NZ TRANSPORT AGENCY
WAKA KOTAHI

Roads of national significance

16 20 Western Ring Route – Waterview Connection

Assessment of Vibration Effects

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newzealand.govt.nz

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 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 pedestrian / cycle way that will connect between the Northwestern and SH20 pedestrian / cycle ways.

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

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 pedestrian / cycle way 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 (RMA) 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

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[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:

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

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.

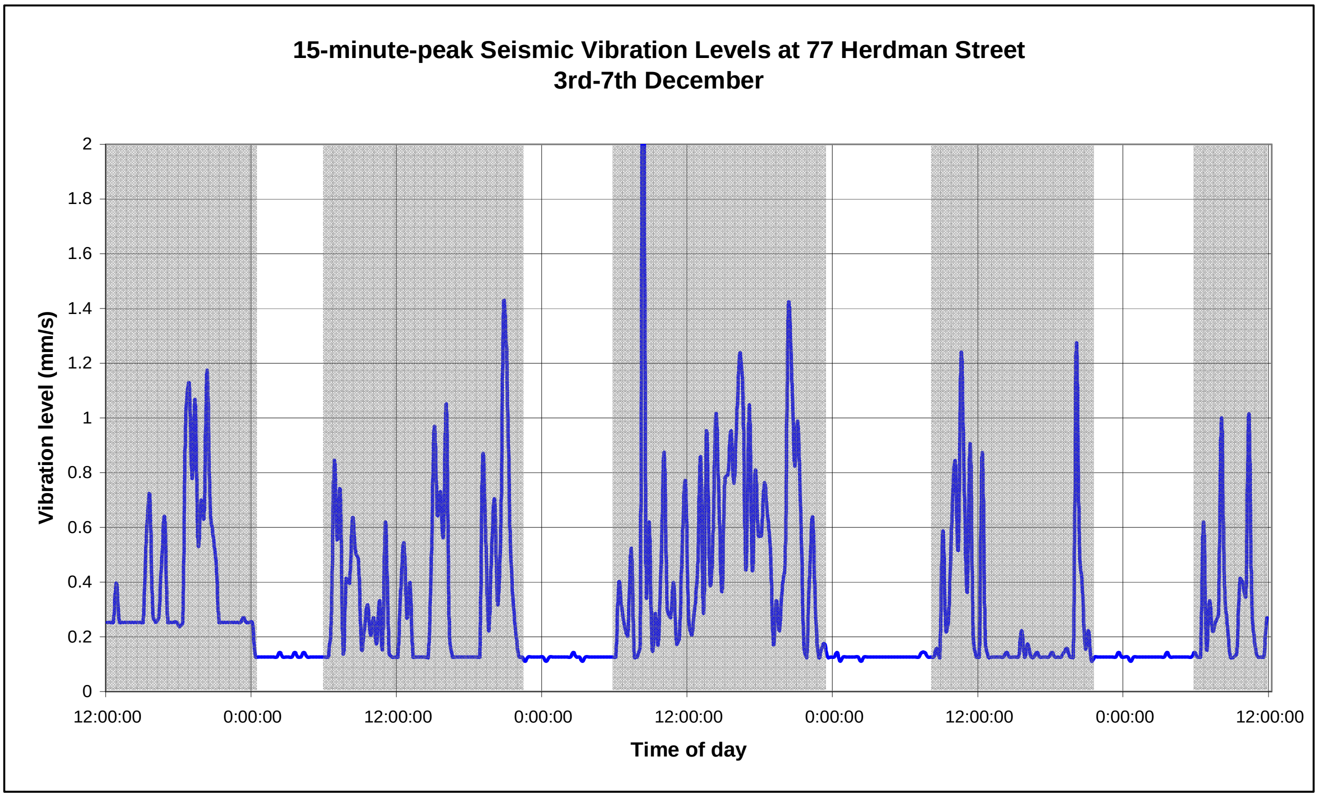

Figure 4.1 – Example of measured time trace, with occupant-based regions highlighted

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**.

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

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.

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:

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

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:

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

[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.

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 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.

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[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

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.

[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.

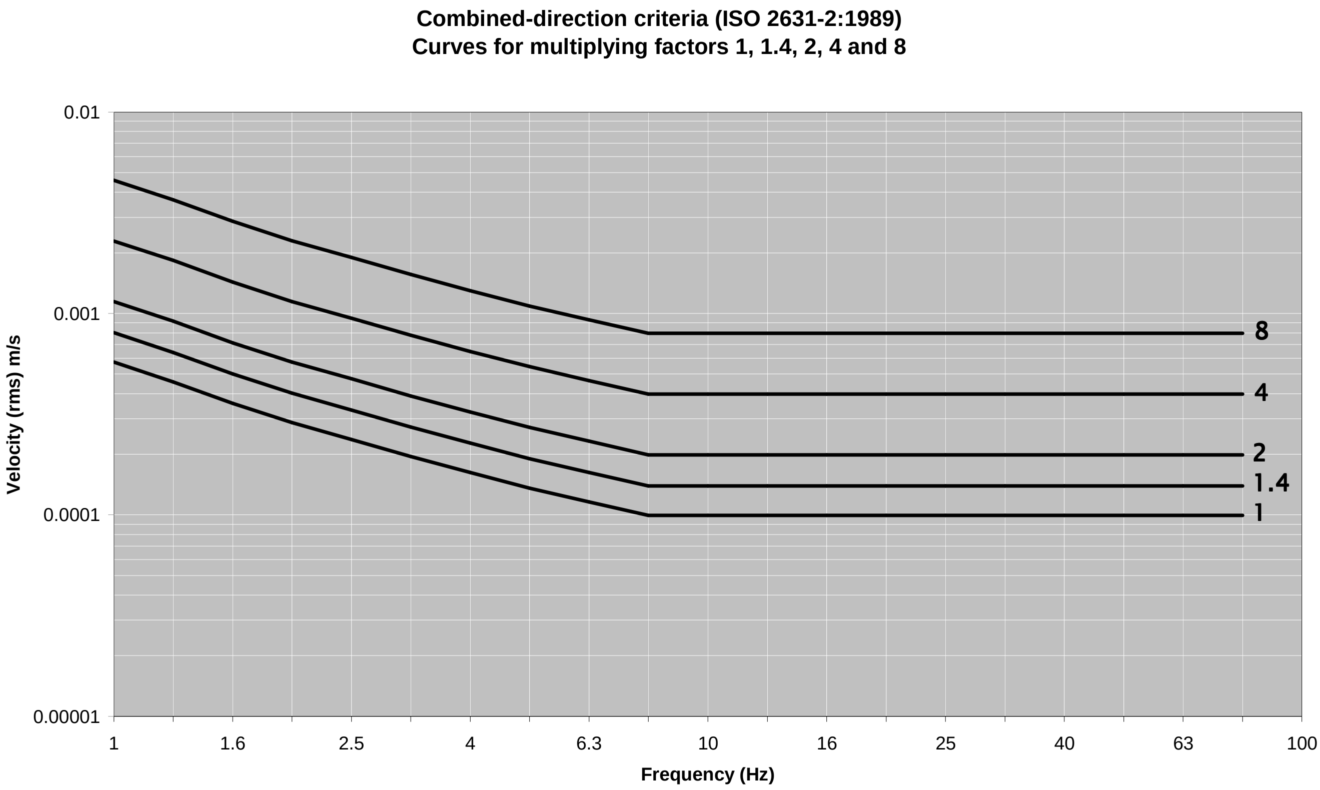

Figure 6.1 – Combined-direction weighting curves from ISO 2631-2:1989

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.

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

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 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.