Roads of national significance

Ara Tūhono - Pūhoi to Wellsford

Pūhoi to Warkworth

Vibration Assessment Report

August 2013

FURTHER NORTH

Pūhoi to Warkworth

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Glossary of abbreviations

Abbreviation	Definition
AEE	Assessment of Environmental Effects
BPO	Best Practicable Option
BS 5228-2:2009	British Standard BS 5228-2:2009 *"Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration"*
CNVMP	Construction Noise and Vibration Management Plan
DIN 4150-3:1999	German Standard DIN 4150-3:1999 *"Structural Vibration – Part 3: Effects of Vibration on Structures"*
HCV	Heavy commercial vehicle
kg	Kilogram
m	Metres
mm/s	Millimeters per second
MIC	Maximum Instantaneous Charge (in blasting)
NS 8176.E:2005	Norwegian Standard NS 8176.E:2005 *"Measurement of vibration in buildings from land based transport and guidance to evaluation of its effects on human beings"*
NZTA	NZ Transport Agency
OPW	Outline plan of works
PPFs	Protected premises and facilities (from the NZ 6806 road noise Standard)
PPV	Peak particle velocity
RMA	Resource Management Act 1991
RoNS	Roads of National Significance
SHx	State Highway (number)
$v_{w,95}$	Vibration metric used by the Norwegian Standard NS 8176.E:2005 to assess human response to traffic vibration. It is the 5^{th} percentile of a measured velocity signal that has had a frequency weighting applied.

Glossary of defined terms

Term	Definition
Ambient sound / vibration	The total sound or vibration existing at a specified point and time associated with a given environment, excluding the sound or vibration requiring control. It is a composite of all noise or vibration sources, near and far.
Auckland Council	The unitary authority that replaced eight councils in the Auckland Region as of 1 November 2010.
Building condition survey	A survey (by a structural engineer) recording and documenting any damage to the building structure - including superficial damage. Used to track the occurrence or exacerbation of building damage over time to provide objective proof in the event of any damage claims.
Earthworks	The disturbance of land surfaces by blading, contouring, ripping, moving, removing, placing or replacing soil or earth, or by excavation, or by cutting or filling operations.
Maximum instantaneous charge (MIC)	The weight (in kilograms) of a single explosive charge. It is used in a prediction model to predict how blast vibration propagates with distance.
Motorway	Motorway means a motorway declared as such by the Governor-General in Council under section 138 of the PWA or under section 71 of the Government Roading Powers Act 1989.
Peak particle velocity (PPV)	A vibration metric which has the unit millimetres per second (mm/s). A triaxial vibration measurement records PPV in all three axes and there is a separate PPV value for each axis.
Pier	Vertical support structure for a bridge.
Project	Pūhoi to Warkworth section of the Pūhoi to Wellsford Road of National Significance project.
Project area	From the Johnstone's Hill tunnels portals in the south to Kaipara Flats Road in the north.
Vibration radius	The distance from a high-vibration construction source at which vibration levels are predicted to comply with the construction risk assessment criterion of 5 mm/s PPV. There is a risk of building damage for receivers inside this distance.

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Appendix A. Regression curves of construction activity

1. Introduction

We (Marshall Day Acoustics) have assessed the vibration effects of the Pūhoi to Warkworth Project on receivers along the Project's indicative alignment. The vast majority of these receivers are residences.

The indicative alignment passes close to two residential areas: Pūhoi, and the Wyllie Road area west of Warkworth.

1.1 Purpose of report

This report forms part of a suite of technical reports prepared for the NZ Transport Agency's (NZTA's) Ara Tūhono Pūhoi to Wellsford Road of National Significance (RoNS) Pūhoi to Warkworth Section (the Project). Its purpose is to inform the Assessment of Environmental Effects (AEE) and to support the resource consent applications and Notices of Requirement for the Project.

Vibration effects for a roading project of this scale might include:

- Damage to buildings and other structures caused by high vibration construction methods; and
- Disturbance of people in their homes or workplace.

We (Marshall Day Acoustics) have assessed the vibration effects of the Project by:

- Adopting relevant vibration standards into 'Project criteria';
- Predicting vibration levels from construction activities and traffic;
- Identifying any receivers for whom the project criteria may be exceeded; and
- Proposing mitigation measures where required, including vibration management techniques for the construction phase of the Project.

The indicative alignment shown on the Project drawings has been developed through a series of multi-disciplinary specialist studies and refinement. A NZTA scheme assessment phase was completed in 2011, and further design changes have been adopted throughout the AEE assessment process for the Project in response to a range of construction and environmental considerations.

It is anticipated that the final alignment will be refined and confirmed at the detailed design stage through conditions and outline plans of works (OPW). For that reason, this assessment has addressed the actual and potential effects arising from the indicative alignment, and covers the proposed designation boundary area.

Except as noted in this report the recommendations we propose to mitigate adverse effects are likely to be applicable to other similar areas within the proposed designation boundary, subject to confirmation of their suitability at the detailed design stage.

1.2 Project description

This Project description provides the context for this assessment. Sections 5 and 6 of the Assessment of Environment Effects (Volume 2) further describe the construction and operational aspects of the Project and should be relied upon as a full description of the Project.

The Project realigns the existing SH1 between the Northern Gateway Toll Road (NGTR) at the Johnstone's Hill tunnels and just north of Warkworth. The alignment will bypass Warkworth on the western side and tie into the existing SH1 north of Warkworth. It will be a total of 18.5 km in length. The upgrade will be a new four-lane dual carriageway road, designed and constructed to motorway standards and the NZTA RoNS standards.

1.3 Project features

Subject to further refinements at the detailed design stage, key features of the Project are:

- A four lane dual carriageway (two lanes in each direction with a median and barrier dividing oncoming lanes);
- A connection with the existing NGTR at the Project's southern extent;
- A half diamond interchange providing a northbound off-ramp at Pūhoi Road and a southbound on-ramp from existing SH1 just south of Pūhoi;
- A western bypass of Warkworth;
- A roundabout at the Project's northern extent, just south of Kaipara Flats Road to tie-in to the existing SH1 north of Warkworth and provide connections north to Wellsford and Whangarei;
- Construction of seven large viaducts, five bridges (largely underpasses or overpasses and one flood bridge), and 40 culverts in two drainage catchments: the Pūhoi River catchment and the Mahurangi River catchment;
- A predicted volume of earthworks being approximately 8M m^3 cut and 6.2M m^3 fill within a proposed designation area of approximately 189 ha earthworks;
- Blasting may be required at some areas along the route.

The existing single northbound lane from Waiwera Viaduct and through the tunnel at Johnstone's Hill will be remarked to be two lanes. This design fully realises the design potential of the Johnstone's Hill tunnels.

The current southbound tie in from the existing SH1 to the Hibiscus Coast Highway will be remarked to provide two way traffic (northbound and southbound), maintaining an alternative route to the NGTR. The existing northbound tie in will be closed to public traffic as it will no longer be necessary.

1.4 Interchanges and tie-in points

The Project includes one main interchange and two tie-in points to the existing SH1, namely:

- The Pūhoi Interchange;
- Southern tie-in where the alignment will connect with the existing NGTR; and
- Northern tie-in where the alignment will terminate at a roundabout providing a connection with the existing SH1, just south of Kaipara Flats Road north of Warkworth.

1.5 Route description by Sector

For assessment and communication purposes, the Project has been split into six sectors, as shown in Figure 1. Section 5.3 of the AEE describes these sectors.

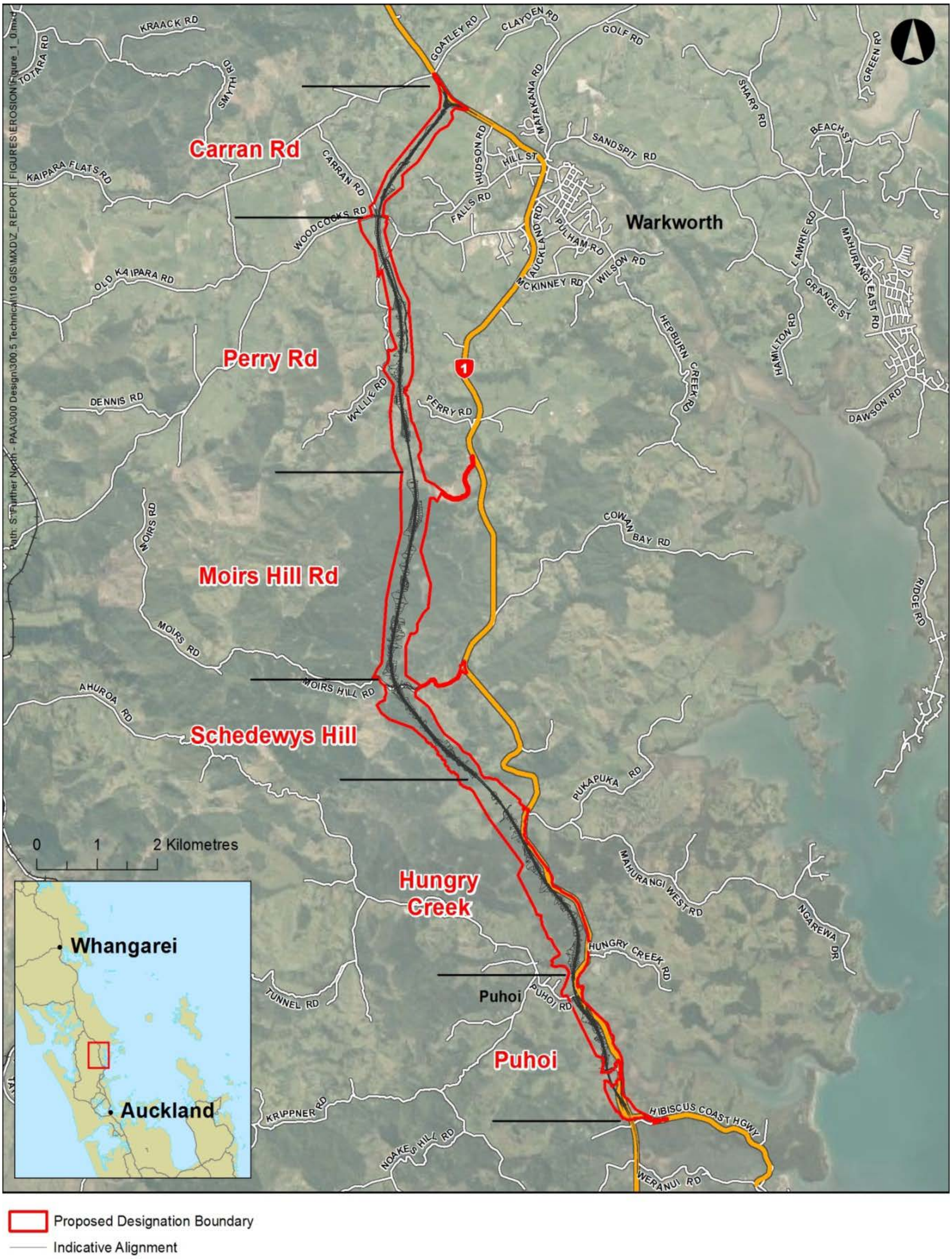

Figure 1: Project sectors

2. Vibration performance standards

There are no current New Zealand standards that address construction or traffic vibration. Accordingly, we have proposed Project criteria similar to those adopted for other large infrastructure projects in New Zealand, including other RoNS, as follows:

Construction vibration:

- The NZTA *State highway construction and maintenance noise and vibration guide (August 2013)*; and
- Table 2 from DIN 4150-3:1999 *Structural Vibration – Effects of Vibration on Structures* for effects of vibration on buried pipes.

Traffic vibration:

- Norwegian Standard NS 8176.E:2005 *Measurement of vibration in buildings from land-based transport and guidance to evaluation of its effects on human beings.*

The NZTA vibration guide uses two international vibration standards (German Standard DIN 4150-3:1999 and British Standard BS 5228-2:2009) which are the two that are commonly adopted for large infrastructure projects in New Zealand.

2.1 International standards

There are no current New Zealand standards that address construction or traffic vibration, so international standards are generally adopted for large infrastructure projects in New Zealand, including other RoNS, and they are:

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

Additional background on international vibration standards and their use in New Zealand is contained in my 2011 paper.[1]

2.2 NZTA Guide

The NZTA has issued a *"State highway construction and maintenance noise and vibration guide (August 2013)"*, (the NZTA Guide) which I helped to develop. The NZTA Guide adopts the German and British standards noted in the list above, and applies them in a progressive manner that addresses both annoyance and building damage effects. Prior to the development of this Guide

[1] Whitlock, J., "A Review of the Adoption of International Vibration Standards in New Zealand", New Zealand Acoustics, vol. 24, no. 2, pp. 24-23, 2011.

annoyance criteria were not usually applied to construction works, so the Guide adds this additional level of protection for receivers.

The NZTA Guide is available at http://acoustics.nzta.govt.nz/management/construction. An excerpt from the document, which contains the vibration criteria, is shown in Figure 2 below:

Criteria

On the basis of the standards discussed above, the criteria in table 2.3 can be used to manage the effects of construction vibration and airblast[23]. These are structured as part of a process whereby construction should be managed to comply with the Category A criteria. If measured or predicted vibration and airblast levels exceed the Category A criteria then a suitably qualified expert should be engaged to assess and manage construction vibration and airblast to comply with the Category A criteria as far as practicable (see figure 2.5). If the construction vibration exceeds the Category B criteria then construction activity shall only proceed if there is appropriate monitoring of vibration levels and effects on those buildings at risk of exceeding the Category B criteria, by suitably qualified experts.

TABLE 2.3 | **Construction vibration criteria**

Receiver	Location	Details	Category A	Category B
Occupied PPFs	Inside the building	Night-time 2000h - 0630h	0.3mm/s ppv	1mm/s ppv
		Daytime 0630h - 2000h	1mm/s ppv	5mm/s ppv
		Blasting - vibration	5mm/s ppv	10mm/s ppv
	Free-field	Blasting - airblast	120dB L_{Zpeak}	-
Other occupied buildings	Inside the building	Daytime 0630h - 2000h	2mm/s ppv	5mm/s ppv
All other buildings	Building Foundation	Vibration - transient (including blasting)	5mm/s ppv	BS 5228-2 Table B.2
		Vibration - continuous		BS 5228-2 50% of Table B.2 values
	Free-field	Airblast	-	133dB L_{Zpeak}

TABLE 2.4 | **Table B.2 from BS 5228-2**

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

Additional criteria should be used in the case of historic, vibration-sensitive or multi-storey buildings. Advice on such buildings is given in BS 5228-2[07] and DIN 4150-3[18]. Similarly, if there is history of foundation settlement, then expert geotechnical advice should be sought regarding specific vibration criteria.

Figure 2: Excerpt from the NZTA Guide showing the vibration criteria

Note that this excerpt refers to 'Figure 2.5' which has not been transcribed here. It contains a flow diagram outlining the management steps described in the text. It also uses the term 'PPFs' (protected premises and facilities). The New Zealand Road Traffic Noise Standard NZS 6806:2010 defines PPFs as: dwellings, educational facilities and play grounds within 20m of educatonal facilities, boarding houses, homes for the elderly and retirement villages, marae, hospitals that contain in-house patient facilities and temporary accommodation (e.g. motels and hotels) in residential zones. I consider that, for the purposes of my vibration assessment, playgrounds are not sensitive receivers, and motels and hotels outside residential zones (such as the Hungry Creek Bed and Breakfast[2]) are.

In general terms, the Category A criteria of the NZTA Guide aim to avoid annoyance of receivers. Because these criteria are conservative, there is a provision in the Guide to relax them if they cannot be practicably met, provided a vibration expert is engaged. The focus is then shifted to avoiding building damage rather than annoyance by applying the Category B criteria. If the Category B criteria are achieved, then building damage is unlikely to occur, but if they are exceeded, then monitoring of vibration levels and building condition must occur to allow assessment and response to any effects.

The DIN 4150-3:1999 Standard, which the 5mm/s Category B criteria are taken from, is a conservative standard designed to avoid *all* damage to buildings i.e. even superficial damage like cracking in plaster. Significantly higher limits would be applied if damage to structural foundations was the only consideration.

2.3 Norwegian Standard NS 8176.E:2005

The Norwegian Standard NS 8176.E:2005 specifically addresses transportation vibration. It is referenced in the NZTA Environmental Plan and has been adopted in other large New Zealand roading projects such as MacKays to Peka Peka, Waterview Connection and Transmission Gully.

The Standard's criteria (shown in Table 1 below) are based on studies of vibration annoyance in residences, and it provides guideline values for four vibration "classes". The appropriate class for this Project is Class C, which is the "recommended limit value … in connection with the planning and building of new transport infrastructures"[3]. According to the Section B.3.3 of the Standard, at this level of vibration "about 15% of the affected persons in Class C dwellings can be expected to be disturbed by vibration" and this is deemed by the Standard to be acceptable.

Table 1: Human response criteria for transport sources in NS 8176.E:2005

Type of vibration value	Class A	Class B	Class C	Class D
Statistical maximum value for weighted velocity, $v_{w,95}$ (mm/s)*	0.1	0.15	0.3	0.6

* $v_{w,95}$ = value exceeded for 5% of events (equivalent to L_{05} centile level in noise terminology)

[2] This receiver is located at 5 Hungry Creek Road, and is zoned General Rural in the Rodney District Plan.

[3] From NS 8176.E:2005, Annex B.3.

Note that compliance with these criteria would also ensure ready compliance with the building damage criteria in DIN 4150-3:1999.

2.4 A comment on perception thresholds

In a residential environment, people can usually perceive vibration at a level of 0.3 mm/s[4], but the risk of building damage only exists above 5 mm/s[5]. So, vibration is felt at levels significantly lower than those that would cause buidling damage.

This fact is not well understood by the general public, and it is common for people to become concerned about building damage at levels well below the relevant threshold. As a result, most complaints during construction activities are borne out of concern about potential building damage.

The NZTA Guide incorporates both perception and damage thresholds, and applies them in such a way that annoyance is considered in the first instance, but in areas of high-vibration construction, building condition is the bottom line. This approach to applying the criteria is a pragmatic way to ensure that projects do not become unnecessarily constrained by potential vibration effects, while at the same time ensuring that people's expectations and concerns are addressed.

2.5 Other reference documents

2.5.1 Resource Management Act

Under sections 16 and 17 of the Resource Management Act 1991 (RMA), there is a duty to adopt the best practicable option (BPO) to ensure that the noise from any development does not exceed a reasonable level.[6] The definition of 'noise' in the RMA includes vibration.

2.5.2 Auckland Council District Plan (Rodney Section) 2011

The Project covers an area under the jurisdiction of the former Rodney District, now part of the Auckland Council. Section 16.9.2.2.5 of the Operative Auckland Council District Plan (Rodney Section) contains vibration criteria based on the human response weighting curves of the BS 6841:1987 Standard[7].

However, these criteria are not mandatory in consideration of this Project because the NZTA is not seeking land-use consent. Furthermore we consider them to be outmoded and unsuitable for this assessment.

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[4] From BS 5228-2:2009, Annex B. Refer Category A criteria in Section 2.2

[5] From DIN 4150-3:1999. Refer Category B criteria in Section 2.2

[6] Defined in section 2 of the RMA as, in relation to the discharge of a contaminant or an emission or noise, the best method for preventing or minimising the adverse effects on the environment having regard, among other things, to:

(a) The nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects; and

(b) The financial implications, and the effects on the environment, of that option when compared with other options; and

(c) The current state of technical knowledge and the likelihood that the option can be successfully applied.

[7] British Standard BS 6841:1987 "*Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock*"

There is also a section in the District Plan on noise from new roads (section 16.9.2.2.1.2) but it does not mention vibration, so it is not relevant to my assessment.

2.5.3 National Environmental Standards

There is no National Environmental Standard (NES) to control noise and vibration from construction works or traffic operation. However, we note that the NES for Electricity Transmission Activities references DIN 4150-3:1999, in relation to vibration control of construction activities where it might impact on existing transmission lines. We are not aware of any such issues in the Project, but the DIN 4150-3:1999 are integrated into the Project criteria so the same level of protection is provided.

2.5.4 DIN 4150-3:1999 – Effects on buried pipework

The German Standard DIN 4150-3:1999 primarily addresses building damage (refer Section 2.2) but it also contains guidance values for vibration effects on buried pipework. This Standard is needed to assess the effects of vibration on the Vector gas main near the Wyllie Road overpass at CH50000. The values are given in Table 2 of the Standard, as shown below:

Table 2: Guideline values for vibration effects on buried pipework (DIN 4150-3:1999)

Pipe material	Guideline values for PPV measured on the pipe (mm/s)
Steel (including welded pipes)	100
Clay, concrete, reinforced concrete, pre-stressed concrete, metal (with or without flange)	80
Masonry, plastic	50

We have not predicted the vibration levels that may be received by the Vector gas main, but note that it is a steel pipe so 100 mm/s would be an appropriate criterion. Construction vibration would only reach such a level in very close proximity to high-vibration machines (i.e. less than 1m from vibratory rollers). We consider this issue can be managed through a Construction Noise and Vibration Management Plan (CNVMP) (refer Section 4.5.1), with monitoring and assessment of the pipe condition where construction activities occur within 5m.

2.6 Project criteria

It is our opinion that the following vibration criteria are appropriate for this Project:

- The NZTA Guide for construction vibration (refer Section 2.2);
- Table 2 of DIN 4150-3:1999 for construction vibration effects on buried pipework (refer Section 2.5.4); and
- Norwegian Standard NS 8176.E:2005 for traffic vibration (refer Section 2.3).

We recommend designation conditions be developed that require compliance with the construction criteria above (i.e. the first two bullet points).

3. Existing environment

The existing environment is predominantly rural with small pockets of residences in Pūhoi and the Wyllie Road area. In lieu of ambient vibration monitoring, and to ensure a conservative assessment, we have assumed the existing vibration environment at these residences is below the threshold of human perception (0.3 mm/s peak particle velocity (PPV)).

The ground conditions along the majority of the route are competent to hard; accordingly, there will be less vibration attenuation with distance than there would be for softer ground.

3.1 Ambient vibration conditions

Preliminary vibration monitoring may be undertaken to establish the existing ambient conditions, however on this Project most of the indicative alignment runs thorough undeveloped forestry land, with only two small residential areas at either end (Pūhoi and the Wyllie Road area). Ambient vibration levels would therefore typically be very low, except in areas of industry i.e. tree felling, the use of farm machinery and heavy commercial vehicles (HCVs) along haulage or local roads etc.

The extent to which residential receivers are impacted by vibration from these activities depends on how close they are. In the case of HCVs, their numbers on local roads are likely to be low so the effects on residences would be limited to a small number of short-term events.

In order to set a baseline for the ambient vibration environment, we have assumed in this vibration assessment that there are currently no vibration issues from industry or traffic within the Project area.

The British Standard BS 5228-2:2009 states that a level of 0.3 mm/s peak particle velocity (PPV) "*might be just perceptible in residential environments*".[8] So if we assume there are currently no vibration issues for residents, then we are implying that existing vibration levels are below this value.

Assuming an imperceptible ambient environment for all receivers makes this assessment of effects conservative, because the increase in level due to construction is assumed to be greater than it may in fact be.

3.2 Ground conditions

We have reviewed the geological long sections provided by the Project geotechnical engineer.

In summary, the majority of the route is Waitemata Group (Pakiri formation), weathered to varying degrees according to its depth, with various deposits of alluvium and colluvium in valleys and on hillsides respectively.

[8] BS 5228-2:2009 at Table B.1.

From a vibration propagation point of view, these ground types would be roughly classified as competent to hard,[9] and there would be less attenuation with distance than in softer ground.

[9] Hassan, O. *"Train-Induced Groundborne Vibration and Noise in Buildings"*, Multi-Science Publishing, 2006.

4. Assessment of construction vibration effects

The highest vibration levels will occur during the construction phase of the Project. The key sources of construction vibration for the Project will be heavy construction activities, such as vibratory rollers, piling, rockbreaking, bulldozing and blasting.

These activities generate vibration levels that can impact on receivers such as buildings, building occupants and structures. Blasting has the potential to cause the highest vibration levels and may be required in isolated areas within the Pūhoi to Perry Road Sectors.

We have analysed vibration data to determine a “vibration radius” for each source of vibration. Within this radius the vibration effects will comply with Project construction criteria.

We predict compliance with the Category B (building damage) criteria for all receivers along the route, and exceedance of the Category A (annoyance) criteria at 15 receivers.

To mitigate and manage construction vibration effects, we consider a Construction Noise and Vibration Management Plan (CNVMP) should be prepared as part of the OPW. The CNVMP would contain the Project criteria and provide detail for a methodology for pro-actively avoiding, or responding to, any issues that may arise during construction.

The NZTA Guide “State highway construction and maintenance noise and vibration guide” contains information on the content of CNVMPs and management and mitigation measures. This guide is a useful tool when preparing a CNVMP and developing appropriate measures prior to and during construction.

In the event of changes to the construction design that result in exceedance of the Category B criteria, we recommend that pre-construction building condition surveys and construction monitoring be required in accordance with the CNVMP.

The key sources of construction vibration for the Project will be heavy construction activities, such as vibratory rollers, piling, rockbreaking, bulldozing and blasting. These activities generate vibration levels that can impact on buildings, building occupants and structures. Blasting has the potential to cause the highest vibration levels and may be required in isolated areas within the Pūhoi to Perry Road Sectors.

4.1 Construction timeframe

The construction programme for the Project indicates a duration of approximately five years including a 100 – 120 day earthworks season in each year.

The programme does not specify whether any night-time construction works are required, but we note that there is a Category A value in the Project criteria to address this (0.3 mm/s PPV). We note there are some areas of the indicative alignment (e.g. in the Schedewys Hill and Moirs Hill Sectors) with no receivers nearby, so night-time construction is highly unlikely to cause any adverse vibration effects in those areas.

4.2 Receivers

Receivers for the construction phase of the Project include buildings, building occupants and structures that may be affected by vibration. Refer to Section 2.2 for the full list of PPFs for vibration.

The vast majority of these are dwellings, so these are the focus of our assessment. We are not aware of any historic (i.e. heritage listed), vibration-sensitive or multi-storey buildings adjacent to the indicative alignment or the proposed designation.

4.3 Construction vibration levels

The following sections outline the procedure we used for predicting vibration levels from construction activities. The outcomes of these predictions are given in Section 4.4.

4.3.1 Prediction methodology

We have adopted the standard prediction model for vibration propagation with distance[10], which is:

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

Where: K = the ground transmission constant (for a given ground type)

D = Distance from source to receiver

n = a measured 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 of measured data, and is usually between 0.5 and 1.5.

We used the same vibration prediction model in the MacKays to Peka Peka and Waterview Connection projects and consider it is the most suitable model for this Project.

4.3.2 Vibration sources

We have assumed typical earthmoving and road building machinery that would be used for a Project of this scale, with some details provided by the Project construction engineer[11]. The anticipated vibration-inducing machines include:

- Blasting
- Piling (bored piles with casings vibrated in using a vibro-hammer)
- Bulldozer
- Vibratory Roller
- Rockbreaker (excavator mounted)

[10] This model is contained in Hassan, O., *"Train Induced Groundborne Vibration and Noise in Buildings"*, Multi-Science Publishing Co., 2006, and many other texts.

[11] Pers. comms. Mike Collins.

4.3.3 Vibration source data

We have acquired vibration data for high vibration construction machinery from two sources:

- Measured data from site measurements for other NZTA roading projects; and
- British Standard BS 5228-2:2009, Annex C.

We have assembled all data and undertaken regression analysis to produce regression curves that show what vibration levels can be expected at different distances from the source of the vibration (refer **Appendix A** to this report). The datasets incorporate a variation of equipment types, soil conditions and measurement distances. This variety provides a good spread of data to encompass the varying soil conditions of this Project.

To ensure the regression curves are conservative, we have applied a safety factor of two, as recommended by Professor Hugh Hunt in his 2010 paper[12]. Once testing of actual vibration data has been measured on-site as part of construction monitoring, the regression curves can be refined and more accurate predictions can be made.

On each regression curve we have read off the distance corresponding to the Category A for that source (i.e. 5 mm/s PPV for blasting and 1 mm/s PPV for all other sources). This distance defines a 'vibration radius' for that source. Section 4.4 gives the vibration radius for each item of high-vibration machinery and lists any receivers in each Project Sector that lie inside them.

We have also some vibration data for a hydraulic rockbreaker, but that data is not sufficient to allow for statistical analysis. We have chosen to apply a vibration radius of 30m for the rockbreaker for the Project, as a best estimate from the available data.

4.3.4 Prediction accuracy

Vibration prediction is less reliable than noise prediction because, as a propagation medium, the ground is much more complex and difficult to model than air. Also, there are large variables in construction vibration including (but are not limited to) machine type (and the energy it delivers into the ground), operating mode, operator skill, strata and sediment layers, ground saturation, the presence of submerged solid objects (e.g. boulders), measurement technique and apparatus accuracy.

Because of this, we must make generalisations in our predictions and rely on a suitable safety margin to ensure they are conservative. As discussed in Section 4.3.3, UK vibration expert Professor Hugh Hunt claims that vibration prediction models can only achieve accuracy to within ± 100% at best (i.e. doubling or halving).

This safety margin is not applied to blasting predictions because the relationship between vibration level and explosive charge weight is well established (refer Section 4.3.5 below), and the

[12] 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.

regression analysis is not based on collected measurement data i.e. there are less variables to manage.

The CNVMP (refer 4.5.1) should require that the first use of each high vibration source is monitored to assess compliance with the Project criteria (refer Section 2.6). This monitoring will also develop the on-site dataset needed to refine the existing regression curves (which are currently based on data from other projects), and may trigger a contingency assessment (refer Section 4.4.1).

4.3.5 Blasting

We have treated blasting slightly differently from other vibration sources because there is a theoretical prediction method in common use. The prediction method still uses regression curve analysis, but the curve itself can be predicted quite accurately, using the method below, rather than relying on a dataset of site measurements.

The typical prediction model for blasting[13] is similar to Equation 1 shown in Section 4.3.1, but it includes a variable for explosive charge weight (E). The charge weight is usually expressed as Maximum Instantaneous Charge weight (MIC) in kg. The other variables are the same as in Equation 1. The blasting prediction model is:

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

The factors K and n are ground condition values obtained from blasting measurements on-site, which have not occurred yet. The Waitemata Group of the Project (refer Section 3.2) is a hard rock. I have discussed the issue with the Project's geotechnical engineers and we agreed that until site specific data is obtained it would be pragmatic to use ground condition data for hard rock (basalt) from the Waterview Connection vibration assessment. That data indicated that the ground condition values for basalt are K = 206 and n = 1.19.

Applying these values to Equation 2, we have predicted the distance that is required to achieve the NZTA Guide Category A criterion of 5 mm/s PPV for blasts of different MIC. Results are shown in Table 3 below.

[13] ETI "Blaster's Handbook", Explosive Technologies International, Wilmington, Deleware, 1998.

Table 3: Approximate MIC and vibration radii relationships for blasting in hard rock[14]

Maximum instantaneous charge weight (MIC) (kg)	Vibration radius to achieve 5mm/s PPV (m)
5	50
10	70
12.5	80
15	90
20	100

We understand from discussions with the Project's geotechnical engineers that an MIC of around 12.5kg may be required, so the vibration radius for blasting will be around 80m. Other MIC values may be used as required, and the same model can be used to predict their radii, and therefore the likely effects.

Ultimately the responsibility for the blasting programme, as well as the monitoring and review of vibration radii, should lie with the Project blasting contractor and be required by the NZTA. Measuring the vibration level of every blast is standard practice, and if there are receivers close to any proposed blasting areas, test blasts are often performed to refine the vibration radii. We consider these methods should be outlined in the CNVMP (refer Section 4.5.1).

4.3.6 Construction traffic on local roads

The Project alignment will be the primary haul road, but new access roads will need to be constructed to connect the alignment with the local road network (e.g. Moirs Hill Road and Woodcocks Road) and SH1.Traffic vibration is assessed as a weighted maximum velocity (refer NS 8176.E:2005 Standard in Section 2.3) so adverse effects will only occur for receivers where maximum vibration levels increase as a result of the Project. The character of road trucks used for the Project will be the same as HCVs that can travel along local roads by right. Furthermore, the number of construction trucks is generally small compared to the number of HCVs that currently travel on local roads (refer Section 6.9 of the Construction Noise Assessment Report) so I do not anticipate any effects from construction traffic on local roads. We note that vibration levels will not be high enough to cause building damage.

We consider that if there were any complaints about vibration from Project construction traffic, then this could be assessed on a case-by-case basis. For ongoing complaints, some mitigation measures could be implemented through the CNVMP (refer Section 4.5.1), such as reducing vehicle speed in the vicinity of that receiver, assessing the road surface for significant bumps and dips and repairing or upgrading it where necessary.

[14] Based upon basalt data and applied to the Project as a conservative assumption for Waitemata Group materials.

4.4 Risk of construction vibration effects

We have applied Project construction criteria of 5 and 1 mm/s PPV for blasting and other construction activities respectively, and calculated the 'vibration radii' using the regression curve of each high-vibration construction source. These are shown in Table 4 below:

Table 4: High vibration sources and their vibration radii (predicted)

Source	Project criterion Cat A (PPV)	Vibration radius (m)
Blasting (12.5kg charge weight)	5 mm/s	80
Vibro-hammer piling rig	1 mm/s	120
Bulldozer	1 mm/s	110
Vibratory Roller	1 mm/s	90
Rockbreaker	1 mm/s	30

These vibration radii are predictions based on previous measurements, and as recommended in Section 4.3.3, monitoring should be undertaken on-site to ensure they are accurate.

To assess the Project's potential construction vibration effects we have reviewed the applicable construction drawings[15], and identified any dwellings that lie inside the vibration radii of any sources. Buildings inside the proposed designation footprint have been excluded from this assessment as we understand they will be uninhabited during construction.

We have made some assumptions about the location of certain construction activities, and applied these to visible references in the construction drawing set, as follows:

- Piling will occur only around bridges. The exact locations of piers may vary, so it is assumed that piling could occur at any point along the bridge;
- Vibratory rollers will only operate on the alignment;
- Bulldozer will operate to the extent of the cuts and fills shown on the plans; and
- Blasting will occur in the cut areas shown on the construction drawing set.

The result of our construction vibration assessment for the Project is shown in Table 5 below. The table lists potential vibration 'hotspots', where the Category A criteria may be exceeded. In all other locations we predict the NZTA Guide Category A criteria will be met. The Project construction vibration criteria (refer Section 2.6) require that a suitably qualified expert be engaged to assess and manage the construction works for these receivers.

[15] Construction Drawings, No C-101 to C-117.

Table 5: Receivers that lie within the vibration radii for certain construction activities

Receiver	Construction activity	Vibration radius (m)	Distance from construction activity to receiver (m)
Pūhoi Sector			
3 Fowler Access Road	Vibratory roller	90	75
5 Fowler Access Road	Vibratory roller	90	40
20 Fowler Access Road	Vibratory roller	90	35
466 SH1 Pūhoi	Vibratory roller	90	30
Hungry Creek Sector			
20 Pūhoi Cl	Bulldozer	110	105
682 SH1 Pūhoi	Bulldozer	110	85
Schedewys Hill Sector			
101 Moirs Hill Road	Bulldozer Vibratory roller	110 90	75 75
187 Moirs Hill Road	Bulldozer	110	75
Perry Road Sector			
75 Wyllie Road	Bulldozer	110	105
371 Woodcocks Road	Bulldozer Vibratory Roller	110 90	105 60
372 Woodcocks Road	Piling Vibratory Roller	120 90	120 50
Carran Road Sector			
141 Carran Road	Bulldozer	110	105
62 SH1 Warkworth	Bulldozer	110	70
102 SH1 Warkworth	Bulldozer	110	95
104 SH1 Warkworth	Bulldozer Vibratory Roller	110 90	45 50

We predict compliance with the Category B construction vibration criteria for all receivers.

4.4.1 Contingency assessment

In the event that high vibration construction sources operate closer to receivers than indicated in Table 5, or if on-site measurements lead to increased vibration radii, we recommend that this assessment be reviewed.

If vibration at any receiver is predicted to exceed the Category B Project criteria, we recommend pre-construction building condition surveys be undertaken, as well as monitoring during the first use of that activity.

Additional vibration monitoring and follow-up building condition surveys should be undertaken in response to complaints, to ensure the Project construction activities comply with the Category B criteria and that no building damage has occurred. If any construction-induced damage were shown to have occurred as a result of Project construction activities, we consider the NZTA should be required to remedy this in full.

4.5 Mitigation measures

The typical measures for mitigating and managing construction vibration effects include:

- Liaison with affected parties;
- Monitoring of vibration levels and building condition;
- Using low-vibration techniques and managing the timing of activities where practicable; and
- Reducing the charge weight used in blasting.

We consider detailed management and mitigation options for Project construction vibration should be contained in the CNVMP (refer Section 4.5.1).

For blasting, both noise and vibration effects can be mitigated using best practice blasting methods[16]. The blasting contractor for the Project will be responsible for implementing these methods within the blasting vibration radius, as part of the overall design of the blasting programme.

We note that there may be time implications for some mitigation measures e.g. smaller charge weights can be used, but then more blasts would be needed. Some receivers may be prepared to tolerate larger blasts in the interests of getting the work done more quickly (provided monitoring is implemented to manage building damage risk).

[16] Best practice methods for blasting include (but are not limited to) pre-warning sensitive receivers, blasting at fixed times targeted at least disturbance, limiting the number of blasts per day, decked charges, frequency control, pre-splitting the rock, careful selection of charge weight, effective use of detonator time delays and use of alternative methods (such as penetrating cone fracturing (PCF)) if needed.

4.5.1 Vibration management through the CNVMP

We consider the OPW for the Project should include a CNVMP to address the Project's potential construction vibration effects, set out the appropriate standards that must be complied with (i.e. the Project criteria) as well as the BPOs for management and mitigation. CNVMPs are commonly used for large construction projects where details are not all fully known at the outset of construction and where flexibility is required to respond to construction issues as they occur. The framework of the CNVMP enables the construction team to take ownership of the vibration issues they may encounter. The Plan should be updated throughout the Project to reflect any significant changes.

The CNVMP should include (but not be limited to) the following vibration management content:

- The Project criteria for construction vibration;
- A list of high vibration sources to be used;
- Hours of operation, including times and days when high vibration sources would be used, and where;
- Requirements for vibration monitoring of high-vibration sources prior to construction or during their first use;
- Requirements for building condition surveys of identified receivers prior to construction works, and during the works if required;
- Roles and responsibilities of personnel on site;
- Construction operator training procedures;
- Construction vibration monitoring and reporting requirements;
- Details of the blasting contractor's programme, proposed charge weights and monitoring locations;
- Mitigation options, including alternative strategies in the event Project criteria cannot be achieved;
- Methods for receiving and handling complaints about construction vibration, including setting up a hotline number; and
- Procedure for managing vibration damage to services such as roads and underground pipelines.

We recommend a designation condition requiring a CNVMP that includes these vibration management procedures.

4.6 Summary of construction vibration effects

We predict that all construction activities in the current Project design will readily comply with the Category B (building damage) Project criteria, so the risk of building damage is low. Table 5 lists 15 receivers where Category A (annoyance) may be exceeded. The blasting programme should be designed by the blasting contractor, who should also carry out vibration monitoring of each and every blast.

We note that even moderate vibration in dwellings can result in breakage of crockery, ornaments, or pictures falling off walls etc, but this risk depends on how well these items have been secured.

For example, there would not be sufficient vibration to cause items to ‘jump’ off a shelf but if the shelf was not level an object could, over time, slowly creep over the edge. Communication with residents is the key here, including recommendations that any valuables are secured during periods of vibration (which they should be notified about).

With the management and mitigation measures we recommend, we predict that Project construction activities will comply with the Project criteria for construction vibration for all receivers, and the effects will be minor.

5. Assessment of traffic vibration effects

Traffic vibration is usually only generated when HCVs drive over bumps or dips in the road.

We have assessed traffic vibration risk by reviewing data of HCVs travelling on existing roads with a range of surface conditions. Assessing this data against the Project traffic vibration criterion (Class C of the Norwegian Standard NS 8176.E:2005) indicates that compliance with the criteria can be achieved at 25m from the road edge, even for roads in a degraded state.

With the implementation of the NZTA road maintenance policy, it is unlikely that the Project road surface will degrade significantly so we predict that the effects will be negligible for all receivers. However, if the road does degrade, the effects would still only be minor provided that compliance with the Project traffic vibration criterion is maintained.

5.1 Introduction

When the Project is completed, the only likely source of vibration will be HCVs that utilise the Project. Whether a heavy vehicle generates vibration is entirely dependent on the state of the road surface, and effects can be avoided altogether if the pavement is kept smooth and free of bumps or dips.

The assessment tool for determining whether traffic vibration is reasonable is Norwegian Standard NS 8176.E:2005, which we have adopted as part of the Project criteria (see Section 2.6).

The proposed road surface of the motorway is chip seal. Porous pavement (i.e. open grade porous asphalt) has been recommended for noise mitigation (refer Section 6.2.2.3 of the Operational Noise Assessment Report). There is a difference in roughness between these surfaces, but the effect of the different surfaces on vibration production is negligible compared to that of bumps and dips.

Vibration issues most commonly arise when road surface repairs, particularly backfilled trenches, are carried out poorly.

As will be explained, we do not anticipate any building damage effects from traffic vibration as vibration levels will not be high enough.

5.2 Receivers

The receivers of potential traffic vibration from the Project are essentially the same as for the construction phase i.e. close to the motorway alignment, but the radius of effects is much smaller.

When assessing traffic vibration, we shift the focus from buildings and structures to effects on human comfort, which may include annoyance, sleep disturbance etc. This focus means that the threshold criterion is lower than in the construction phase.

5.3 Traffic vibration levels

As we have discussed above, traffic vibration effects can be contained if the road surface is kept smooth and free from imperfections. As the motorway surface will degrade over time, we have looked at the range of vibration effects that may occur at different stages of its degradation.

To assess vibration effects from roads with degraded surfaces, we have used measurement data from the Waterview Connection and MacKays to Peka Peka projects. These were measurements of HCVs on different road surfaces, carried out and assessed in accordance with NS 8176.E:2005.

The results are shown in Table 6 below. Note that the statistical weighted velocity ($v_{w,95)}$ values are not peak particle velocities, so they cannot be directly compared with the values used in the construction assessment.

Table 6: Measurements of traffic vibration on different roads

Location	Description of road surface	Distance from road edge (m)	NS 8176.E:2005 assessment	
			Statistical weighted velocity $v_{w,95}$ [17] (mm/s)	Dwelling Class
SH20 Mt Roskill, Auckland	Freshly laid, smooth surface	10m	0.01	A*
SH1 Raumati South, Auckland	Well-used surface showing some signs of degradation	34m	0.06	A*
Quarry Road, Drury, Auckland	Degraded road surface near entrance to a quarry	25m	0.18	C

* Class A is the most favourable dwelling class in NS 8176.E and corresponds to “very good vibration conditions, where people will only perceive vibration as an exception”.

We have proposed Class C as the traffic vibration criterion for this Project (refer Section 2.6). The measurements in Table 6 show that this criterion was achieved at 25m from a degraded road surface. We have reviewed and interpolated this data, and consider that 20m would be a suitable distance to ensure compliance with the criterion. There are no receivers this close to the indicative alignment.

Furthermore, for a well maintained surface, traffic vibration is expected to be less than 0.05 mm/s at the closest dwelling (4 Wyllie Road), and the levels at all other receivers along the route would be even less. Therefore traffic vibration levels are predicted to comply with the Project criterion.

[17] Note that $v_{w,95}$ values are not peak particle velocities, so they cannot be directly compared with the values used in the construction assessment.

5.3.1 Viaduct piers

In areas where the motorway is elevated, the vibration path from traffic to receiver is quite different, and so the compliance distance will also be different. For viaducts, vibration generated by traffic is transmitted into the ground only at certain locations through the piers, and radiates outwards from there.

We have not undertaken vibration measurements near the piers of any existing viaducts. We expect each structure to have its own unique vibration transmissibility. Therefore, such measurements would not translate well to this Project.

However, using a first-principles approach, we are confident that vibration levels from a bridge would be less than a road on-grade, because vibration energy dissipates whenever it crosses a boundary layer of one material to another (Nelson[18]). There are many junctions and connections in a bridge system, so by the time vibration energy enters the ground via the piers, it will have lost a great deal more energy than if it had transferred directly into the ground.

We have predicted that traffic vibration will comply with the Project criterion for on-grade roads. Accordingly we consider it will also comply for the viaducts.

5.4 Mitigation measures

Good road surface maintenance is key to avoiding traffic vibration effects. Road surface maintenance is a policy issue for the NZTA and the NZTA has a framework to ensure the pavement of State highways does not degrade below a certain level. The relevant information is contained in Chapter 9 of the NZTA's *State Highway Asset Management Plan*[19]*.*

5.5 Summary of traffic vibration effects

The traffic vibration effects from the motorway are expected to be negligible (i.e. very unlikely to cause annoyance), provided the road surface is monitored and maintained in accordance with the NZTA policy. This policy is the primary mitigation tool, and the BPO for avoiding and mitigating operational vibration effects.

In the unlikely event of significant road surface degradation, the effects are still expected to be minor given the distances to the closest receivers in this Project. The Norwegian Standard states that some perceivable vibration is acceptable in dwellings (refer Section 2.3) provided it does not exceed the Class C criteria.

We recommend that vibration monitoring and assessment in accordance with the Norwegian Standard should be undertaken on a case-by-case basis if complaints about traffic vibration are received.

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

[19] NZTA *State Highway Asset Management Plan 2012-2015*, New Zealand Transport Agency, ISBN 978-0-478-38050-7, 2011.

6. Recommendations and conclusions

We have assessed the potential vibration effects of the Pūhoi to Warkworth Project on receivers along the route, applying relevant performance standards as Project criteria, to ensure acceptable outcomes.

We predict compliance with the Category B (building damage) Project construction criteria for all receivers and exceedance of the Category A (annoyance) criteria for 15 receivers.

We also predict that traffic vibration effects will comply with the Project criteria, and that these effects will be negligible provided the NZTA road maintenance policies are applied.

We recommend designation conditions that require compliance with the Project criteria, and development of a CNVMP through the OPW.

We predict that construction vibration levels will not exceed the NZTA Guide Category B (building damage risk) criteria for any receiver along the Project route, but they may cause annoyance for 15 receivers. These receivers have been identified and listed in Table 5.

Construction vibration effects will be managed by a CNVMP (to be developed through the OPW). The CNVMP should contain the Project criteria for construction vibration, complaints management and procedures to monitor and mitigate both annoyance and potential building damage effects, including monitoring of key high-vibration activities (refer Section 4.5.1). We consider that managing construction vibration in this way is the best practice for avoiding, remedying and mitigating effects, and that compliance with the Project criteria for construction will ensure that the effects are minor.

Traffic vibration effects are caused by heavy vehicles driving over bumps or dips in the road surface, and the NZTA has maintenance policies to monitor and manage the quality of the road surface. We consider that with the implementation of these policies, effects will be negligible. If in the event the road surface degrades significantly and complaints about traffic vibration are received, effects can be assessed in accordance with NS 8176.E:2005. If vibration levels are shown to comply with the Class C criterion in that Standard we consider that the effects will be minor.

We recommend designation conditions that require compliance with the Project construction vibration criteria, and development of a CNVMP.

7. References

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

ETI *Blaster's Handbook*, Explosive Technologies International, Wilmington, Delaware, 1998

DIN 4150-3:1999 *Structural vibration – Part 3: Effects of vibration on structures*, Deutsches Institute für Normung, 1999

Hassan, O. A. B., *Train-Induced Groundborne Vibration and Noise in Buildings*, Multi-Science Publishing Ltd, ISBN 0906522 439, 2006

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

Nelson, P., *Transportation Noise Reference Book*, Butterworth & Co. Ltd, ISBN 0-408-01446-6, 1987

NS 8176.E:2005 *Vibration and shock – Measurement of vibration in buildings from land based transport and guidance to evaluation of its effects on human beings*, Standards Norway, 2005

NZS 6806:2010 *Acoustics - Road-traffic noise - New and altered roads*, Standards New Zealand, 2010

NZTA *State highway construction and maintenance noise and vibration guide*, New Zealand Transport Agency, ISBN 978-0-478-38065-1, 2013

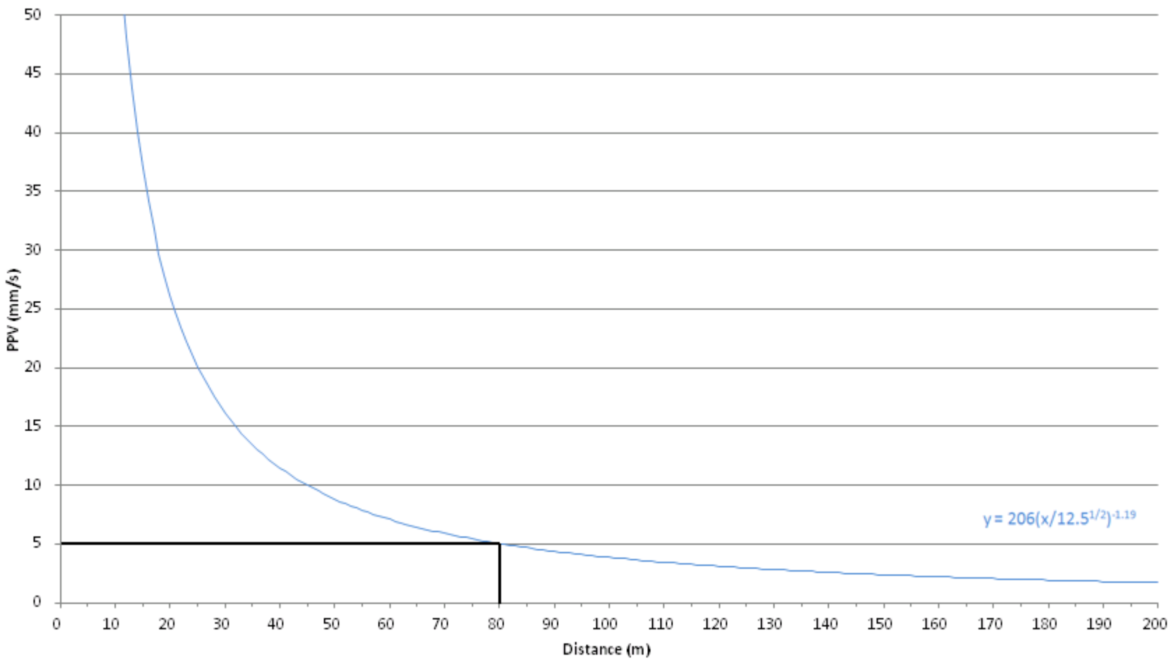
NZTA *State Highway Asset Management Plan 2012-2015*, New Zealand Transport Agency, ISBN 978-0-478-38050-7, 2011

Whitlock, J., *A Review of the Adoption of International Vibration Standards in New Zealand*, New Zealand Acoustics, vol. 24, no. 2, pp. 24-23, 2011

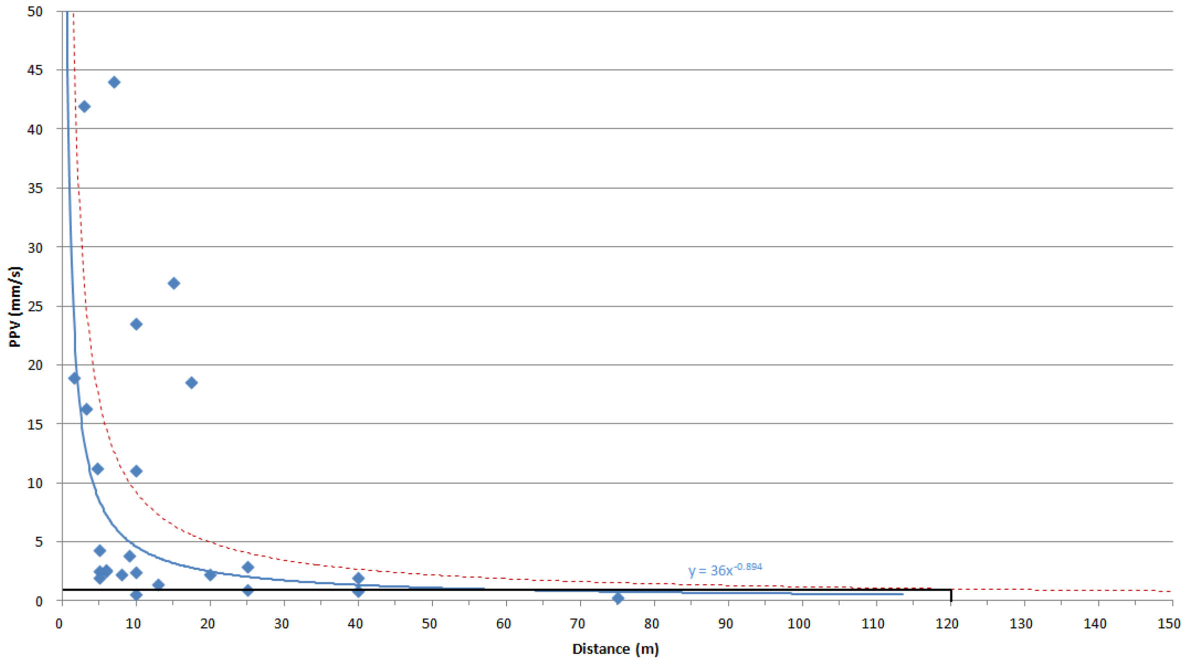
Appendix A. Regression curves of construction activity

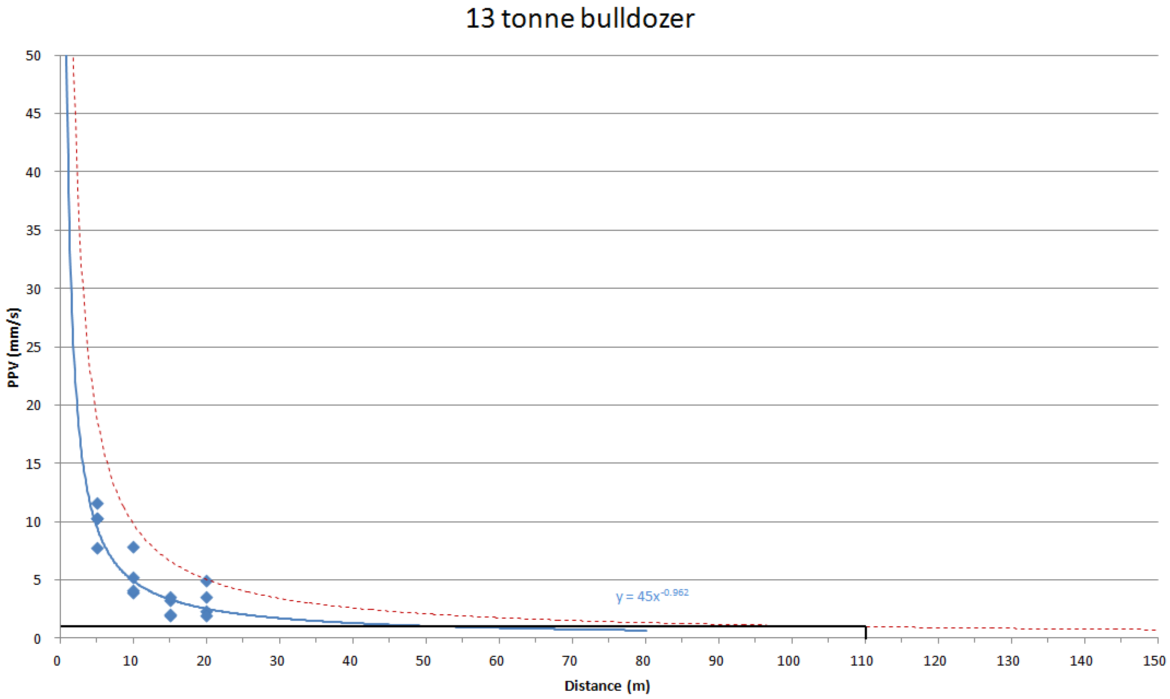
Regression line of collected data +100% safety factor Vibration radius

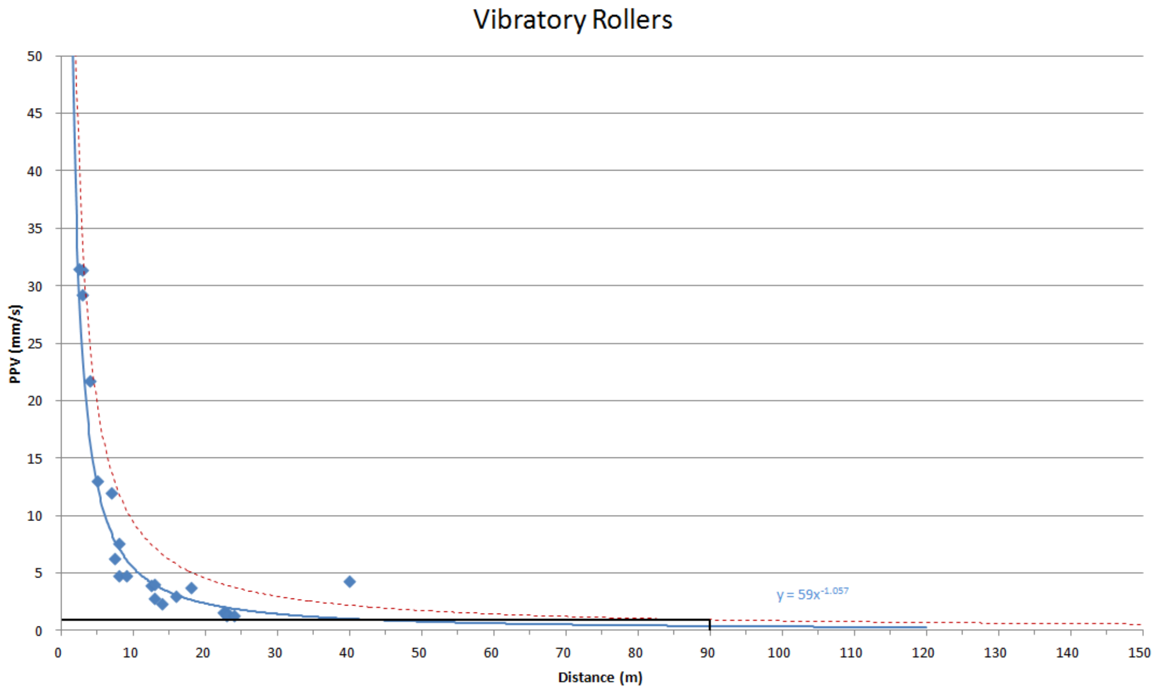
Blasting (theoretical, with MIC of 12.5 kg)



Vibro-hammer piling - BS 5228-2:2009 data




13 tonne bulldozer
PPV (mm/s)
Distance (m)
y = 45x-0.962


Vibratory Rollers
PPV (mm/s)
Distance (m)
y = 59x-1.057