REPORT

Watercare Services Limited

Northern Interceptor
Construction Vibration Assessment

Report prepared for:

WATERCARE SERVICES LIMITED

Report prepared by:

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Term	Definition
Northern Interceptor	New wastewater interceptor to convey wastewater flows from the Northern Strategic Growth Area (NorSGA) and South Rodney (Kumeu/Huapai/Riverhead) via a new pumping station at Hobsonville to the Rosedale Wastewater Treatment Plant (WWTP).
Phase 1	To be completed in 2020, Phase 1 transfers the existing Hobsonville Pump Station flows to Rosedale WWTP through a 600mm ID rising main crossing the Upper Harbour, and through Greenhithe, The North Shore Memorial Park, the North Shore Golf Club and Rosedale Industrial areas. The majority of the construction will be open trenched.
Gravity Sewer	Is an underground carriage system specifically for transporting sewage from residential and industrial buildings under gravity through pipes for treatment.
Horizontal Directional Drilling	Is a steerable trenchless method of installing underground pipes in a shallow arc along a prescribed bore path using a surface launched drilling rig.
Micro-tunnelling	Is a digging technique used to construct small tunnels, the Micro-tunnel boring machine and jacking frame are installed in a shaft at the required depth. The Micro-tunnel boring machine is directed by an operator located at the surface.
Rising main	From the Hobsonville pump station to the Rosedale WWTP the Phase 1 sewer is pressurised by pumping and is termed a rising main.

Abbreviation	Definition
AEE	Assessment of Effects on the Environment
CMP	Construction Management Plan
CNVMP	Construction Noise and Vibration Management Plan
HDD	Horizontal Directional Drill
NSGC	North Shore Golf Club
NZGS	New Zealand Geotechnical Society
PAUP	Proposed Auckland Unitary Plan (Notified 30 September 2013)
PPV	Peak Particle Velocity
RL	Reduced Level
RM	Rising Main
Watercare	Watercare Services Limited
WWTP	Wastewater Treatment Plant

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1 Introduction

Watercare Services Limited ("Watercare") is proposing to build new wastewater pipelines and associated infrastructure to convey wastewater from north-western parts of Auckland to the Rosedale Wastewater Treatment Plant ("WWTP") in Albany. This project is known as the "Northern Interceptor". Construction of the Northern Interceptor is intended to be staged, with the timing of various stages depending on the rate of population growth.

Tonkin & Taylor Ltd has been commissioned by Watercare to assess the potential vibration effects related to the construction, operation and maintenance of the proposed Northern Interceptor Phase 1 ("the Project").

The proposed work requires various resource consents under the Resource Management Act 1991 ("RMA"). This technical report provides specialist input for the Northern Interceptor Phase 1 – Assessment of Effects on the Environment report ("the main AEE") prepared by MWH New Zealand Limited, which supports the resource consent application.

This report provides the following:

- A brief overview of the proposed works (in Section 2);
- A description of the environmental baseline for the particular receiving environment(s) potentially affected by the project;
- Description of specific aspects of the project in relation to the subject area being investigated;
- A brief outline of the statutory framework relevant to vibration effects;
- Description of the investigations undertaken to assess vibration effects;
- An assessment of the actual or potential effects on the environment (construction, operation and maintenance), having reference to the statutory framework and any other environmental factors considered relevant. This includes the identification of activities that could result in adverse effects and, in turn, identifying design refinements or construction methodologies that could avoid, remedy or mitigate such effects;
- Recommended mitigation and management measures.

2 Proposed works

The proposed Northern Interceptor Phase 1 will transfer existing flows from the Hobsonville Pump Station to the Rosedale WWTP. The proposed route is from the existing Hobsonville Pump Station, under the State Highway 18 motorway, along the northern side of the motorway causeway, and then under the Upper Waitemata Harbour, through Greenhithe and then the commercial area of Rosedale.

Key elements of the project include:

- Upgrading of the existing Hobsonville Pump Station
- Installation of a pipe under State Highway 18
- Installation of pipelines in a widened section of the existing motorway causeway
- Installation of dual pipelines across the Upper Waitemata Harbour to Greenhithe via marine trenching or horizontal directional drilling ("HDD")
- Installation of dual pipelines under Te Wharau Creek via HDD
- Construction of a pipe bridge between Witton Place and North Shore Golf Course

- Installation of dual pipelines under Alexandra Stream via HDD
- Trenched construction for pipeline installation in roads, open space and other land; and installation of associated infrastructure, including minor aboveground structures

With the exception noted below, the proposed works are described in detail in the main AEE. The works described in the main AEE and shown on the appended drawings are assessed in this report.

Watercare is proposing some widening along the existing State Highway 18 motorway causeway near Hobsonville to provide for proposed water and wastewater infrastructure, including a section of the Northern Interceptor Phase 1 pipeline. That work forms part of Watercare's proposed Greenhithe Bridge Watermain Duplication and Causeway project. That project is part of a separate resource consent package, and is described in a report titled Greenhithe Bridge Watermain Duplication and Causeway – Assessment of Effects on the Environment, prepared by Aecom New Zealand.

3 Methodology

The methodology adopted for this assessment has been undertaken in accordance with the following:

1. Review of documentation provided by Watercare and MWH to identify key issues relating to vibration effects for construction and operation of the works.
2. Site appreciation including a drive over survey of the proposed route, identification of critical receivers and structures potentially affected by the effects of vibration.
3. Review of applicable vibration standards and regulatory requirements to establish recommended project criteria.
4. Assess and measure ambient conditions for sensitive receivers and critical structures.
5. Evaluate construction activities expected to generate significant vibration levels.
6. Establish attenuation characteristics of the route and the likely effects of vibrations on sensitive receivers and critical structures. Establish a list of any at risk structures.
7. Identify mitigation measures and contingency measures applicable if vibration levels are likely to exceed criteria for disturbance or potential damage.
8. Preparation of draft recommendations for inclusion in a Construction Noise and Vibration Management Plan (CNVMP).

4 Construction methodology

The proposed construction of the Phase 1: Pipeline will involve construction of a rising main from the existing Hobsonville Pump Station to Rosedale WWTP. The works involve a combination of construction methods including trenching, horizontal directional drilling and microtunnelling. The methodology expected to be adopted for each section of pipeline is shown on the main AEE drawing set but details may vary depending on particular methodologies offered by Contractors.

Details of the proposed works and expected construction activities are provided in the construction methodology (Chapter 2, Volume 1 of the main AEE document).

The construction methodology provides detailed discussion on each section of the pipeline route including scope of works, description of typical equipment types, and approximate duration as well as identifies the likely environmental effects during construction and operations. The route has been divided into 18 segments with similar characteristics for the vibration assessment including two options for the Harbour Crossing.

The segments are summarised in Table 1 and the construction activities expected to be the principal sources of any significant vibrations are included.

Table 1: Pipeline Sections and Construction Method Summary

Section	Section Description	Geological Conditions	Principal Construction Methodology	Plant & Activities Vibration Sources	Sensitive Receivers and Distance to Closest Structures (m)
1	Existing Hobsonville Pumping Station	Pleistocene Age sediments over residual ECBF	Excavation, compaction	Excavators, trucks, compaction plant, generator, pile driving equipment	NIL
2	Upper Harbour Highway Crossing	Pleistocene Age sediments over residual ECBF	Jacking shaft, micro-tunnelling	Pile driving equipment, micro-tunnel jacks, generator, trucks	Nil
3	Trenched Pipe to Causeway	Pleistocene Age sediments over residual ECBF	Open cut trenching and pipe laying	Excavations, trench shields, cranes and dewatering pumps, compactors	Town Houses 20 m) Residence (>30 m)
4	Causeway to Harbour Crossing – Section not included in this project				
5a	Harbour Crossing Marine Trenching	Marine sediments	Marine Trenching	Excavators, barge/dredge tenders, jet trenching and mudflow excavators, tipper trucks, mobile crane, concrete pump	Scout hall Rahui Rd (20 m)

Section	Section Description	Geological Conditions	Principal Construction Methodology	Plant & Activities Vibration Sources	Sensitive Receivers and Distance to Closest Structures (m)
5b	Harbour Crossing Directional Drilling	Marine sediments over Pleistocene Age sediments and Residual ECBF	Excavation of HDD Pits. Directional drilling from Causeway end	Mobile crane, excavator, compactors, HDD Rig, piling rig, mud separator, concrete pump	Scout hall Rahui (30 m)
6	Trenched Pipeline Rahui Rd to Traffic Rd (16 Rahui Rd – 1 Traffic Rd)	Pleistocene over residual ECBF	Open cut trenching up to 5 m depth and pipe laying	Excavator, trench shields, cranes, compaction plant	1 Traffic Rd (12m) 9,11,16,16 /7 18 Traffic Rd (12-15 m)
7	Trenched Pipeline 1 – 75 Greenhithe Road	Residual ECBF	Open cut trenching to 7 m depth and pipe laying	Excavator, trench shields, cranes, compaction plant	4-12 & 34 Greenhithe Rd - Residential, commercial buildings (15 m)
8	Trenched Pipeline Wainoni Park	Pleistocene over residual ECBF	Open cut trenching to 7 m depth and pipe laying	Excavator, trench shields, cranes, compaction plant	34, 36, 66, and 72 Te Wharau Dr (10m)
9	Te Wharau Creek - Tidal Inlet Crossing by Directional Drilling	Marine sediments, Pleistocene at HDD Pits	Directional drilling from Wainoni Park	Mobile crane, HDD rig, excavator, piling rig, concrete truck, sheet piling, compactor	Nil
10	Trenched Pipeline NSMP	Pleistocene Age sediments	Open cut trenching to 7 m depth and pipe laying	Excavator, trench shields, cranes, compaction plant	Nil
11	Trenched Pipeline 224 Schnapper Rock Rd - 11 Witton Place	Pleistocene Age sediments	Open cut trenching to 7 m depth and pipe laying	Excavator, trench shields, cranes, compaction plant	222,224 Schnapper Rock Road (5 m) 30, 32, 34 Newbury Place (5 m) 9, 17 Newbury Place (10 m)
12	Pipe Bridge Witton Place to NSGC 11 Witton Place -NSGC	Pleistocene Age sediments over ECBF	Open trench Pipe bridge	Piling, cranes, trucks, excavators and compaction plant	9 Witton Place 15 m 11 Witton Place 20 m
13	Trenched Pipeline NSGC – Albany Highway	Pleistocene Age sediments	Open cut trenching and pipe laying	Excavator, trench shields, cranes, compaction plant	111 Laurel Oak Dr, 10 & 12 Appleby Road (10 m)

Section	Section Description	Geological Conditions	Principal Construction Methodology	Plant & Activities Vibration Sources	Sensitive Receivers and Distance to Closest Structures (m)
14	Trenched Pipeline Across Albany Highway	Pleistocene Age sediments	Open cut trenching and pipe laying, sawcutting	Excavator, trench shields, cranes, compaction plant	Nil
15	Trenched Pipeline Albany Highway to William Pickering Drive	Pleistocene Age sediments	Open cut trenching and pipe laying, directional drilling, sawcutting, compaction	Excavator, trench shields, cranes, compaction plant	12/327 Albany Highway (5m) 315, 321 Albany Highway (10 m) 317 Albany Highway (15 m) 24 William Pickering Drive (15 m)
16	Trenched Pipeline Piermark Road and Kea Access Road	Pleistocene Age sediments	Open cut trenching and pipe laying, directional drilling, sawcutting, compaction	Excavator, trench shields, cranes, compaction plant	1 Piermark Dr. Commercial building (15 m) 169 Bush Rd. Commercial building (4 m)
17	Alexandra Stream Gully Crossing to Rosedale Directional Drilling	Pleistocene Age sediments, ECBF pile foundations	Directional Drilling	HDD, excavator, sheet piling, concrete pumps, mud separator plant	Nil
18	Trenched Pipeline Rosedale Park and WWTP	Pleistocene Age sediments	Open cut trenching and pipe laying	Excavator, trench shield, compaction, cranes, pipe laying	Nil

5 Geology

The geological conditions along the pipeline route have been determined by site mapping and preliminary geotechnical investigations. A developed geological long section is incorporated in The Assessment of Groundwater and Settlement Effects, AEE Vol 2, Technical Report J. A summary of the geological conditions expected to be encountered by the works in each of the sections are included in Table 1 above.

In summary, the majority of the trenched pipeline work on the route will encounter Pleistocene Age sediments. These are firm to stiff moderately over-consolidated clayey silts with some sands with moderate plasticity. The trenched pipeline at the Greenhithe Road section (Section 7) will encounter residual East Coast Bays Formation (ECBF) which are formed by weathering of the underlying basement ECBF rock. Piles for the pipe bridge at Witton Pl to NSGC may extend into the ECBF rock.

The marine sediments in the Upper Harbour Crossing (Section 5) and Te Wharau Creek crossing (Section 9) are expected to be soft silts and loose sands with moderate to high plasticity. The Pleistocene Age sediments and residual ECBF materials encountered in the HDD Pit at each end will be similar to the soils described above for the trenched segments. ECBF weak rock is likely to be exposed in the base of the HDD pits and much of the HDD pipelines will be bored in ECBF. The presence of ECBF rock may limit the depth of driving of sheet piling for the HDD pits. Weak ECBF rock may be specified for founding of driven or bored piles for pipe bridge in Witton Place to NSGC (Section 12).

The geological conditions expected to be encountered on the route are generally suitable for excavation and pipe installation using conventional earthworks plant.

Trench shoring using shields or sheet piling will be necessary over much of the length of the trench excavations for safe operations and to ensure deformations do not impact on nearby services. Where the former is used these will be managed on site by excavators or light cranes. Sheet piling use is expected to be limited to HDD pits deep valve stations. These works are all located at large distances from sensitive structures or receivers. The deep trench section in Greenhithe Rd (Section 7) may require use of heavier plant and sheet piling.

Piling works for the pipe bridge at Witton Place are also expected to be located at large distances from sensitive structures and receivers except at the 'southern' abutment of the Witton Place pipe bridge that is within 15 m of 9 and 11 Witton Place.

6 Vibration effects and site characteristics

Ground borne vibrations are generated by oscillating motion that is transmitted by contact between particles in the ground. The vibration wave forms in the ground propagate as either compression (P) waves or shear (S) waves. The interaction of these waves with the ground surface produces Rayleigh (R) and Love (L) waves. The Rayleigh waves are particularly important as they generally produce the largest particle velocities which directly impact on the imposed strain in structures. Measurements of vibration for the assessment of risk to structures are therefore generally measured in terms of peak particle velocity, ppV. The human body is primarily responsive to the forces imposed on it. Hence the effect on the human body is usually measured in terms of acceleration. By assuming a regular sinusoidal wave form, the corresponding limits may be expressed in either acceleration or ppV for any given frequency.

The magnitude of the vibrations are influenced by a number of factors, the principal variables being the energy of the source and the distance to the receiver. Other variables which are generally less significant include the geology, the surface topography and groundwater.

The simplified prediction model that is applied for propagation of vibrations with distance is:

$$ppV = k\left(\frac{D}{\sqrt{E}}\right)^{-n}$$

where k = site constant

D = distance from the source to the receiver

E = Energy of source

n = attenuation factor, primarily dependent on geology and groundwater, generally between 0.9 to 1.5 for Auckland geological conditions.

Where the energy source is constant then the equation reduces to:

$$ppV = k'd^{-n}$$

The site constants are generally determined for each activity based on trials or using experience in similar areas. The predictive models may then be utilised to assess the effects on receivers. For design it is useful to establish the confidence limits of the activities and establish a compliance approach based around these limits (e.g. for pile driving or blasting design, the upper 95% confidence limit is targeted to meet the conservative recommendations of limits to protect property from minor damage). As noted above, this promotes and rewards the use of best practice in the construction industry, whereby constructors which apply high levels of quality control can benefit by use of larger plant or targeting higher charge weights for blasting works. The application of this method, together with an upper "regulatory" limit, has been utilized for the trenching and pipelaying at the Waterview Connection Project, see Appendix A, and this is applied on many of the major infrastructure projects and quarries in the Auckland region, see Auckland City District Plan 8.8.2.7(b).

7 Vibration criteria

7.1 Review of Applicable Vibration Standards

A review of vibration standards has been undertaken. This has included review of the international standards that apply to the physiological effects of vibrations on people and the potential to cause damage to structures. This is included in **Appendix A**. A summary of the vibration criteria contained within the operative District Plans and Proposed Auckland Unitary Plan (PAUP) is also provided in the following sections together with recommendations for controls for this project.

7.2 District Plan controls

7.2.1 District Plan (North Shore City) – Operative 2002

The North Shore City Council District Plan contains specific controls relating to vibration. Section 10.3.4 vibration status on objective "to ensure that any adverse effects from vibration of equipment is avoided, or reduced to an acceptable level". The expected environmental result is that "Building vibration restricted to a level with low probability of human reaction on adjoining sites, as measured by an annual assessment of Councils Complaints Register.

Section 10.7 Vibration: Rules provides the following controls:

a) *No activity shall be permitted to create vibration levels (acceleration in metres per second squared) relative to frequency which affect occupants of adjacent buildings by exceeding the base curves of Figures 2a (z axis), 3a (x and y axis), and 4a (combined xyz axis) of International Standard ISO 2631-2:1989 – Evaluation of human exposure to whole-body vibration – Part 2: Continuous and shock-induced vibration in buildings (1 to 80 Hz).*

b) *Annex A and Table 2 of ISO 2631-2:1989 shall be used for the assessment of continuous, intermittent and transient (impulsive) vibrations.*

c) *Instruments to measure such vibration, and methods of measurement shall comply with Australian Standard AS 2973:1987 and AS 2187.2:1993.*

Explanation and Reasons

This control deals with human response to building vibration. Standards formulated to control vibration are generally related to the tolerance of a sitting or standing person.

Annex A and Table 2 of the Standard give consideration to the time of the day and use made of the occupied space in the building.

Situations may exist where vibration levels above those specified can be tolerated for temporary disturbances and infrequent events of short-term duration, e.g. blasting, construction and excavation projects.

The reason for adopting the ISO and Australian Standards is to ensure a consistent and internationally recognised assessment procedure is used.

The District Plan does not include any specific controls relating to vibration levels for structures.

Waitakere City District Plan – Operative 2003

The District Plan contains specific controls relating to vibration. Rule 14 of the Human Environment and Rule 10 of the Living Environment both contain rules which are consistent with the North Shore City Council District Plan.

7.2.2 Proposed Auckland Unitary Plan (PAUP)

The PAUP was notified in 2013. It is not yet operative but Part 3, Chapter H, Section 6.2.1.5 addresses vibrations. It requires that blasting and pile driving activities must be controlled to ensure that any resulting ground vibrations does not exceed the levels set out in Table 1 of DIN 4150-3:1999, when measured as the foundation or the horizontal plane of the highest floor of an affected building.

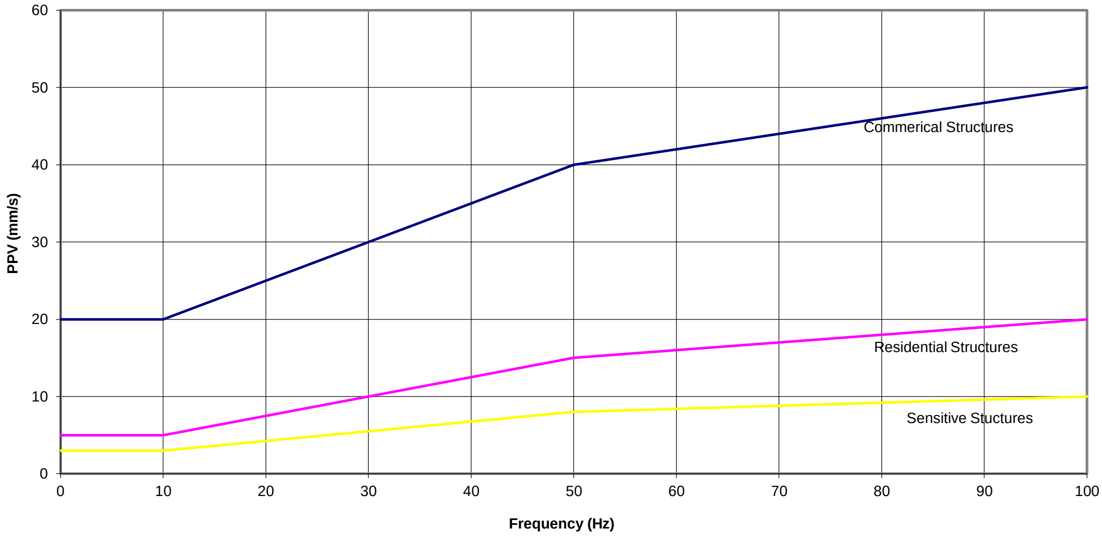
The DIN 4150:1999 Standard is discussed in detail in Appendix A. The recommended criteria are provided in Table A.5 and Table A.6. These have been combined as Table 2 below and shown in Figure 1.

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

Line	Type of Structure	Vibration Velocity (mm/s)				
		Short Term				Long Term
		Foundation Frequency			Plane of Floor of Uppermost Storey	Plane of Floor of Uppermost Storey
		Less than 10 Hz	10 to 50 Hz	50 to 100* Hz	Frequency Mixture	
1	Buildings used for commercial purposes, industrial buildings and buildings of similar design	20	20 to 40	40 to 50	40	10
2	Dwellings and buildings of similar design and/or use	5	5 to 15	15 to 20	15	5
3	Structures that, because of their sensitivity to vibration, do not correspond to those listed in lines 1 and 2 and are of great intrinsic value (e.g. buildings that are under a preservation order)	3	3 to 8	8 to 10	8	2.5

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

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



The DIN 4150-3:1999 standard has been widely applied in New Zealand and includes conservatively based criteria to ensure a low risk of minor damage to non-structural elements of buildings, e.g. hairline cracking of plaster joints. It provides a high factor to limit the risk of damage to structural elements. For vibration sources of relatively short duration such as blasting, piling transient and construction operations, this criteria will also ensure that the effects of vibrations on people will not exceed acceptable disturbance levels.

For operational controls the PAUP Rule requires that stationary vibrating, reciprocating and rotating machinery and all piping, ducting and other equipment attached to such machinery must be installed and maintained so that any resulting vibration does not exceed the levels of Table 2 when measured in adjacent buildings or areas of building under different ownership from the source of the vibration.

For continuous long term vibration sources, Table 3 of the Standard DIN 4150-3:1999 (reproduced as the last column on Table 1 above) applies for structures but the more limiting effects of the physiological criteria for occupied buildings may also apply.

7.3 Project criteria

The DIN 4150-3:1999 standard is the appropriate control for construction of this project. The standard includes vibration criteria that have been widely applied in New Zealand to successfully complete infrastructure construction works with a low level of complaints of disturbance and damage. The limits ensure a low risk of surficial damage to residential and sensitive structures and also provide an acceptable level of disturbance to most receivers for short duration activities during normal working hours. It is not expected that trenching works will extend into the night in proximity to residential structures. However, it is likely that the HDD crossings, Upper Harbour Highway and major road crossings (Albany Highway and William Pickering Drive) may involve some night works.

Provided residents are adequately notified in advance of activities and they are given opportunity to record and have concerns considered (and if necessary addressed), the potential physiological effects can be managed, in accordance with the recommendations of the CNVMP in Section 10 below.

8 Vibration sources and Effects

8.1 General

The proposed construction methodology is discussed in the main AEE document. The plant identified as the most significant sources of vibration on each segment of the works is listed in Table 3. The absence of rock over the majority of the works, and the large distances to sensitive receivers where piling is likely to extend into rock, means that the principal vibration sources will be conventional earthworks construction operations.

The plant types and typical distances beyond which the vibration levels generated by their operation in the expected geological conditions are not expected to exceed vibration criteria or result in significant disturbance to occupants are also listed in Table 3. The rate of progress expected to be achieved in the pipe trenching segments means the period of disturbance associated with construction will be relatively short and tolerance to vibration will be increased relative to long term continuous sources. It is therefore expected that the vibration controls will be determined by the potential effects on structures and the recommended criteria of DIN 4150-3:1999 will be applicable.

For the trenched pipeline the typical plant operations using conventional excavators and handling equipment are not expected to exceed the DIN 4150-3:1999 criteria at distances of greater than 5 m. The largest source of vibrations is expected to be the installation and removal of trench shields and locally the driving of sheet piling. The latter is unlikely to extend to rock and light driving plant will be utilized to install and recover the sheets. The trench alignments have been located to exceed the distances in Table3 over the majority of the route.

The exceptions to this are listed in Section 8.4. There is a deep section of trenched pipeline in Greenhithe Rd (CH 2550-2750) where heavy excavator, sheet piling and handling plant may be required.

Construction of the scour and air vent chambers, as well as the HDD pits, will generally be undertaken using the same plant as for the pipe trenches. Ground support may involve greater use of sheet piling for temporary support.

As noted above, works involving piling for the pipe bridge structures will generally be undertaken at remote locations where vibrations will not be significant. An exception to this will be at 9 and 11 Witton Place where piling for foundations is expected to be required and may involve pile driving plant. Alternative options to limit noise and vibration effects are to use bored or screwed piles. A more detailed assessment of the magnitude of vibrations caused by the plant and potential effects on the properties along the route is provided below.

The effects of construction also need to consider the current vibration background environment.

8.2 Ambient conditions

The current environment along the route comprises a combination of residential, commercial, open space and arterial roading. The primary source of vibrations is vehicles utilizing the roading system with occasional work on infrastructure and building. No site specific background monitoring has been undertaken but experience would indicate that vibration levels beyond 5 m from the edge of pavements would generally be less than PPV = 0.5 mm/s, i.e. at or below perception levels, with occasional peaks from heavy vehicles and construction works up to 1-2 mm/s.

Vibrations generated by frequent activities of occupants of dwellings such as jumping, moving furniture and dropping items are expected to range up to 2mm/s while occasional events such as an out of balance spin cycle of a washing machine can generate vibrations exceeding 10mm/s.

8.3 Construction vibration estimates

The works will generally involve the use of medium size construction methods (e.g. 20 tonne diggers and small piling plant). There is no hard rock present that will require the use of heavy plant, rock breakers or blasting. This section identifies the main construction activities, and associated plant, and assesses the likely effects on nearby receivers. It includes consideration of the likely magnitude of any generated vibrations, the duration of the work, the potential effects on sensitive receivers and property, as well as discusses potential mitigation measures that may be required.

It is assumed in this assessment that the majority of surface works undertaken will generally be limited to daytime hours. Only work directly associated with major road crossings and the Horizontal Directional Drilling works (which may require continuous rotation of the head while boring) will include night-time operations and, if necessary, this may impose limits to surface support activities such as spoil removal and material delivery. In business areas some additional night time work may also be scheduled to reduce impacts.

The activity sources that are expected to be the potential generators of the highest levels of vibrations from the project are listed in Table 3. The table also identifies the expected distance where the recommended vibration limit criteria are likely to be exceeded. Note it does not consider effects of air transmitted noise. The potential for regenerated noise which results from excitation of a surface structure in response to continuous low amplitude ground transmitted vibrations is considered but expected to be low.

The vibration design distance includes consideration of duration of the activities, allows for increased vibration levels for short term works such as establishment activities and the short time a property will be affected as the pipeline excavation rapidly progresses. The distances also include adopting limits that are low in the recommended range for longer activities such as shaft excavation.

This information has been used to identify those sites where the activities may require modification to normal construction practices or the use of mitigation measures, see Section 8.3 below.

Table 3: Safe design distances for construction activities

Work Type	Source	Ground type	Design Distance (m)		Comments
			Structures	People	
Site Establishment	Diggers, Loaders, Trucks etc.	TG/Residual ECBF	3-5	5	Higher tolerance for short term access works.
	Site Buildings Construction	TG/ Residual ECBF	3	3	
	Access Road works	TG Residual ECBF	3	3	
Shaft and Chamber	Diggers, Cranes, Trucks	TG/ Residual ECBF	5	5	

Excavation – soft to hard ground	Piling / Diaphragm Wall Equipment	TG/ Residual ECBF	10	20	Higher vibrations may be generated by dropping buckets to expel spoil.
	Sheet pile driving (Soft to hard ground)	Alluvium/TG/ECBF	10	15	
Horizontal Directional Drilling (HDD)	Drill Equipment	Alluvium/TG/ECBF	5	10	The remoteness of these works from dwellings mean that potential effects from regenerated noise[2] are expected to be negligible.
	Crane	-	3	5	
	Pipe Handling Equipment	-	5	10	
	Muck Truck Movements	-	3-5	5	
Trenched Pipeline	Shored Trenches	TG/ECBF	3	5	
	Sheet piled Trench	Alluvium/TG/ECBF	10	15	
	Vibrating Rollers	-	10	15	Road and Site Remediation
	Truck Movements	-	3-5	5	

Note:. The safe design distances are based on a combination of published information, experience and the site characteristics measured. The safe distances for critical operations need to be confirmed on site. Works that need to be undertaken within these distances should also give consideration to methods and plant that could reduce generated vibrations at the source or mitigate effects.

8.4 Specific Assessment of sensitive receivers and potential for damage to neighbouring properties

An initial assessment of the effects on adjacent properties of vibrations generated by construction and operations of the project has been undertaken. This has involved review of the likely construction methods, the levels of vibration that they will generate and estimation of the distances where vibration levels will exceed the proposed limits for both structural damage and sensitive receivers. As noted in Section 7.4, we conclude that the structural damage criteria will control the levels of vibration for the works.

A summary of construction activities and safe distances for vibration design has been provided in Table 4. This is based on the expected distance required to achieve the proposed vibration limits. The following discussion sets out an assessment of potential vibration effects on neighbouring properties. A list of properties most affected by the construction vibrations is provided in this table. The risk of vibrations impacting on residents or structures has been assessed for the critical activities listed in Table 3 according to the following criteria:

- Low Risk – May be perceptible to residents but should not cause disturbance. Risk of damage less than minor

- Moderate Risk – May cause minor discomfort and should be acceptable for limited periods. No risk to health. Minor risk of cosmetic damage to dwellings but no risk of structural damage. Condition surveys of closest structures recommended.

- High Risk – May be acceptable to receivers for occasional short term events. Likely to cause significant discomfort if vibrations are continuous. Minor risk to health to sensitive receivers and may require relocation. Moderate risk of cosmetic damage but low risk of damage to structural elements. Condition surveys of all potentially affected structures recommended.
- Very High Risk – Potential risk to health and relocation recommended. Significant risk to sensitive structures. Condition surveys of all structures and application of mitigation measures recommended.

Generally the effects of vibration on these properties is low risk and can be managed by control of construction methods to limit vibration levels at the source. Where the works are to be undertaken over a short period and there is low risk of structural damage, there is the option to also consult with residents on a level of acceptable exceedance. If necessary, other mitigation measures may also be considered, see Section 10.

The properties potentially most affected are listed below together with discussion over the options to mitigate vibration levels. In all cases there are no risks of damage to structures but works may result in some level of disturbance to occupants.

Table 4: Summary of potential effects of vibrations on closest structures in each Section

Section (refer Table 1)	Closest Affected Structures	Min. Distance (m)	Risk	Comment
4	Summerset Townhouses	20	Low	The trench will be constructed about 20 m from these structures. Depth to inverts is about 3 m and soils are expected to be stiff requiring a light shield. No risk to structures. Vibration levels should be barely perceptible and similar in level to background traffic utilizing the roundabout. No mitigation is expected to be required.
6	9,11, 16 & 18 Traffic Road	12-15	Low	Pipeline between Rahui and Traffic Roads. Minimum distance 12-15 m. This section will be trenched up to 5 m depth in residual ECBF soils using small conventional excavation and pipe laying plant. No risk to structures. Vibration levels will be clearly perceptible but will be completed over a short period and should not be highly disturbing to residents.
7	1 Traffic Road	12	Low	Pipeline 4 m depth. Minimum distance 12 m from dwelling. No risk to structures. Vibrations may be mildly disturbing to residents for a short period.
7	4-12 Greenhithe Road	15	Low	Trench up to 7 m depth in residual soils. Distances to affected dwellings are greater than 15 m. Deep trenching will require larger plant and shoring works and may generate higher levels of vibration than other trenched sections. No risk to structures. Effects may be mildly disturbing to sensitive receivers.

7	34 Greenhithe Road	15	Low	4-5 m deep trench within 15 m from dwelling. No risk to structures. Works will be clearly perceptible but should not cause significant discomfort.
8	Wainoni Park 34, 36, 66 & 72 Te Wharau Drive	10	Low	Construction works up to 4-5 m depth at a distance of 10 m from dwellings. Low risk to structures. These works will occur over an extended period and vibrations may be mildly disturbing but should not result in discomfort to residents.
11	Row 30, 32 and 34 Newbury Place, 222, 224 Schnapper Rock Road	5	Low to Moderate	The section of pipeline to be constructed about 5m from dwellings on the right of way between 30, 32 and 34 Newbury Place, 222, 224 Schnapper Rock Road will utilize small plant and the reduced clearance in this area will need particular care to limit vibrations. The depth of the trench in this section is limited to about 2.6 m so light excavation plant should be suitable for the work. Low risk to structures but works may cause mild discomfort to residents.
11	9, 17 Newbury Place	10	Low	4-5 m trench within 10 m from dwelling. No risk to structures. Works will be clearly perceptive but should not cause significant discomfort.
12	9 & 11 Witton Place – Pipe Bridge Foundations	8-15	Low to Moderate	Trenching 8m from 9 Wilton Pl. Pipe bridge about 15 m from dwellings will require use of light (digger mounted) piling equipment. Low risk to structures. These works are expected to be clearly perceptible to mildly disturbing to residents but excavations for pile shafts should be completed over a short period (2-5 days).
13	111 Laurel Oak Drive,	3-5	moderate	3-4 m deep trench using light excavation plant within 3-5 m of dwellings. This should be completed with light equipment over a short period and may cause moderate discomfort but should not be disturbing to occupants. No risk to structures.
	10 & 12 Appleby Road	10	Low	3-4 m deep trench using light excavation plant within 10 m of dwellings. This should be completed over a short period and may cause mild discomfort but should not be disturbing to occupants. No risk to structures.
15	12/327 Albany Highway	5	Low-moderate	3-4 m deep trench using light excavation plant within 5 m of dwellings. This should be completed with light equipment over a short period and may cause moderate discomfort but should not be disturbing to occupants. No risk to structures
15	William Pickering Drive	15	Low	4 m deep trench 15 m from light industrial building. No risk to structures. Vibration effects may cause mild discomfort to occupants but should not be disturbing.

16	169 Bush Road	5	Low	4 m deep trench at 5 m from industrial building. No risk to structures. Vibration effects may cause mild discomfort to occupants but should not be disturbing.

8.5 Effects on services

There are a large number of services within the roading system that will be located close to the pipeline route. Construction works in close proximity to these services will generate vibrations that may impact on their performance. There is considerable experience in undertaking such works and this should be applied in development of the site management plans to ensure vibration levels are maintained within the design tolerances.

An infrastructure report will be prepared as part of the detailed design that will identify any critical services. Generally buried services and ducted cables have a relatively high tolerance to vibrations. Sisken (2000) recommends a limit of PPV < 120 mm/s for such services. For the construction plant identified in the previous sections, this should allow works to within 1 m of the in ground services. Specific methodologies should be provided for working at closer distances.

8.6 Summary of Effects of Construction Activities

This assessment of effects of the construction of the pipeline in Phase 1 has determined that, over the majority of the route where conventional trenching and pipe laying equipment will be utilized, the DIN 4150-3:1999 criteria for vibrations will not be exceeded at distances greater than 5 m. The likelihood that occupants of dwellings or commercial buildings will experience discomfort is expected to be low at distances of over 10 m and vibrations will be barely perceptible beyond 10-12 m.

There are a small number of properties identified where the pipe laying works may result in a minor risk of disturbance to residents but these are expected to be for short periods that can be addressed by application of appropriate mitigation measures. There are no properties considered to be at risk of exceeding the damage criteria of DIN 4150-3:1999.

9 Mitigation options

It is expected that works will be designed to be undertaken in compliance with vibration limits proposed for the project, viz DIN4150:1999. However, construction processes contain inherent risks such that the targeted vibration levels are not always achieved. This requires that a margin of safety is provided in the target vibration levels for "outlier" conditions. Where monitoring of activities is undertaken that enables the distribution of vibration levels generated, a statistical approach may be adopted to provide a high level of confidence that limits will not be exceeded. The cause of any exceedance of targeted levels should be investigated and changes made in the methodology where practicable to address the magnitude of vibrations generated by the source.

If full compliance with the vibration criteria cannot be achieved by modifying the method, it may be necessary to consider other methods to reduce the effects. These could include:

- communication with adjacent affected residents
- coordination with residents to carry out works when they are likely to be out
- use of an alternative method of construction with reduced vibration effects
- Obtain agreement with affected parties to apply higher criteria for specific activities

These are expected to address any issues but should they not be adequate other mitigation measures include

- temporary relocation of residents during the activity where it is close to property
- Temporary bracing or strengthening of sensitive building structures to change the response characteristics
- Isolation of very sensitive equipment such as utilising an airbag or floating slab.

It is noted that the recommended DIN 4150:1999 standard includes substantial margins to limit the risk of damage and no structural damage is likely within a distance of half that given in Table 3.

10 Operational vibration effects

The general operations of the pipeline are unlikely to generate levels of vibrations that will be perceptible to occupants of private dwellings or commercial/industrial properties along the route. Measurements of vibration levels have previously been undertaken on the manhole structures on the Orakei Sewer tunnel. These provided vibration levels that were below the human perception threshold, i.e. less than 0.3mm/s. It is concluded that vibrations are unlikely to be perceptible beyond the manhole structures.

Access for maintenance and repair to pipes,valves and Hobsonville Pump Station will be necessary but, other than for major works, these should be for short periods and are expected to be limited to truck movements and light equipment. The location of these items provide adequate distance from the nearest structures such that the vibration levels generated by works should not result in any effects exceeding mild disturbance.

11 Conclusions

The construction of the Phase 1 pipeline will comprise trenching, horizontal directional drilling and short section of pipe bridging. The route has been selected to follow existing roading over much of the route and is generally positioned to ensure works will be undertaken a minimum of 15 m from any structures. At these distances the effects of vibrations from plant identified as suitable to complete the works are expected to be less than minor. Locally there are some properties where works will be 5-15 m from structures but trench depths in these locations are relatively shallow and small plant may be used to control vibration levels to ensure effects do not result in unacceptable levels of disturbance to occupants.

Vibrations from well managed construction activities should not exceed the recommended structural vibration limits included in DIN 4150-3:1999 and there will be no significant risk of damage to dwellings, buildings or services.

12 References

BS 6472-1:2008 Guide to Evaluation of Human Exposure to Vibration in Buildings Vibration Sources Other Than Blasting.

BS 6472-2:2008 Guide to Evaluation of Human Exposure to Vibration in Buildings Vibration Sources Other Than Blasting – Blast Induced Vibration.

BS 5228-1:2009 Code of Practice for Noise and Vibration Control on Construction and Open Sites.

DIN4150-3:1999 Structural Vibration. Part 3: Effects of Vibration on Structures.

ISO 2631-2:2003 Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration. Part 2: Vibration in Buildings (1Hz to 80 Hz).

ISO 10137:2009 Bases for Design of Structures – Serviceability of Buildings and Walkways against Vibrations.

NZ/ISO 2631-2:1989 Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration. Part 2: Vibration in Buildings (1Hz to 80 Hz) – Withdrawn Standard.

Siskind DE, Stagg MS, Kopp JW, and Dowding CH – 1980 Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting. Report on Investigations 3507 USBM Washington DC, USA.

NZ 8176:2005 Vibration and Shock. Measurement of Vibrations in Buildings from Land based Transport and Guidance to Evaluation of its Effects on Human Beings. Morsk Standard.

13 Applicability

This report has been prepared for the benefit of Watercare Services Limited with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor LTD

Environmental and Engineering Consultants

Report reviewed by:	Prepared and authorised for Tonkin & Taylor Ltd by:
....	....
Cameron Lines	Peter Millar
Senior Engineering Geologist	Senior Geotechnical Engineer

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Appendix A: Vibration Criteria Review

B1 Vibration Standards

A number of Standards are applied for vibrations generated by construction activities and operation of equipment in NZ. These standards are applied to limit the discomfort or impact on well-being of occupants of nearby properties as well as provide protection from damage of structures. A summary of the relevant standards is provided below.

B2 Human Response Standards

The principal physiological effect standard that has historically been applied in New Zealand was NZS/ISO 2631-2:1989 "Evaluation of human response exposure to whole body vibration – Part 2: Continuous and Shock Induced Vibrations in Buildings (1 to 80 H_z)". This standard is referenced in the North Shore City and Waitakere City District Plans but does not form part of the PAUP.

The ISO/NZ 2631:1989 Standard provided factored curves for vibration limits for activities based on time of day, duration as well as level of potential impact on receivers. The criteria corresponds to a ppV of about 0.3 mm/s for continuous vibrations during the day (curves 2-4), which is at perception levels, while 5-10 mm/s is recommended for transient events (curves 30-90). The levels should ensure that most receivers are not subject to significant discomfort. The limits are above perception levels, particularly the higher limits recommended for daytime activities, but they should not result in disturbance and are about 10% of the levels likely to cause fatigue or affect health.

ISO2631-2:1989 is easily applied and provides ranges of magnitudes ranging from sensitive conditions to circumstances where short term activities and well informed receivers could permit increased vibration limits. These higher levels would be clearly perceptible but ensure they should not cause unacceptable levels of discomfort to receivers. The Standard was superseded in 2003 by an informative Standard which contains no vibration criteria. This standard was subsequently withdrawn by Standards NZ but has continued to be referenced by Councils. A new Standard ISO 10137:2007 Basis for Design of Structures – Serviceability of Buildings and Walkways against Vibrations applies the same criteria as the superseded ISO 2631:1989 Standard but is not referenced in the District Plans or PAUP.

BS6472-2:2008 Guide to Evaluation of Human Exposure to Vibration in Buildings, Blast Induced Vibration includes similar criteria for vibration to ISO2631:1989 but its application is limited to blasting. A separate standard applies to other activities (see below). It is also noted that the criteria for human response in these standards are closely aligned to the building damage criteria, see Section 4.1.2 below.

The British Standard BS 5228-2:2009 "Code of Practice for Noise and Vibration Control on Construction and Open Sites – Part 2 Vibration- Annex B" contains human response Standards, see Table 4.1 The criteria are set to avoid adverse comment and are therefore generally lower than BS6472-2:2008. They correspond closely to the low range in the ISO2631 Standard.

Table B.1: BS 5228-2:2009. Guidance on effects of vibration levels

Vibration level	Effect
0.14 $mm.s^{-1}$	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 $mm.s^{-1}$	Vibration might be just perceptible in residential environments.
1.0 $mm.s^{-1}$	It is likely that vibration of this level in residential environments will cause complaint.
10 $mm.s^{-1}$	Vibration is likely to be intolerable for any more than a very brief exposure to this level.

BS6472-1:2008 "Guide to assessing the human susceptibility impacts of vibration from traffic and intermittent events" adopts an entirely different approach to its companion standard for blasting. It utilises an index known as vibration dose value (VDV) which is frequency weighted and dependent on the amplitude of the event relative perception levels, the frequency of occurrence and time of day.

The following formula is used to determine vibration dose

$$VDV_{b/d,day/night} = \left[\int_o^T a^4(t)dt\right]^{0.25}$$

Where VDV b/d day/night is the vibration dose (value in $m/s^{1.75}$)

b/d is the weighting curves for vertical (b) or horizontal (d) vibration

a(t) is the frequency weighted acceleration (in m/s^2)

T is the total period of the day or night (in s) when vibration can occur.

Table 4.2 shows vibration dose ranges that might result in probability of adverse comment within residential buildings. For offices and workshops, increased factors of 2 and 4 apply respectively to the dose value ranges for a 16 hour day.

An estimate of VDV may be obtained from the following

$eVDV = 1.4\ a(rms)\ xt^{0.25}$

Table B.2: Vibration Dose Values for Residential Buildings ($m/s^{1.75}$) as given by BS 6472-1:2008

Place and Time	Probability of Adverse Comment		
	Low	Moderate	High
Residential Building (16 hour day)	0.2 to 0.4	0.1 to 0.8	0.8 to 1.6
Residential Buildings (8 hour night)	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

This Standard has been applied on several roading projects in NZ but the Norwegian Standard NS8176E:2005 "Vibration and Shock – Measurements of Vibrations in Buildings from Land based Transport and Guidance to Evaluation of its Effects on Human Beings" is generally more favoured for these projects as it considers the cumulative effects of sources of varying magnitude. It does provide an alternative basis for assessing operational vibration sources. The performance criteria are given in Table 4.3.

Table B.3: Dwelling Classification and the Likelihood of Moderate to High Annoyance

Type of Vibration	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)	3.6	5.4	11	21

The majority of residences are expected to be Class C receivers in terms of the standards criteria which applies to new (transportation) infrastructures. This corresponds to conditions where about 15% of affected persons will be disturbed by the levels of vibration but less than 15% will experience discomfort. As noted above, this Standard is widely used for roading but is not considered applicable over the full range of activities for this project.

B3 Application of Human Response Standards

Our experience is (as expected for such experience based Standards), there is little difference in the levels of recommended vibrations to avoid adverse comment between the human response Standards. Most standards, however, do not provide for an increase in permitted levels of vibration if the work is undertaken in accordance with a well developed management plan that recognises that some minor discomfort may be acceptable by receivers provided close controls are implemented. This includes good communication and notification and, if necessary mitigation to assure receivers they are not at risk. Only the BS6472-2:2008 and ISO2631:1989 Standards provide for this. The former standard only applies for blasting and the latter has been superseded. The ISO 10137:2007 provides an alternative standard that utilises the same criteria as ISO 2631:1989.

The construction activities on this project which occur within close proximity to dwellings and sensitive receivers are generally short term activities where the applicable base multiplier curves of 60-90 recommended by ISO2631:1989 and ISO 10137:2007 will exceed the recommended criteria of the building damage standards, see below. Hence construction works may be controlled by the single vibration limits as set out in DIN4150:1999.

This BS5228-1:2009 standard has been used for operational vibrations for many NZ projects and is readily applied (PPV limits of 1.0m/s for daytime and 0.3m/s for night-time works) but we note that BS6472-1:2008 is being promoted by CIRIA (2011) in the UK and CIRIA has a strong influence on construction practice in NZ.

B4 Building Damage Standards

The Standards addressing susceptibility of damage to buildings invariably reference work undertaken by Siskind et al (1980) as the basis for setting criteria. They applied probabilistic methods to damage threshold from blasting. This work is summarised in Table B.4.

Table B.4: Vibration Damage Threshold (mm/s) after Siskind et al (1980)

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

The CIRIA (2011) guidelines recommend that extrapolation of the data be undertaken to reduce the probability of damage (due to transient events) with a confidence limit greater than 95%.

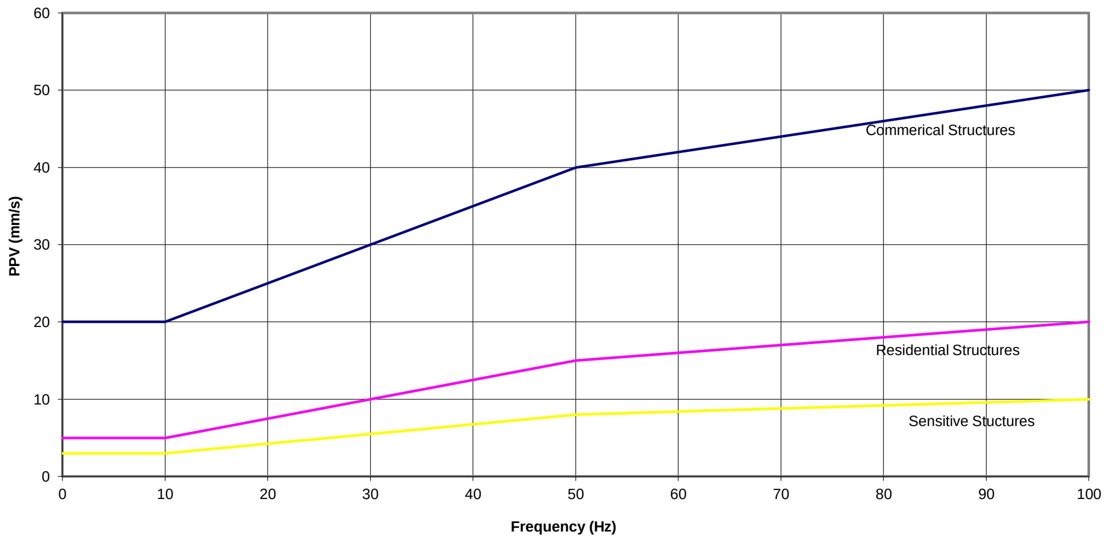
The standards have adopted factors applied to these thresholds to limit the potential for damage to acceptable levels. The most commonly used Standard for structural damage is the German standard DIN 4150-3:1999 “Structural Vibration – Part 3: Effects of Vibration on Structures”. The DIN 4150 guidelines for vibrations are summarised in Table B.5 and shown in Fig B.1. They include guidelines for residential buildings together with criteria for both commercial/ industrial buildings and high sensitivity structures. The guidelines provide for increased levels of vibration as the wave frequency increases, recognising that structures will generally have increased response in the low (1 to 10Hz) range. Conversely, the body has increased sensitivity at increased frequency which tends to cap the level of vibration able to be tolerated for construction activities.

Table B.5 Guideline values of vibration velocity, for evaluating the effects of short-term vibration, DIN4150-3:1999

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

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

Figure B.1 Baseline Curves Representing Short-Term Vibartion Effects to Structures in Relation to Recorded Data



For continuous (steady state) levels of vibration DIN 4150-3:1999 recommends a limit of 5mm/s as measured in the plane of the uppermost storey be applied to all buildings other than Category 3 (sensitive or high intrinsic value) structures.

The use of statistical design approaches for developing construction methods is being increasingly used for management of vibrations. There are clear benefits in applying best practice methods to blasting and other activities that generate significant levels of vibrations that may impact on adjacent properties. Where works are undertaken to a well developed methodology and management plan, staff are well trained, outcomes are monitored and results analysed to assess statistical parameters, then the designs can be targeted closer to the limits. This rewards good practice by reducing cost, controlling risk and generally achieving a better outcome for both the project and receivers. The application of the method is described further in Section 6.3.

The AS2187.2-2006 "Explosives - Storage, Handling and Use" cites more conservative guideline values from British Standard (BS) 7385-2 *Evaluation and measurement for vibration in buildings; Part 2: Guide to damage levels from ground-borne vibration* for cosmetic and minor structural damage to residential and commercial structures. Table B.6 presents vibration criteria for commercial and residential buildings.

Table B.6: BS7385-2 Transient vibration guide values for cosmetic damage[1]

Type of Building	**Peak component particle velocity**	
	4Hz to 15Hz	**15Hz and above**
Reinforced or framed structures. Industrial and heavy commercial buildings	50 mm/s at 4Hz and above	
Unreinforced or light framed structure. Residential of light commercial type buildings	15 mm/s at 4Hz increasing to 20 mm/s at 15Hz	120 mm/s at 15Hz increasing to 50 mm/s at 40Hz and above

Note 1: Reproduced from Appendix J of AS2187.2:2006

While this standard is widely referenced in New Zealand for storage, handling and monitoring methods for works using blasting methods, the DIN 4150:1999 criteria is the most widely applied guidelines for vibrations limits. The accepted use of statistical design methods with this standard also favours its application for this project. It should be noted, however, that lower limits may apply for highly sensitive plant such as some hospital and laboratory equipment.

As noted above, the damage criteria for structures recommended by the DIN4150:1999 are expected to be lower than the physiological criteria for intermittent works provided in ISO2631:1989 and therefore the single DIN4150:1999 standard has been recommended as the controls for this project.