine the safe distances and risk levels.

5.6.1 Sector 1 – Te Atatu Interchange

Table 5.4: Risk assessment for construction activities in Sector 1

Source	Soil Class	Design safe distance (m)	Risk	Sensitive Receivers
Vibratory rollers for road construction	II	15m	High	16 Milich Terrace 10 Titoki Street
			Med	141C Flanshawe Road 7, 17A, 23, 25 Marewa Street 22 Paton Avenue 17 Milich Terrace 32, 34 Titoki Street
			Low	9, 13, 19A, 27 Marewa 20 Paton Avenue 12 McCormick Road 356 Te Atatu Road
Excavators	II	3m	High	16 Milich Terrace 1, 12 Alwyn Avenue 92, 92A Royal View Road
			Med	14 Milich Terrace 10 Titoki Street 25 Marewa Street 354 Te Atatu Road
			Low	7, 13 Marewa Street 8 Alwyn Avenue

5.6.2 Sector 2 – Whau River

Table 5.5: Risk assessment for construction activities in Sector 2

Source	Soil Class	Design safe distance (m)	Risk	Sensitive Receivers
Vibratory rollers for road construction	II	15m	Low	40, 42 Alwyn Avenue
Piling for bridge abutments	II	18m	Low	40, 42 Alwyn Avenue

5.6.3 Sector 3 – Rosebank – Terrestrial

Table 5.6: Risk assessment for construction activities in Sector 3

Source	Soil Class	Design safe distance (m)	Risk	Sensitive Receivers (Commercial)
Vibratory rollers for road construction	II	8m	Med	85 Patiki Road
			Low	702 Rosebank Road

5.6.4 Sector 4 – Reclamation

No vibration effects on receivers are anticipated in Sector 4 because the source-receiver distances are sufficiently large.

5.6.5 Sector 5 – Great North Road Interchange

Table 5.7: Risk assessment for construction activities in Sector 5

Source	Soil Class	Design safe distance (m)	Risk	Sensitive Receivers
Vibratory rollers for road construction	IV	30m	Low	31 Waterbank Crescent
Piling	IV	25m	Med	31 Waterbank Crescent
			Low	29 Waterbank Crescent

5.6.6 Sector 6 – SH16 to St Lukes

Table 5.8: Risk assessment for construction activities in Sector 6

Source	Soil Class	Design safe distance (m)	Risk	Sensitive Receivers
Vibratory rollers for road construction	IV	30m	High	26 Carrington Road 6A, 8A, 10, 12A Sutherland Road 23, 25, 34 Parr Road South 12, 13 Nova Place 1054A, 1044, 1042A, 1036, 1036B, 1102E, 1102F, 1102G, 1102H, 1102J Great North Road
			Med	6 Carrington Road (shop), 8, 18 Sutherland Road 12 Parr Road North 27, 34A, 34B Parr Road South 10, 11 Nova Place 1042, 1054 Great North Road
			Low	29 Parr Road South 28 Carrington Road 1046 Great North Road 1216 – 1236 (even numbers only) Great North Road (shops)
Piling for Carrington Road Bridge	IV	25m	High	26 Carrington Road
			Med	6 Carrington Road (shop)
			Low	28 Carrington Road 1236, 1238, 1232 Great North Road (shops)
Blasting	IV	90m (dependant on MIC)	High	Refer Aerial Photos in Appendix J

5.6.7 Sector 7 – Great North Road Underpass

Table 5.9: Risk assessment for construction activities in Sector 7

Source	Soil Class	Design safe distance (m)	Risk	Sensitive Receivers
Vibratory rollers for road construction	IV	30m	High	2, 4 Oakley Avenue 1467, 1471, 1479, 1481 Great North Road Waterview Kindergarten
			Med	1469, 1487 Great North Road
			Low	6 Oakley Avenue 1A, 1C, 3 Alford Street
Piling for secant pile and diaphragm walls	IV	25m	High	2 Oakley Avenue 1467, 1471, 1481 Great North Road
			Med	1479 Great North Road Waterview Kindergarten
			Low	1469, 1487 Great North Road

5.6.8 Sector 8 – Avondale Heights Tunnel

Table 5.10: Risk assessment for construction activities in Sector 8

Source	Soil Class	Design safe distance (m)	Risk	Sensitive Receivers
Tunnelling: Road header	III	6m	Med	1510 Great North Road
Tunnelling: Excavator – Bucket only	III	2m	Low	1510 Great North Road
Tunnelling: Excavator mounted rockbreaker	III	4m	Low	1510 Great North Road

5.6.9 Sector 9 – Alan Wood Reserve

Table 5.11: Risk assessment for construction activities in Sector 9

Source	Soil Class	Design safe distance (m)	Risk	Sensitive Receivers
Vibratory rollers for road construction	IV	30m	Med	105 Hendon Avenue 194A Methuen Road 5 Barrymore Road
			Low	75 – 93 (odd numbers only), 99, 101, 103 Hendon Avenue 190, 194 Methuen Road 3 Barrymore Road 17 Valonia Street
Drilling for grout curtain and secant piles	IV	15m	High	75, 77, 105, 129 Hendon Avenue
			Med	79 – 87 (odd numbers only), 99, 101, 103 Hendon Avenue
			Low	89, 91, 93, 129A Hendon Avenue 5 Barrymore Road
Piling	IV	25m	Med	105 Hendon Avenue 194A Methuen Road 5 Barrymore Road
			Low	75 – 93 (odd numbers only), 99, 101 Hendon Avenue 190, 194 Methuen Road 3 Barrymore Road 17 Valonia Street
Rockbreakers	IV	15m	Low	75 – 93, 99 – 105 (odd numbers only) Hendon Avenue 190, 194, 194A Methuen Road 3, 5 Barrymore Road 17 Valonia Street
Blasting	IV	90m (dependant on MIC)	High	Refer Aerial Photos in Appendix J

5.7 Assessment of Effects – Construction Phase

The effects of construction vibration involve large variables, predominantly with regard to different construction methods, vibration source energies, variable ground type and the behaviour of vibration waves through this inhomogeneous medium.

The most significant vibration sources and most sensitive receivers for each Sector have been predicted, and conservative calculations of critical distances in ground types relating to each Sector have been undertaken.

These results are provisional however, and must be refined and supported by site-specific measurements once construction begins, as recommended in the draft CNVMP attached in Appendix K. For crucial activities, such as blasting, vibratory compacting and pile driving, where large vibration energy is typically produced, test measurements of the initial works are recommended. The blasting programme, in particular, is heavily dependant on trial blasts to establish limits for MIC, and investigation of alternative rock-breaking methods, if appropriate.

As the repository of on-site measurements increases, the models can be refined to allow more accurate prediction of the subsequent construction stages, hence improved controls can be achieved.

The initial predictions indicate that in all Project Sectors, except Sector 4, there is some degree of risk that the Project Criteria may be exceeded. Tables 5.4 – 5.11 above outline the risk level associated with activities proposed for each Sector, and identify the sensitive receivers that would be affected by such activities.

The draft CNVMP (Appendix K) sets out the Project Criteria for control of construction activities, reiterates the risk analysis from Section 5.6, and provides details on mitigation measures that must be adopted throughout the entire Project construction. It also outlines requirements for reporting to affected parties and the Contractor Environmental Manager.

Furthermore, it is recommended that blasting activities occur only between 0900 to 1700, Monday to Saturday.

6.0 Operation Vibration

This section of the assessment addresses the operational vibration effects of the Project. That is, the vibration from traffic – in particular, heavy vehicles - on the new road alignment once completed.

6.1 Sensitive Receivers

The sensitive receivers for the operation phase of the Project are the same for the construction phase outlined in Section 5.2, i.e. residences, schools, offices, churches, rest homes and buildings that may contain vibration-sensitive equipment such as scientific or medical laboratories. However, the focus is shifted from effects on building structure to effects on human comfort.

6.1.1 Comments on Human Response to Vibration

Building damage due to vibration from the operation of the Project is considered to be highly unlikely because the vibration levels produced by traffic, even on dilapidated road surfaces, are relatively low. The ambient vibration surveys (refer Section 4.1) also indicate that building damage from Project operation is highly unlikely as the surveys recorded vibration levels (that could reasonably be attributed to traffic) no higher than 0.5 mm/s on houses adjacent to existing motorways, whereas the conservatively based building damage criteria for residences is an order of magnitude greater than this, at 5 mm/s.

Therefore, whilst the primary focus of the Project construction assessment was building damage, the primary focus of the Project operation assessment is human response.

Key aspects of the Project that may have particular vibration significance (though not necessarily any adverse effects) for sensitive receivers are:

- Establishment of roads where previously there were none
- Widening of existing roads resulting in reduced distance to receivers
- Maintaining the quality of road surface over time to ensure vibration production from traffic does not increase due to pavement dilapidation

The ambient vibration surveys outlined in Section 4.1 have established a baseline against which future vibration surveys, after completion of the Project, may be compared to identify any increase in operation vibration levels.

6.2 Operation Vibration Criteria

The Project Criteria for the operation phase are contained in Section 3.3 above. The recommended building damage criteria are the same as for the construction phase (i.e. DIN 4150-3:1999), but the Norwegian Standard NS 8176.E:2005 has been adopted for assessment of human response.

In Section 6.3.3 below, the Norwegian Standard is compared with the commonly applied (but defunct) ISO 2631-2:1989. This allows comparison and validation of the Norwegian Standard in the context of a familiar assessment framework. A similar comparison involving more standards is also contained in Whitlock, 2010 (Appendix C).

6.3 Vibration Assessment

The primary assessment of operation vibration for this study was undertaken through site measurements. The Norwegian Standard requires vibration assessments to be based on measurement of “a minimum of 15 single passings of a heavy vehicle (i.e. train, tram or heavy road vehicles with a gross weight greater than 3500kg)” and this requirement has formed the measurement methodology for this assessment.

To address vibration from surface roads, measurements of heavy vehicles on existing roads were undertaken in two locations. The first location was adjacent to State Highway 20, Mt Roskill which is the most recently opened section of SH20 just south-east of where the Project begins. This nearby site was chosen as the geology matches that of Project Sector 9, and the road surface (open grade porous asphalt (OGPA)) matches the proposed road surface for the Project.

The second location was in Quarry Road, Drury. This site was chosen because Quarry Road is dilapidated and presents a worst-case scenario should the Project road surface degrade significantly over time (although this is highly unlikely due to NZTA road maintenance policies), and because heavy trucks frequent the road.

To estimate vibration levels from the Project tunnel, site surveys in Wellington and Lyttelton were undertaken. These measurements were undertaken on occupied residential structures above the existing Terrace tunnel in Wellington and Lyttelton tunnel in Lyttelton.

6.3.1 State Highway 20, Mt Roskill

This measurement was undertaken on 5th March 2010 at the recently opened State Highway 20 alignment, approximately 300 metres south-east of the Sandringham Road Extension roundabout. Two vibration monitors[8] were placed 10 metres north of the closest (eastbound) lane of the four lane motorway (two lanes in each direction) – NZTM Coordinates: 5914065.8 N ; 1754078.7 E.

The geology close to the measurement location was provided by URS Ltd. The ground comprised gravely fill underlain with alluvium over East Coast Bays Formation at depth, so would be categorised as Class II according to Table G.2 in Appendix G. This is the same as for Sector 9 (in those areas without the basalt layer).

Seventeen truck passes in the closest lane were measured, as well as three short ambient measurements i.e. where there were no trucks and little or no car traffic on the eastbound lanes.

The results obtained from the Minimate did not show any significant difference between the truck passes and the ambient measurements, whereas the Norsonic did show a clear difference. This indicates that the Norsonic instrument has sufficient sensitivity to pick up such low vibration levels whereas the Minimate does not.

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[8] Instantel Minimate Plus with triaxial geophone and Norsonic 140 Sound Level Meter with Brüel & Kjær type 4370 accelerometer, all with current calibration certification). The Minimate geophone was fixed to the ground with ground-spikes and weighted with a sandbag, and the Bruel & Kjaer accelerometer was buried in the soil at a depth of approximately 100mm.

The measured velocity data from the Norsonic was weighted and averaged according to the NS 8176.E:2005 standard. The results are shown in Table 6.1 below:

Table 6.1: SH20 measurements at 10 metres from carriageway, classified according to NS 8176.E:2005

Source	Mean maximum weighted velocity $v_{w,max}$ (mm/s)	Std deviation σ (mm/s)	Statistical weighted velocity $v_{w,95}$ (mm/s)	Dwelling Class
17 truck passes	0.007	0.002	0.01	A
Ambient (no trucks)	0.004	0.0003	0.005	A

The Project Criterion for operation vibration is a maximum $v_{w,95}$ of 0.3 (refer Section 3.3), so these measurements comfortably comply with the criteria.

This positive result can be applied to the entire Project alignment, subject to consideration of the following factors:

- Whether any receivers will be significantly closer than 10 metres (i.e. the assessment distance) to the alignment
- Whether a harder ground type (i.e. Class III or IV) would significantly increase the vibration level
- Whether the road surface is well maintained

Whilst the effects of distance and ground type would increase the vibration level to a degree (as evidenced by the calculations associated with the construction assessment), compliance with the Project Criterion is predicted for receivers greater than 2 metres from the new motorway. There are no receivers this close to the proposed Project alignment.

Road surface maintenance is a policy issue, and there is an existing NZTA framework to ensure the pavement of the new motorway does not degrade below a certain level of roughness. In New Zealand this roughness is categorised using the National Association of Australian State Road Authorities (NAASRA) method which uses a surface profiling machine to evaluate the state of the road surface. It is understood that State Highways will generally be resurfaced for roads with NAASRA counts greater than 70 counts/km[9]. Surface roughness data for the measured section of SH20 was obtained from the NZTA and states an average NAASRA count of 25 counts/km, as at 14 January 2010.

6.3.2 Quarry Road, Drury

To assess the variation in vibration level from vehicles due to road surface roughness, measurements were also undertaken adjacent to a dilapidated road – Quarry Road, Drury.

[9] NZTA Network Operations Technical Memorandum No. TNZ TM 7003 v1 "Roughness Requirements for Finished Pavement Construction", 2006.

These measurements were undertaken near to the entrance of the Stevenson Drury Quarry, approximately 150 metres east of the Quarry Road/Fitzgerald Road roundabout - NZTM Coordinate Ref: 5889432.2 N ; 1775612.1 E. This is not an NZTA road so there is no surface roughness data available, but an inspection of the surface suggested that it would be somewhat rougher than the minimum NAASRA 70 counts/km recommendation for State Highways.

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

The geology close to the measurement location was provided by BECA. The ground comprised medium-dense gravel, clayey silt and stiff to very stiff silty clay so would be Class II according to Table G.2 in Appendix G. This is the same as for Sector 9 in those areas without the basalt layer.

Fifteen truck passes were measured, as well as an ambient measurement i.e. with no traffic on the road.

The noise-floor of the Minimate was not a significant issue because the truck vibration level was sufficiently above the ambient level.

The measured velocity data was weighted and averaged according to the NS 8176.E:2005 standard. Note that there was only one ambient measurement, so the standard deviation and thus the $v_{w,95}$ could not be calculated. However, the $v_{w,max}$ levels can be compared to ensure a sufficient signal-to-noise ratio. The results are shown in Table 6.2 below:

Table 6.2: Quarry Road measurements classified according to NS 8176.E:2005

Source	Mean maximum weighted velocity $v_{w,max}$ (mm/s)	Std deviation σ (mm/s)	Statistical weighted velocity $v_{w,95}$ (mm/s)	Dwelling Class
15 truck passes	0.11	0.04	0.18	C
Ambient (no trucks)	0.02	-	-	-

These measurements also comply with the Project Criteria of $v_{w,95}$ 0.3 mm/s, and the Norwegian Standard would rate a house in this location (notwithstanding the transfer function into the house structure) as a Class C building.

A calculation of the effect of ground type and distance has been undertaken to provide an indication of the level of risk associated with truck movements on a road in this condition. If the ground were Class IV soil type, then the Project Criterion of $v_{w,95}$ 0.3 mm/s would be exceeded for distances less than approximately 15 metres. However this is a worst case scenario and not considered applicable to the Project alignment, which will (through NZTA maintenance policy) have a well maintained road surface.

6.3.3 Verification of NS 8176.E:2005 through comparison with ISO 2631-2:1989

The data from the truck drive-by measurements (refer Sections 6.3.1 and 6.3.2 above) has also been assessed according to ISO 2631-2:1989 which has traditionally been the human response standard adopted in New Zealand. However, as discussed in Section 3, it was revised in 2003 by a standard which no longer has any vibration criteria and the New Zealand Standards Authority's adoption of the 1989 version (NZS/ISO 2631-2:1989) was withdrawn in 2005.

It is nonetheless valuable to compare both ISO 2631-2:1989 and the Norwegian Standard NS 8176.E:2005 adopted in the Project Criteria, so as to validate the selection of NS 8176.E:2005 in terms of the current framework and the common expectations regarding human response to vibration.

The metric in ISO 2631-2:1989 is different from NS 8176.E:2005. It contains weighting curves for the frequency range 1 – 80 Hz and the criteria for different receivers are based on multiplying factors of these curves. Figure 6.1 below shows the combined-direction (i.e. vertical and horizontal axis combined) weighting curves for the multiplying factors 1 – 8. These curves correspond to the criteria given in Table 6.5.

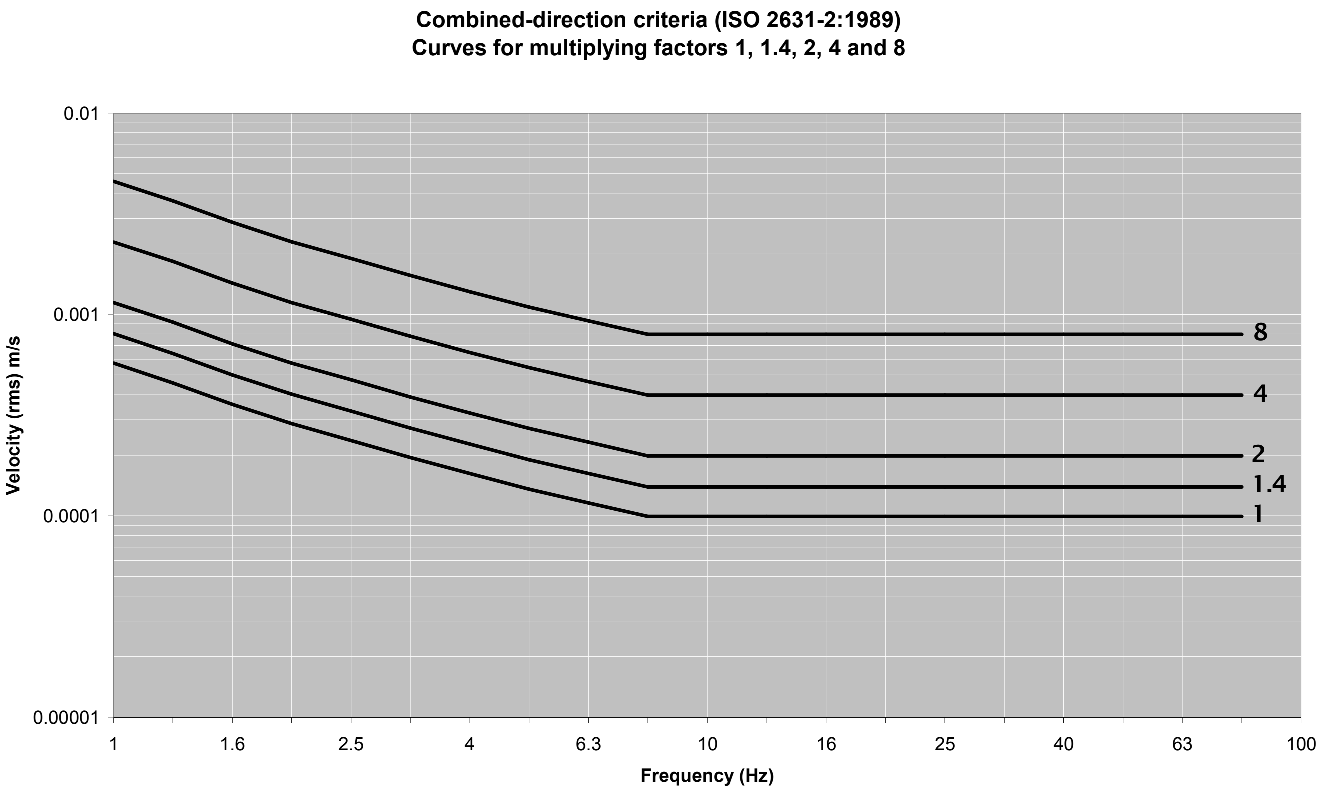


Figure 6.1 – Combined-direction weighting curves from ISO 2631-2:1989

The Standard refers to three vibration types: continuous, intermittent and transient. It states that traffic would typically be classed as intermittent as it is "as string of vibration incidents, each of short duration, separated by intervals of much lower vibration magnitudes".

The ISO 2631-2:1989 criteria for intermittent sources are summarised in Table 6.5 below:

Table 6.5: Multiplying factors to specify satisfactory vibration magnitudes for human response (ISO 2631-2:1989)

Place	Time	Continuous or intermittent vibration (Multiplying factor)
Critical working areas	Day Night	1
Residential	Day	2 to 4
	Night	1.4
Office	Day Night	4
Workshop	Day Night	8

Another difference between the two standards is that ISO 2631-2:1989 does not contain an averaging function, so for the SH20 and Quarry Road data, each truck pass is individually assessed. The quoted value in Table 6.6 below is the rating of the highest recorded truck pass.

Table 6.6 below shows the results of the four operation assessments according to both NS 8176.E:2005 and ISO 2631-2:1989.

Table 6.6: Comparison of ISO 2631-2:1989 and NS 8176.E:2005 ratings of measured road data.

Measurement Location	NS 8176.E:2005		ISO 2631-2:1989
	$v_{w,95}$ (mm/s)	Class	Multiplying factor
State Highway 20, Mt Roskill	0.01	A	1
Quarry Road, Drury	0.18	C	4

These results indicate good agreement between the two standards. The SH20 measurements were deemed to comply with the most stringent class in both standards, and for the Quarry Road measurements, both Class C (NS 8176.E:2005) and Multiplying factor 4 (ISO 2631-2:1989) are deemed the appropriate limit for residences (daytime). The two standards give equivalent assessment ratings to the same dataset, which supports the adoption of NS 8176.E:2005 as being consistent with historic NZ practice.

6.3.4 Lyttelton and Wellington

These measurements were carried out to provide information on vibration levels received by residential buildings above existing tunnels.

The two tunnels above which measurements were undertaken, were the Lyttelton tunnel in Lyttelton and the Terrace tunnel in Wellington. Both tunnels service sizable traffic volumes and, in Lyttelton's case, relatively high heavy vehicle numbers. Basic information on both tunnels is included in Table 6.3 below.

The survey locations were 18 Ticehurst Road, Lyttelton and 32 Macdonald Crescent, Te Aro, Wellington. The measurements were undertaken between 6th – 9th July 2010 using a Minimate Pro6 vibration logger (Serial No. MP12633) with a triaxial geophone transducer (Serial No. SD12580). The time trace plots are attached in **Appendix I**.

Table 6.3: Tunnel information – Lyttelton and Wellington

Tunnel Name	State Highway	Construction method	AADT[10] (2008)	Heavy Vehicles (%)	Speed limit
Lyttelton Tunnel, Lyttelton	SH 74	Drill and blast Excavation	10772	12.8%	50 kph
Terrace Tunnel, Wellington	SH 1	Road header	45394	5%	80 kph

6.3.4.1 Tunnel Geology

Information on the geology of the ground below each measurement location and the depth of each tunnel below the receivers was provided by Tonkin & Taylor Limited.

The crown of the Lyttelton tunnel is approximately 35 metres below the dwelling at 18 Ticehurst Road, Lyttelton. The geology comprises a thin zone of loess, silt and some fine sand over basalt rock. The tunnel runs through the basalt. This would be categorised as Class II over Class IV soil according to Table G.2 in Appendix G.

The geology below 32 Macdonald Crescent, Wellington is likely to comprise stiff clayey silt (derived by weathering of the underlying greywacke rock). This would be classed as Type II graduating to Type IV. The crown of the Terrace tunnel is understood to be approximately 17 metres below this residence.

Table G.1 in Appendix G shows the geology above the Project tunnel (Sector 8) to be Class III, with some Class IV basalt near the surface in places. This is slightly harder material than the two tunnels in the survey, meaning vibration energy through the soil may attenuate slightly less with distance.

6.3.4.2 Measured Vibration Levels

The measured vibration levels are consistent with those measured in the ambient vibration survey (refer Section 4.2), and the mean ambient PVS levels readily comply with the 0.3 mm/s PPV criterion for just perceptible vibration contained in BS 5228-2:2009. The Wellington dataset contains a number of periods with

[10] AADT is the Annual Average Daily Traffic flow. Data given is total for all lanes.

frequent peaks, including a maximum PVS level of 6.4 mm/s. These peaks are likely to be occupant-generated (i.e. they do not occur at night-time when the occupants would be asleep). It is noted that in addition to any tunnel traffic vibration, there could be some influence from traffic on local surface roads. Table 6.4 below contains the summary data:

Table 6.4: Ambient vibration results – Lyttelton and Wellington

Address	Mean Ambient PVS (mm/s)	Maximum PVS (mm/s)
18 Ticehurst Road, Lyttelton	0.28	0.98
32 Macdonald Crescent, Wellington	0.1	6.4

A degree of assurance that the vibration peaks must be due to occupants, can be obtained by extrapolating the measured level down to tunnel depth and predicting the magnitude of source vibration that would be required to produce the measured levels. In Wellington, for example, the 6.4 mm/s PPV peak may be projected as requiring a source vibration exceeding 250 mm/s. It is inconceivable that any traffic activity could generate this level of vibration, which would be more typical of an explosive blast.

The key findings are:

- When questioned, the occupants at 32 Macdonald Crescent, Wellington and 18 Ticehurst Road, Lyttelton expressed no concern over vibration of any kind. In fact, the Lyttelton residents seemed unaware that they lived directly above the tunnel.
- The level of vibration generated by occupant activity exceeds the levels recommended as either operation or construction activity limits.

6.4 Assessment of Effects – Operation Phase

An assessment of vibration effects from the operation phase of the Project has been undertaken in the following manner:

- Measurement of heavy vehicle movements on various road surface types, according to the NS 8176.E:2005 standard
- Assessment of the effect of ground type and distance on these measurements to establish the minimum safe distance under least favourable conditions
- Measurement of vibration levels on two houses above existing State Highway Tunnels and assessment of the measured levels according to NS 8176.E:2005
- A comparison of the measured levels as assessed by both ISO 2631-2:1989 and NS 8176.E:2005 standards to validate the adoption of NS 8176.E:2005.

The effects of vibration from road traffic, in particular heavy vehicle movements, are expected to be les than minor provided the Project road surface is monitored and maintained in accordance with the NZTA policy for road roughness. It is noted that there is a significant safety margin here, as significant road surface degradation (in excess of the NZTA controls) would be required to generate an adverse effect.

7.0 Summary and Conclusions

A detailed assessment of construction and operation vibration effects has been undertaken for the Waterview Connection Project. The assessment has identified and quantified potential vibration risks associated with construction activities, and the likelihood of ongoing effects from traffic vibration after completion.

The assessment of effects draws on data obtained through on-site measurements of existing vibration environments, review and implementation of historical construction vibration measurements, and the use of empirical prediction models.

The use of the collected historical dataset of construction vibration measurements has, at this stage, provided general guidance on safe distances for construction plant and activities which has, in turn, allowed identification of at-risk receivers. However, site-specific measurements are needed to refine the prediction models and, hence, the risk categories, so a comprehensive vibration assessment during the early stages of construction is recommended.

The building damage assessment, which is the focus of the Project construction phase, is based on German Standard DIN 4150-3:1999, which is the commonly adopted control used in New Zealand. It is anticipated that the Project's most significant vibration effects are likely to come from the excavation of basalt rock in Sectors 6 and 9. The blasting programme will need to be carefully designed and monitored to ensure the vibration levels are kept within the Project Criteria as far as practicable.

In general, initial predictions of construction vibration levels indicate there is some degree of risk that the Project Criteria may be exceeded. The development of a Construction Noise and Vibration Management Plan (CNVMP) is recommended as the tool to ameliorate this risk, and should outline the methodology for assessing, managing and mitigating the Project construction effects.

The assessment of human response to vibration, which is most relevant to operation effects once the Project is complete, is based on the Norwegian Standard NS 8176.E:2005. The operation vibration effects are predicted to be negligible, provided the road surface of the new motorway is maintained in accordance with NZTA standard policy.

These assessments lead to the following recommendations:

- Prior to the Project commencement, an ambient vibration survey should be undertaken involving measurements at locations nominated by NZTA
- A Construction Noise and Vibration Management Plan (CNVMP) should be developed, with contents in accordance with Section 5.2 of this assessment. A draft CNVMP is attached in Appendix K
- The Project construction should be measured and assessed in accordance with the German Standard DIN 4150-3:1999 and should, as far as practicable, comply with the criteria in that Standard
- Blasting activities should be undertaken only between 0900 – 1700hrs, Monday to Saturday

Overall, it is considered that the Waterview Connection Project can be constructed and operated such that adverse vibration effects can be avoided, remedied or mitigated.

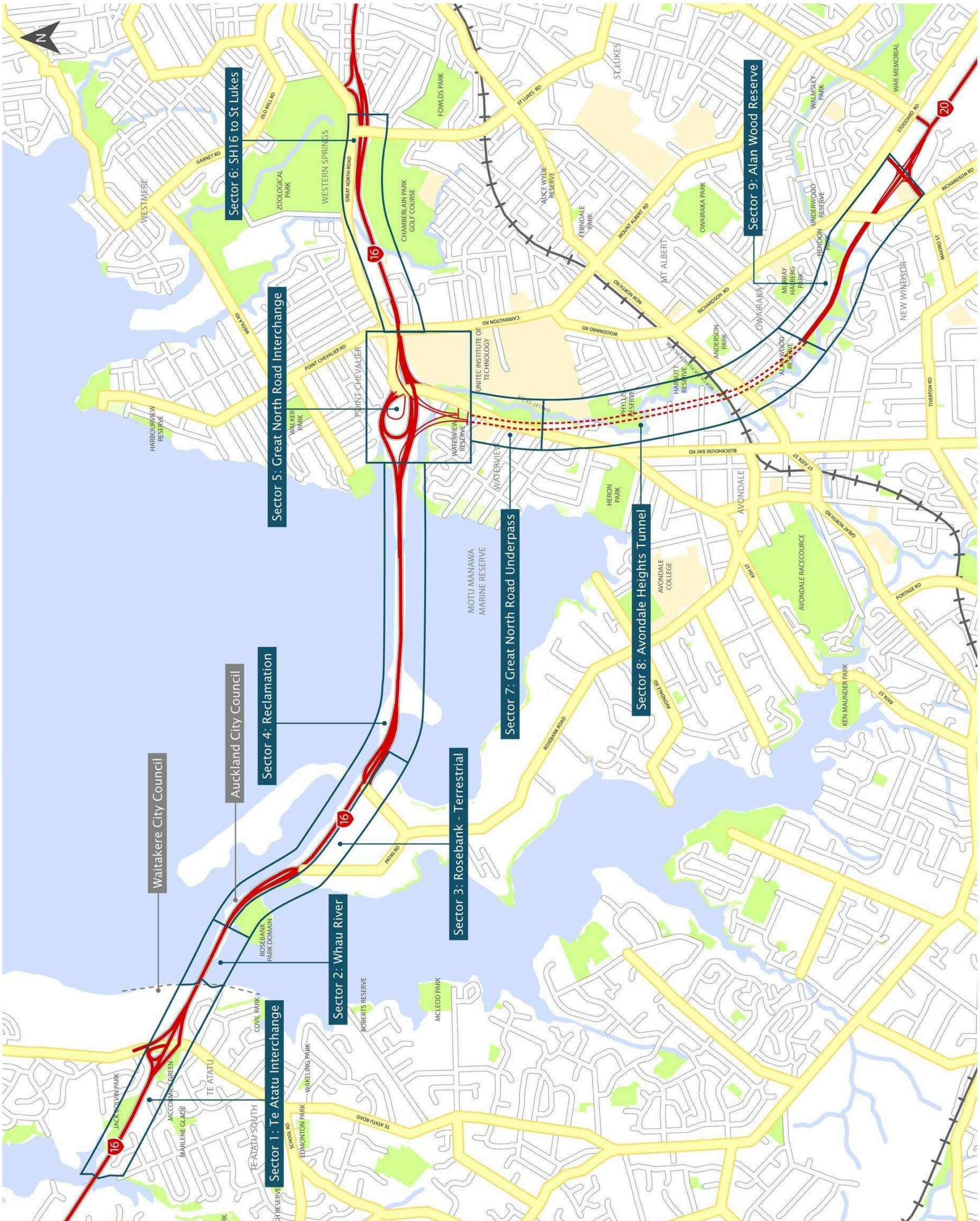
APPENDIX A

Glossary of Terms

CNVMP	Construction Noise and Vibration Management Plan.
Coupling Loss	The reduction in vibration energy across the interface between the ground and a building structure.
Geophone	Measurement transducer which measures vibration velocity. Usually triaxial.
Ground attenuation	The reduction in vibration level over distance due to spreading, absorption and dissipation of the vibration energy. Vibration level typically attenuates according to an inverse power-law relationship, which is heavily dependant on ground conditions
Longitudinal Axis	Vibration axis in the horizontal plane , where the particle movement is parallel to the direction of the source i.e. forward and back
MIC	Maximum Instantaneous Charge weight. Used in blasting calculations to represent the amount of explosive per hole. Units are kilograms (kg)
NAASRA Count	National Association of Australian State Road Authorities' method of quantifying road roughness.
Noise-floor	The noise floor of a measurement device is an underlying signal generated by the device's electronic components, meaning it cannot measure an absolute zero level. For measurements in very low vibration environments, the recorded data may show the noise-floor because any actual vibration is too low for that device to measure.
OGPA	Open Grade Porous Ashpalt. A low noise and vibration road surface proposed for the Project alignment
PPV	Peak Particle Velocity. Standard metric for building damage assessments. Units are mm/s
PVS	Peak Vector Sum. The vector sum of the PPV levels in all three axes
Sensitive receivers	Buildings and/or occupants of buildings for which vibration effects should considered due to their proximity to vibration sources and/or particular sensitivity to vibration (i.e. sleep disturbance). Building structure is the primary concern for the construction phase, whereas the comfort of building occupants is the primary concern for the operation phase
Transverse Axis	Vibration axis in the horizontal plane, where the particle movement is perpendicular to the direction of the source i.e. side to side
Triaxial	Measures vibration in all three axes (longitudinal, transverse and vertical) simultaneously
Vertical Axis	Vibration axis in the vertical plane where the particle movement is perpendicular to the ground surface i.e. up and down

APPENDIX B

Project Sector Diagram



Western Ring Route: Waterview Connection (SH16-20) - Sector Diagram

APPENDIX C

Vibration Standards Review Paper – J Whitlock, 2010

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

James Whitlock – Marshall Day Acoustics **June 2010**

1.0 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 their 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).

The New Zealand Standards authority currently has no environmental vibration standards 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 for assessments of human response to vibration, and the German Standard DIN 4150-3:1999 is commonly adopted for building damage assessments.

The common use of a superseded standard is open to criticism, particularly when applied to large infrastructure projects such as the Waterview Connection Project where, due to the resource management hearing review process, current and appropriate criteria must be used in assessing vibration effects on sensitive receivers.

This paper reviews a number of relevant international vibration standards considered to be relevant to building damage risk and human response. The criteria and methodologies 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.

2.0 HUMAN RESPONSE STANDARDS

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

During construction activities, the level of tolerance tends to relate to peoples' concern over possible building damage to dwellings from particular activities, whereas any effects from the operation of a project may occur over a longer timescale as health and/or annoyance effects become apparent. Standards regarding building damage risk assessments are addressed in Section 4.0 below.

Human response standards use a range of calculation methods, weightings and rating curves to establish vibration values suitable for the assessment of human exposure. Therefore it is difficult to directly compare and contrast them based on the criteria alone. In Section 3.0 below, a comparison of three 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.

2.1 ISO 2631-2:1989

The 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 Section 2.2) and the assessment criteria were removed from the 2003 version due to international criticism.

However, the 1989 Standard is still referenced (due to its assessment criteria) by a number of New Zealand’s legislative and requiring authorities, as follows:

- 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 Agency (NZTA) Environmental Plan

The criteria contained in the Standard are multiplying factors of base curves (expressed as both acceleration and velocity values) 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.”

There are 3 sets of base curves for each metric (i.e. 3 expressed in acceleration and 3 in velocity). The first are for z-axis (foot-to-head) vibration, the second for x-axis or y-axis (side-to-side or back-to-chest) vibration, and the third for combined-axis vibration where the worst-case combination of the previous sets is applied. Generally the third set are used for preliminary investigations to decide whether further investigation is necessary.

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

"Table 4 – 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 excitation with several occurrences per day***
Critical working areas	*Day* *Night*	*1*	*1*
Residential	*Day*	*2 to 4*	*30 to 90*
	Night	*1.4*	*1.4 to 20*
Office	*Day* *Night*	*4*	*60-128*
Workshop	*Day* *Night*	*8*	*90-128"*

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.

2.2 ISO 2631-2:2003

In April 2003, the 1989 version of ISO 2631-2:1989 was superseded and the revised version contained no assessment criteria. It removed the guidance values (Table 4 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 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.

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.

2.3 AS 2670-2:1990

The Australian Standard AS 2670-2:1990 is identical to ISO 2631-2:1989, and despite the ISO Standard having been superseded, the AS Standard 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.

AS 2670-2:1990 could be adopted in New Zealand in order to, in essence, retain ISO 2631-2:1989. However, such adoption would ignore the deliberate action of the ISO retracting the Standard, and is not recommended.

2.4 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 also similar to ISO 2631-2:1989. The weighting base-curves for vertical and horizontal vibration match (with very few exceptions) the ISO curves, and the recommended criteria are very similar if slightly more stringent.

Unlike ISO 2631-2:1989, the ANSI 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 unachievable criteria.

The ANSI Standard was developed in 1983, but was revised in 2006; the introduction in the revised Standard 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.

2.5 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 4.1 below).

The DIN 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[1] 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.

[1] DIN 45669-1:1995 "Mechanical vibration and shock measurement – Part 1: Measuring equipment"

In general, the DIN 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.

2.6 NS 8176E:2005

The Norwegian Standard NS 8176.E:2005 "Vibration and shock – Measurement of vibration in buildings from landbased 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.[2]

The NS Standard outlines the requirements for measuring equipment, and outlines a measurement procedure which requires a minimum of 15 single 'passings' of a heavy vehicle (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[3], 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[4].

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 that can assist in predicting and quantifying vibration effects. It is similar to Shultz curves[5] for noise but may not have been as thoroughly tested to determine the veracity of the curves.

[2] SH1 Waiouru Peninsular Connection, SH1 North Shore Busway, Esmonde Rd Interchange, SH16 Western Ring Route - Henderson Creek to Waimumu Bridge.

[3] The W_m weighting curve is defined in ISO 2631-2:2003

[4] 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

[5] Schultz, T. J. "Synthesis of social surveys on noise annoyance", Journal of the Acoustical Society of America, 64, pp 377-405, 1978

Appendix B of the NS Standard gives guidance classification of dwellings in relation to their sensitivity to vibration. The four classes of dwelling[6] 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

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 B.1 Guidance classification of swellings with the upper limits for the statistical maximum value for weighted velocity $v_{w,95}$ or acceleration $a_{w,95}$

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"*

It is noted that 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.

[6] Established in NS 8175:2005 "Sound conditions in buildings – Sound classes for various types of buildings"

2.7 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 contains VDV ranges which may result in adverse comment in residential buildings, as follows:

"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 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*

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 h day."

There is however some controversy surrounding the use and usability of VDV. Its calculation method is complex and results in values with the rather maladroit units of $ms^{-1.75}$. Additionally, 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, 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)[7].

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

2.8 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.

[7] Greer, R., Thornley-Taylor, R. et al. "ANC round robin VDV measurement exercise analysis of eVDV data", Acoustics Bulletin Mar/April 2005.

The recommended criteria are as follows:

"Table 1 ***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*
	Day	*6.0 to 10.0*
Residential	*Night*	*2.0*
	Other times	*4.5*
Offices	*Any time*	*14.0*
Workshops	*Any time*	*14.0*

NOTE 1 This table recommends magnitudes of vibration below which the probability of adverse comment is low (noise caused by any structural vibration is not considered)

NOTE 2 Doubling the suggested vibration magnitudes could result in adverse comment and this will increase significantly if the magnitudes are quadrupled

NOTE 3 For more than three occurrences of vibrations per day see the further multiplication factor in 6.2"

When compared with ISO 2631-2:1989 and NS 8176.E:2005 (see Section 3.0), the recommended criteria in both BS 6472 Parts 1 and 2 are very lenient. For instance, it can be seen that vibration levels of 6 - 10 mm/s PPV (which would exceed the DIN 4150-3:1999 standard for residential building damage risk between 1-10Hz) are 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 (refer Section 4.2 and 4.3) are significantly less stringent than those in the commonly adopted DIN 4150-3:1999 (Section 4.1).

This BS 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". This Australian Standard also references BS 7385-2 in relation to building damage.

It is possible that the lenient approach taken by the British Standards is defendable, 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.

2.9 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), which are described in Sections 2.6, 2.7 and 4.2, 4.3 respectively).

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.*

Table B.1 ***Guidance on the effects of vibration levels***

Vibration level (PPV)	*Effect*
0.14 mm/s	*Vibration might be just 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 be just 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."*

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 project specific construction management plans.

2.10 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 New Zealand adoption of this Standard (NZS/ISO 2631-2:1989) was therefore withdrawn by Standards New Zealand.

Relevant international standards from the UK, Europe, United States and Australia have been reviewed. 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 assessing vibration effects of traffic and rail, as it contains a statistical approach to vibration events and community response relationships, has a history of successful implementation in major roading projects in New Zealand, 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 the Norwegian Standard only addresses 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 (see Section 3.0 below) and further investigation would be required to rationalise the criteria before it could be considered for adoption in New Zealand.

3.0 EQUIVALENCY STUDY

To compare and contrast the human response standards, a dataset of truck drive-by measurements were assessed against the standards contained in Section 2.0 above – ISO 2631-2:1989, ANSI S2.71-1983 (R 2006), NS 8176.E:2005 and BS 6472-1:2008. 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.

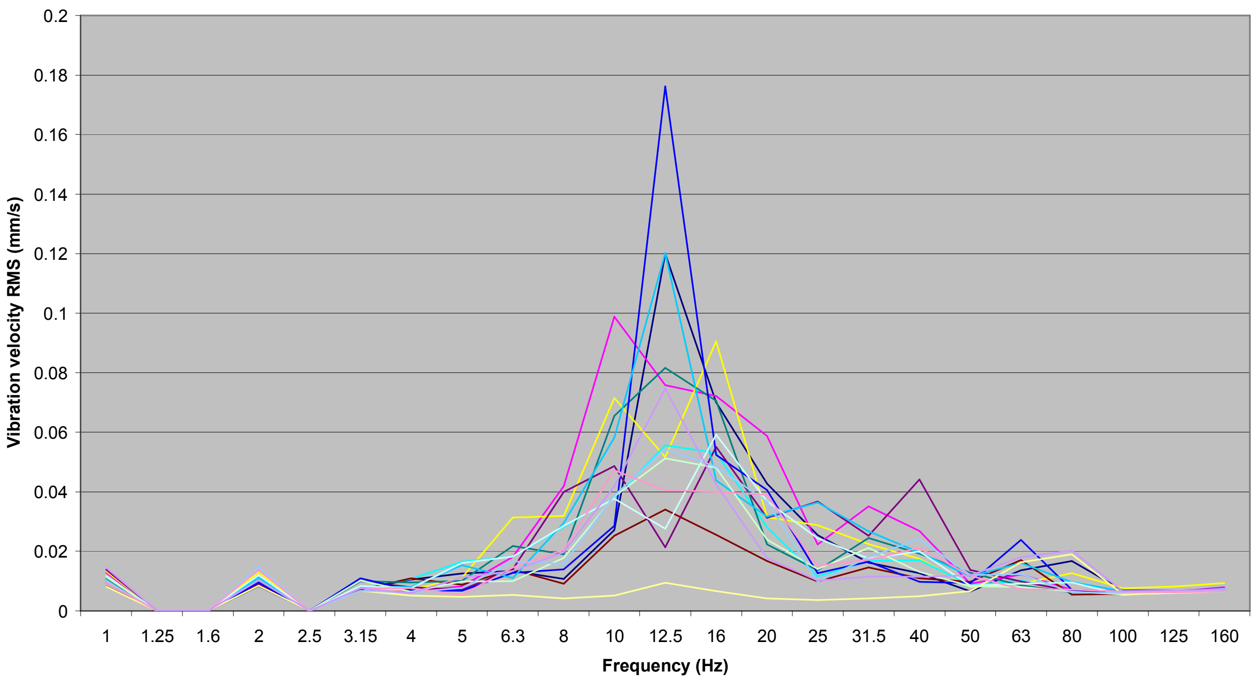
The measurements were undertaken on 13th January 2010 using an Instantel Minimate Plus vibration meter with tri-axial geophone. The meter was positioned 25 metres from the closest lane of the two lane road (one lane in each direction). The geophone was fixed to the ground with ground-spikes and weighted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

Figure 1 below shows a plot of the RMS velocity data in 1/3 octave frequency bands:

Figure 1: Measured Truck Vibration Velocities



The measured vibration velocity data was processed using the calculation methods contained in the four standards. The results are shown in Table 1 below:

Table 1: 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)	Dwelling Class	VDV ($m{\cdot}s^{-1.75}$)	Multiplying factor (worst truck pass)	Multiplying factor (worst truck pass)
Calculated Vibration Level	0.18	C	0.016	4	4
Assessment	Complies for criterion for existing dwellings. Approx. 12% may be moderately/highly annoyed		Readily complies with residential night-time criterion (0.1 $m{\cdot}s^{-1.75}$). Low probability of adverse comment	Complies with residential daytime criterion, but exceeds night-time criterion	Complies with residential daytime criterion but exceeds night-time criterion

This comparison indicates 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.

Subjectively, 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[8], 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 2 above for these standards generally represents the entire dataset.

4.0 BUILDING DAMAGE STANDARDS

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

4.1 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[9]. Two versions of the standard – the current 1991 version, and the earlier 1986 version – are referenced in several local government and requiring authority documents, for example:

[8] The ‘frequency of occurrence multiplying factor’ in the ANSI standard is not an averaging method, but rather a method to estimate the cumulative effect of multiple occurrences of one event. It has not been applied due to the reservations expressed in Section 2.4.

[9] State Highway 20 Avondale, Vic Park Tunnel, State Highway 18 Greenhithe, Northern Busway, Auckland War Memorial Museum

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 or pile driving.
- Waitakere City District Plan - rule 13.1(c) regarding blasting in quarry areas
- The New Zealand Transport Agency (NZTA) Environmental Plan

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 2 below. This table is a combination of Tables 1 and 3 of the Standard:

Table 2: 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 (mm/s)	PPV at horizontal plane of highest floor (mm/s)
	1 - 10Hz (mm/s)	10 - 50 Hz (mm/s)	50 - 100 Hz (mm/s)		
Commercial/Industrial	20	20 – 40	40 – 50	40	10
Residential/School	5	5 – 15	15 – 20	15	5
Historic or sensitive structures	3	3 – 8	8 – 10	8	2.5

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 precedent for this approach in Section 8.8.2.7e of the Auckland City District Plan – Isthmus Section for blasting, which states:

> *"… blasting activities undertaken at the Mt Wellington Quarry and Three Kings Quarry and any extensions to those quarries shall be conducted so that 95% of the blasts undertaken (measured over any twenty blasts on the foundation of any building outside the Business 7 zone) shall produce peak particle velocities not exceeding 5mm/s and 100% of the blasts undertaken shall not exceed 10mm/s irrespective of the frequency of the blast measured".*

It is considered appropriate to adopt this methodology for blasting. For all other construction activities, it should be noted that exceedance of the Standard does not necessarily imply damage will be caused and management of any measured exceedances should be addressed in a project specific vibration management plan.

4.2 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 (refer Section 4.3), 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:

- *"Cosmetic*
  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
- *Minor*
  The formation of large cracks or loosening and falling of plaster or drywall surfaces, or cracks through bricks/concrete blocks
- *Major*
  Damage to structural elements of the building, cracks in support columns, loosening of joints, splaying of masonry cracks etc."

This BS Standard is not known to be referenced in any New Zealand standards, or by any regional authorities.

4.3 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, as follows:

"Table 1 – 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 Hz to 15 Hz	***15 Hz and above***
1	*Reinforced or framed structures Industrial and heavy commercial buildings*	*50 mm/s at 4 Hz and above*	
2	*Unreinforced or light framed structures Residential or light commercial type buildings*	*15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz*	*20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above*

NOTE 1. Values referred to are at the base of the building (see 6.3)
NOTE 2. For line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded."

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 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.

4.4 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 – see Section 2.8).

However, the British Standards 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 construction projects. Its criteria are more conservative than BS 7385-2:1993, but have 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 the most suitable to assess and quantify the risk of building damage from vibration.

5.0 SUMMARY AND CONCLUSIONS

A number of international 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 that 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 the 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. It 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

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

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

The recommended standard for building damage risk is DIN 4150-3:1999 as it is widely recognised and successfully implemented in New Zealand. It contains conservative criteria, so the application of a statistical approach to its implementation is considered appropriate.

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, the British suite contains significantly more lenient criteria. This is not to say that the criteria are wrong, but an abrupt change 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.

6.0 REFERENCES

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APPENDIX D

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BS 5228-2:2009 "Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration", British Standards Institute, 2009

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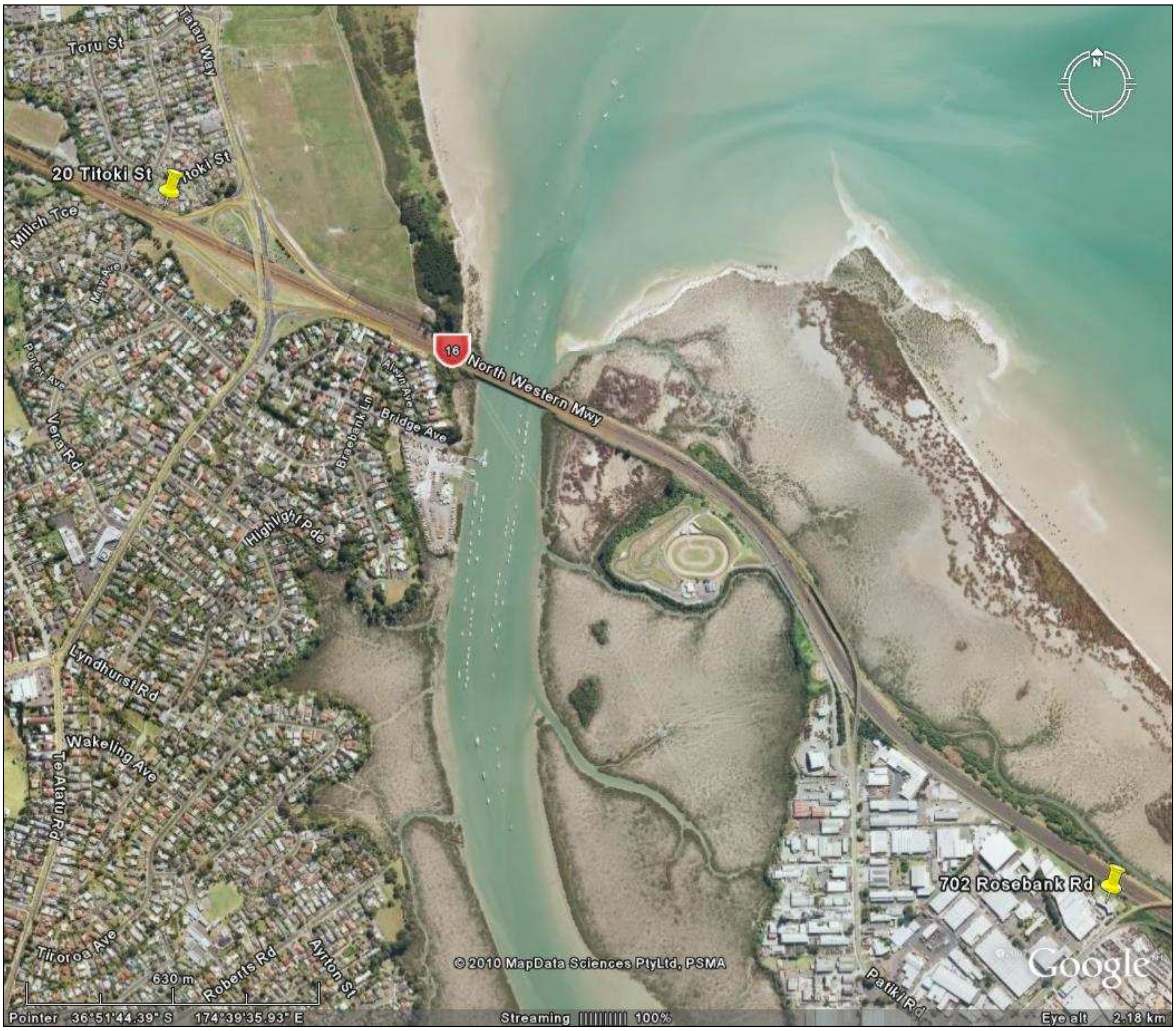
APPENDIX E

Ambient Vibration Survey – Aerial Photographs of Locations

Position 1 – 20 Titoki Street, Te Atatu
Position 2 – 702 Rosebank Road, Avondale



Position 3 – 77 Herdman Street, Waterview
Position 4 – 1102g Great North Road, Point Chevalier
Position 5 – Waterview Primary School, Waterview
Position 6 – 58 Blockhouse Bay Road, Avondale

Position 7 – 204 Methuen Road, New Windsor
Position 8 – Christ the King School, New Windsor

APPENDIX F

Ambient Vibration Survey – Survey Sheets

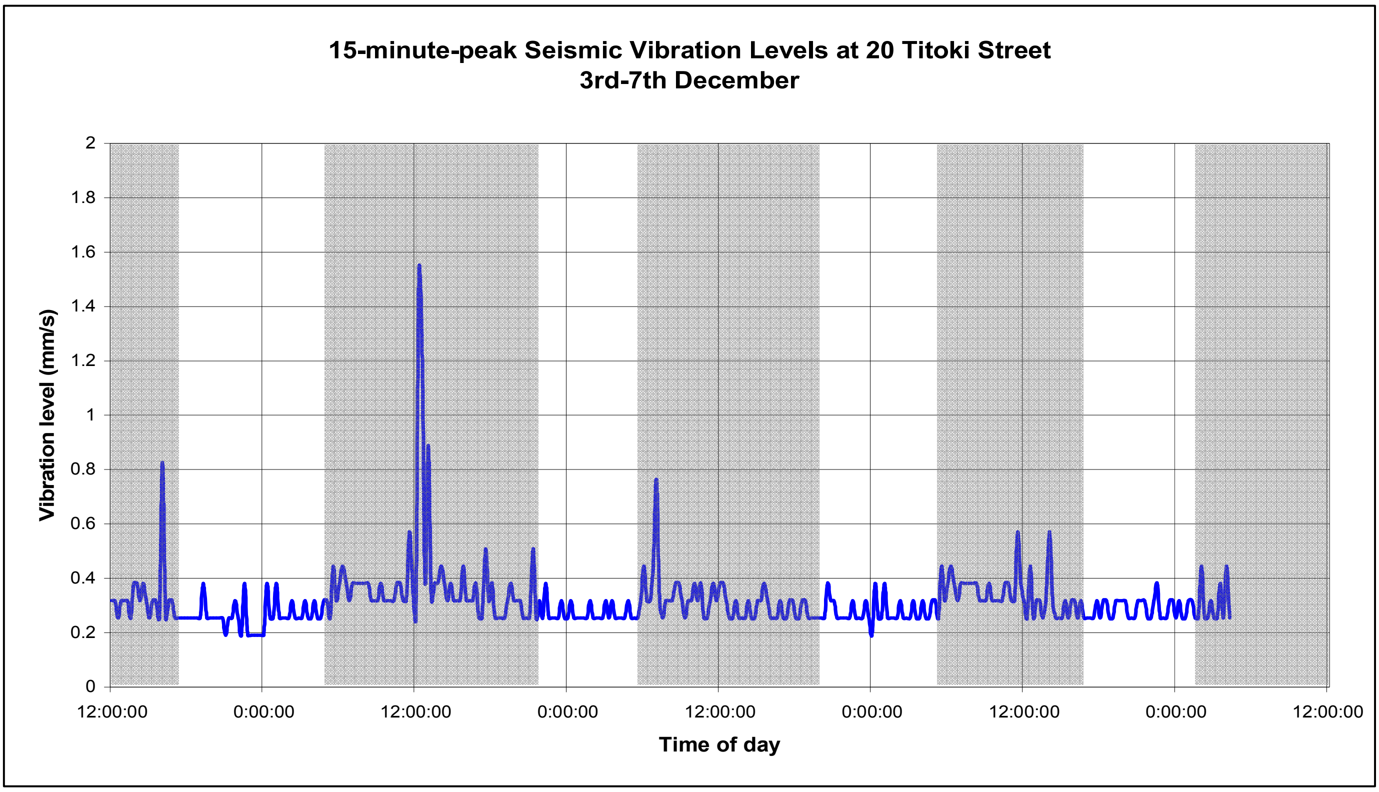
Waterview Connection - Ambient Vibration Monitoring Results

Location: 20 Titoki Street
Project Sector: 1
Date: 3rd – 7th December 2009
Distance to major road: 33 metres from SH16
Equipment: Nomis Mini Supergraph

Maximum peak vector sum (PVS): 1.5 mm/s
Mean ambient PVS: 0.28 mm/s

Setup comment: The geophone was clamped to mid-span of a timber sub-floor bearer under the west side of the house.

Results comment: The dwelling was inhabited by a single elderly occupant. The vibration peaks are most likely due to movements on the floor above the transducer.



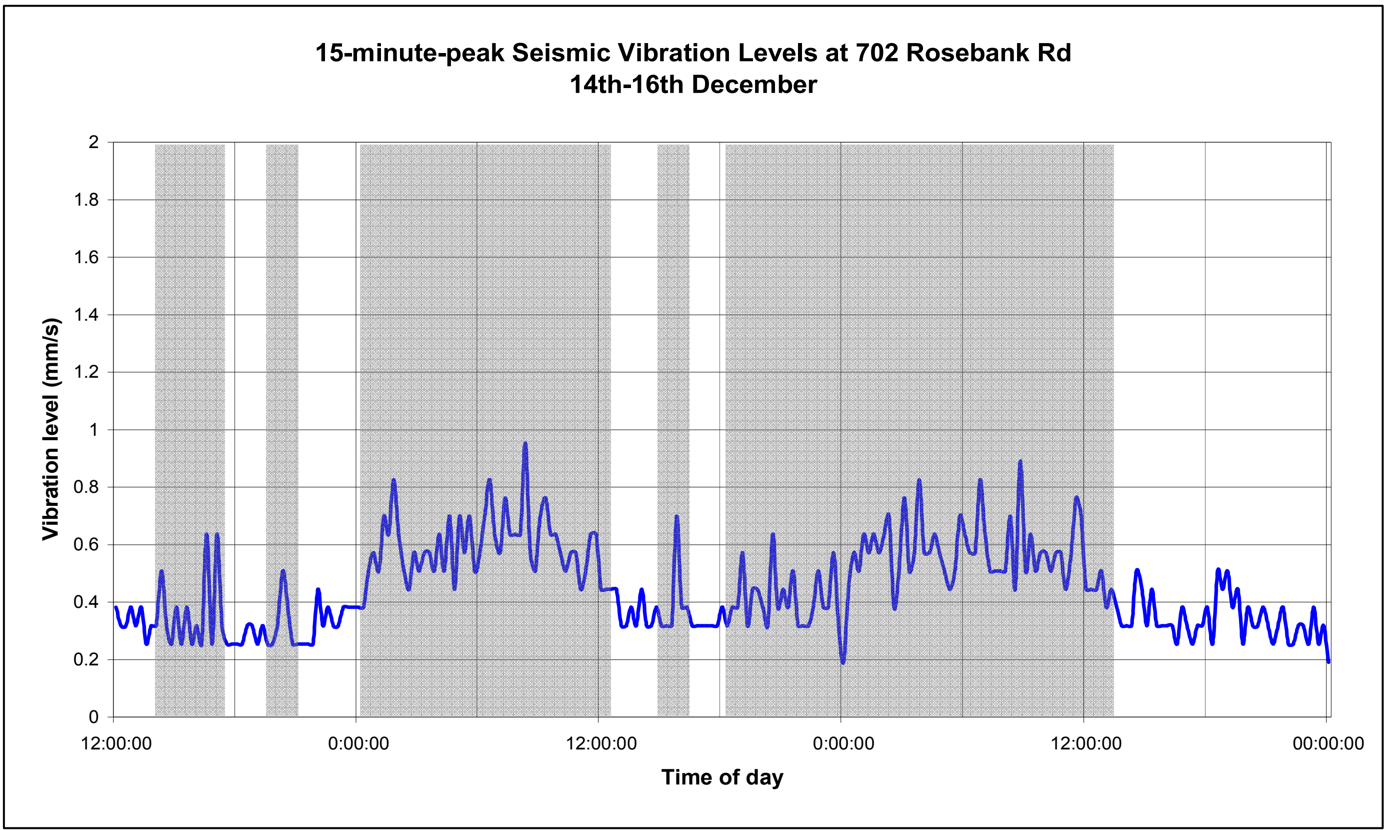
Waterview Connection - Ambient Vibration Monitoring Results

Location:	702 Rosebank Road
Project Sector	3
Date:	14th – 16th December 2009
Distance to major road:	36 metres to SH16
Equipment:	Nomis Mini Supergraph

Maximum peak vector sum (PVS):	0.95 mm/s
Mean ambient PVS:	0.2 mm/s

Setup comment: The geophone was placed on patio tiles and weighted with a sandbag.

Results comment: The vibration pattern is irregular and difficult to explain, but the levels are not high. Construction and heavy manufacturing were occurring 50 metres away.



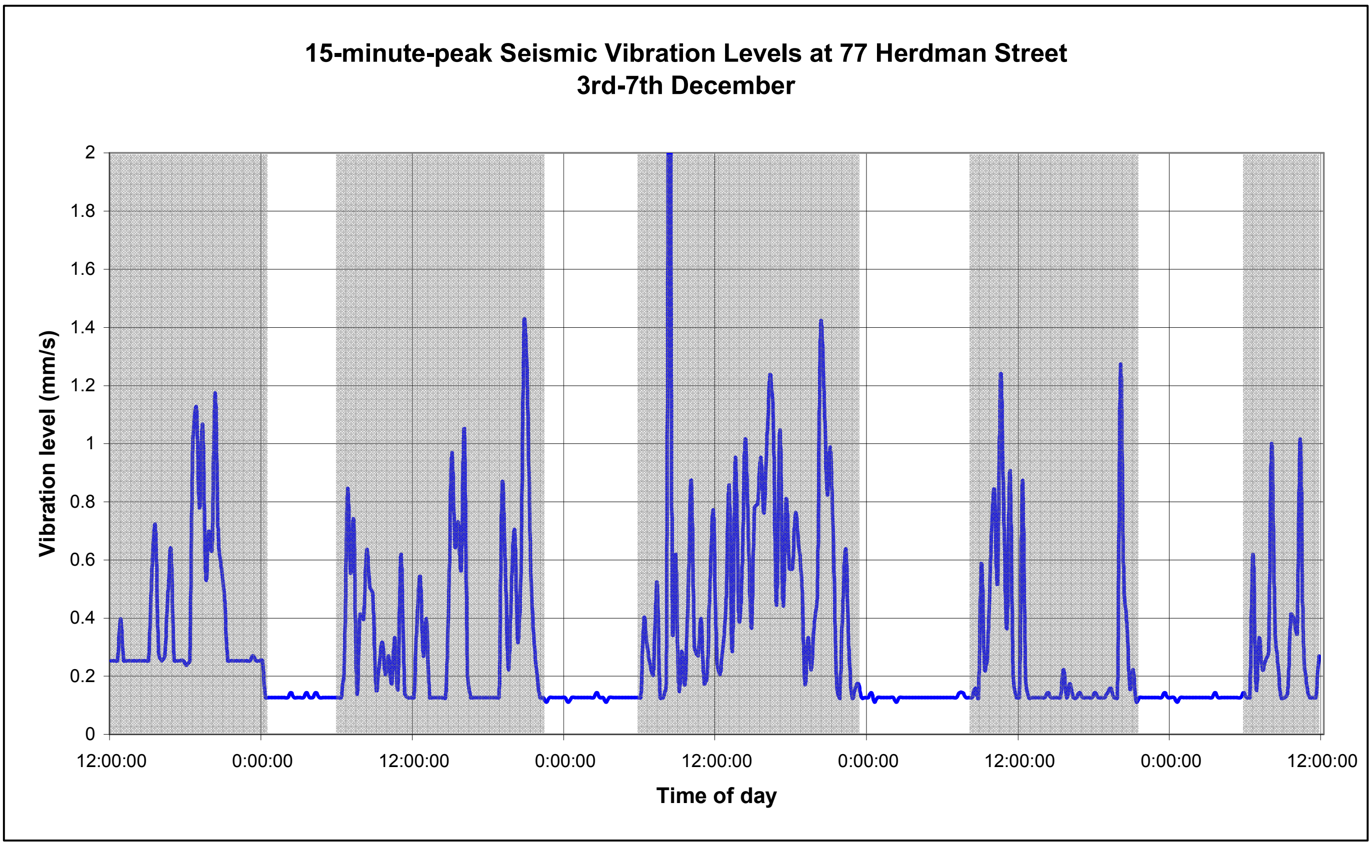
Waterview Connection - Ambient Vibration Monitoring Results

Location:	77 Herdman Street
Project Sector	5
Date:	3rd – 7th December 2009
Distance to major road:	140 metres from SH16
Equipment:	Nomis Mini Supergraph

Maximum peak vector sum (PVS):	2.7 mm/s
Mean ambient PVS:	0.13 mm/s

Setup comment: The geophone was clamped to a timber sub-floor perimeter bearer under the north side of the house.

Results comment: Due to the distance from any major roads, all large vibration peaks shown below are likely to be due to activity within the house rather than traffic.



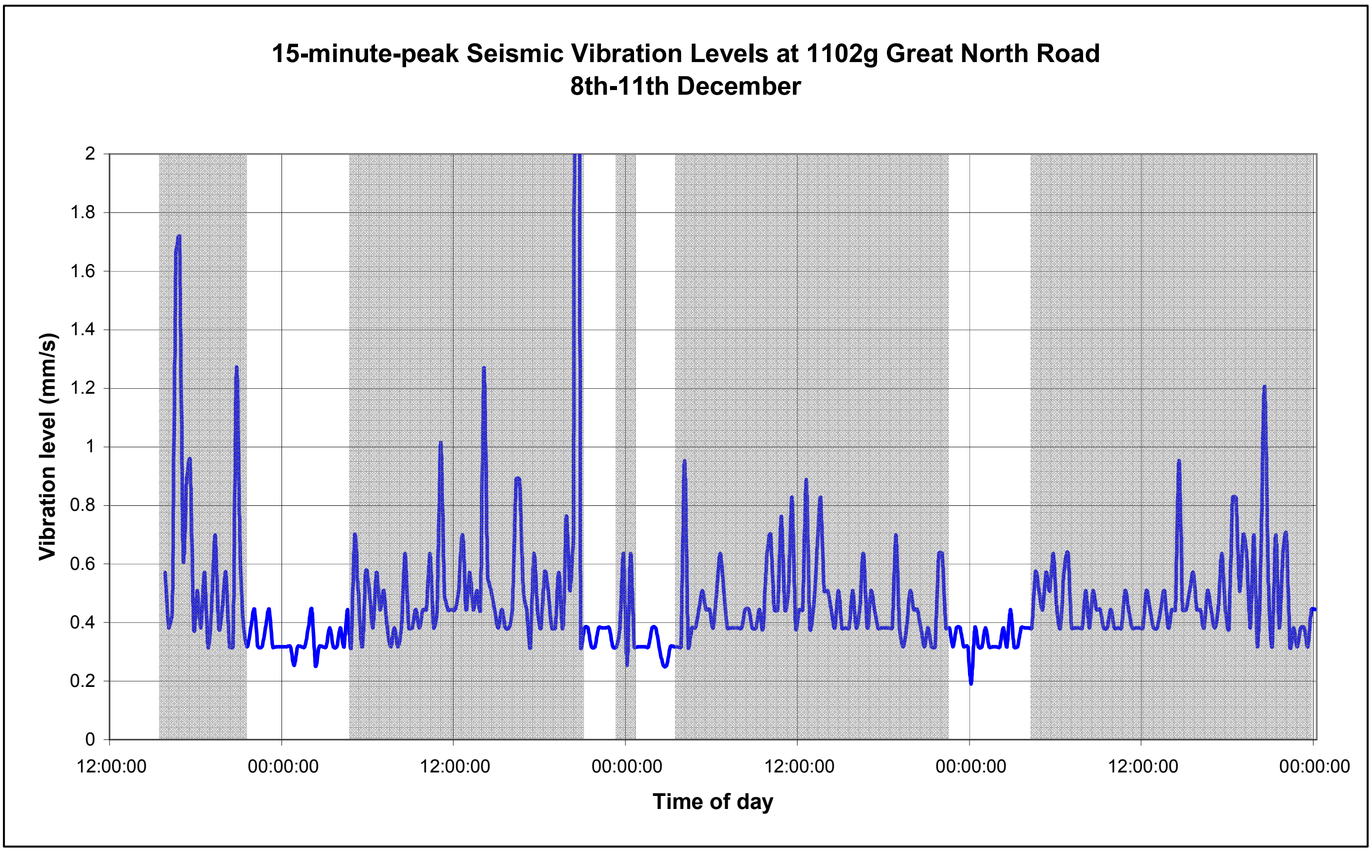
Waterview Connection - Ambient Vibration Monitoring Results

Location:	1102g Great North Road
Project Sector:	6
Date:	8th – 11th December 2009
Distance to major road:	18m from SH16
Equipment:	Nomis Mini Supergraph

Maximum peak vector sum (PVS):	7.4 mm/s
Mean ambient PVS:	0.34 mm/s

Setup comment: The geophone was clamped to the top of a window opening in the concrete basement wall.

Results comment: The vibration peak which reaches over 7 mm/s is an order of magnitude greater than normal background vibration, and hence unlikely to be due to traffic.



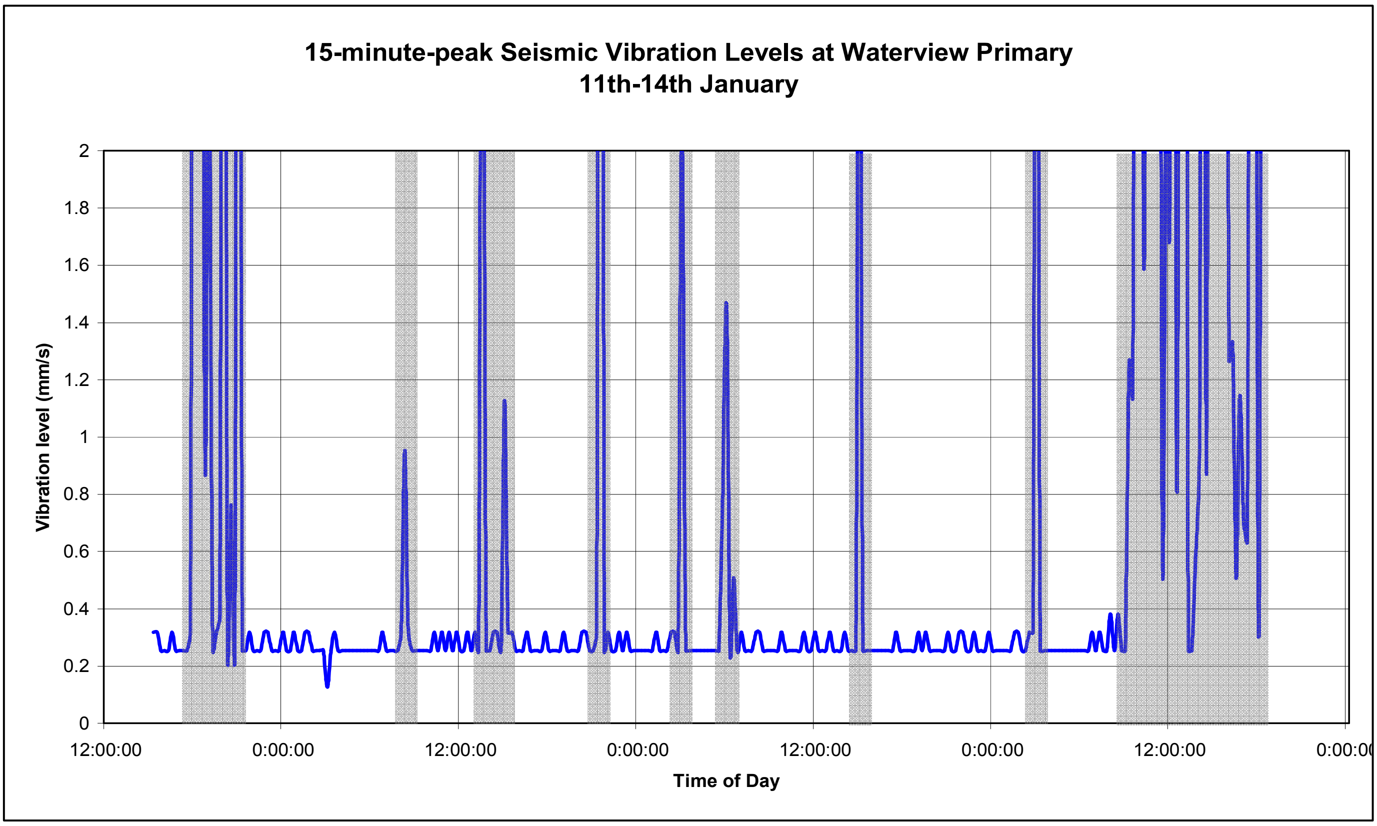
Waterview Connection - Ambient Vibration Monitoring Results

Location:	Waterview Primary School
Project Sector:	7
Date:	11th – 15th January 2010
Distance to major road:	87 metres from Great North Road
Equipment:	Nomis Mini Supergraph.

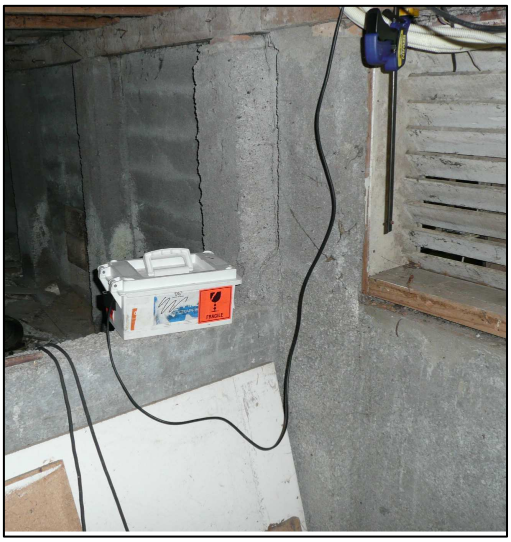
Maximum peak vector sum (PVS):	8 mm/s
Mean ambient PVS:	0.27 mm/s

Setup comment: The geophone was clamped to the side of a timber sub-floor bearer (approximately 200mm from a pile) under the school hall bathrooms.

Results comment: The clusters of vibration peaks are likely due to activities in the hall which is generally not used during normal teaching hours, or possible due to water-hammer in the adjacent pipes.



Waterview Connection - Ambient Vibration Monitoring Results

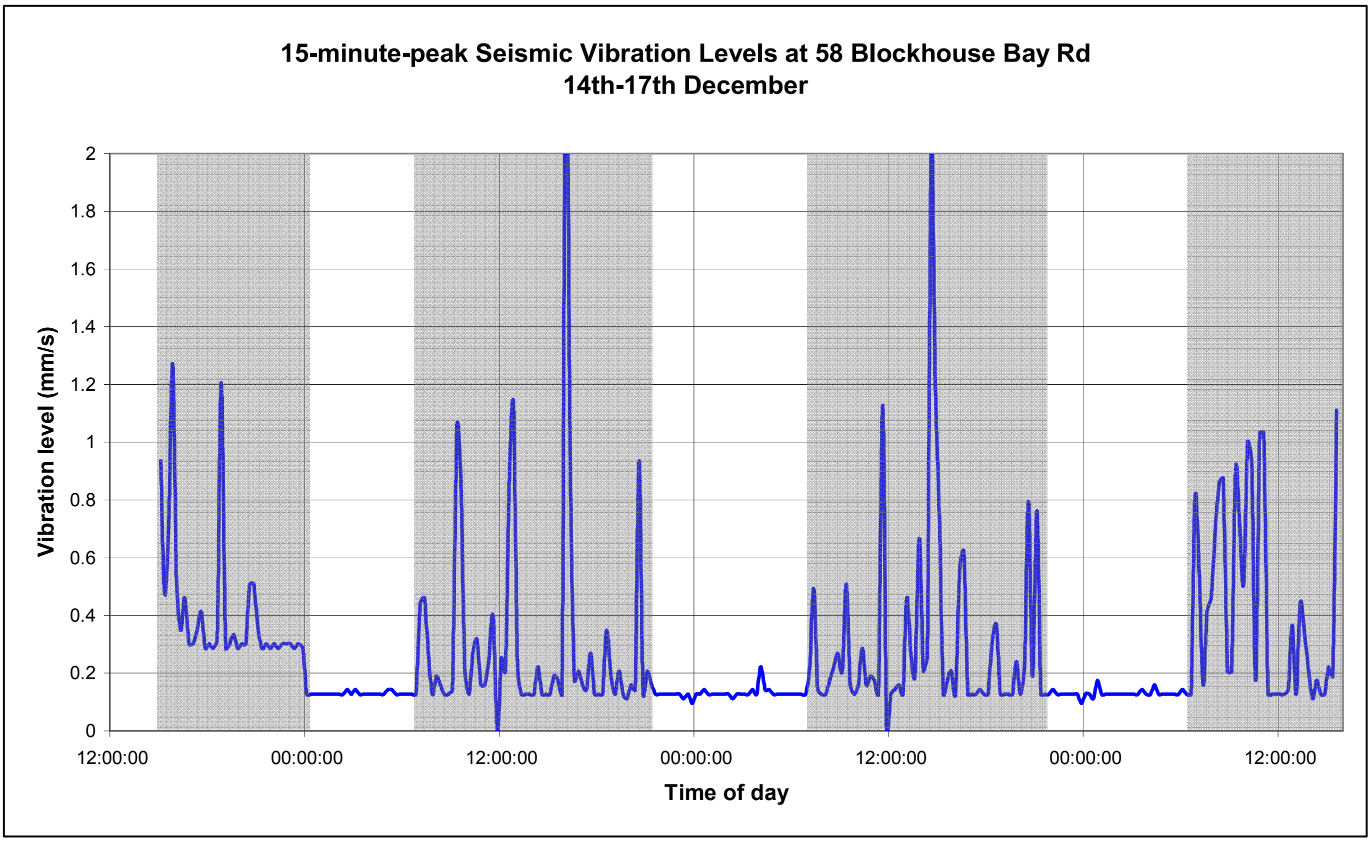


Location:	58 Blockhouse Bay Road
Project Sector:	8
Date:	14th – 17th December 2009
Distance to major road:	90 metres from Blockhouse Bay Road
Equipment:	Nomis Mini Supergraph

Maximum peak vector sum (PVS):	2.6 mm/s
Mean ambient PVS:	0.12 mm/s

Setup comment: The geophone was clamped to the mid-span of a sub-floor perimeter bearer above a window opening.

Results comment: Due to the distance from any major roads, all large vibration peaks shown below are likely to be due to activity within the house rather than traffic.



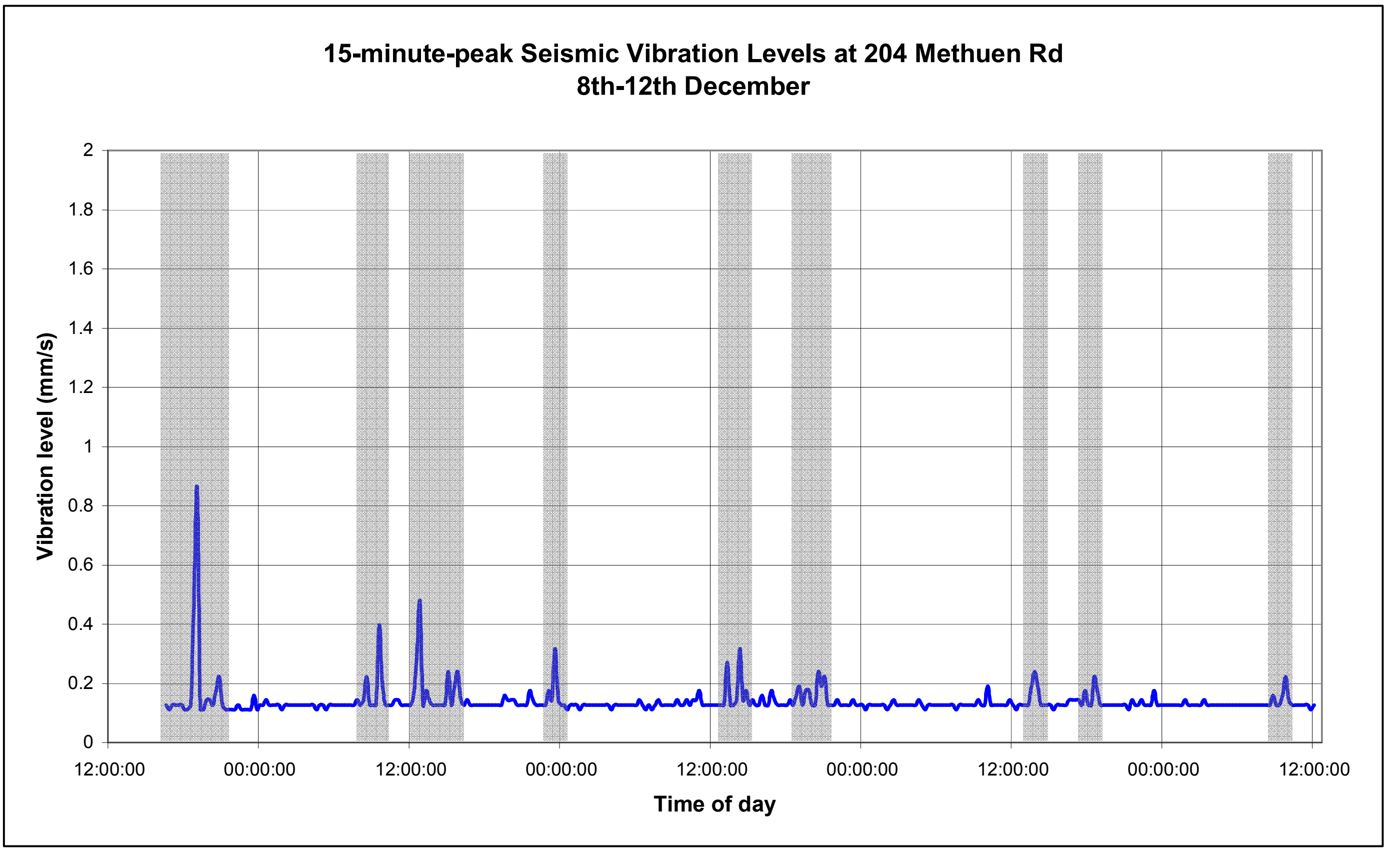
Waterview Connection - Ambient Vibration Monitoring Results

Location:	204 Methuen Road
Project Sector	9
Date:	8th – 12th December 2009
Distance to major road:	630 metres from Blockhouse Bay Road
Equipment:	Nomis Mini Supergraph

Maximum peak vector sum (PVS):	0.9 mm/s
Mean ambient PVS:	0.13 mm/s

Setup comment: Geophone was located just inside the garage on the concrete slab floor, weighted with a sandbag (see red cross in photo).

Results comment: The vibration peaks shown in the graph are likely due to human activity such as opening and closing the garage door.



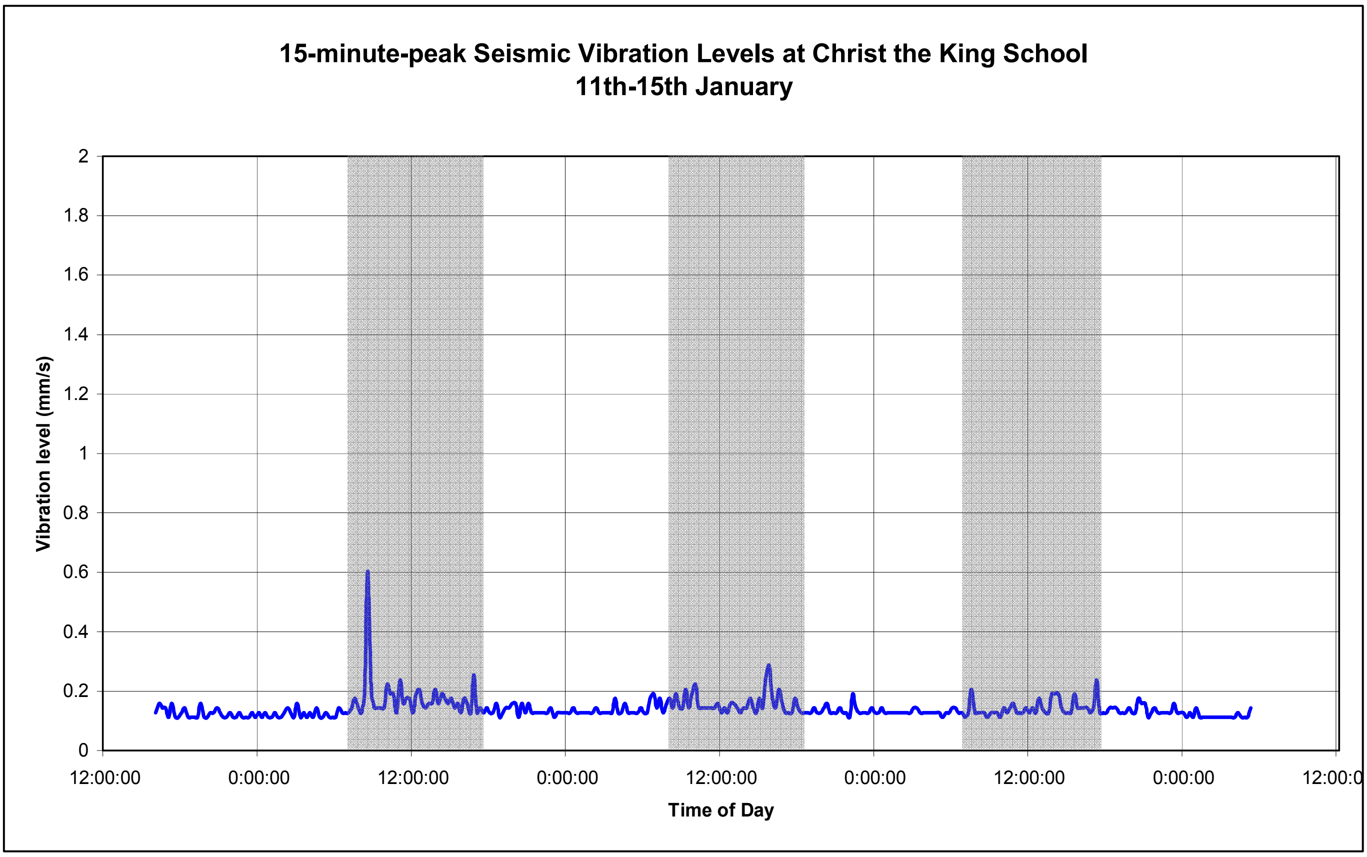
Waterview Connection - Ambient Vibration Monitoring Results

Location:	Christ the King School, New Windsor
Project Sector:	9/10
Date:	11th – 15th January 2010
Distance to major road:	22 metres from Maioro Road.
Equipment:	Nomis Mini Supergraph.

Maximum peak vector sum (PVS):	0.6 mm/s
Mean ambient PVS:	0.13 mm/s

Setup comment: The geophone was clamped to the lip of a protruding vent cinder-block in the wall of classroom number eight.

Results comment: The vibration levels are fairly constant and at low levels.



APPENDIX K

Construction Noise and Vibration Management Plan

NZ TRANSPORT AGENCY
WAKA KOTAHI

Roads of national significance

16 20 Western Ring Route – Waterview Connection

Construction Noise and Vibration Management Plan

MARSHALL DAY Acoustics

newzealand.govt.nz

Quality Assurance Statement	
	Prepared by: Siiri Wilkening, Associate, and James Whitlock, Consultant (Marshall Day Acoustics)
	Reviewed by: Stephen Chiles, Principal (URS)
	Approved for Issue by: Siiri Wilkening, Associate (Marshall Day Acoustics)

Contents

Appendices

1. Introduction

This Construction Noise and Vibration Management Plan (CNVMP) (the Plan) forms part of a comprehensive suite of environmental controls within the Construction Environmental Management Plan (CEMP) for the construction phase of:

- State Highway: 16 and 20
- Project: The Western Ring Route - Waterview Connection project ("the Project")
- Construction location: Sectors 1 – 9 (SH20 connection to Te Atatu Interchange & St Lukes Interchange
- Construction start date: **[Contractor to complete]**
- Construction finish date: **[Contractor to complete]**
- Designation number: **[Contractor to complete]**
- NZTA CSVue permit #: **[Contractor to complete]**

This CNVMP identifies the minimum standards that must be complied with as well as best practicable options for noise and vibration management for the Project. It is intended as a framework for the development of particular noise control practices and procedures to minimise affects on health and safety and to reduce the impact on the environment.

The CNVMP will be updated, with the necessary approval, throughout the course of the Project to reflect material changes associated with any changes to the construction methodologies or techniques or the natural environment. Approval from the [Auckland City] will be required for any relevant revisions of a material nature for the TSMP. The document shall be reviewed yearly to reflect any changes.

The Project is divided into 9 Sectors. A diagram showing the location and the extent of each Sector is attached in Appendix B.

This CNVMP will be implemented in alignment with information, management tools and standards as specified on the NZTA website for the management of transport noise located at http://acoustics.nzta.govt.nz/construction-noise-management.

2. Noise Performance Standards

2.1 Construction Noise excluding Blasting

Table 2.1: Project Construction Noise Criteria: Residential Receivers

Time of week	Time period	Project Construction Noise Criteria (Long Term Construction) dB		
		Sectors 1 to 7	Sectors 8 and 9	All Sectors
		$L_{Aeq(10-60 min)}$	$L_{Aeq(10-60 min)}$	L_{AFmax}
Monday - Saturday	0630-0730	60	45	75
	0730-1800	70	70	85
	1800-2000	65	65	80
	2000-0630	60	45	75
Sundays and Public Holidays	0630-0730	45	45	75
	0730-1800	60	45	85
	1800-2000	45	45	75
	2000-0630	45	45	75

Table 2.2: Project Construction Noise Criteria: Commercial and Industrial Receivers

Time period	Project Construction Noise Criteria (Long Term Construction) dB
	$L_{Aeq(10-60 min)}$
0730 – 1800	70
1800 – 0730	75

Table 2.3: Project Construction Noise Criteria: Internal for Residential Receivers

Time period	Project Construction Noise Criteria (Inside)	Habitable Rooms
0730 – 1800	35 dB $L_{Aeq(16h)}$	All habitable rooms
1800 – 0730	30 dB $L_{Aeq(8 h)}$	Bedrooms

The following activities require specific mitigation in order to achieve compliance with the Project construction noise criteria above.

Daytime

- Retaining wall construction, road milling, road construction and surfacing, cycle underpass construction (Sector 1)

- Bridge pad footing construction, precast segment delivery/craning, span finishing, bridge surfacing (Sector 3 – industrial receivers only)
- Most activities associated with the Great North Road interchange (Sector 5)
- Retaining wall construction, construction of additional lanes (Sector 6)
- Most activities associated with the construction of the northern portal (Sector 7)
- Emergency smoke stack installation by helicopter (Sector 8)
- Preliminary portal works with equipment at ground level, grout curtain, road construction and finishing, basalt crushing (Sector 9)

Night Time

- Road construction and surfacing (Sector 1)
- Bridge pad footing construction (Sector 3)
- Most activities associated with the Great North Road interchange (Sector 5)
- Construction of additional motorway lanes (Sector 6)
- Most activities associated with the construction of the northern portal (Sector 7)
- Richardson Road overbridge segment launching and finishing (Sector 9)
- Contractor Yard operation (Sector 9)

2.2 Noise from Blasting

Noise from blasting shall be predicted, measured and managed in accordance with *AS 2187.2:2006 Explosives - Storage, transport and Use. Part 2: Use of Explosives.*

Table 2.4: Project Construction Noise Criteria: Airblast

Category	**Type of Blasting Operations**	**Peak Sound Pressure Level (L_{Zpeak} dB)**
	Human Comfort Limits	
Sensitive Site	Operations lasting longer than 12 months or more than 20 Blasts	**115 dB** for 95% blasts per year. **120 d**B maximum unless agreement is reached with occupier that a higher limit may apply
Sensitive Site	Operations lasting less than 12 months or less than 20 Blasts	**120 dB** for 95% blasts per year. **125 dB** maximum unless agreement is reached with occupier that a higher limit may apply
Occupied non-sensitive sites such as factories and commercial premises	All blasting	**125 dB** maximum unless agreement is reached with the occupier that a higher limit may apply. For sites containing equipment sensitive to vibration, the vibration should be kept below manufacturer's specifications of levels that can be shown to adversely affect the equipment operation
	Damage Control Limits	
Structures that include masonry, plaster and plasterboard in their construction and also unoccupied structures of reinforced concrete or steel construction	All Blasting	**133 dB** unless agreement is reached with owner that a higher limit may apply.
Service structures such as pipelines, powerlines and cables located above ground	All Blasting	Limit to be determined by structural design methodology

3. Vibration Performance Standards

Two construction vibration standards have been adopted for use in this Project:

- DIN 4150-3:1999 for building damage risk and
- BS 5228:2009 for human response

3.1 Building Damage Risk: DIN 4150-3:1999

Table 3.1: Summary of Building Damage criteria

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	**1 - 50 Hz**	**50 - 100 Hz**		
Commercial/Industrial	20	20 – 40	40 – 50	40	10
Residential/School	5	5 – 15	15 – 20	15	5
Historic or sensitive structures	3	3 – 8	8 – 10	8	2.5

A statistical method may be applied to the assessment of blasting activities (which are categorised as short term activities in Table 3.1 above). This methodology requires that vibration from each and every blast is measured. Survey results are used to ensure that activities are conducted so that 95 % of the 20 most recent events, measured on the foundation of any building, produce peak particle velocities not exceeding the criteria specified for short-term activities in Table 3.1 above, and 100 % of the measured events do not exceed twice these criteria.

3.2 Human Response: BS 5228:2009 Appendix B

The criteria in British Standard BS 5228:2009 (Appendix B.2) shall be used for the management of complaints relating to construction vibration. Compliance with the criteria set out in Table 3.2 below are not mandatory, but provide contextual information on people’s expected response to vibration.

Table 3.2: Human Response to Vibration

Vibration level (PPV)	Effect
0.14 mm/s	Vibration might be just 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 be just 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.

4. Key Construction Noise and Vibration Effects

The Project construction involves significant numbers of machinery operating in close proximity to noise and/or vibration sensitive receivers. Night-time construction is required in certain areas.

The primary effects of construction noise relate to annoyance and disturbance of people.

The primary effects of construction vibration relate to building damage. Secondary vibration effects relate to annoyance and disturbance of people. Responding to and mitigating the primary (building damage) effects often alleviates the secondary (annoyance) effects.

A list of the predominant noise and vibration generating activities in each Sector are outlined in Table 4.1 below:

Table 4.1: Key Construction Noise and Vibration Activities

Sector	Noise generating activities	Vibration generating activities
1	Base course and sealing of SH16 and Te Atatu Interchange Noise barrier construction	Vibratory rollers for base course and sealing of SH16 and Te Atatu Interchange
2	Piling for bridge construction Road milling and sealing	Piling for bridge construction
3	Bridge construction and surfacing Road widening and sealing	Vibratory rollers for base course and sealing of SH16
4	Causeway fill delivery for construction/ reclamation Piling Road sealing	Vibratory rollers for base course and sealing of SH16, and piling for bridge abutments
5	Interchange ramp footing and segment construction Piling Concrete batching	Vibratory rollers for base course and sealing of on-grade ramps
6	Piling, blasting and rockbreaking for widening works and retaining walls	Piling, blasting and rockbreaking for widening works and retaining walls Vibratory rollers for base course and sealing of on-grade ramps
7	Piling for diaphragm wall Excavation Road realignment and resurfacing	Piling for diaphragm wall Excavation plant Vibratory rollers for road realignment and resurfacing

Sector	Noise generating activities	Vibration generating activities
8	Tunnelling (road header or excavators) Construction of emergency smoke extract vent and services building Helicopter delivery of materials	Tunnelling (road header or excavators)
9	Blasting for portal construction Drilling for portal construction and grout curtain Rock breaking for portal construction Piling for portal construction Road basecourse and sealing Crushing of basalt Batch plant operation House demolition Noise barrier construction	Blasting for portal construction Drilling for portal construction and grout curtain Rock breaking for portal construction Piling for portal construction Vibratory rollers for road construction

Other construction machinery and activities, not specified in the above table, will produce noise and ground vibration also, but generally to a lesser degree.

5. Timeframe

The overall construction timeframe for the entire Project is expected to be five and a half years. This will comprise of the following activities:

- Tunnel construction: 4 years
- Te Atatu Interchange: 4 years
- Causeway and the Whau River bridge construction: 5 years
- Great North Road interchange: 2 years
- Widening works on SH16: 1 year
- SH20 from tunnel to Maioro Interchange: 1 year

6. Hours of Operation

Hours of operation are generally:

- Sectors 1, 2, 3, 5, 6, 7 and 9: Generally daytime operation, 6 days per week. Some night-time operation for specific areas.
- Sector 4: Causeway construction will occur at varying times throughout any 24 hour period at low tide.
- Sector 8: Tunnelling: 24 hours per day, 7 day per week

Blasting activities shall occur between 9 am and 5 pm, Monday to Saturday, only.

7. Roles and Responsibilities

Section 3.1 of the CEMP details roles and responsibilities associated with managing environmental effects from construction on the Project. The contractor will appoint a Contractor Environmental Manager who has the overall responsibility for the implementation of this CNVMP, including all required noise and vibration monitoring, and leading the review of results with appropriate communication to Local Authorities and the NZTA.

The following is a schedule of contact details for key personnel connected to the Construction Phase of the Project: **[The following schedule of contact details shall be completed by the contractor prior to commencement of the Project]**

Table 7.1 Schedule of Contact Details

Role	Name	Organisation	Phone	Email
Contractor Environmental Manager				
Client		NZTA		
Engineer				
Project Acoustic and Vibration Consultants				
Contractor				
Contractor's acoustics advisor				
Council – Noise/ Environmental Health				
Public complaint contact number				

[Contractor to insert name and company of appropriate person] will be responsible for ensuring that this CNVMP is correctly implemented. He/she will review all documentation relating to construction noise and vibration before it is issued.

All site personnel will be required to read this CNVMP and sign appropriate induction forms and any relevant schedules. All personnel working on the Project, including Contractor employees and subcontractors, are responsible for following the requirements of this CNVMP.

8. Training

Environmental training for all staff will be undertaken as part of the site induction programme as described in section 3.2 of the CEMP. Training for all site personnel shall be undertaken as part of the site induction programme. This requires all new staff to participate in an induction training session when they commence work, and regular (annual as a minimum) refresher courses.

Environmental Induction will include information on the following aspects of this CNVMP:

- Roles and responsibilities for management of Project noise and vibration issues
- Designation requirements/conditions
- Information about noise and vibration sources on site, and locations of critical receiver positions
- Noise and vibration management procedures
- Complaints management procedures

If required, training of site personnel in matters relating to construction noise and vibration will be provided by a suitably qualified person.

9. Monitoring

9.1 Noise

Construction noise levels shall be monitored and assessed:

- generally in accordance with the requirements of NZS 6801:2008 "Acoustics - Measurement of Environmental Sound", NZS 6802:2008 "Acoustics - Assessment of Noise" and NZS 6803:1999 "Acoustics - Construction Noise"
- at monthly intervals throughout construction, but not at pre-arranged times
- as and when required, during critical phases of construction, i.e. when possible exceedance of the Project noise criteria is anticipated
- in response to reasonable noise complaints being received
- at locations representative of sensitive receivers in the vicinity
- at 1 metre from the most affected façade, or, if this position is not accessible, at an equivalent position where practicable. If this is not possible, measured noise levels shall be adjusted for distance and façade reflections if necessary.
- to reflect representative construction activities, and shall be no less than 10 minutes and longer than 60 minutes duration. The measured noise level shall be stated with the measurement duration: $L_{Aeq(T)}$
- by a suitably qualified acoustic specialist
- for any and all blasting activities (this would typically be undertaken by the blasting contractor)

General monitoring locations may include, but are not limited to:

- Sector 1: Residential areas near Te Atatu Interchange
- Sector 2: Residential areas overlooking bridge widening
- Sector 5: Residential areas located near retaining structures
- Sector 6: Adjacent to Ramp 2 and Ramp 4
- Sector 7: Adjacent to the tunnel portal

- Sector 8: Dwellings located above the tunnelling operation
- Sector 9: Adjacent to the tunnel portal, Richardson Road underpass and Contractor's Yard 10

9.2 Vibration

Prior to construction, trial measurements of high-vibration activities (including blasting) shall be undertaken to establish Project specific ground attenuation characteristics and safe distances to inform the risk categories for the vibration schedules (refer Section 12 below).

During construction, vibration levels shall be monitored and assessed:

- generally in accordance with the requirements of DIN 4150-3:1999
- at monthly intervals throughout construction at high risk receivers as set out in the vibration schedules
- as and when required, during critical phases of construction, i.e. when possible exceedance of the Project vibration criteria is anticipated
- in response to reasonable vibration complaints being received
- to reflect representative construction activities, and shall comprise measurements of peak particle velocity (PPV) at one second intervals
- by a suitably qualified and experienced specialist

The monitoring and complaints management procedure for vibration sources other than blasting is outlined in the second flowchart (for continuous vibration sources) attached in Appendix C.

For blasting activities:

- each and every blast shall be monitored by the blasting contractor at the high-risk receiver(s) in the vicinity (or equivalent location if access to the building structure is not granted)
- the criteria in DIN 4150-3:1999 apply, however the statistical method outlined in Section 3.1 above shall be applied such that 95% of all measurements must comply with the DIN criteria, and 100% of all measurements must comply with twice these criteria.

The monitoring and complaints management procedure for blasting is outlined in the first flowchart (for impulsive vibration sources) attached in Appendix C.

9.3 Contingency Measures

In the event that a measurement shows non-compliance with the Project criteria, the following procedures shall be implemented:

- For vibration, a building condition survey shall be undertaken and a report prepared by a suitably qualified person, including photographs, detailing the state of repair of the existing structure, and an opinion as to whether any damage may be due to construction activity.

- For noise, further measurements shall be undertaken where necessary, to determine the extent of non-compliance.

- A report shall be prepared, outlining the non-compliance and, if required, potential mitigation and management measures.

- Upon implementation of any additional mitigation measures, further measurements shall be undertaken to confirm the effectiveness of those mitigation measures.

- The Contractor Environmental Manager shall liaise with affected receivers throughout this process.

9.4 Reporting

Any noise, vibration or building condition surveys shall be summarised in a report, to be submitted to the Contractor Environmental Manager within one week of the assessment. Monitoring records shall be kept at the site office and made available upon request.

10. Procedures for Handling Noise and Vibration Complaints

Complaints procedures are detailed in section 3.6.1 of the CEMP. As part of the liaison process, affected parties shall be informed to direct noise and/or vibration complaints to the Contractor Environmental Manager. A flowchart outlining the process for noise complaints is contained in Appendix D.

The following complaint procedures shall be followed:

- The Contractor shall maintain a 24 hour hotline and this number shall be displayed in all consultation material and other publications
- Upon receiving a complaint, the complainant's name, contact details and the nature of their complaint will be noted and immediately forwarded to a designated Contractor staff member
- The Contractor staff member shall contact the complainant within one hour during the day and 15 minutes at night (10:00 pm to 7:00 am), or as soon as practicable thereafter, to address their concerns
- If practicable and appropriate, construction workers shall be instructed to modify the activity of concern and the complainant shall be informed
- If the complaint is in regards to building damage from construction vibration, the activity of concern shall cease and a building condition survey shall be undertaken. Flowcharts outlining the processes for blasting and other vibration sources are contained in Appendix C.

For on-going complaints, the Project Manager shall request additional measurements by a suitably qualified and experienced acoustic specialist targeting the specific noise or vibration source. The investigation of an ongoing noise or vibration complaint may include the following:

- Identification of noise or vibration inducing activities at the time of complaint, and measurement and assessment of noise or vibration levels from these activities
- Determination of the best practicable mitigation options in conjunction with the Contractor Environmental Manager
- Measurement of noise or vibration levels following implementation of mitigation action(s)
- Communication with complainant
- Reporting of findings and actions to the Contractor Environmental Manager

In addition, a complaints file will be maintained at the Project office, and available for inspection during normal office hours by affected parties and the relevant local authority.

11. General Management Procedures and Mitigation Measures

The following sections outline noise and vibration management and mitigation measures that shall be implemented throughout construction of the Project.

Sector specific mitigation measures are provided in Section 12 of this CNVMP and shall be implemented in addition to the general measures outlined below.

11.1 Consultation

Consultation with affected parties shall be carried out prior to commencement of construction activities as follows:

- Receivers within **100 metres** of the construction area: Written notification and a Project description shall be provided to raise awareness of the Project, its expected activities and duration in the vicinity.

  For blasting activities, written notification shall be provided for all receivers within **200 metres**.

  Where noisy activities are to be conducted during the night-period, it should be suggested to residents that they keep their windows shut when sleeping.

- Receivers within **50 metres** of the construction area: Individual notification shall be provided and opportunity made available for discussions on a case-by-case basis, if required by the occupants/owners.

- Receivers within **20 metres** of the construction area: Individual discussions shall be held and, if required, suitable alternatives and/or mitigation options explored that are acceptable to both parties. Ongoing consultation shall be carried out throughout the duration of construction.

For vibration, the distances specified above represent a suitable basis for standard consultation practice.

Further detail on identifying at-risk receivers in each Sector in relation to construction noise and vibration effects are contained in Schedules [xx] in Appendix F. **[Schedules xx of at-risk buildings and high-vibration equipment shall be completed by the contractor prior to commencement of the Project]**

11.2 Training of Personnel

All personnel on site shall be made aware of the importance of operating in the least disruptive manner. All personnel working on the Project, including Contractor employees and subcontractors, shall be familiar with, and be responsible for, implementing this CNVMP.

11.3 Selection of Low Noise and Vibration Plant

Low noise and vibration plant shall be selected and used wherever practicable. Where plant is identified as being particularly noisy and/or vibration inducing, action shall be taken to reduce emissions. This may involve the fitting of mitigation measures, such as silencers, enclosures or isolation pads. Plant shall be maintained to ensure that noise and vibration emissions remain as low as practicable.

11.4 Night-Time Operation

In close proximity to residences, high-noise and/or vibration activities shall be scheduled for the daytime where practicable, and avoided during the night-time.

In close proximity to schools and commercial buildings, high-noise and/or vibration activities shall be scheduled during the evening and night-time period where this is practicable.

For contractors yards located adjacent to noise sensitive receivers, noisy vehicles shall enter and leave the site during daytime hours, where practicable. Where this is not practicable, truck routes shall be chosen so as to minimise disruption to sensitive receiver positions.

11.5 Blasting

If blasting is required, this shall be notified at least 24 hours in advance to all receivers within 200 metres of the blast site. Blasts shall be performed at set times during the daytime between 9:00am and 5:00pm Monday to Saturday only.

Blasting activities will generate the highest noise and vibration levels of all construction activities. Prior to blasting works commencing, the blasting contractor shall undertake trial blasts to assess the potential for noise and vibration effects on critical receivers, and design the blasting programme.

In areas close to sensitive receivers alternative rock excavation methods shall be implemented, such as hand-drilling for small MICs, or PCF (gas).

Noise and vibration monitoring shall be undertaken for every blast to assess compliance and effects on critical buildings and building occupants. Blasting records shall be kept at the site office with weekly reports submitted to the Contractor Environmental Manager.

11.6 Noise Barriers and Enclosures

In areas where the Project noise criteria may be exceeded, noise barriers shall be used where they provide effective mitigation (i.e. break acoustic line-of-sight and are close to either the source (preferable) or the receiver).

Where practicable, permanent (traffic) noise barriers required for operational noise mitigation following completion of the Project shall be erected early during construction. This is relevant for Sectors 1, 6 and 9 specifically where substantial traffic noise barriers are required. Permanent noise barriers can be constructed in their final form and utilising the proposed final materials. Alternatively, permanent framing of barriers can be used in conjunction with temporary barrier materials such as plywood which, after completion of construction, can then be replaced with permanent materials. This may be practicable where permanent materials may be damaged by construction activities.

Temporary noise barriers shall be utilised for those areas where no permanent noise barriers are required or where these cannot be practicably implemented early during construction. Temporary barriers are typically constructed from plywood, shall contain no gaps and be of sufficient height to screen line-of-sight between the receiver and the source. Alternative barrier constructions may include fibre cement, shipping containers or mass-loaded vinyl etc

Where a noise barrier is not sufficient to achieve compliance with the Project noise criteria, an enclosure may be used where practicable, i.e. stationary plant such as conveyors or crushers. The enclosure shall be designed by a suitably qualified and experienced acoustic specialist.

11.7 Reversing Alarms

All equipment operating on any of the Project construction sites during night-time shall be fitted with alternatives to tonal reversing alarms. Such alternatives may include, but not be limited to, broadband auditory devices, visual signals, etc.

11.8 Concrete Batching and Crushing Plant Management

The concrete batching plants required in Sectors 5 and 9 will operate 24 hours per day, 7 days per week. The basalt crushing plant will operate in Sector 9 during daytime only.

The contractor must therefore ensure that all practicable noise mitigation measures are implemented at all plants.

Specific management and mitigation measures for the concrete batching plants and crushing plant are set out in the Concrete Batching and Crushing Plant Management Plan (CBCPMP).

11.9 Building Condition Surveys

Prior to the commencement of Project construction operations, a detailed pre-construction building condition survey of identified at-risk buildings, services and structures shall be conducted by a suitably qualified engineer. The survey shall include, but not be limited to, the following:

- Existing condition of buildings, services or structures, including existing levels of any aesthetic damage or structural damage
- Record (including photographs) of the major features of the buildings, services and structures including location, type, construction, age and present condition, including defects
- Foundation type of the building, service or structure
- Preparation of a report recording the findings of the survey. A copy of each report shall be forwarded to the Contractor Environmental Manager and kept at the site office
- Resurvey of buildings, services and structure, which are the subject of complaints or if the vibration criteria have been exceeded and there is potential for damage to have occurred
- Within six months of completion of the Project, a detailed post-construction condition survey of the same buildings, services and structures shall be conducted and a report prepared

11.10 Vibration Barriers

Vibration barriers can provide limited attenuation for ground-borne vibration. Accordingly, the practicability of implementing vibration barriers shall be assessed on a case-by-case basis by a suitably qualified and experienced specialist.

Vibration barrier options include, but are not limited to; open trenches, backfilled trenches, concrete-filled trenches, sheet pile walls, concrete pile walls, grout curtains etc.

The required depth of the barrier is based on the frequency characteristics of the vibration source.

11.11 Mechanical Ventilation of Dwellings

Where external windows of a residence must be closed in order to achieve compliance with the internal night-time Project noise criteria, the installation of mechanical ventilation shall be considered for that residence. This shall be investigated only after all other general noise management and mitigation have been deemed impracticable.

11.12 Temporary Resident Relocation

Where all practicable noise and vibration management and mitigation measures have been implemented, but compliance with the Project criteria is still not achievable, relocation of affected receivers may need to be considered.

Relocaiton shall be considered in exceptional cases only, and expert advice from a suitably qualified and experienced acoustics specialist shall be sought.

12. Sector-specific Noise and Vibration Management and Mitigation Measures

12.1 Noise Mitigation

Sections 12.3 to 12.11 below outline site specific noise mitigation measures that are required in each of the Project Sectors in addition to the general measures noted in Section 11 above.

Noise mitigation and management shall be implemented throughout the Project.

12.2 Vibration Risk

The primary management measure for vibration is to identify and develop awareness of vibration risk, i.e. which construction sources impose a risk of exceeding the Project criteria. The tables in the following sections specify key vibration sources and their 'design safe distances'.

The design safe distances are based on theoretical models, and should be updated to become 'safe distances' (i.e. no longer for design purposes only) as site-specific measurement data becomes available.

The 'safe distances' shall be used to identify at-risk receivers.

Risk is categorised as Low, Medium or High and each risk category requires specific actions to be undertaken when working in those areas, as follows:

High Risk: Receivers that are located within the 'design safe distance'
- Individual discussion with building owners and ongoing consultation
- Building condition survey prior to construction
- Site-specific vibration measurements to assess damage risk

Med Risk: Receivers that are close to the 'design safe distance' (safe distance + 20%)
- Notification of building owners and opportunity for discussion if requested
- Site-specific vibration measurements to assess damage risk if requested

Low Risk: Receivers that are further than the 'design safe distance' + 20%
- Notification of building owners

12.3 Sector 1 – Te Atatu Interchange

Table 12.1: Sector 1 Specific Noise Mitigation

Activity	Mitigation Measures	Detail
• Road Milling • Road Construction and Surfacing	Night-time restriction of noisy activities	• noisy activities to be programmed for daytime • restrict night-time works to quieter activities • for construction activities during both daytime and night-time, works should be scheduled to ensure that operation nearest to dwellings occurs during the day period with night-time operation occurring as far from dwellings as possible.
• Road Construction and Surfacing	Noise barriers	• installation of traffic noise barriers shall be programmed for construction early in the construction period, if practicable. • if not practicable, localised screening around noisy equipment or screening at property boundaries
• Pedestrian cycle underpass	Cover cut early on	• construction should be performed underneath the cover as early on in the construction period as possible • excavation should be performed from underneath the capping, if practicable.

Retaining wall construction, road milling, road construction and surfacing and cycle underpass construction are all likely to exceed the Project noise criteria.

Estimated design safe distances for vibration including activities in Sector 1 are shown in Table 12.2 below.

Table 12.2: Estimated design safe distances for vibration from construction activities in Sector 1

Source	Design safe distance
Vibratory rollers for road construction	15 m
Excavators	3 m

12.4 Sector 2 – Whau River

No specific noise mitigation measures are required for Sector 2.

Estimated design safe distances for vibration inducing activities in Sector 2 are shown in Table 12.3 below.

Table 12.3: Estimated design safe distances for vibration from construction activities in Sector 2

Source	Design safe distance
Vibratory rollers for road construction	15 m
Piling for bridge abutments	18m

12.5 Sector 3 – Rosebank Terrestrial

Bridge pad footing construction, precast segment delivery/craning, span finishing and bridge surfacing are all activities that are likely to exceed the Project noise criteria. For these activities, the general noise mitigation measures outlined in Section 11 shall be implemented and are considered the best practicable mitigation options.

Estimated design safe distances for vibration inducing activities in Sector 3 are shown in table 12.4 below.

Table 12.4: Estimated design safe distances for vibration from construction activities in Sector 3

Source	Design safe distance
Vibratory rollers for road construction	8 m

12.6 Sector 4 – Reclamation

Compliance with the Project noise and vibration criteria is anticipated for Sector 4.

12.7 Sector 5 – Great North Road Interchange

Table 12.5: Sector 5 Specific Noise Mitigation Measures

Activity	Mitigation Measures	Detail
• Contiguous bored piling • Pad footing construction or pier construction • Precast segment delivery, etc. • Span finishing • Sealing works	Noise Barriers	• temporary noise barriers to be erected around noisy activities such as drilling, jack hammering, noisy hand tools, concrete slumping areas, cranes, concrete pumping plant, etc • temporary noise barriers not required for certain activities if the activities are restricted to daytime hours or to distances greater than set out below
	Night-time restriction of noisy activities	• where practicable, noisy operations on the ramps shall be scheduled for daytime where operational areas are close to receivers or noise sensitive activities • night-time construction shall be scheduled for ramp structures that are located further from residential areas (Ramp 1, 3 and some parts of 4) • recommended minimum distances between dwellings and activities for night-time construction operation are: ▪ Contiguous bored piling – 200m ▪ Pad footing construction or pier construction – 300m ▪ Precast segment delivery, etc. – 120m ▪ Span finishing – 120m ▪ Sealing works – 100m
	Resident relocation	• where night construction must occur in close proximity to dwellings and no other mitigation measure is found to be practicable, affected residents may need to be temporarily relocated where noise levels would exceed the Project criteria • relocation should be considered on a case-by-case basis. Before the implementation of this measure, advice shall be sought from an acoustic specialist

Activity	Mitigation Measures	Detail
Batch plant operation	Enclosure/operation	night-time operation of the batch plant in Construction Yard 6 will require the following noise mitigation measures: • Batch plant located as far as possible from sensitive receivers • Enclosure of mixing vessels or dry mixing hoppers • Enclosure of conveyors • Enclosure or screening of truck load-out area • Truck slumping below ground level where practicable • Daytime operation of equipment such as loaders. Conveying of material to be used in preference to driven loaders • Noise barriers located around concrete batch plant • Batch plant designed and located such that reversing of trucks is not required • Enclosure and treatment of other noisy equipment where identified • Driver and operator education regarding noise mitigation

Estimated design safe distances for vibration inducing activities in Sector 5 are shown in Table 12.6 below.

Table 12.6: Estimated design safe distances for vibration from construction activities in Sector 5

Source	Design safe distance
Vibratory rollers for road construction	30m
Piling	25m

12.8 Sector 6 – SH16 to St Lukes

Table 12.7: Sector 6 Specific Noise Mitigation Measures

<table>
<tr><th>Activity</th><th>Mitigation Measures</th><th>Detail</th></tr>
<tr><td rowspan="3">• Retaining Wall Construction
• Construction of additional lanes</td><td>Noise barriers</td><td>• installation of permanent traffic noise barriers shall be programmed early in the construction programme if practicable
• otherwise, localised screening around noisy equipment or screening at property boundaries will be required</td></tr>
<tr><td>Night-time restriction of noisy activities</td><td>• noisy activities shall be programmed to occur during the daytime, with night-time activities restricted to quieter activities</td></tr>
<tr><td>Resident relocation</td><td>• where night construction must occur in close proximity to dwellings and no other mitigation measure is found to be practicable, affected residents may need to be temporarily relocated where noise levels would exceed the Project criteria
• relocation should be considered on a case-by-case basis. Before the implementation of this measure, advice shall be sought from an acoustic specialist</td></tr>
<tr><td>• Construction Yard</td><td>Noise barriers</td><td>• temporary noise barriers on the western and northern sides of the yard
• limit operation of material handling and lime drying on site during the night time period</td></tr>
</table>

Estimated design safe distances for vibration inducing activities in Sector 6 are shown in Table 12.8 below.

Table 12.8: Estimated design safe distances for vibration from construction activities in Sector 6

Source	Design safe distance
Vibratory rollers for road construction	30m
Piling for Carrington Road Bridge	25m

12.9 Sector 7 – Great North Road Underpass

Table 12.9: Sector 7 Specific Mitigation Measures

Activity	Mitigation Measures	Detail
• Cut and cover tunnelling	Top down construction	• top down construction is the preferred methodology from a noise perspective
• Great North Road realignment • Retaining wall construction • Vent building construction • Construction Yard 7	Night-time restriction of noisy activities	• all noisy surface activity (i.e. pre-tunnel capping) shall be performed during the day-period where practicable
	Noise Barriers	• noise barriers may be required if surface night-time operation is undertaken
• Great North Road realignment • Retaining Wall Structure	Resident relocation	• where night construction must occur in close proximity to dwellings and no other mitigation measure is found to be practicable, affected residents may need to be temporarily relocated where noise levels would exceed the Project criteria • relocation should be considered on a case-by-case basis. Before the implementation of this measure, advice shall be sought from an acoustic specialist

Estimated design safe distances for vibration inducing activities in Sector 7 are shown in table 12.10 below.

Table 12.10: Estimated design safe distances for vibration from construction activities in Sector 7

Source	Design safe distance
Vibratory rollers for road construction	30m
Piling for secant pile and diaphragm walls	25m

12.10 Sector 8 – Avondale Heights Tunnel

Table 12.11: Sector 8 Specific Mitigation Measures

Activity	Mitigation Measures	Detail
Tunnelling (Continued overleaf)	Choice of methodology	• conventional excavator/trucks should be considered in the selection of an appropriate methodology as they result in lower re-radiated noise
	Daytime operation	• at commencement of construction, noise levels from tunnelling are expected to be above the Project night-time noise criteria • where the tunnelling has not yet progressed deep inside the tunnel, a restriction to daytime operation may be required until sufficient depth is obtained to mitigate noise
	Tunnel breakout noise control	• at commencement of construction, noise levels from tunnelling are expected to be above the Project night-time noise criteria • if night-time operation is required, noise emissions may be reduced through the provision of baffles or acoustic screens at the outlet of the tunnel.

Activity	Mitigation Measures	Detail
Tunnelling (Continued)	Resident relocation	• if internal noise levels are unreasonable due to re-radiated noise, temporary relocation of residents may be requried • relocation may be required for around 7 days at the worst affected locations
	Monitoring	• noise levels should be monitored at receivers from the beginning of the tunnel construction, and as needed throughout • data obtained should be used to update the noise mitigation measures required
Above ground activity	Conveyors	• conveyors between the construction face and the construction yards should be selected to be as quiet as possible • conveyors may require enclosure
Helicopter delivery	Scheduling	• helicopter delivery of materials shall occur for no more than 10 times in any month • residents within 200 metres shall be notified in advance of the helicopter delivery schedule • a tight timeframe shall be maintained

Estimated Design safe distances for vibration inducing activities in Sector 8 are shown in table 12.12 below.

Table 12.12: Estimated design safe distances for construction activities in Sector 8

Source	Design safe distance
Tunnelling: Road header	6m
Tunnelling: Excavator – Bucket only	2m
Tunnelling: Excavator mounted rockbreaker	4m

12.11 Sector 9 – Alan Wood Reserve

Table 12.13: Sector 9 Specific Mitigation Measures

Activity	Mitigation Measures	Detail
Operation occurring at ground level for: • Southern portal construction • Roading construction • Richardson Road overbridge • Contractor Yards 9 and 10	Noise Barriers	• for noisy operation occurring at ground level, provide noise barriers between noisy sources and nearby receivers • permanent traffic noise barriers should be constructed early in the programme to provide acoustic screening of dwellings • for dwellings that are not protected by noise barriers, provide temporary noise barriers for the duration of above-ground construction. • contractor yards should be surrounded with solid hoarding where this provides line-of-sight screening between noise sources and dwellings
Richardson Road Overbridge construction	Daytime Operation	• Richardson Road overbridge construction has the potential to exceed the Project night-time criterion • noisy activities should be programmed to occur during the daytime, with night-time activities restricted to quieter activities • where night-time operation is critical, temporary noise barriers should be implemented around noisy sources
Batch plant (Continued overleaf)	Location, enclosures and alternatives	• batch plants required for 24 hour use will require noise control measures to be applied. • the batch plant should be located on the edge of the cut and designed such that the batch plant can load out to trucks below • design of the batch plant in this manner will ensure that trucks do not need to be loaded out and slump at ground level.

Activity	Mitigation Measures	Detail
Batch Plant (Continued)	Location, enclosures and alternatives	Noisy areas of the batch plant will need to be enclosed or screened from surrounding receivers. Mitigation may include but shall not be limited to: • Batch plant located as far from receivers as possible; • Enclosure of mixing vessels or dry mixing hoppers; • Enclosure of conveyors; • Enclosure of truck loadout area. Alternatively the batch plant may be able to be constructed such that trucks remain inside the tunnel cutting and are loaded out from above; • Truck slumping to occur in the tunnel cutting and not at ground level where practicable; • Daytime operation of equipment such as loaders. Conveying of material to be used in preference to driven loaders; • Noise barriers located around concrete batch plant yard; • Batch plant designed and located such that reversing of trucks is not required; • Enclosure and treatment of other noisy equipment where identified; and • Good driver and operator education regarding noise mitigation. Dwellings within 150 metres of the batch plant may still experience noise levels of above 45 dB $L_{Aeq\ (t)}$ during night-time. If noise levels from the batch plant exceed the Project criteria, mechanical ventilation/air conditioning may need to be provided where external windows need to remain shut. The affected area is shown in Appendix E. The following alternative locations should also be considered for the batch plant: • at the bottom of the cut near the southern portal (this will result in noise sources being further from residents and very well screened by the edges of the cut) • in the industrial area to the east of the operation (Stoddard Road Area), or in an industrial area further afield, together with a combination of noise enclosure and screening (truck movements to and from the tunnel would be well screened by cuttings, however temporary noise barriers may be required at some locations)

Activity	Mitigation Measures	Detail
Crushing	Management and location	• crushing plant shall be enclosed, where practicable, with a well sealed enclosure with lined feed and output conveyor chutes • a large sheet steel enclosure lined internally with a heavier panel such as fibre cement may be the best solution • crushing shall occur during the daytime only • choose quiet plant for operation in and around the crusher, such as quiet loaders.
Blasting	Notification	• blasting shall occur between the hours of 9am and 5pm, Monday to Saturday only • predictions of blast overpressure shall be performed prior to any blasting and charge sizes selected to ensure that the Project noise criteria are complied with • residents within 200 metres of the blast shall be notified prior to blasting
All operation	Resident relocation / façade improvements	• where noisy construction techniques are critical and must occur regardless of the exceedance of the Project noise criteria, temporary relocating of affected residents shall be considered on a case-by-case basis • where residents are unwilling to relocate or the construction period is sufficiently long as to make relocation not practicable, the improvement of the sound insulation of dwelling façades should be considered as an alternative, on a case-by-case basis and only after all other practicable noise control options have been considered.

Preliminary portal works with equipment at ground level, grout curtain, road construction and finishing, basalt crushing, Richardson Road overbridge segment launching and finishing and contractor yard operation may all exceed the Project noise criteria. Within this sector, careful implementation of the general and specific noise mitigation measures is necessary and all practicable steps should be taken to reduce noise emissions.

Estimated design safe distances for vibration including activities in Sector 9 are shown in Table 12.14 below.

Table 12-14: Estimated design safe distances for construction activities in Sector 9

Source	Design safe distance
Vibratory rollers for road construction	30m
Drilling for grout curtain and secant piles	15m
Piling	25m
Rockbreakers	15m
Blasting	Depends on Charge Weight

13. Construction Noise and Vibration Management Schedule

Once the contractor has defined the construction methodology and all proposed plant and equipment, management schedules for construction noise and vibration shall be prepared for each Sector.

The vibration schedules (Schedules [xx] in Appendix F) shall detail high-vibration equipment, their safe distances and all sensitive receivers within the high and medium risk categories (refer Section 12.2).

The noise schedules (Schedules [xx] in Appendix F) shall detail high-noise equipment and all sensitive receivers as follows:

- for daytime work: within the 20 metre and 50 metre categories and
- for night-time work: within the 20 metre, 50 metre and 100 metre categories (refer Section 11.1)

The schedules shall be completed prior to commencement of construction works in each Sector. An example schedule can be found at http://acoustics.nzta.govt.nz/file/construction-noise-management-schedule-template.

14. CNVMP Review

This CNVMP, including environmental controls and procedures, shall be reviewed to ensure that it remains applicable to the activities being carried out.

The CNVMP will be reviewed by the contractor after confirmation of the resource consent and designation conditions and will be revised in accordance with these conditions. The CNVMP will be updated, with the necessary approval, throughout the course of the Project to reflect material changes associated with changes to construction techniques or the natural environment. Approval from the [Auckland Council] will be required for any relevant revisions of a material nature for the CNVMP

A management review of the CNVMP will be undertaken at least annually by the Project Management team and the NZTA Environmental Representative. The management review will be organised by the Environmental Manager, and the Project team will be informed of any changes to this plan through the regular project communications processes.

The review will take into consideration:

- Significant changes that affect the noise and/or vibration generation
- Key changes to roles and responsibilities within the Project
- Changes in industry best practice standards
- Changes in methodology or management in response to noise and/or vibration monitoring showing non-compliance
- Changes in legal or other requirements (social and environmental legal requirements, consent conditions, NZTA objectives and relevant policies, plans, standards, specifications and guidelines)
- Public complaints

Reasons for making changes to the CNVMP will be documented. A copy of the original CNVMP document and subsequent versions will be kept for the Project records, and marked as obsolete. Each new/updated version of the CNVMP documentation will be issued with a version number and date to eliminate obsolete CNVMP documentation being used.

APPENDIX A

Glossary of Terminology

Parameter	**Description**
dB	A measurement of sound level which has its frequency characteristics modified by a filter (A-weighted) so as to more closely approximate the frequency bias of the human ear.
$L_{Aeq(60\ min)}$	The A-weighted, time averaged sound level (on a logarithmic/energy basis) over the measurement period.
L_{A95}	The sound level which is equalled or exceed for 95% of the measurement period.
L_{A90}	The sound level which is equalled or exceed for 90% of the measurement period. L_{A90} is an indicator of the mean minimum noise level and is used in New Zealand as the descriptor for background noise (normally A-weighted).
L_{A10}	The sound level which is equalled or exceeded for 10% of the measurement period.
L_{AFmax}	The maximum sound level recorded during the measurement period (normally A-weighted).
L_{Zpeak}	The peak instantaneous pressure level recorded during the measurement period (flat weighted (Z)).
Noise	A sound that is unwanted by, or distracting to, the receiver.
NZS 6801:2008	New Zealand Standard NZS 6801:2008 "*Acoustics - Measurement of Sound*"
NZS 6802:2008	New Zealand Standard NZS 6802:2008 "*Acoustics - Environmental Noise".*
NZS 6803:1999	New Zealand Standard NZS 6803:1999 "*Acoustics – Construction Noise*".
Ambient Noise	Ambient Noise is the all-encompassing noise associated with any given environment and is usually a composite of sounds from many sources near and far.

Vibration

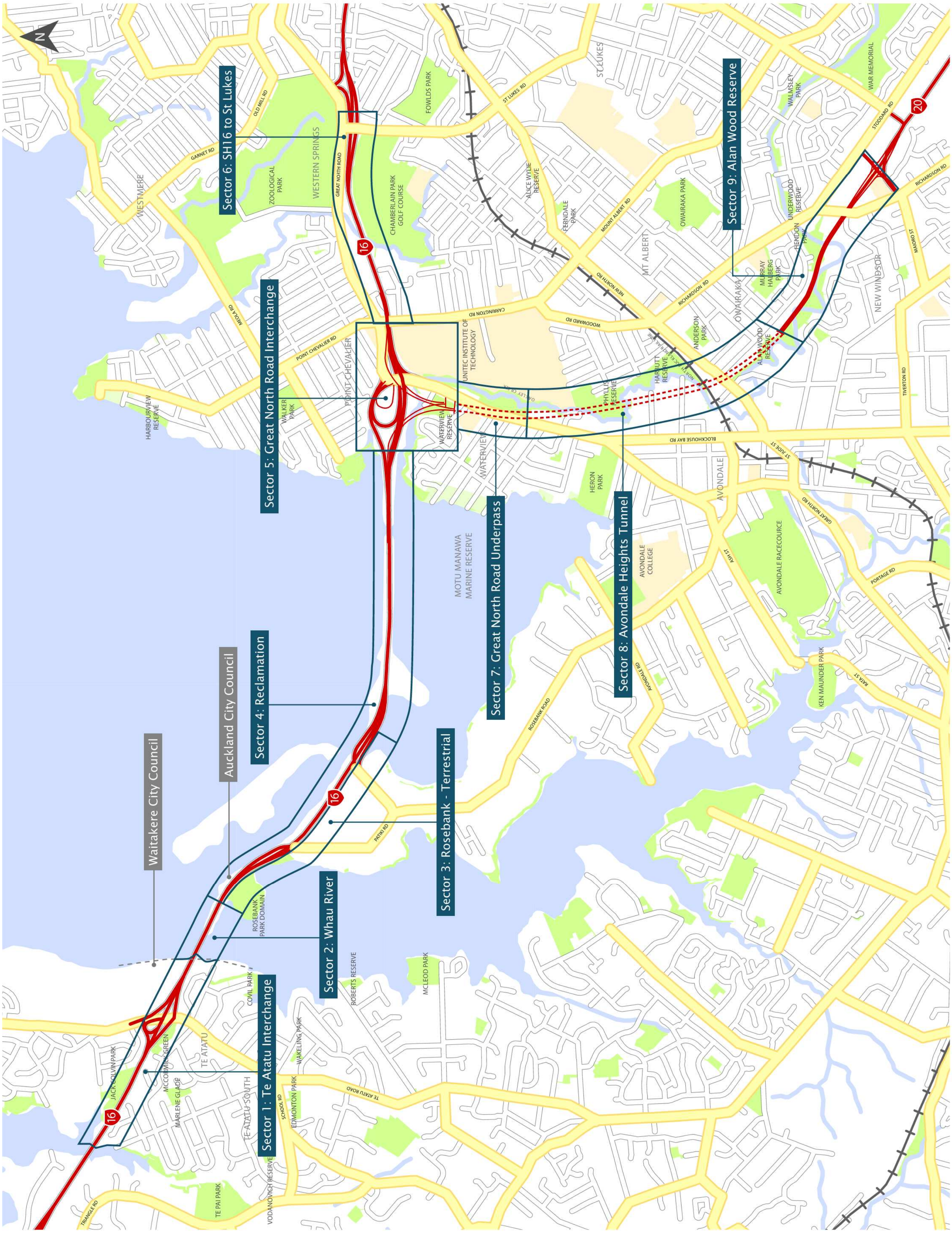
PPV	Peak Particle Velocity, measured in mm/s. This is the standard metric for assessing construction vibration levels.
DIN 4150-3:1999	German Standard DIN 4150-3:1999 "Structural Vibration – Part 3: Effects of vibration on structures". This standard generally adopted in NZ to assess building damage.
BS 5228-2:2009	British Standard BS 5228-2:2009 "Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration". This is the standard adopted for this Project to assess human response to construction.
MIC	Maximum Instantaneous Charge Weight. In blasting, this is the weight of explosive (in kg) used.

General

CNVMP	Construction Noise and Vibration Management Plan. This document
AEE	Assessment of Environmental Effects. A document relating to, and assessing the effects of a specific element of the Project e.g. Noise, Air Quality, Traffic, Vibration

APPENDIX B

Project Sector Diagram


Sector 1: Te Atatu Interchange
Sector 2: Whau River
Sector 3: Rosebank - Terrestrial
Sector 4: Reclamation
Sector 5: Great North Road Interchange
Sector 6: SH16 to St Lukes
Sector 7: Great North Road Underpass
Sector 8: Avondale Heights Tunnel
Sector 9: Alan Wood Reserve
Waitakere City Council
Auckland City Council
MOTU MANAWA MARINE RESERVE
POINT CHEVALIER
WESTERN SPRINGS
WESTMERE
ST LUKES
MT ALBERT
OWAIRAKA
NEW WINDSOR
AVONDALE
WATERVIEW
TE ATATU
TE ATATU SOUTH
AVONDALE RACECOURSE
AVONDALE COLLEGE
UNITEC INSTITUTE OF TECHNOLOGY
CHAMBERLAIN PARK GOLF COURSE
ZOOLOGICAL PARK
ROSEBANK PARK DOMAIN
16
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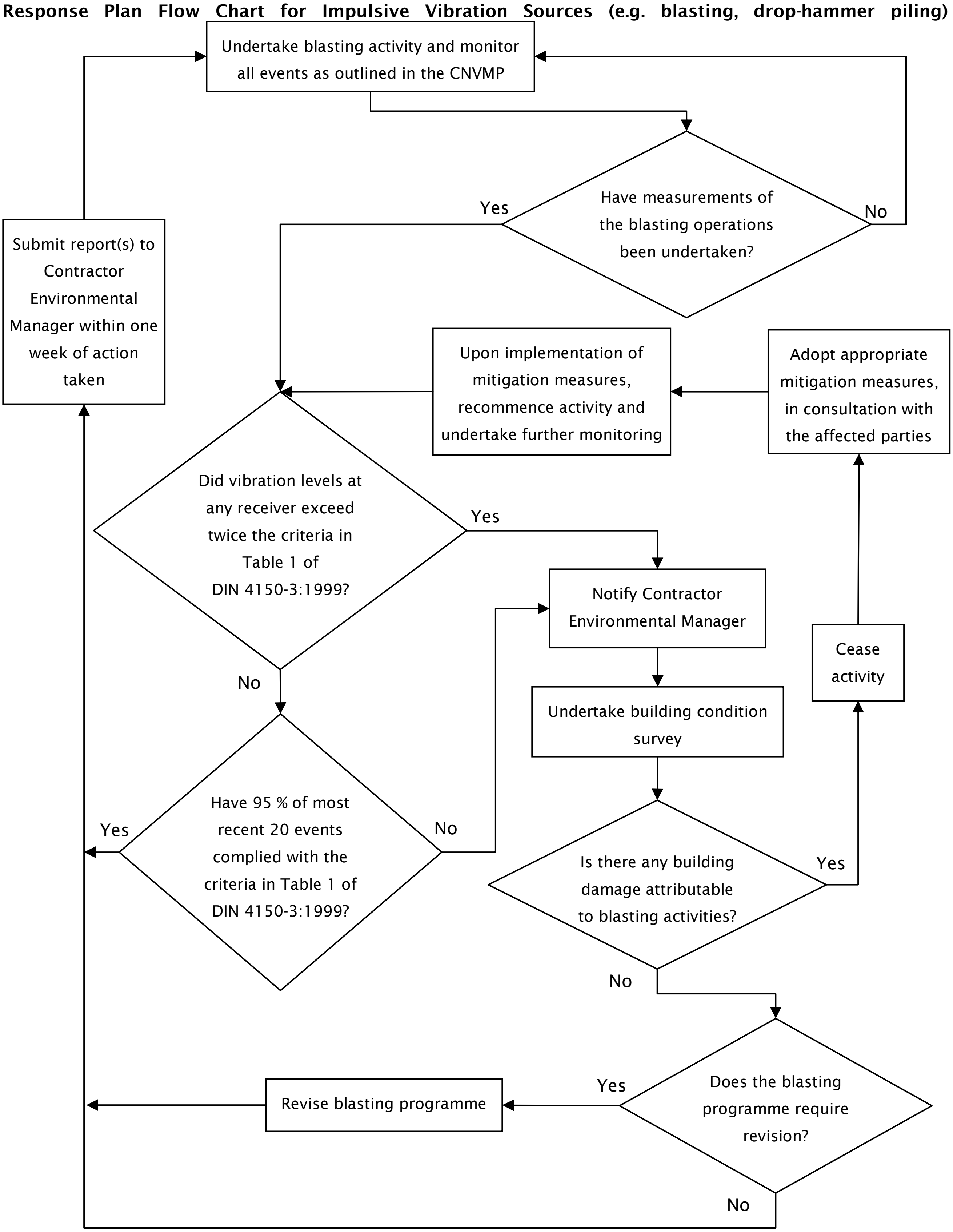
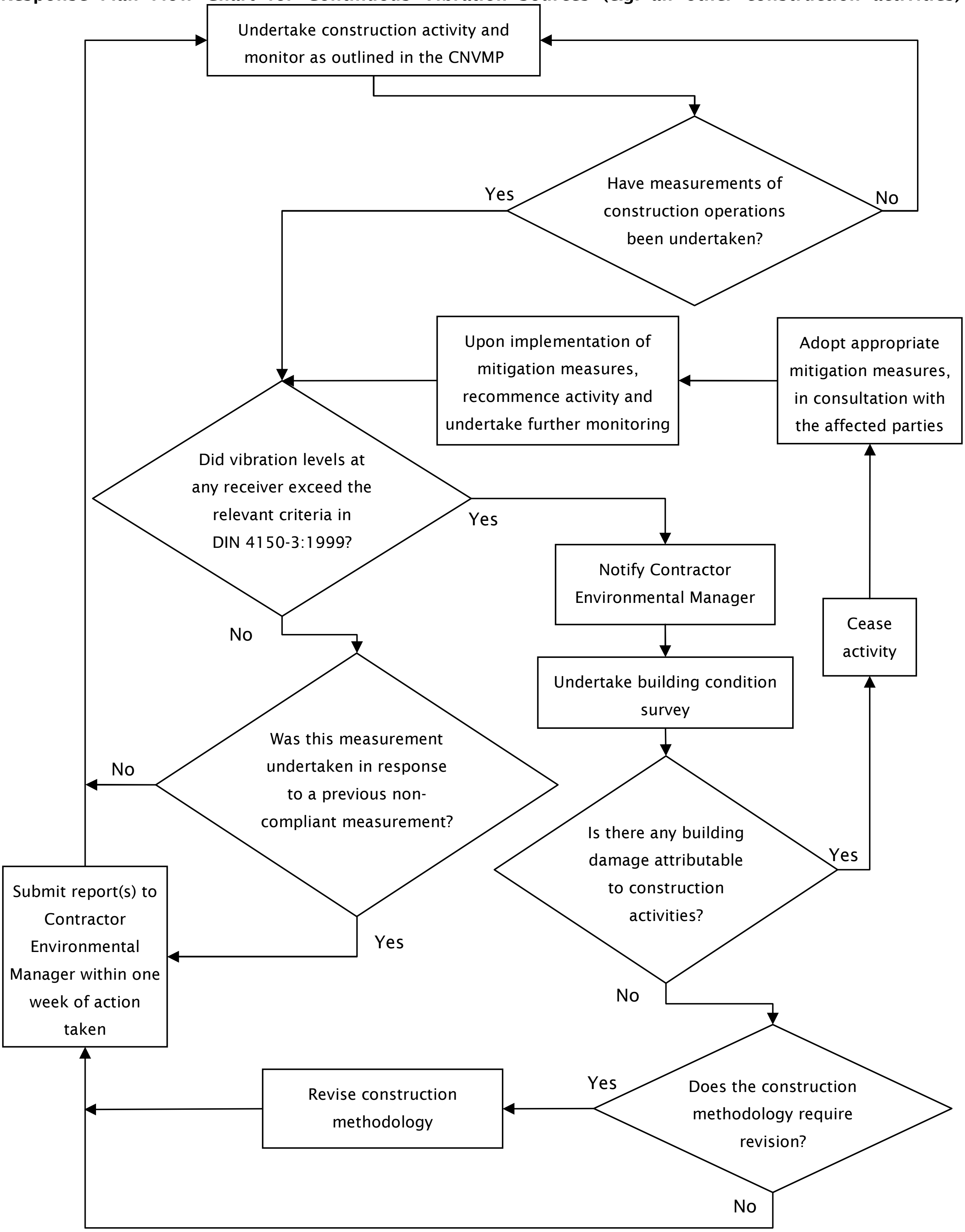
APPENDIX C

Response Plans for Construction Vibration Issues

Response Plan Flow Chart for Impulsive Vibration Sources (e.g. blasting, drop-hammer piling)



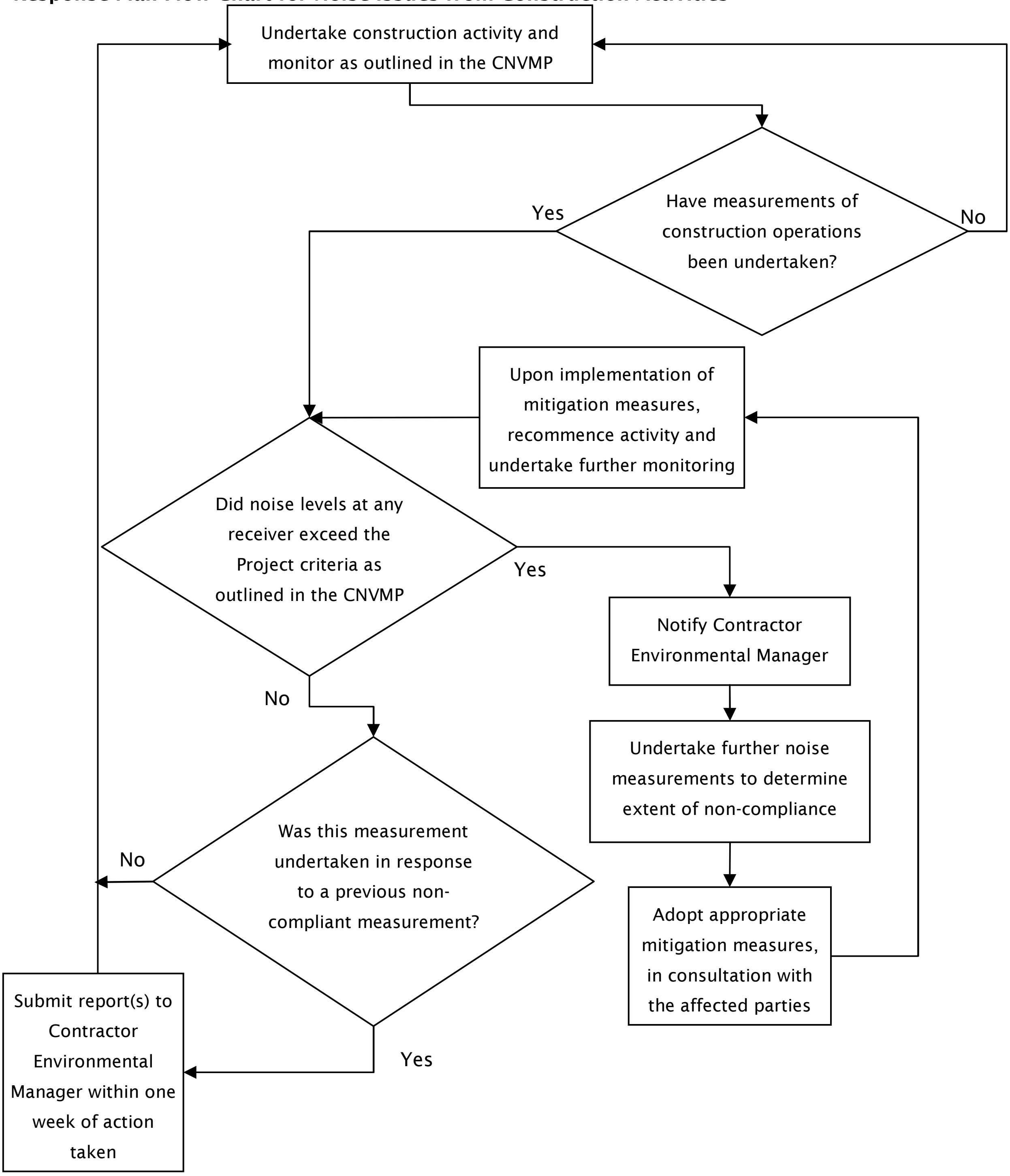
Response Plan Flow Chart for Continuous Vibration Sources (e.g. all other construction activities)



APPENDIX D

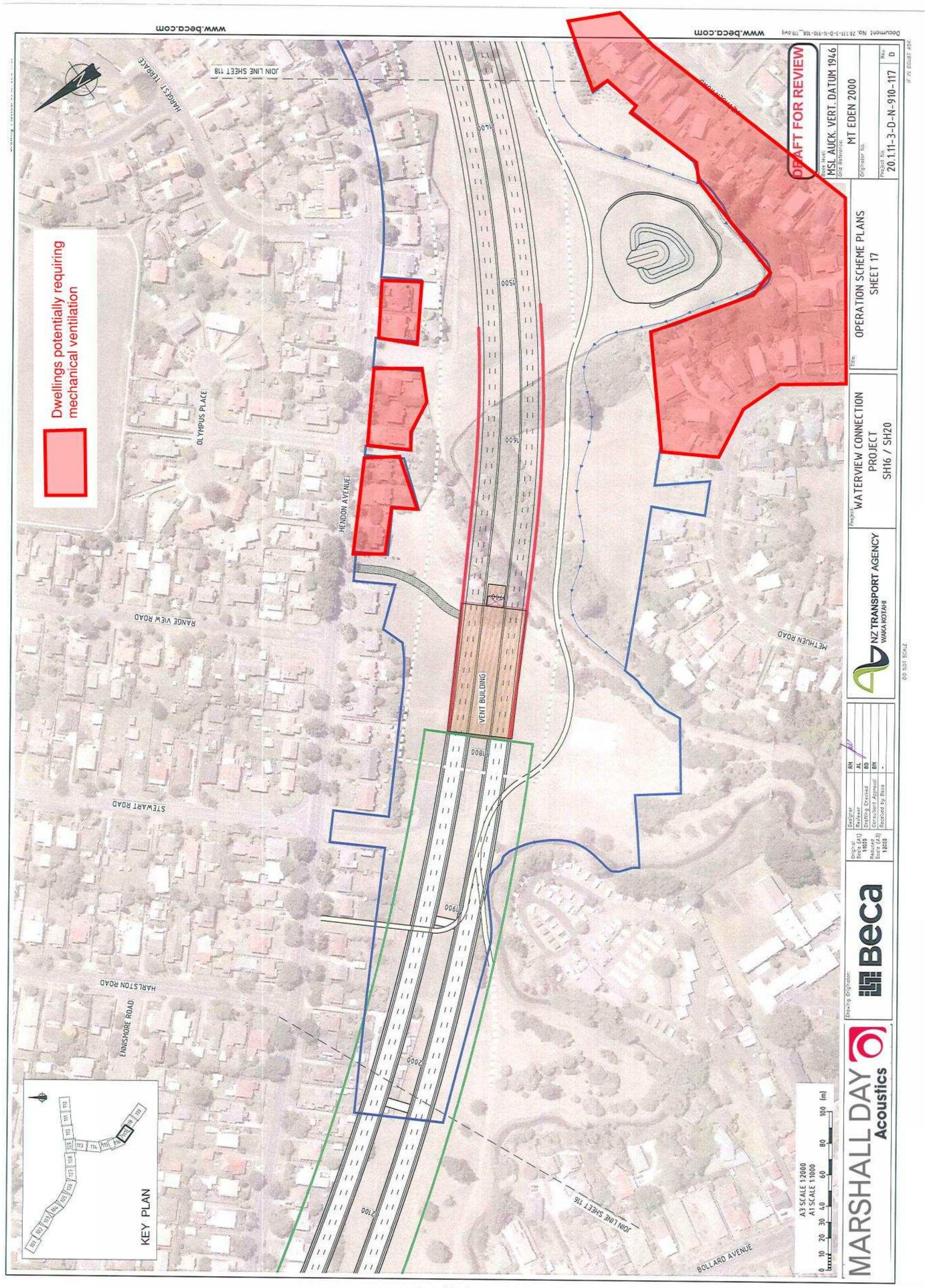
Response Plan for Construction Noise Issues

Response Plan Flow Chart for Noise Issues from Construction Activities



APPENDIX E

Dwellings potentially requiring mechanical Ventilation due to Batching Plan (Sector 9)


Dwellings potentially requiring mechanical ventilation
DRAFT FOR REVIEW
MSL AUCK. VERT. DATUM 1946
MT EDEN 2000
20.1.11-3-D-N-910-117
OPERATION SCHEME PLANS
SHEET 17
WATERVIEW CONNECTION PROJECT
SH16 / SH20
NZ TRANSPORT AGENCY
WAKA KOTAHI
Beca
MARSHALL DAY
Acoustics
KEY PLAN
VENT BUILDING
HARGEST TERRACE
OLYMPUS PLACE
HENDON AVENUE
RANGE VIEW ROAD
STEWART ROAD
HARLSTON ROAD
ENNISMORE ROAD
METHUEN ROAD
BOLLARD AVENUE
JOIN LINE SHEET 118
JOIN LINE SHEET 116
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APPENDIX F

Schedules of at-risk buildings and high-vibration generating equipment

[Schedules of at-risk buildings and high-vibration equipment shall be completed by the contractor prior to commencement of the Project]

APPENDIX G

Supplementary Information on Prediction Methodologies

The following text provides supplementary information for the AEE including calculation procedures used in the ambient vibration, construction and operation assessments.

G.1 Equipment Sensitivity

The quoted measurement range for both the Nomis and Instantel vibration monitors is 0 – 254 mm/s. However this range may not be accurate at the low end as there is some possible influence of the equipment noise floor (i.e. electrical signal inherent in the machine which shows as a baseline vibration level) on the ambient results, that is, the equipment is not sensitive enough to measure the very low levels of ambient vibration.

Despite the 0 mm/s quoted lower limit, analysis of the raw 1 second and 5 second data suggests that both monitors appear to have noise floors which vary between 0.127 and 0.254 mm/s PVS for the Nomis, and 0.176 mm/s PVS for the Instantel. These values are of a similar magnitude to most of the recorded mean ambient PVS values, so the actual source of these low vibration levels is uncertain.

Notwithstanding this, the measured data is still useful as, regardless of the apparatus noise floor, the actual ambient vibration levels must be equal to, or less than the mean ambient PVS values.

G.2 Classification of Project Geology

The crucial variables when reusing historical data are those of distance and ground conditions. The effect of distance is dependant on ground conditions because different ground types attenuate vibration energy at different rates i.e. a vibration measurement of a machine in one ground type does not directly relate to another. Therefore, to predict vibration levels for the Waterview Connection, the ground type must be considered.

It is noted that there are other variables in vibration prediction which have a greater influence on the level, such as variability of the energy source and distance attenuation (independent of the modifying effects of ground type). However, the Project encompasses a wide geographical and geological area and so the effect of ground type is considered relevant.

An explanation of the classification of different ground types according to Hassan (2006) is contained in Table G.2 below.

To make use of the historical measurement data, the ground type of each measurement has been inferred from photos and site notes and categorised according to these soil type classifications.

Geology data for the Project alignment has been obtained from Tonkin & Taylor and Aurecon (SH20 and SH16 respectively). Table G.1 below indicates the general geology of each Project Sector, and the estimated corresponding soil class according to Table G.2.

Table G.1: Project geology, and the corresponding soil class according to Hassan (2006)

Project Sector	Geology	Soil Class (see Table G.2 below)
1	Fill over Tauranga Group (TG) Cohesive Material, or Residual East Coast Bays Formation (ECBF)	Class II – Competent Soils
2	Fill over Recent Alluvium	Class II – Competent Soils
3	Fill over Tauranga Group (TG) Cohesive Material, TG Sand or TG Organic Material	Class II – Competent Soils
4	Fill over Recent Alluvium	Class II – Competent Soils
5	Basalt/Tuff over TG, or TG over Weathered ECBF	Class II – Competent Soils (TG), ranging to Class IV – Hard Competent Rock (Basalt)
6	TG, or Basalt/Tuff (over Weathered ECBF (assumed))	Class II – Competent Soils (TG), ranging to Class IV – Hard Competent Rock (Basalt)
7	TG over Weathered ECBF	Class II – Competent Soils
8	Fill, Basalt, Weathered Parnell Grit, TG and Weathered ECBF over ECBF Siltstone & Sandstone (soft rock)	Class III – Hard Soils (ECBF Siltstone & Sandstone) Note, despite the presence of basalt etc near the surface, Class III is the most relevant classification as this is the tunnelling Sector and the tunnel passes through ECBF Siltstone and Sandstone only. The vibration energy must pass up through several layers to reach receivers
9	Basalt/Tuff and TG over Weathered ECBF, or Weathered ECBF only	Class II – Competent Soils (TG, ECBF) Class IV – Hard Competent Rock (Basalt)

G.3 Soil Type and Prediction of Ground Attenuation

Hassan's 2006 book "Train-Induced Groundborne Vibration and Noise in Building" contains calculation methods for vibration propagation in different soil types. In this text soils are categorised in the following types, each of which has corresponding attenuation coefficients for the 5Hz and 50Hz frequency bands:

Table G.2: Vibration Attenuation Co-efficients of different soils (Hassan, 2006)

Class	Attenuation coefficient α	Description of Material
I	5 Hz: 0.01 to 0.03 (1/m) 50 Hz: 0.1 to 0.3 (1/m)	Weak or Soft Soils – lossy soils, dry or partially saturated peat and mulch, mud, loose beach sand and dune sand, recently plowed ground, soft spongy forest or jungle floor, organic soils, top soils (shovel penetrates easily)
II	5 Hz: 0.003 to 0.01 (1/m) 50 Hz: 0.03 to 0.1 (1/m)	Competent Soils – most sands, sandy clays, silty clays, gravel, silts, weathered rock (can dig with shovel)
III	5 Hz: 0.0003 to 0.003 (1/m) 50 Hz: 0.003 to 0.03 (1/m)	Hard Soils – dense compacted sand, dry consolidated clay, consolidated glacial till, some exposed rock (cannot dig with shovel, must use pick to break up)
IV	5 Hz: < 0.0003 (1/m) 50 Hz: < 0.003 (1/m)	Hard, Competent Rock – bedrock, freshly exposed hard rock (difficult to break with hammer)

The effects of ground type have been considered through using Equation 1 below in the following manner:

1. The source vibration level is calculated from the historical data on measured level, distance and ground type
2. This source level is used in conjunction with distances and ground type relating to the Project, to predict the vibration level (PPV) at distance
3. The distance is modulated until the predicted PPV level just complies with the Project Criteria. This provides a minimum safe distance for that source, in that ground-type

The prediction method used is adopted from Hassan's book "Train-Induced Groundborne Vibration and Noise in Building" which, unlike many other methods, contains frequency-dependant ground attenuation formulae. This method yields slightly more conservative results than Gutowsky & Dym and Nelson so is considered preferable in effects assessment. The Hassan prediction formula is as follows:

$$v = v_0 (r/r_0)^{-n} e^{(-\alpha(r-r_0))} \qquad \text{--- (1)}$$

Where: v = vibration velocity (PPV) at distance r

v_0 = vibration velocity (PPV) at the reference point r_0

r = distance from vibration source (in metres)

r_0 = distance from the source to a reference point on the ground

n = geometric attenuation coefficient (n = 0.5 for Rayleigh (surface) waves from a point source)

α = attenuation coefficient (from Table G.1 above)

Wave propagation in the ground is broadly categorised into four wave types – Shear waves and Compression waves (for sub-surface propagation) and Rayleigh waves and Love waves (surface waves). Each wave type has a corresponding attenuation coefficient based on its geometric spreading, expressed as *n* in Equation (1) above.

Rayleigh waves are the most appropriate wave type for surface vibration calculations, and have been used for all calculations of surface construction activities (see description for *n* in Equation (1) above). Vibration from tunnel construction is different as the vibration source is subterranean so shear and compression wave spreading (which both have the same *n* value of 1) has been adopted.

It is noted that the effect of ground type on vibration level is minor when compared to distance attenuation and the variability inherent in construction methods.

G.4 Regression Analysis for Collected Historical Measurements

The regression follows a simple power law equation according to the form of Equation (1) above. The Explosive Technologies International (ETI) "Blaster's Handbook" expresses the relationship in terms of ground constants, source energy and distance and takes the form:

$$PPV = K(D/E^{1/2})^{-n} \qquad \text{--- (2)}$$

Where: K = the ground transmission constant (for a given ground type)
D = Distance from source to receiver
E = Energy of source
n = empirical constant based on a number of factors such as the geology, ground profile, frequency of transmitted wave, predominant waveform. The value of n is obtained from regression analysis and generally has a value between 0.5 and 1.5.

This is the prediction formula used for predicting blasting vibration where the value of E is the Maximum Instantaneous Charge (MIC) i.e. the maximum amount (in kg) of explosive detonated on any one delay interval (provided the blast intervals are at least 8 milliseconds apart)

For a given construction source say, it may be assumed that the energy delivered into the ground is constant (over a sufficient timescale), therefore the equation reduces to:

$$PPV = K \cdot D^{-n} \qquad \text{--- (3)}$$

The regression plots for each source and the corresponding level-distance formulae are attached in Appendix H. From these plots, the conservative minimum safe distance to achieve the Project Criteria (i.e. 5 mm/s PPV for residential dwellings) has been scaled.

G.5 Additional Information on Roadheader Vibration Measurements – Vector Tunnel Project

This assessment was undertaken at St Matthew's church in Auckland City on 20 March 1998 by Vibration Consultants Ltd using Instantel Minimate Plus vibration loggers and the data was provided by Tonkin & Taylor Ltd with permission from Vector Ltd.

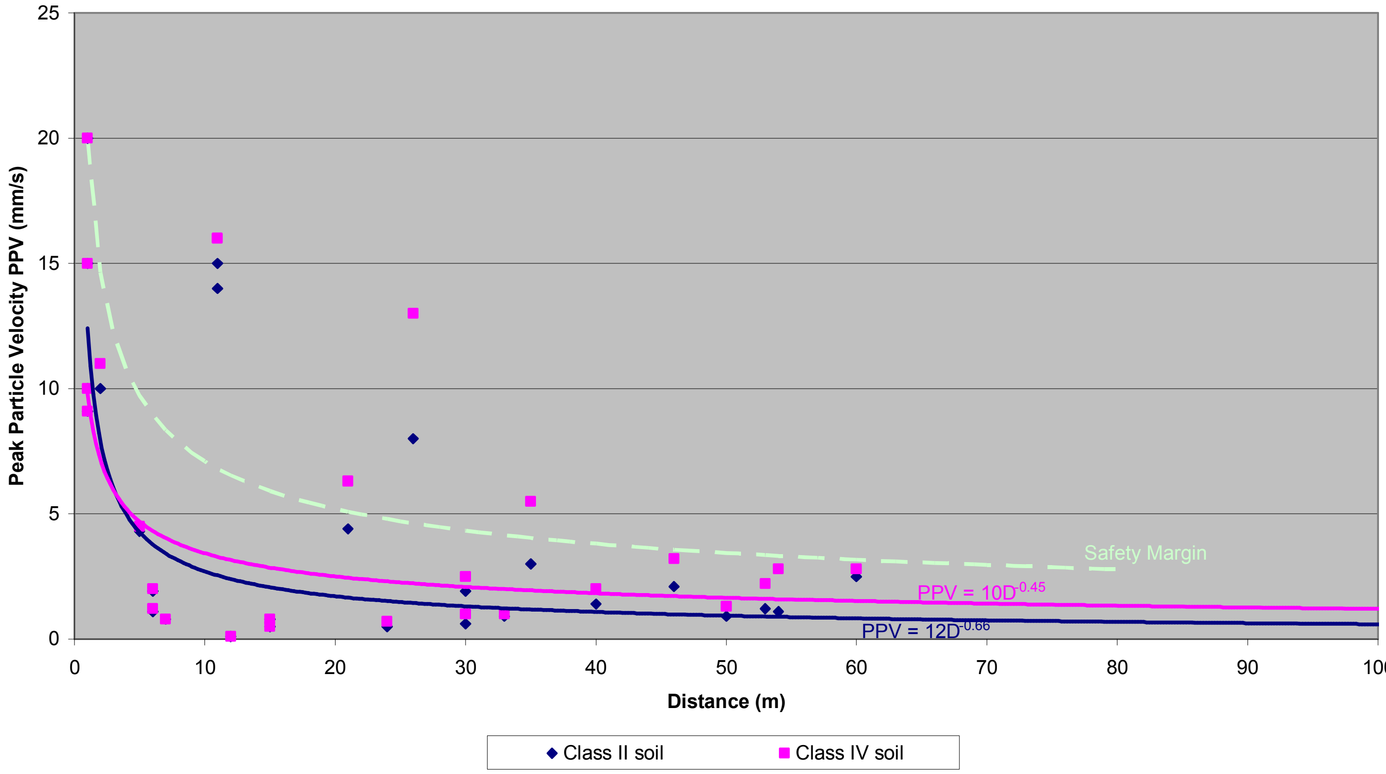
The vibration monitor was positioned on the crypt floor entrance to St Thomas' Chapel, approximately 46 metres above the tunnelling operations. The measured level during tunnelling operations did not exceed 0.2 mm/s PPV in any axis. It is noted that this level is close to the noise floor of the Minimate Plus so may not actually be due to the roadheader. However it is clear that the roadheader vibration was 0.2 mm/s PPV at most, so this is a suitable value for assessment purposes.

It is understood that the ground conditions at the site comprised ECBF rock at tunnel level with a thin weathered zone and consolidated stiff sediments above. This would be classed as Class II - III soil according to Table G.2, which is similar to the Project geology.

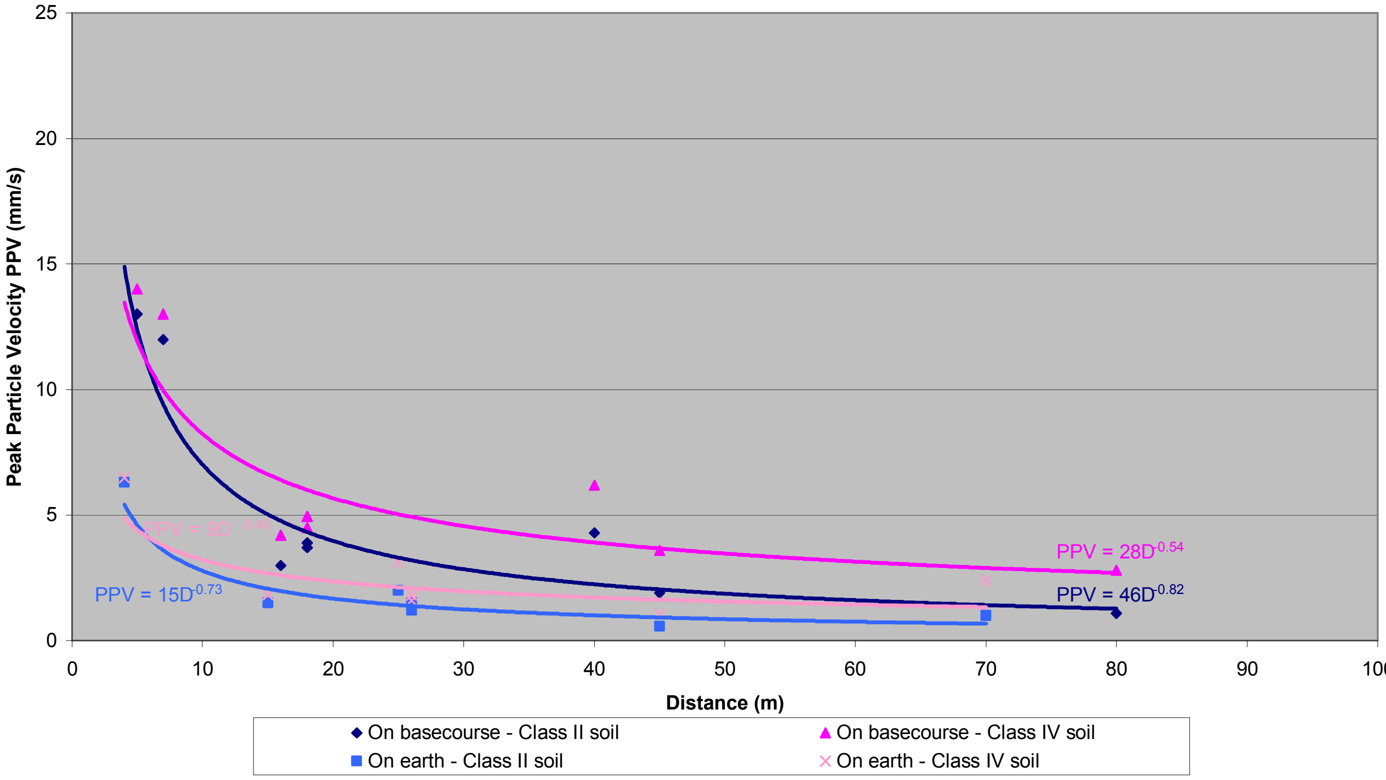
APPENDIX H

Collected Vibration Measurement Data with Regression Curves

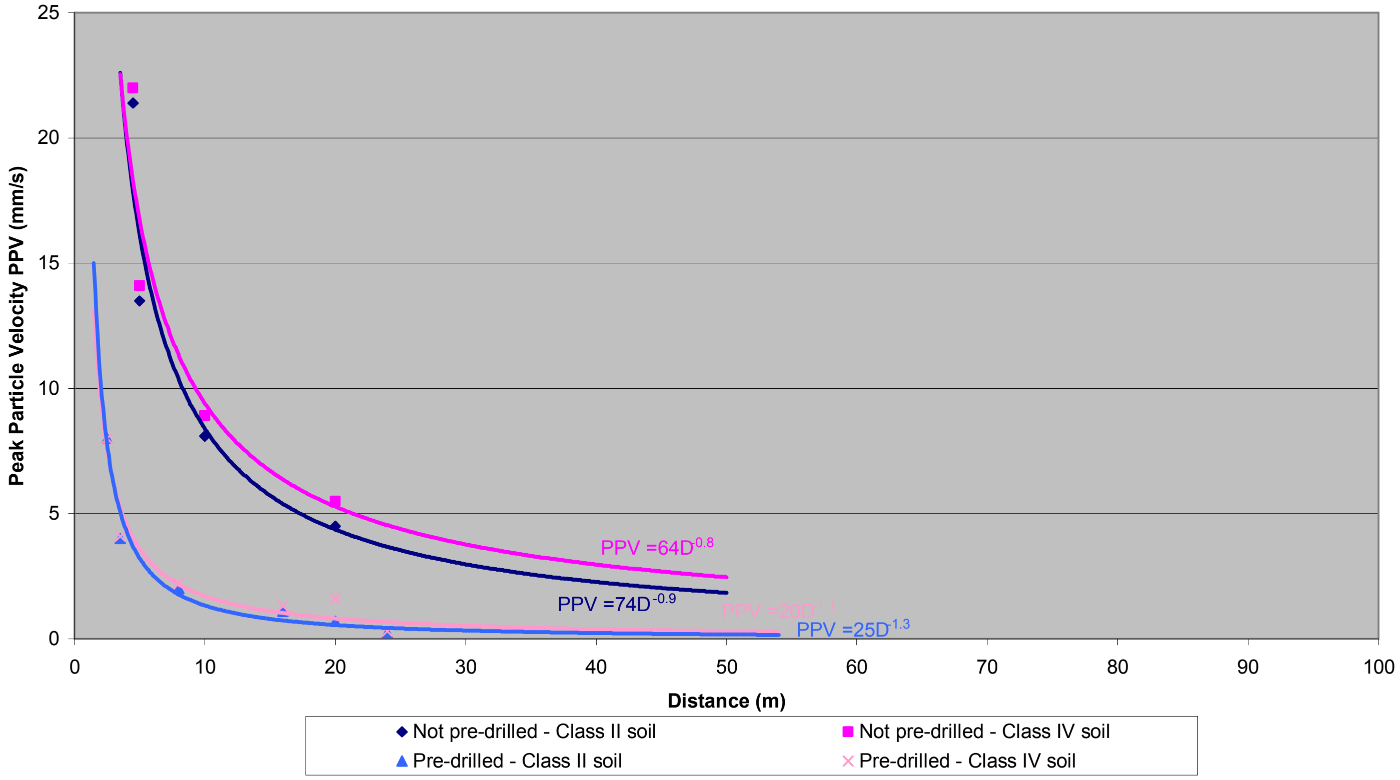
Sheet Piling - Measured Vibration Data
(normalised for ground type)



Vibrating Rollers - Measured Vibration Data
(normalised for ground type)



Vibrated Casing Piling - Measured Vibration Data (normalised for ground type)



The following Table H.1 contains collected data from historical MDA measurements and BS 5228-2:2009 on the vibration levels generated by various 'high-vibration' construction sources. The data has been corrected for soil type, and the values for the soil in which that source is proposed calculated using the methodology described in Appendix G.

Table H.1: Collected vibration measurement data, corrected for Soil Class IV (competent rock)

Source	Soil-corrected Vibration Level	
	Distance (m)	PPV (mm/s)
Drop-hammer Piling	26	12.3
	27	10
	54	2.8
	55	6.2
	80	8
Drilling (for piling)	45	0.7
	75	0.3
Excavator mounted rockbreaker	45	0.34
Excavator – general operations with bucket	10	1.5
	15	1.2

APPENDIX I

Maps and Ambient Monitoring Results for Wellington and Lyttelton

18 Ticehurst Road, Lyttelton, Canterbury

32 Macdonald Crescent, Te Aro, Wellington

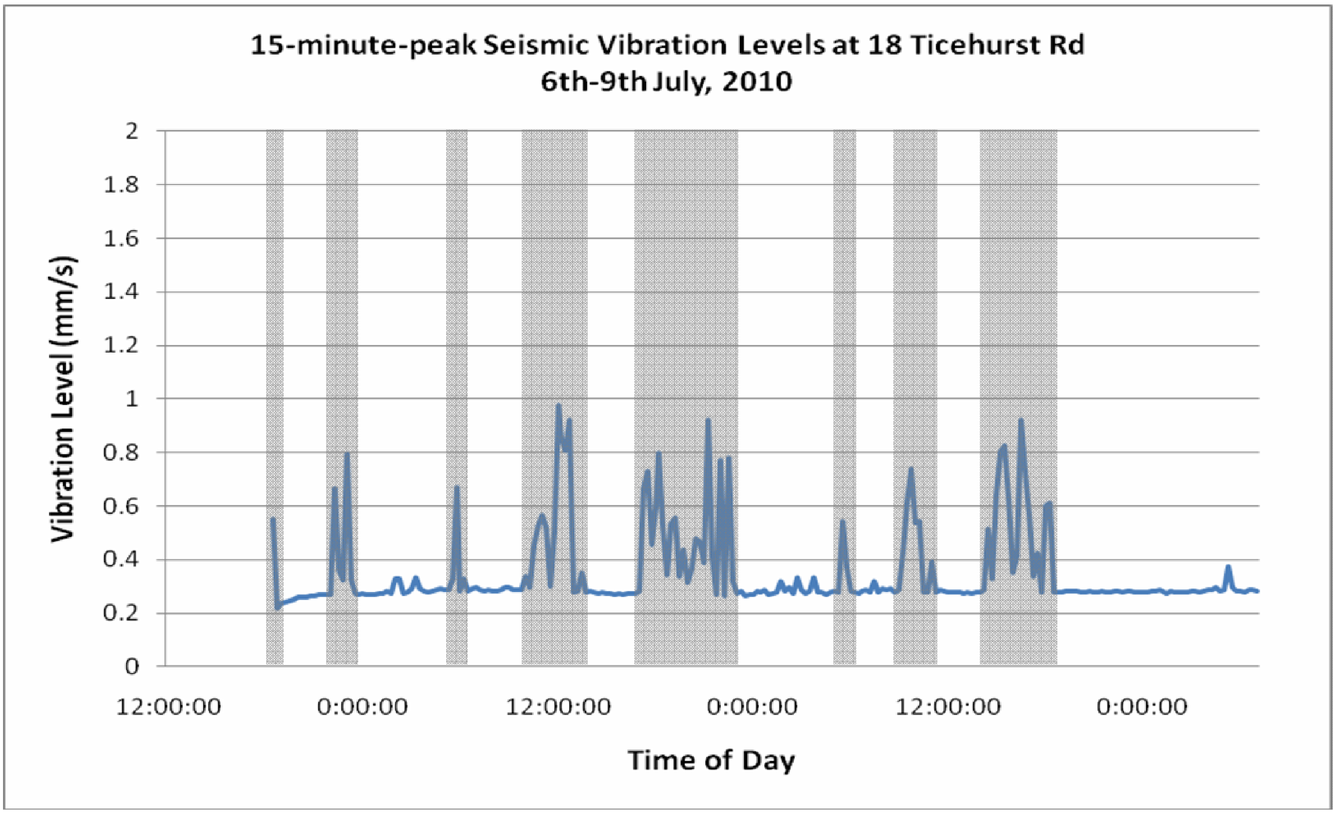
Waterview Connection – Tunnel Vibration Monitoring Results

Location:	18 Ticehurst Road, Lyttleton
Tunnel:	Lyttelton Tunnel
Date:	6th – 9th July 2009
Distance to major road:	Approx. 35m above tunnel crown. Located on SH74
Equipment:	Instantel Minimate Pro6

Maximum peak particle velocity (PPV): 0.98 mm/s
Mean uncontaminated PPV: 0.28 mm/s

Setup comment: The geophone was clamped to top plate of subfloor façade wall adjacent to joist.

Results comment: Generally low vibration levels with some periods of vibration peaks consistent with expected timing of occupant movement (e.g. morning, lunchtime, evening). Occupants stated that they experience no vibration issues from traffic (tunnel or otherwise).



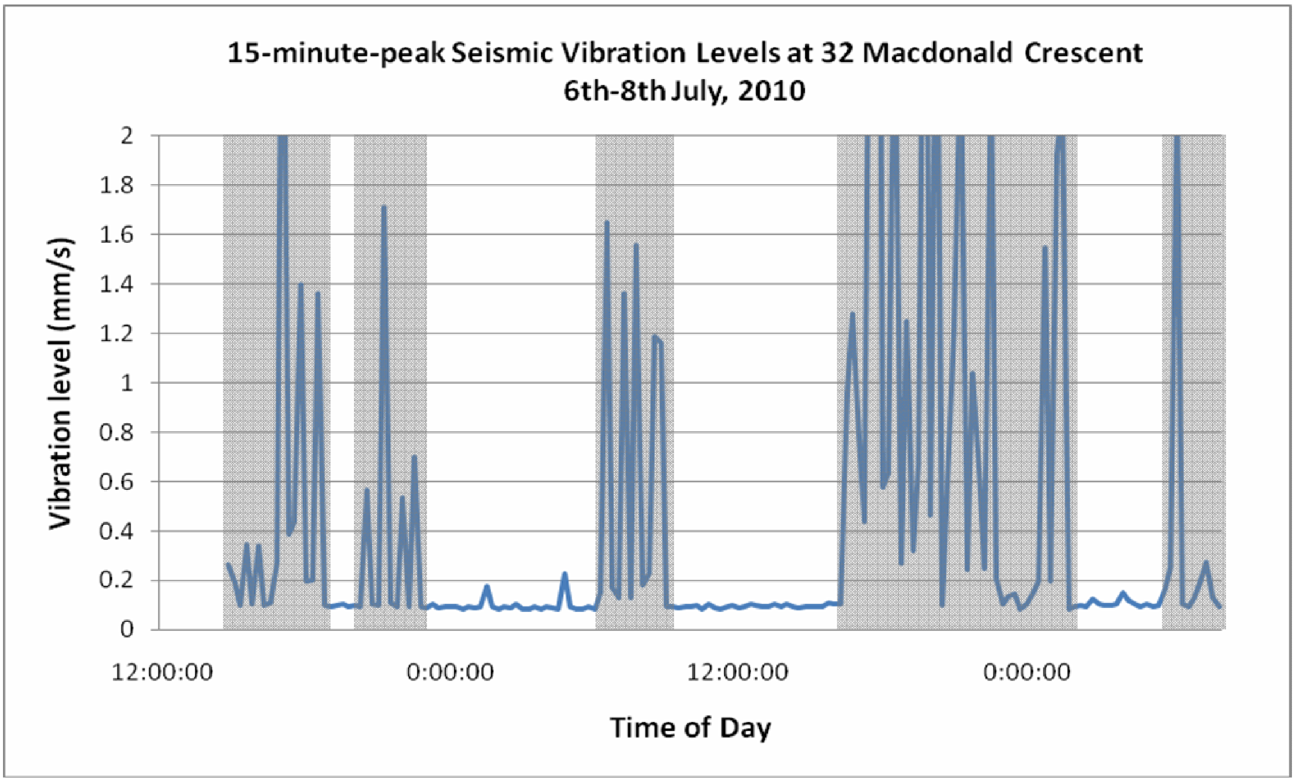
Waterview Connection - Tunnel Vibration Monitoring Results

Location: 32 Macdonald Cres, Wellington
Tunnel: Terrace Tunnel
Date: 6th – 8th July 2010
Distance to major road: Approx. 17 m above tunnel crown. Located on SH1
Equipment: Instantel Minimate Plus

Maximum peak particle velocity (PPV): 6.4 mm/s
Mean uncontaminated PPV: 0.1 mm/s

Setup comment: The geophone was secured with cable-ties to a sub-floor timber bearer directly above a pile.

Results comment: The time trace indicates occupant-generated vibration consistent with a typical daily routine, with periods of inactivity at night (i.e. occupants sleeping) and during the day (i.e. occupants at work etc). The 6.4 mm/s maximum PPV was likely due to footsteps on the floor directly above the transducer. Occupants stated that they experience no vibration issues from traffic (tunnel or otherwise).



APPENDIX J

Blasting Risk Diagrams – Sectors 6 and 9


Alignment
Base Alignment (December 2009)
Planning Information
SH20 Draft Footprint (01/07/10)
Risk
- High Risk
- Medium Risk
- Non-residential receivers: Low - Medium Risk due to more heavyweight structure
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WAKA KOTAHI
May contain information sourced from LINZ. Crown Copyright Reserved ®
May contain information sourced from ACC.
May contain information sourced from Watercare.
May contain information sourced from Vector.
Electronic information is indicative, accuracy +/- 10m.
Permits must be obtained prior to any site works.
Waterview Connection
Sector 6 Risk Diagram - Blasting
Produced by ex_jwhitlock 09:12 20/07/2010
Approximate Map Scale 1:3883 at a3
This map contains data derived in part or wholly from sources other than Beca, and therefore, no representations or warranties are made by Beca as to the accuracy or completeness of this information.
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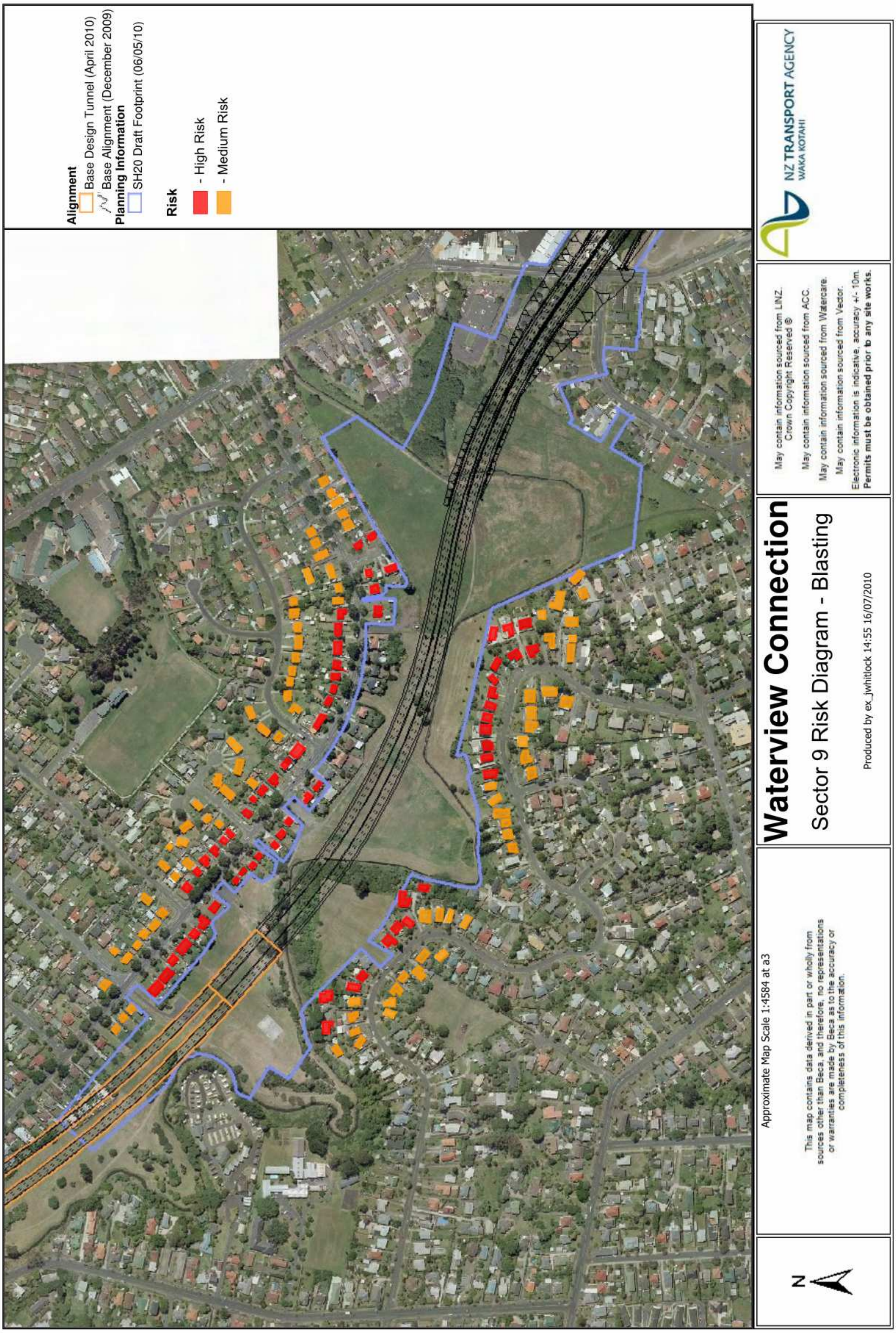
Alignment
Base Design Tunnel (April 2010)
Base Alignment (December 2009)
Planning Information
SH20 Draft Footprint (06/05/10)
Risk
- High Risk
- Medium Risk
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May contain information sourced from Watercare.
May contain information sourced from Vector.
Electronic information is indicative, accuracy +/- 10m.
Permits must be obtained prior to any site works.
Waterview Connection
Sector 9 Risk Diagram - Blasting
Produced by ex_jwhitlock 14:55 16/07/2010
Approximate Map Scale 1:4584 at a3
This map contains data derived in part or wholly from sources other than Beca, and therefore, no representations or warranties are made by Beca as to the accuracy or completeness of this information.
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