Ashburton Second Urban Bridge and Associated New Road

Vibration Assessment

Ashburton District Council

Ashburton Second Urban Bridge and Associated New Road

Vibration Assessment

Ashburton District Council

Prepared By

Peter Cenek
Research Manager

Reviewed By

Alan Sutherland
Research Scientist (Geophysics)

Opus International Consultants Ltd
Christchurch Office
20 Moorhouse Avenue
PO Box 1482, Christchurch Mail Centre,
Christchurch 8140
New Zealand

Telephone:	+64 3 363 5400
Facsimile:	+64 3 365 7858

Date:	September 2013
Reference:	
Status:	Final

Contents

Executive Summary

This report presents an assessment of ground-borne vibrations resulting from the construction of the Ashburton second urban bridge project and from traffic once it becomes operational. Particular emphasis has been placed on determining critical separation distances between construction and heavy goods vehicle (HGV) traffic vibration sources and receivers to ensure the generated vibrations are not problematic from the perspectives of annoyance and structural damage.

The methodology adopted in making the assessment utilised both measurements of traffic induced vibrations along the proposed route and application of predictor equations.

Both the measured and estimated vibration levels were assessed from the perspectives of human comfort and cosmetic building damage using guidelines given in:

- British Standard BS 5228 2:2009, Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration;
- British Standard, BS 6472-1:2008. Guide to evaluation of human exposure to vibration in buildings – Part 1: Vibration sources other than blasting; and
- German Standard DIN 4150-3:1999, Structural vibration – Part 3: Effects of vibration on structures.

The principal findings arising from this assessment of ground vibrations generated by the construction and operation of the Ashburton second urban bridge project are as follows:

1. The existing environment along the proposed route is exposed to low level traffic-induced vibrations. These vibrations are considered to be acceptable as they are within recognised guidelines for human comfort applied internationally. The Ashburton second urban bridge project, once operational will not result in any worsening of existing traffic-induced vibration levels but will increase the number of occurrences of vibration events that occur during the course of a 16 hour daytime.
2. Vibration effects from the operation of the Asburton second urban bridge project are such that no specific mitigation is considered necessary provided the volume of heavy goods vehicle traffic is less than 700 HGV's per day.
3. Should heavy goods vehicle traffic exceed 700 HGV's per day, more attention to road roughness management will be required to ensure that the average road roughness is about 25% less than at present so adverse comment can be avoided.
4. It is understood that the new road will be surfaced with a bituminous mix surface, either asphaltic concrete or open graded porous asphalt (OGPA). Also, Chalmers Avenue, which is presently surfaced with chipseal, will be progressively sealed with bituminous mix as sections of the chipseal surface come up for resealing. As bituminous mix surfaces provide a considerably smoother riding surface than chipseal surfaces because of their ability to smooth out corrugations in the underlying surface layer, a reduction in the average 100 m lane roughness of 25% or more over that at present should be easily achieved.
5. Vibration levels generated by construction are likely to be higher than those from operation but would be temporary and of a limited duration.

6. There is potential for adverse effects from construction but these can be appropriately mitigated through a Construction Vibration Management Plan as the mitigation measures relate to selection of equipment and processes and the location and operation of the equipment.
7. Specifically, pile operations associated with construction of the bridge piers may cause damage to nearby buildings and underground services if separation distances are insufficient for the piling technique employed.
8. Also, for the greenfield road construction between the west bank of the Ashburton River and Grahams Road, the separation distance between the designation and neighbouring residential properties is too short to ensure the structural damage threshold of 3 mm/s PPV is not exceeded at 7 residential properties, with the most at risk being 64 Wilkins Rd and 119 Grove St. Therefore, the Construction Vibration Management Plan must ensure that the selection and operation of mechanised construction equipment to be used on the project complies with draft State Highway Construction and Maintenance Noise and Vibration Guide (NZTA, 2012)
9. Between now and when construction of the Ashburton second urban bridge (ASUB) project commences, houses can by right be built right up to the designation boundary in both the Residential C and Residential D Zones. The exception is where the designation boundary utilises existing property boundaries through the Residential D Zone, in which case a house could be built up to 6m from the designation boundary. These separation distances are less than the estimated 7 m required to ensure the structural damage threshold of 5 mm/s PPV for new residential buildings is not exceeded.
10. The three recommended options for minimising Ashburton District Council's exposure to claims for damage caused by construction of the ASUB project to houses that may be built in the interim period before the construction commences are:
    a. Extend both sides of the designation boundary by 7 m, wherever it runs through properties.
    b. Impose a performance condition on the designation to manage vibrations in accordance with the draft State Highway Construction and Maintenance Noise and Vibration Guide (NZTA, 2012). Furthermore, when assessing the potential of construction equipment to cause structural damage to neighbouring dwellings before being brought on to site, the criteria that should be applied to the measured vibrations is as listed in line 2 of table 1 of the German Standard DIN 4150-3:1999. These measurements should be made at a distance from source that corresponds to the minimum distance between where the equipment is expected to operate within the designation and the foundations of the bordering dwellings.
    c. Construct the Grahams Road to Johnstone Street section of the proposed road before any subdivision development occurs within the Residential C Zone. This is not considered necessary for the Residential D zone due to the larger allotment sizes (even at 4,000m^2, assuming reticulated sewage is available) providing greater flexibility for landowners to site a dwelling away from the proposed designation boundary.
11. The recommended minimum separation distances between source and receiver for operational vibrations of 8 m (for avoiding disturbing building occupants) and for piling operations of 42 m (for avoiding structural damage) can be readily accommodated within the existing designation boundary.

Therefore, it is concluded that:

1. By imposing conditions on the proposed designation, construction vibration can be managed to ensure adverse effects on both existing and future dwellings will be minor.
2. Vibration effects resulting from the operation of the second bridge and local feeder roads are likely to be of such a nature that no specific mitigation is considered necessary.

1 Introduction

This report presents an assessment of ground-borne vibrations resulting from the construction of the Ashburton second urban bridge project and from traffic once it becomes operational. The assessment has been predicated on the results of ground vibration measurements made at six locations in the vicinity of Chalmers Avenue on the 8th of August 2013. The measurements were undertaken to:

- quantify the current vibration magnitudes induced by traffic operating on local Ashburton roads;
- establish how quickly the traffic vibrations decay with distance for the local soil types; and
- derive site-specific soil attenuation coefficients for use in estimating the magnitude of ground vibrations resulting from impact related construction activity such as piling.

The principal objectives of measurements were to provide an indication of existing traffic-induced vibration levels (the baseline case) and the expected vibration magnitudes that will arise as a result of the construction and operation of the project.

The measurement of the traffic-induced ground-borne vibrations and their attenuation were carried out using an array of four triaxial accelerometers evenly spaced along a line perpendicular to the road. The traffic-induced ground-borne vibrations were monitored at each site investigated for a sufficient length of time to capture one or more passes of a heavy goods vehicle.

The measurement of the ground vibrations conformed to the following International Organisation for Standardisation (ISO) standards:

- International Standard ISO 8041:2005, Human response to vibration - Measuring instrumentation, and
- International Standard ISO 4866:2010, Mechanical vibration and shock – Vibration of fixed structures – Guidelines for the measurement of vibrations and evaluation of their effects on structures.

The measured traffic-induced vibrations and estimated construction related vibrations have been assessed from the perspectives of human comfort and building structural damage using guidelines given in British Standard BS 5228-2:2009, Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration, British Standard BS 6472-1:2008 Guide to evaluation of human exposure to vibration in buildings – Part1: Vibration sources other than blasting and German Standard DIN 4150-3:1999, Structural vibration – Part 3: Effects of vibration on structures.

The report has been structured as follows:

- Section 2 presents an overview of the project.
- Section 3 highlights key aspects of the project from a vibrations perspective.
- Section 4 details the criteria by which the measured vibrations were evaluated from the perspectives of human comfort and cosmetic building damage.
- Section 5 describes the vibration measurement methods utilised.

- Section 6 summarises the key results from the measurement programme.
- Section 7 discusses baseline conditions and identifies possible issues related to construction and operational traffic vibrations generated from the project along with suggested mitigation measures.
- Section 8 provides suggested related conditions for managing vibrations generated during the construction and operation of the ASUB project.
- Section 9 presents the main conclusions resulting from the assessment.

2 Project Description

The Ashburton District Council (ADC) proposes to construct, use and maintain a new 2-lane bridge across the Ashburton River and an associated road that directly links Chalmers Avenue through ‘green fields’ to the east of Tinwald to a connection with Grahams Road, Ashburton. The proposed new bridge and associated new road is collectively referred to herein as the Ashburton Second Urban Bridge project (ASUB) (see figure 2-1). The ASUB will provide an alternative urban route between east Tinwald and Ashburton township. The distance of the ASUB is approximately 2 kilometres (km).

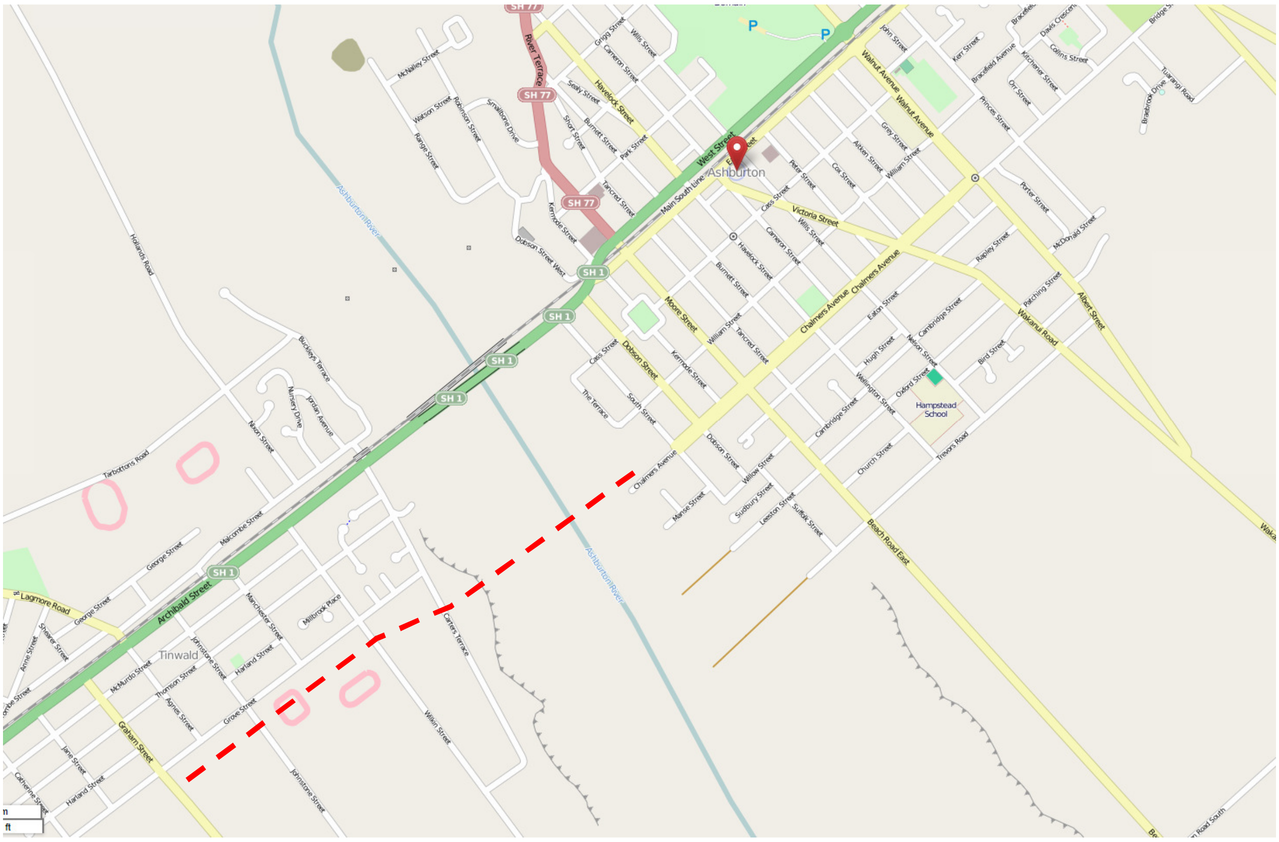

Figure 2-1: Overview Plan (approximate location shown by red dashed line)

The proposed ASUB project is only one of a number of related transport projects for the Ashburton urban area that was identified in the Ashburton Transportation Study (ATS) completed in 2006. The purpose of this study was to identify present and future transportation demands within the Ashburton study area for the 20 year period through to 2026, and to recommend measures to optimise the performance of the land transport system within Ashburton township. The proposed ASUB project is not being undertaken in isolation but rather fits within an overall strategy for transport network improvements within the township.

ADC is seeking a new designation to include the entire infrastructure associated with the ASUB including a 2-lane bridge, traffic lanes (including cycle lanes and parking), footpaths / pedestrian connections, intersections, stormwater infrastructure, landscaping, ancillary road infrastructure (e.g. services within the road corridor) and road construction.

The area through which the proposed designation runs is currently 'green fields', and comprises rural-residential allotments ranging in size from 4,820 m² (0.4820 ha) to 50,507 m² (5.5070 ha). The 2010 Ashburton District Plan review rezoned approximately 71.6ha of land located to the east of the current Tinwald urban boundary. 15.7 ha has been rezoned to Residential C, which allows subdivision down to 360 m² except where public sewage reticulation is not available, in which case 1,000 m² is the minimum allotment size. The remaining 55.9 ha has been rezoned to Residential D, which allows subdivision down to 4,000 m² except where public sewage reticulation is not available, in which case the minimum allotment size is 10,000 m² (1 ha). The current Tinwald urban area is zoned Residential C.

Traffic modelling indicates that traffic volumes on key routes throughout Ashburton are likely to increase significantly by 2026 regardless of a second bridge. This is expected to result in significant congestion and delays at a number of locations, including the existing bridge and the intersection of SH1 with Moore Street (SH77).

Vehicle number plate surveys undertaken in 2006, and repeated again in 2012, confirm that the bulk of the traffic on the existing bridge during peak times is local traffic between Tinwald and Ashburton. Less than 30% of the traffic is "through traffic" on SH1. The existing state highway bridge is nearing capacity at present, but is still functioning adequately most of the time. ADC and the NZ Transport Agency (NZTA) have agreed that the traffic issue on the current bridge is primarily a local traffic issue and that the ASUB project in the first place will be to serve the local traffic needs of the Tinwald and Ashburton communities. Once constructed, the ASUB will become an extension of the existing urban road network within east Tinwald and Ashburton township and will be maintained and controlled by ADC. It will not become the state highway.

Physical construction of the ASUB is not required until approximately 2026, at which time traffic congestion on the existing bridge is expected to reach a point which justifies the need for a second bridge. Traffic modelling indicates that up to 14,000 vehicles per day (vpd) are likely to use a second bridge by 2026, with between 5-10% expected to be heavy goods vehicles (HGV's). This traffic is likely to distribute amongst side roads to the north and south of the bridge and is expected to result in an overall reduction in total average travel time for all vehicles in the Ashburton urban area.

It is expected that by the time the ASUB project is required to be constructed, the environment within which the proposed designation is located will have undergone a degree of change from the current low density rural-residential land use to a land use that is in accordance with the new residential zonings within the district plan. ADC wishes to protect the route for a future bridge and associated new road before too much further development occurs. The designation for the ASUB is being sought now in order to secure the required land to ensure the project can proceed at the time that it is needed.

3 Key Considerations

3.1 General Background

With reference to Hunaidi (2000), vibration amplitudes and the predominant frequencies are influenced significantly by the soil type and stratification. The lower the stiffness and damping of the soil, the higher the vibration. For impact loads, ground vibrations are highest at the natural frequencies of the site. At these frequencies, the soil, like any structural system, offers the least resistance and therefore the greatest response to loads. For soils, the natural frequencies depend on stiffness and stratification.

Vibration amplitudes decrease with distance from the vibration source. The decay is faster in softer soils than stiffer soils. Also vibrations of a higher frequency decay faster than those of lower frequency. However, because of the complex nature of soil characteristics, attenuation relationships are site-specific.

Road traffic tends to produce vibrations with frequencies predominantly in the range from 5 to 25 Hz (oscillations per second). The amplitude of the vibrations ranges between 0.05 and 25 mm/s measured as velocity. The predominant frequencies and amplitude of the vibration depend on many factors including the condition of the road; vehicle weight, speed and suspension system; soil type and stratification; season of the year; distance from the road; and type of building. The effects of these factors are interdependent and it is difficult to specify simple relationships between them. The effect of vehicle speed, for instance, depends on the roughness of the road. Generally, the rougher the road, the more speed affects the vibration amplitude. The effect of the suspension system type also depends on vehicle speed and road roughness. For low speed and smooth road conditions, the effect of the type of suspension system is not significant. However, for high speeds and rough roads, the type of suspension system becomes important.

The key considerations for the ASUB project from a vibrations perspective are expanded on below.

3.2 Operational Traffic

The ASUB project will have a 50 km/h posted speed in place. Therefore, because of the slow speed, a deterioration of the existing traffic-induced vibration conditions can only occur if the project brings traffic closer to neighbouring buildings.

3.3 The Bridge Element

The bridge element has the potential to generate problematic vibrations. Firstly, during the construction of the bridge piers, as this will necessitate vibration inducing piling operations. Secondly from operational traffic if the transitions at the bridge abutments and expansion joints aren't sufficiently smooth to limit impact wheel loading.

3.4 Underground Services

Construction activities, such as pile driving and dynamic compaction, and traffic generate vibrations that are transmitted through the ground in the form of stress waves. When these waves encounter an underground structure such as a pipeline, part of the wave is reflected and part of it is transmitted into the structure. The cyclic nature of these vibrations will induce changes in the stress levels in the pipes. This in turn may lead to fatigue related damage, such as crack propagation. There is also the potential for failure from distortion due to the vibrations causing settlement of the ground surrounding the service pipes. Therefore, it is an important consideration that the level of surface vibrations generated by the ASUB project during construction and once operational will be insufficient to cause damage to underground services.

4 Assessment Criteria

4.1 Background

Plans that are relevant to the ASUB project are:

- Canterbury Regional Council (Environment Canterbury): Natural Resources Regional Plan and the proposed Land and Water Regional Plan
- Ashburton District Council: Partly Operative Proposed District Plan

These plans contain no specific vibration provisions related to construction and traffic.

Current standards considered appropriate for assessing the effects of vibration caused by the ASUB project from the perspectives of human comfort and damage to buildings are discussed below. Preference has been given to standards that state ground vibration in terms of peak particle velocity (PPV) with no requirement for frequency weightings as this simplifies their application to output from predictive models.

4.2 Human Comfort

4.2.1 Peak Vibration Levels

The British Standard, BS 5228.2, 2009, "Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration," is a current standard that is commonly adopted in New Zealand to provide guidance on the response of humans to vibration levels. This is reproduced below as table 4-1 for ready reference.

Table 4-1: Guidance on effects of vibration levels (from British Standard BS 5228-2:2009, Annex B)

Vibration level	Effect
0.14 mm/s	Vibration might be just perceptible in the most sensitive situation for most vibration frequencies associated with construction. At lower frequencies, people are less sensitive to vibration.
0.3 mm/s	Vibration might be just perceptible in residential environments.
1.0 mm/s	It is likely that vibration of this level in residential environments will cause complaint, but can be tolerated if prior warning and explanation has been given to residents.
10 mm/s	Vibration is likely to be intolerable for any more than a very brief exposure to this level.

The vibration levels in table 4-1 are in terms of PPV, which is the vibration parameter routinely measured when assessing potential building damage.

Although BS 5228-2:2009 is concerned with construction related vibrations, it is valid to apply the guidance on effects of vibration levels given in this standard to traffic vibrations. This is because most vibration frequencies associated with construction and traffic are greater than 8 Hz eliminating any frequency dependency effects. As a result, there is complete agreement between the withdrawn New Zealand standard, NZS/ISO 2631 (1989): "Evaluation of Human Exposure to Whole Body Vibration, Part 2: Continuous and Shock Induced Vibration in Buildings (1 to 80 Hz)," which has been incorporated in a number of District Plans, and BS 5228-2:2009 for vibration levels that are just perceptible in the most sensitive of situations (0.14 mm/s PPV) and just perceptible in residential environments (0.3 mm/s PPV).

4.2.2 Exposure to Vibration

The ASUB project is expected to maintain the maximum traffic-induced vibrations levels as at present if the 50 km/h and road maintenance practices remain as now. However, their frequency of occurrence will increase due to the projected increase in HGV traffic to between 700 and 1400 HGV per day by 2026.

British Standard BS 6472-1:2008 "Guide to evaluation of human exposure to vibration in buildings – Part1: Vibration sources other than blasting" allows the impact of this increased exposure on building occupants to be determined.

BS 6472-1:2008 is not widely adopted in New Zealand, but is attractive for use in assessment of intermittent vibration effects due to its dose-response metric, Vibration Dose Value (VDV). VDV is defined in equation 4-1.

$$VDV = \left(\int_0^T a^4\,(t)dt\right)^{0.25} \qquad \text{(Equation 4-1)}$$

where: VDV = Vibration Dose Value $(m/s^{-1.75})$

$a(t)$ = frequency-weighted root-mean-square (r.m.s) acceleration (m/s^2) over the frequency range 1 to 80 Hz

T = total period of the day or night (in seconds) during which vibration can occur

The use of the fourth power method makes VDV more sensitive to peaks in the acceleration waveform. VDV accumulates the vibration energy received over the day-time and night-time periods. Acceptable values of vibration dose for intermittent vibrations are presented in table 4-2.

Table 4-2: ***Vibration Dose Value ranges which might result in various probabilities of adverse comment within residential buildings (reproduced from BS 6472-1:2008)***

Place and time	Low probability of adverse comment $(m/s^{-1.75})$	Adverse comment possible $(m/s^{-1.75})$	Adverse comment probable $(m/s^{-1.75})$
Residential buildings 16 hr day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8 hr night	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8
NOTE: For offices and workshops, multiplying factors of 2 and 4 respectively should be applied to the above vibration dose value ranges for a 16 h day.			

BS 6472-1:2008 states that the VDV values in table 4-2 represent the best judgement currently available and may be used for both vertical and horizontal vibration, provided that they are correctly weighted.

It will be noted that the VDV criteria have been presented as ranges rather than discrete values. This stems largely from the widely differing susceptibility to vibration evident among members of the population, and also from their differing expectation of the vibration. Therefore, some judgement has to be exercised when applying the VDV criteria.

With reference to table 4-2, adverse comment is not expected for VDV values less than 0.2 $(m/s^{-1.75})$ during the day-time and 0.1 $(m/s^{-1.75})$ during the night-time. Conversely, adverse comment is extremely likely for VDV values above 1.6 $(m/s^{-1.75})$ during the day-time and 0.8 $(m/s^{-1.75})$ during the night-time.

4.3 Building Damage

The German Standard DIN 4150-3 (1999) "Structural vibration – Part 3: Effects of vibration on structures" provides guideline vibration levels which, "when complied with, will not result in damage that will have an adverse effect on the structure's serviceability." For residential buildings, the standard considers serviceability to have been reduced if:

- Cracks form in plastered surfaces of walls.
- Existing cracks in the building become enlarged.
- Partitions become detached from load bearing walls or floors.

These effects are deemed 'minor damage' in DIN 4150-3.

The DIN 4150-3 (1999) guideline values for evaluating short-term and long-term vibration on structures are given in table 4-3 where short-term vibrations are defined as those that do not occur often enough to cause structural fatigue and do not produce resonance[1] in the structure being evaluated and long-term vibrations are all the other types of vibration.

Table 4-3: Vibration guidelines from DIN 4150-3:1999 for assessing effects of vibrations on buildings

Type of Structure	Vibration Thresholds for Structural Damage, PPV (mm/s)				
	Short-Term				Long-Term
	At Foundation			Uppermost Floor	Uppermost Floor
	0 to 10 Hz	10 to 50 Hz	50 to 100 Hz	All Frequencies	All Frequencies
Commercial /industrial	20	20 to 40	40 to 50	40	10
Residential	5	5 to 15	15 to 20	15	5
Sensitive/Historic	3	3 to 8	8 to 10	8	2.5

Note: When a range of velocities is given, the limit increases linearly over the frequency range.

With reference to table 4-3, the German Standard DIN 4150-3 (1999) recognises commercial buildings can withstand higher vibration levels than residential and historic buildings. Also, the guideline values for short-term vibration increase as the vibration frequency increases.

[1] Resonance is the condition occurring when a vibrating system is subjected to a periodic force that has the same frequency as the natural vibrational frequency of the system. At resonance, the amplitude of vibration is a maximum.

4.4 Vibration Guidelines Used by NZ Transport Agency

4.4.1 Construction Related Vibrations

For recent NZ Transport Agency roading projects, vibration criteria given in the draft State Highway Construction and Maintenance Noise and Vibration Guide (NZTA, 2012) have been used as a basis to manage construction related vibrations. These criteria are derived from BS 5228.2, 2009 and DIN 4150-3 (1999).

As an example, construction vibration criteria to be used on the Basin Bridge project in Wellington have been tabulated in table 4-4.

Table 4-4 Construction Vibration Criteria for NZTA's Basin Bridge Project

Receiver	Details	Category A	Category B	Location
Occupied dwellings	Daytime 6: am to 8:00 pm	1.0 mm/s PPV	5.0 mm/s PPV	Inside the building
	Night time 8:00 pm to 6: am	0.3 mm/s PPV	1.0 mm/s PPV	
Other occupied buildings	Daytime 6: am to 8:00 pm	2.0 mm/s PPV	10.0 mm/s PPV	
All buildings	Transient vibration	5.0 mm/s PPV	BS 5228.2 Table B2 values	Building foundation
	Continuous vibration		BS 5228.2 50 percent Table B2 values	
Underground Services	Transient vibration	20mm/s PPV	30 mm/s PPV	On pipework
	Continuous vibration	10mm/s PPV	15 mm/s PPV	

With reference to table 4-4, if measured or predicted vibration levels exceed the Category A criteria then a suitably qualified expert shall be engaged to assess and manage construction vibration to comply with the Category A criteria. If the Category A criteria cannot be practicably achieved, the Category B criteria shall be applied.

If measured or predicted vibration levels exceed the Category B criteria, then construction activity shall only proceed if there is continuous monitoring of vibration levels and effects on those buildings at risk of exceeding the Category B criteria by suitably qualified experts.

4.4.2 Operational Vibrations

For perception of traffic vibration, the criteria commonly used is taken from Annex B, table B.1 of the Norwegian Standard NS 8176.E (2005) "Vibration and shock: Measurement of vibration in buildings from landbased transport and guidance to evaluation of its effects on human beings."

The criterion for class C buildings is typically applied as it corresponds to the recommended limit value for vibration in new residential buildings and in connection with planning and building of new transport infrastructures. This criterion is in terms of statistical maximum value for weighted velocity ($V_{w,95}$) and has a value of 0.3 mm/s. Weighted velocity is the root-mean-square value (r.m.s) of vibration velocity measured by using a frequency weighting filter corresponding to whole-body vibration in buildings, where the weighting is about 1 over the frequency range 1 to 80

Hz. The r.m.s integration time is 1 second and the statistical maximum is derived from the mean and standard deviation of a minimum of 15 single passes of a HGV at a measurement location.

For comparison with the BS 5228.2 guidance values, a $V_{w,95}$ value of 0.3 mm/s corresponds to a value of about 0.42 mm/s PPV.

NS 8176.E states that about 15% of the affected persons in class C dwellings can be expected to be disturbed by vibration.

4.5 Screening Criteria Applied to Project

To identify where construction and operation of the ASUB project may create significant adverse impact, the following criteria has been applied to the output of modelling used to provide estimates of ground-borne vibrations:

- 0.3 mm/s PPV for disturbance of building occupants
- 1 mm/s PPV for complaint by building occupants
- 2.5 mm/s PPV for damage to existing buildings arising from traffic (i.e. long term vibration)
- 3 mm/s PPV for damage to existing buildings arising from construction (i.e. short term vibration)
- 5 mm/s PPV for damage to yet to-be-built buildings arising from both short and long term vibration.

The difference in the damage threshold vibration levels between existing and to-be-built buildings is to recognise:

- new buildings will be constructed to more stringent building codes;
- the expectation that existing buildings will have been subjected to a number of years of deterioration making them more vulnerable to the effects of ground vibration.

The screening criteria have been derived from BS 5228.2, 2009 and DIN 4150-3 (1999) and have deliberately been made more stringent than the criteria used by the NZ Transport Agency because they are being applied to modelled estimates of ground vibrations and not measured ground vibrations. This approach will yield slightly more conservative effects assessments, which is considered preferable.

5 Methodology

5.1 Data Acquisition and Processing

With impact related ground vibrations, such as induced by traffic, radial motion dominates close-in and gives way to a vertical dominance at greater distance. To accurately define this motion, three orthogonal components should therefore be measured (transverse, longitudinal (radial) and vertical). Accordingly, all vibration measurements were made using high-sensitivity Colibrys Si-flex SF3000L tri-axial accelerometers. This enabled acceleration-time histories to be obtained in the three orthogonal components i.e.

- vertical accelerations (in the z axis direction)
- horizontal accelerations in the x-y plane.

For each site, the accelerometers were positioned in a line normal to the road, at distances of approximately 2 m, 5 m, 10 m and 15 m from the lane edge.

The accelerations were recorded using an Iotech LogBook 360 data acquisition system. Each channel was recorded at 1000 samples/s. 10x oversampling was used to improve resolution and reduce signal noise.

Signal processing routines based on the industry standard Matlab™ software package were used to analyse the vibration time histories.

The measured accelerations were band-pass filtered between 2 Hz and 100 Hz, and numerically integrated to calculate the measured vibrations as ground velocities. All vibration measurements presented in this report are either the maximum for a particular orthogonal component or the square root of the sum of the maximums for each axis so are a theoretical maximum resulting in a conservative value (over-estimate).

The accelerometers and data acquisition system employed are traceable to primary standards to ensure the integrity of the vibration measurements.

Particular care was taken in how the accelerometers were mounted to ensure the mounting was firm to prevent slippage. For hard surfaces, such as footpaths and driveways, the triaxial accelerometers were attached by means of a thin layer of plasticine. Where the triaxial accelerometers were mounted on ground, a 2mm thick steel plate with a 90mm long spike attached to its underside was used to provide a rigid coupling. The spike was pressed into the ground until the plate lay flat on the ground surface and the accelerometer fixed to the plate by means of industrial grade magnetic tape.

5.2 Measurement Sites

Measurements of ground vibrations generated by passing traffic were made at six locations in the vicinity of Chalmers Avenue during the day on Thursday, 8th of August 2013. Vibrations were recorded for about half an hour to an hour at each site to ensure one or more passes of a HGV was captured. The locations of the measurements were as follows:

A. South side of SH1 opposite Willis St, accelerometers on firm cleared ground.
B. Corner of Bridge St and Seafield Rd, accelerometers on firm ground parallel to Bridge St.
C. Chalmers Ave between Tancred St and Burnett St, accelerometers on grass centre strip.
D. Chalmers Ave between Cox St and Aitken St, accelerometers on grass centre strip.
E. Corner of Grahams Rd and Grove Farm Rd, accelerometers on grass verge parallel to Grove Farm Rd.
F. Northwest side of SH1 50m northeast of Racecourse Rd, first accelerometer on seal then on open grass area.

The relative spatial location of the sites is shown in figure 5-1.

Measurement site A, which was adjacent to State Highway 1, was selected only to obtain a wider range of HGV induced vibrations so that the representativeness of the other HGV measurements on the less trafficked roads could be assessed.

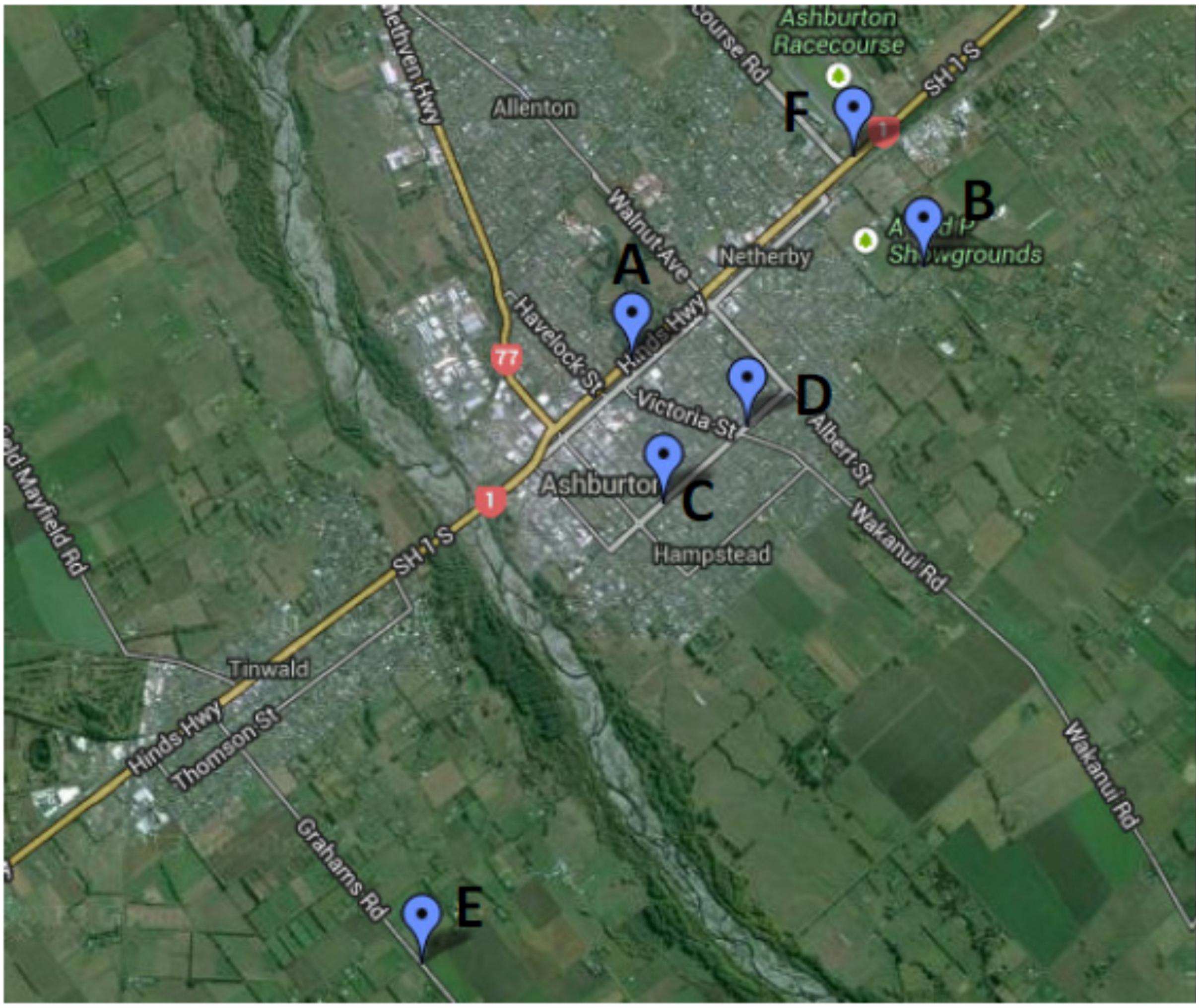

Figure 5-1: Plan of test sites

5.3 Method for Calculating Attenuation Coefficient

The attenuation coefficient, α, is used as a measure of the decrease in measured vibration with increasing distance from the road. It is calculated for pairs of measured vibrations using equation 5-1, taken from Dowding, 2000.

$$\alpha = \frac{-\ln\left[\frac{V_2}{V_1}\left(\frac{R_1}{R_2}\right)^{-0.5}\right]}{R_2 - R_1} \qquad \text{(Equation 5-1)}$$

where: α is the attenuation coefficient [m^{-1}]
V_1 is the vibration velocity nearer to the source [mm/s]
V_2 is the vibration velocity further from the source [mm/s]
R_1 is the nearer distance to the source [m]
R_2 is the further distance to the source [m]

Attenuation of vibrations is dependent on the frequency of the vibrations. Equation 5-2 can be used to convert the attenuation coefficient to a frequency independent value relating to the soil type.

$$\rho = \frac{\alpha}{\pi f} \qquad \text{(Equation 5-2)}$$

where: α is the attenuation coefficient [m^{-1}]
ρ is the frequency independent material property of the soil [s/m]
f is the dominant frequency of the ground vibration [Hz]

5.4 Vibration as a Function of Distance

Soil attenuation coefficients derived as outlined in section 5.3 can be used to estimate the magnitude of ground vibrations at any distance from source using equation 5-3 below, taken from Cenek et al (2012). This allows estimation of critical separation distances required to ensure that the guideline vibration levels for human comfort and building damage given in BS 5228-2:2009 and DIN 4150-3:1999 are not exceeded.

$$V_2 = V_1\left(\frac{R_1}{R_2}\right)^{0.5} e^{-\alpha(f)\times(R_2-R_1)} \qquad \text{(Equation 5-3)}$$

where: V_1 = the measured peak particle velocity (mm/s) at distance R_1 (m)
V_2 = the peak particle velocity (mm/s) at distance R_2 (m) from source
$\alpha(f)$ = soil coefficient for the dominant frequency f (Hz)

6 Results

The maximum vertical ground velocities measured for HGV events is tabulated in table 6-1 for each of the 4 accelerometer locations, identified by the numbers 1 to 4.

Table 6-1: Maximum HGV induced ground velocities, vertical (z) direction (mm/s, PPV)

Site	Event	Distances from lane edge (m)				Vertical PPV (mm/s)			
		1	2	3	4	1z	2z	3z	4z
A South side of SH 1, opposite Willis St.	0	3	6	10	15	0.17	0.13	0.11	0.11
	2	3	6	10	15	0.25	0.16	0.12	0.11
	3	3	6	10	15	0.25	0.17	0.18	0.14
	4	3	6	10	15	0.49	0.37	0.23	0.24
	5	3	6	10	15	0.39	0.26	0.21	0.19
	6	3	6	10	15	0.30	0.25	0.19	0.19
	7	3	6	10	15	0.12	0.09	0.06	0.07
	8	3	6	10	15	0.15	0.12	0.07	0.09
	9	3	6	10	15	0.39	0.29	0.27	0.20
	10	3	6	10	15	0.17	0.10	0.09	0.08
	11	3	6	10	15	0.11	0.09	0.10	0.10
B Corner of Bridge St & Seafield Rd	1	2.5	5	10	15	-	0.09	0.04	0.04
	2	2.5	5	10	15	-	0.21	0.19	0.11
	3	2.5	5	10	15	0.24	0.21	0.25	0.18
C (Southbound) Chalmers Ave (Tancred & Burnett)	1S	1.5	5	7.3	10.6	0.53	0.39	0.31	0.20
	2S	1.5	5	7.3	10.6	0.27	0.24	0.24	0.15
	3S	1.5	5	7.3	10.6	0.32	0.17	0.19	0.12
C (Northbound) Chalmers Ave (Tancred & Burnett)	1N	1.7	5	7.3	10.8	0.28	0.18	0.15	0.12
	2N	1.7	5	7.3	10.8	0.35	0.25	0.21	0.17
	3N	1.7	5	7.3	10.8	0.52	0.33	0.31	0.21
D (Southbound) Chalmers Ave (Cox & Aitken)	1S	2	5	8	11.3	0.26	0.13	0.12	0.09
	2S	2	5	8	11.3	0.26	0.09	0.09	0.07
	3S	2	5	8	11.3	0.22	0.10	0.13	0.09
	4S	2	5	8	11.3	0.29	0.14	0.11	0.09
D (Northbound) Chalmers Ave (Cox & Aitken)	1N	1.7	5	8	11	0.11	0.05	0.05	0.05
	2N	1.7	5	8	11	0.20	0.16	0.15	0.09
	3N	1.7	5	8	11	0.27	0.20	0.18	0.09
	4N	1.7	5	8	11	0.35	0.32	0.21	0.13
E Corner Grahams Rd & Grove Farm Rd	1	2	5	10	15	0.09	0.10	0.05	0.06
F Northwest side of SH1, 50m northeast of Racecourse Rd	1	2	5	10	15	0.09	0.17	0.09	0.07
	2	2	5	10	15	0.10	0.18	0.10	0.08
	3	2	5	10	15	0.17	0.27	0.13	0.10
	4	2	5	10	15	0.14	0.26	0.11	0.08

- Faulty reading so not entered

With reference to table 6-1, accelerometer 1 is closest to the lane edge and accelerometer 4 the furthest. As expected the vertical ground velocities decrease with increasing distance from source apart from site F, where because of space limitations accelerometer 1 had to be placed on seal and accelerometers 2-4 on grass.

Because no one component was consistently dominant, the peak component velocities were additionally combined to provide a maximum vector sum for each triaxial accelerometer. This value is commonly known as the square root of the sum of squares (SRSS). The SRSS peak particle velocity is frequently reported in vibration studies as it provides a conservative estimate of the vibration level as the maximum of each component is used in the calculation regardless of the time when it occurs.

The guideline threshold values given in the standards used to assess the measured vibration levels from the perspectives of human comfort and building damage (BS 5228-2:2009 and DIN 4150-3:1999), are generally based on the peak component (i.e. the worst case of the three axes monitored). Therefore, by applying SRSS based PPV's to the guideline threshold values is not in accordance with the standards but results in the assessment of vibration effects being on the conservative side.

The SRSS values calculated for the second accelerometer from the lane edge and associated soil attenuation coefficient derived from the measurements have been summarised in table 6-2 for use with equation 5-3.

Table 6-2: Average SRSS values and soil coefficient values for each site

Site	Soil Attenuation Coefficient, α (m^{-1})	Distance from Source (m)	Maximum SSRS (mm/s PPV)
A	0.025	6	0.52
B	0.051	5	0.51
C	0.032	5	0.72
D	0.037	5	0.98
E	0.074	5	0.33
F	0.050	5	0.90

The frequencies of the measured vibrations varied between 20 and 30 Hz, which is as expected for HGV traffic. The frequency independent material property of the soil in the vicinity of the ASUB project, ρ, therefore is between 3.18×10^{-4} and 9.42×10^{-4}. With reference to table 6-3 below, this corresponds to weak to competent soils.

Environment Canterbury bore logs indicate sandy gravels are encountered throughout the area, with layers of sand, silt and clay indicated on some bore logs. Accordingly, there is good agreement between the bore logs and the soil type inferred from the decay of traffic induced ground vibrations, providing a degree of confidence in the vibration measurements that have been made.

Root mean square (r.m.s) SRSS accelerations for use with equation 4-1 are tabulated in table 6-4 below for each of the monitored sites. These values have not been weighted over the 2-100 Hz measured frequency range so will yield more conservative results than if the b weightings in table C1 of BS6472-1:2008 had been applied. This is considered preferable in effects assessments.

The typical duration of a passing HGV was measured to be 1.5 seconds.

Table 6-4 additionally contains 16 hour day vibration dose values (VDV) corresponding to the peak flow of 20 HGV/hour observed on the day of the measurements.

Table 6-3: Attenuation characteristics of various soil types (adapted from Amick, 1999)

Class	Description of Soil	Attenuation Coefficient, α, at 5 Hz (m^{-1})	Frequency Independent Soil Property, ρ (s/m)
I	Weak or soft soils (soil penetrated easily); loess soils, dry or partially saturated peat and muck, mud, loose beach sand and dune sand, recently ploughed ground, soft spongy forest or jungle floor, organic soils, topsoil	0.01 - 0.03	$6x10^{-4}$ - $2x10^{-3}$
II	Competent soils (can dig with shovel): most sands, sandy clays, silty clays, gravel, silts, weathered rock	0. 003 - 0.01	$2x10^{-5}$ - $6x10^{-4}$
III	Hard soils (cannot dig with shovel, must use pick to break up): dense compacted sand, dry consolidated clay, consolidated glacial till, some exposed rock	0.0003 - 0.003	$2x10^{-5}$ - $2x10^{-4}$
IV	Hard, competent rock (difficult to break with a hammer): bedrock, freshly exposed hard rock	< 0.0003	< $2x10^{-5}$

Table 6-4: Maximum r.m.s values measured at each site over a 1.5 second interval and associated VDV's

Site	Distance from Source (m)	Maximum r.m.s SSRS acceleration (m/s^2)	Vibration Dose Value ($ms^{-1.75}$)
A	6	0.030	0.20
B	5	0.060	0.39
C	5	0.043	0.28
	7.3	0.031	0.20
D	5	0.98	0.48
	8	0.056	0.37
E	5	0.034	0.22
F	5	0.122	0.80

7 Discussion of Results

7.1 Baseline Conditions

Along the proposed route, the shortest separation distance between the edge of the lane and a residential property is 8 metres. The property concerned is 31 Kitchener Street, which is located directly to the north-east of the intersection of Bridge Street and Kitchener Street.

With reference to table 6-1, vertical ground vibrations generated by passing HGV traffic at this distance was measured to range between 0.05 mm/s to 0.31 mm/s PPV on Chalmers Avenue/Bridge Street. The higher value of the range is likely to be just perceptible in residential environments (refer table 4-1).

Similarly, the calculated vibration dose value based on 320 HGV passes over a 16 hour period ranged from 0.20 $ms^{-1.75}$ to 0.37 $ms^{-1.75}$ for separation distances of 7.3 m to 8 m. These values, despite being conservative because of the absence of weighting and use of maximum vector sum instead of peak component value, correspond to a low probability of adverse comment occurring according to table 4-2.

As the separation distance from the edge of the lane to other residential buildings is greater than 8 m, we can therefore conclude from this analysis that the existing environment around Chalmers Avenue/Bridge Street is exposed to low level traffic-induced vibrations from local HGV traffic. These vibrations are considered to be acceptable as they are within recognised guidelines for human comfort.

7.2 Construction Vibrations

The operation of construction equipment causes ground vibrations that spread through the ground and diminish in strength with distance. Buildings and structures in the vicinity of the construction site respond to these vibrations with varying results ranging from no perceptible effects at the lowest levels, perceptible vibrations at moderate levels and slight damage at the highest levels (Hanson et al, 2006). Construction equipment that generate little or no ground vibrations are air compressors, light trucks, hydraulic loaders etc. whereas construction activities that typically generate the most severe vibrations are pile-driving, vibratory compaction, and drilling or excavation in close proximity to vibration sensitive structures.

With regard to the ASUB project the two construction activities that have the most potential to generate troublesome vibrations are piling associated with the construction of the bridge piers and general road construction. These are expanded on below.

7.2.1 Pile Driving

Two methods are commonly used in New Zealand for driving piles into soil to provide foundation support for bridge structures, these being the impact or recursive hammer and the vibratory hammer. Because the method of piling to be used on the ASUB project has not yet been identified, empirically based predictor equations provided in Table E.1 of BS 5228-2:2009 have been used to determine what critical separation distance will be required to ensure the resulting ground vibrations do not exceed the short term damage threshold of 3 mm/s PPV.

Cenek et al (2012) showed that application of both the BS 5228-2:2009 percussive and vibratory piling predictor equations provided estimates of ground vibration levels which were in close agreement with NZ measurements for representative piling operations and so can be used with confidence.

For vibratory piling, the minimum separation distance will need to be 42 m for a 5% probability that the resulting ground vibrations levels will exceed 3 mm/s PPV.

For percussive piling, the situation is slightly more complicated because the estimated ground vibrations are a function of both hammer energy and slope distance from the pile toe. Therefore, if the vibratory piling separation distance of 42 m is maintained, the maximum hammer energy that can be applied is 9.4 kJ for the pile at refusal. This assumes the upper limit pile toe depth of 27 m allowed for by the BS 5228-2:2009 percussive piling predictor equation, giving a slope distance of 50 m.

Currently, the closest residential properties to the Ashburton River are sited about 80 m from its banks. Therefore, there is sufficient space in which to locate the bridge piers to minimise any likelihood of structural damage to nearby buildings from pile driving operations required for the construction of the piers.

7.2.2 General Road Construction

Table 4.1 in NZTA of Research Report 485 “Ground vibration from road construction” (Cenek et al, 2012) summarises ground vibration data from construction sites throughout New Zealand acquired for representative mechanised construction equipment operating on a range of soil types. The specific equipment monitored comprised, twelve rollers, three dozers, two excavators, one grader and one stabiliser. This table was used to identify the type of mechanical plant that would generate the highest magnitude vibrations when operating on soil types expected along the route of the ASUB project.

In recognition of the variability in source vibration levels of road construction equipment, lower-bound and upper-bound maximum estimates for use with equation 5-3 were employed. The lower-bound value was 3.8 mm/s PPV and refers to a Komatsu DP31P dozer whereas the upper-bound value was 5.4 mm/s PPV and refers to a Sumitomo SH120 Excavator. In both cases the vibration levels apply at a distance of 10 m away from where the equipment is operating.

Of the two source vibration values, the 3.8 mm/s PPV value can be regarded as being the more representative of what can be readily achieved with latest generation road construction equipment that is in good working order, whereas the 5.4 mm/s PPV value is about the 85 percentile value i.e. there is a 15% probability that ground vibrations measured 10 m from any road construction machine will exceed 5.4 mm/s PPV.

To assist the assessment, the separation distances required for (1) building occupants to complain about the vibration levels and (2) minor building damage to occur from use of the excavator were calculated. This was achieved by using the “Goal Seek” function in Microsoft Excel with equation 5-3 to determine what distance from source would be required to achieve the complaint threshold value of 1 mm/s PPV and short–term structural damage threshold value of 3 mm/s for the smallest measured soil attenuation coefficient in the vicinity of the construction works, which was taken to be 0.032 m^{-1} measured in Chalmers Avenue at location C (refer figure 5-1).

For the lower-bound construction vibration level of 3.8 mm/s PPV, the calculated critical separation distances were 33 m for complaint and 13 m for structural damage.

For the upper-bound construction vibration level of 5.4 mm/s PPV, the calculated critical separation distances were 41 m for complaint and 19 m for structural damage.

Table 7-1 lists the properties that are located closest to the greenfield road construction component of the project, where ground vibrations are most likely because of excavation activities. Two separation distances have been tabulated:

1. To the edge of the designation boundary.
2. To the edge of the footpath.

The difference between these two separation distances varies between about 4.7 m to 19 m and corresponds to swale/landscaping/embankment so will not be exposed to the same degree of construction activity as the footpath/road.

Table 7-1: Separation Distances of the Most Effected Properties

Section of ASUB Project	Property	Separation Distance (m)	
		To Designation Boundary	To Footpath Edge
Grahams Rd to Johnstone St	77 Grahams Rd (Jones Residence)	40	44.7
	119 Grove St (Houston Residence)	8	12.7
	70 Johnstone St (Saunders Residence)	14	18.7
Johnstone St to Wilkins Rd	65 Johnstone St (Morris/Adnams Residence)	18	23.7
	77 Johnstone St (Wilson Residence)	20	25.7
	64 Wilkins Rd (Breach Residence)	2	12
	74 Wilkins Rd (Braas Residence)	14	19.7
Wilkins Rd to Carters Tce	60 Carters Tce (Stuthridge Residence)	20	25.7
	69 Carters Tce	12	31.0
	70 Carters Tce (Bell Residence)	26	31.7
	71 Carters Tce	12	31.0

With reference to table 7-1, if we consider the upper-bound value of 5.4 mm/s PPV, the complaint threshold of 1 mm/s PPV will be exceeded at all 11 listed residences if construction activity is to take place up to the designation boundary and there is a risk of structural damage occurring at 7 of these residences.

If major excavation work is limited to the sealed portion of the road corridor, the number of residences at risk of structural damage reduces to 3 but there is still a high likelihood of adverse comment from building occupants, with the 1 mm/s PPV compliant threshold being exceeded at 10 of the 11 residences.

If we consider the lower-bound value of 3.8 mm/s PPV, the complaint threshold of 1 mm/s PPV will be exceeded at 10 of the 11 residences if construction activity is to take place up to the designation boundary and there is a risk of structural damage occurring at 4 of these residences.

If major excavation work is limited to the sealed portion of the road corridor, the number of residences at risk of structural damage reduces to 2 but there is still a high likelihood of adverse comment from building occupants, with the 1 mm/s PPV compliant threshold again being exceeded at 10 of the 11 residences.

This analysis highlights that considerable care will need to be taken when selecting and operating equipment for earthwork activity along the Grahams Rd to Ashburton River section of the ASUB project to ensure no structural damage occurs to nearby buildings, particularly 64 Wilkins Rd and 119 Grove Street. Options for mitigating the excavation/construction related vibrations are discussed in section 7-5 below.

It is known that for situations where vibration related disturbances are temporary, infrequent and of short duration, such as road construction, vibration levels that are above the complaint threshold of 1 mm/s PPV can be tolerated if the startle factor is reduced and fears of damage to property allayed. Therefore, for the ASUB project, it will be very important that there is engagement with occupants of the properties listed in table 7-1 to keep them well informed as to when and for how long vibrations will occur during construction activities and to provide reassurances regarding the damage potential of the vibrations.

7.3 Operational Vibrations

By 2026, the HGV traffic is projected to increase to between 700 and 1400 HGV per day. Because this HGV traffic is expected to be mainly local traffic, it will take place during the 16 hours of daytime. Therefore, the vibration dose values for sites C and D at 7.3 m and 8 m respectfully from the lane edge were recalculated for the increased HGV values of 700 and 1400 HGV passes using the measured r.m.s SRSS accelerations.

At 700 HGV passes the VDV ranges between 0.25 $ms^{-1.75}$ and 0.45 $ms^{-1.75}$ which, with reference to table 4-2, is likely to result in a low probability of adverse comment. However, at 1400 HGV passes, the VDV increases to between 0.29 $ms^{-1.75}$ and 0.53 $ms^{-1.75}$ and so adverse comments are possible.

This result indicates that if HGV traffic grows to the lower estimate of 700 HGV, the road roughness levels delivered by existing road maintenance practices will be sufficient. If the HGV traffic grows to more than the 700 HGV, more attention to road roughness management will be required to ensure that the average 100 m road roughness levels are about 25% less than at present so adverse comment can be avoided.

It is intended that the greenfield section of road will be surfaced with a bituminous mix surface with the Chalmers Avenue section progressively surfaced with bituminous mix as the existing chipseal surface comes up for resealing. Bituminous mix surfaces are known for their ability to smooth out local corrugations to provide a low roughness surface so it can be reasonably expected that at least a 25% reduction in roughness will result from replacing the chipseal surface with a bituminous mix surface such as asphaltic concrete or open graded porous asphalt.

7.4 Underground Services

If buried pipework is in close proximity to where piling operations are to take place, there is potential for the pipework to be damaged.

With reference to British Standard BS 5228-2:2009 , the maximum level of intermittent or transient vibration to which underground services should be subjected to is 30 mm/s PPV if in good condition or 15 mm/s PPV if old or dilapidated. These guideline values are deemed to be applicable to most metal and reinforced concrete service pipes.

There is also the potential for failure from distortion due to the vibrations causing settlement of the ground surrounding the service pipes. British Standard BS 7385:Part2:1993, Annex C, alerts to the possibility of structural damage due to ground vibrations causing consolidation and densification in loose and water-saturated soils as found in the vicinity of the ASUB project. Such soils become vulnerable at PPV values of about 10 mm/s, so in the absence of more specific information, it is recommended that vibrations around buried pipework be limited to 10 mm/s PPV. Therefore, in the case of underground services, acceptable vibrations will be set by considerations of differential settlement rather than damage brought about by dynamic stressing of the pipework.

If vibratory piling is used or if the percussive piling is limited to a hammer energy of no more than 9.4 kJ, then the minimum distance to the nearest point to the piling should be about 16 m.

Damage to underground services once the ASUB project becomes operational is very unlikely because the traffic-induced vibrations in the vicinity of Grahams Road and Chalmers Avenue will be of the same magnitude as at present.

7.5 Mitigation Measures

7.5.1 Impact of Existing District Plan Provisions

As vibration amplitudes decrease with distance from the vibration source, it is important to establish what separation distances can be accommodated into the future without causing compliance issues. Therefore, an analysis of road widths, designation width and land owners' rights to carry out permitted activities under the district plan was carried out.

The total designation width for the road varies as follows:

- 30 m between Grahams Road and Johnstone Street
- 32 m between Johnstone Street to Carters Terrace
- 55 m between Carters Terrace to the bridge at the Ashburton River.

This gives a typical carriageway width of 20.6m incorporating the following:

- 1 x 2m wide flush (i.e. painted) central median
- 2 x 3.5m wide traffic lanes
- 2 x 1.8m wide cycle lanes
- 2 x 2.4m wide parking lanes
- 2 x 1.6m wide footpaths

The remainder of the designation (i.e. between 20.6 m and 30/32 m) for the road consists of roadside swales both sides varying between 4.7 m (for the 30m width) and 5.7 m (for the 32m width). This means that within the 30 m wide part of the designation with the 4.7 m wide swales between Grahams Road and Johnstone Street, the designation boundary will be 10.5 m from the edge of the closest trafficked lane. For the 32 m wide designation between Johnstone Street and Carters Terrace, the designation boundary will be 11.5 m from the edge of closest trafficked lane.

For the majority of the site through which the proposed road will run, the area is zoned Residential D. Minimum allotment size is 4,000 m^2, except that where there is no public reticulated and treated sewage then minimum allotment size is 10,000 m^2. There is no reticulated sewage in this area so future development is currently limited to 10,000 m^2 as a permitted activity.

For part of the route, the area is zoned Residential C. Minimum allotment size is 360 m^2, except that where there is no public reticulated and treated sewage then minimum allotment size is 1,000 m^2. There is no reticulated sewage in this area so future development is currently limited to 1,000 m^2 as a permitted activity.

The District Plan contains rules requiring an internal boundary setback for dwellings from neighbours. Within the Residential C Zone, the minimum internal boundary setback is 1.8 m. Within the Residential D Zone, the minimum internal boundary setback for dwellings is 6 m, or 3 m for non-residential buildings greater than 5 m^2 in gross floor area. Where the proposed designation runs along property boundaries, the internal boundary setback rules will apply to the adjacent property. However, where the proposed designation runs through a property, compared with against a property boundary, the internal setback rules will not apply and a residential dwelling could be constructed against the designation boundary.

7.5.1.1 Residential C Zone

Within the Residential C Zone, the designation boundary runs through properties and therefore dwellings could be constructed right up to the proposed designation boundary in the interim period before the ASUB is constructed. These dwellings would be 10.5 m from the closest trafficked lane once the ASUB was constructed.

7.5.1.2 Residential D Zone

Within the Residential D Zone, the proposed designation runs along property boundaries where possible, but also through properties. Where the designation boundary coincides with a property boundary, the adjacent property will require a minimum building setback of 6m. These dwellings would be 17.5m from the edge of the closest trafficked lane.

However, where the designation boundary runs through properties there is no setback requirement and residential dwellings could be constructed right up to the designation boundary. These dwellings would be 11.5 m from the edge of the closest trafficked lane.

7.5.2 Road Construction

7.5.2.1 Existing Dwellings

The analysis has identified that for the greenfield road construction between the west bank of the Ashburton River and Grahams Road, the separation distance between the designation and existing neighbouring residential properties is too short to ensure the structural damage threshold of 3 mm/s PPV is not exceeded at up to 7 residential properties. The options available to address this are as follows:

a. Realign the road so that a separation distance of at least 13 m is achieved and preferably 19 m.

b. Either relocate all 7 effected residential properties so that at their closest, they are 19 m from the designation boundary or purchase if this is not feasible.

c. Perform "pre" and "post" road construction condition surveys and make good any cosmetic and structural damage that may have occurred.

d. Before commencing construction, ensure that the selection and operation of mechanised construction equipment to be used on the project complies with draft State Highway Construction and Maintenance Noise and Vibration Guide (NZTA, 2012). The recommended procedure for this is to make vibration measurements at an off-site location with similar soil properties to the construction site or on-site during its first use with the on-site location of first use being chosen to be the least sensitive to adjacent land uses. The vibration measurements assessed in this way should be made at a distance from source that corresponds to the minimum distance between where the equipment is expected to operate within the designation and the foundations of the closest bordering dwellings. Furthermore, to be certain that a particular piece of construction equipment will not cause structural damage to neighbouring dwellings, the criteria as listed in line 2 of table 1 of the German Standard DIN 4150-3:1999 should be additionally applied to account for vibration frequency effects.

Of the 4 options listed, option d is preferred for the following reasons:

- It can be readily incorporated within a Construction Vibration Management Plan.
- It recognizes that there is considerable variability in the magnitude and frequency of ground vibrations generated between different makes and models for a particular equipment type. By way of illustration, with reference to Cenek et al (2012), a Caterpillar D4H dozer generates a vibration level at 10 m from source of 11.9 mm/s PPV whereas a Komatsu DP31P dozer generates only 3.8 mm/s PPV despite both dozers being of comparable weight and generating vibrations with the same frequency (12 Hz).
- Most importantly it allows trade-offs between vibration magnitude and frequency. With reference to table 4-3, the DIN 4150-3:1999 guideline thresholds for damage increase as the vibration frequency increases. Therefore, much higher vibration levels can be tolerated if the frequency of the vibrations is high (greater than 20 Hz).

However, it must be recognized that because of the close proximity of both 119 Grove St (Houston residence) and 64 Wilkins Rd (Breach Residence) to the designation, construction of swale and landscaping in the vicinity of these two properties may have to be done by manual means rather than with construction plant, such as excavators or dozers.

7.5.2.2 Future Dwellings

The outcome of increasing the damage threshold from 3 mm/s PPV for existing buildings to 5 mm/s PPV for to-be-built buildings is to reduce the required shortest separation distance from source from 13 m to 7 m.

Between now and when construction of the ASUB project commences, dwellings can by right be constructed right up to the designation boundary in areas zoned Residential C, and in some areas within the Residential D Zone. In other areas of the Residential D Zone where the proposed designation boundary runs along property boundaries, dwellings could be constructed up to 6m from the internal boundary / designation boundary. These separation distances are less than the 7 m required to ensure the structural damage threshold of 5 mm/s PPV is not exceeded.

The three recommended options for minimising ADC's exposure to claims for damage caused by construction of the ASUB project to houses that may be built in the interim period before the construction commences are:

1. Extend both sides of the designation boundary by 7 m.
2. Impose a performance condition on the designation to manage vibrations in accordance with the draft State Highway Construction and Maintenance Noise and Vibration Guide (NZTA, 2012). Furthermore, when assessing the potential of construction equipment to cause structural damage to neighbouring dwellings before being brought on to site, the criteria that should be applied to the measured vibrations is as listed in line 2 of table 1 of the German Standard DIN 4150-3:1999. These measurements should be made at a distance from source that corresponds to the minimum distance between where the equipment is expected to operate within the designation and the foundations of the bordering dwellings.
3. Construct the Grahams Road to Johnstone Street section of the proposed road before any subdivision development occurs within the Residential C Zone. This is not considered necessary for the Residential D zone due to the larger allotment sizes (even at 4,000m^2, assuming reticulated sewage is available) providing greater flexibility for landowners to site a dwelling away from the proposed designation boundary.

7.5.3 Operational Vibrations

7.5.3.1 Existing Dwellings

All existing residential properties are sited 8 m or more away from the closest trafficked lane. This is considered a sufficient separation distance to ensure building occupants will not be disturbed by ground vibrations induced by passing HGV traffic. Therefore, no specific mitigation measures are recommended other than to seal the road with a bituminous mix surfacing when HGV traffic exceeds 700 vehicle passes per day.

7.5.3.2 Future Dwellings

The analysis showed that to maintain vibration levels from traffic to below the perception threshold of 0.3 mm/s PPV, a separation distance between the residential buildings and the lane edge should be at least 8 m. However, as mentioned above the designation boundary will be 10.5 m from the edge of the closest trafficked lane. Therefore, the proposed designation covers sufficient area to ensure an 8 m separation distance between the lane and a residential building can be maintained, provided there are no changes to the proposed carriageway layout, which incorporate swales/landscaping of 4.7 m minimum width, 1.6 m wide footpaths, 2.4 m wide parking lanes and 1.8 m wide cycling lanes.

8 Suggested Conditions

Given the close proximity of existing residential buildings to the designation boundary, in particular 64 Wilkins Rd (2 m from designation boundary), 119 Grove St (8 m from designation boundary) and 69 and 71 Carters Tce (12 m from the designation boundary), and the possibility of new buildings being built right to the designation boundary, there will be a need to carefully manage ground vibrations from mechanised construction equipment. The most appropriate instrument for this is a construction vibration management plan (CVMP). It is recommended that conditions are placed on the designation to address any potential adverse effects arising from construction vibration. The following conditions are considered appropriate for addressing potential adverse effects on both existing and future dwellings:

1. The requiring authority shall implement a Construction Vibration Management Plan for the duration of the construction period of the Project. The CVMP shall be provided to the [council officer] prior to commencement of construction of the project.

2. The CVMP must describe the measures adopted to seek to meet:

   The Category A vibration criteria set out in Condition [4] below, where practicable. If measured or predicted vibration levels exceed the Category A criteria then a suitably qualified expert shall be engaged to assess and manage construction vibration to comply with the Category A criteria. If the Category A criteria cannot be practicably achieved, the Category B criteria shall be applied. If measured or predicted vibration levels exceed the Category B criteria, then construction activity shall only proceed if there is continuous monitoring of vibration levels and effects on those buildings at risk of exceeding the Category B criteria by suitably qualified experts.

3. The CVMP shall address:

   a. The procedure for measuring vibrations.

   b. The criteria for assessing vibrations.

   c. Hours of operation, including times and days when high-vibration machinery would be used.

   d. List of machinery to be used.

   e. Requirements for vibration measurements of relevant machinery prior to construction or during their first operation, to confirm that the vibrations they generate will not be problematic.

   f. Requirements for building condition surveys of critical dwellings prior to and after completion of construction works and during the works if required.

   g. Requirements for identifying any existing infrastructure assets (services, roads etc) which may be at risk of vibration induced damage during construction.

   h. Roles and responsibilities of personnel on site.

   i. Construction operator training procedures, particularly regarding the use of excavators and vibratory compactors.

   j. Construction vibration monitoring and reporting requirements.

k. Mitigation options, including alternative strategies where full compliance with the Project Criteria cannot be achieved.

l. Methods for receiving and handling complaints about construction vibration.

m. Procedures for managing vibration damage to existing services such as roads and underground pipelines.

4. Construction vibration must be measured in accordance with the draft State Highway Construction and Maintenance Noise and Vibration Guide (NZTA, 2012). The construction vibration criteria for the purposes of the CVMP are:

Receiver	Details	Category A	Category B	Location
Occupied dwellings	Daytime: 6.00am to 8:00pm	1.0 mm/s PPV	5.0 mm/s PPV	Inside the building
	Night time 8:00pm to 6.00am	0.3 mm/s PPV	1.0 mm/s PPV	
Other occupied buildings	Daytime: 6.00am to 8:00pm	2.0 mm/s PPV	10.0 mm/s PPV	
All buildings	Transient vibration	5.0 mm/s PPV	BS 5228.2 - Table B2 values	Building foundation
	Continuous vibration		BS 5228.2 - 50 percent Table B2 values	
Underground Services	Transient vibration	20mm/s PPV	30 mm/s PPV	On pipework
	Continuous vibration	10mm/s PPV	15 mm/s PPV	

5. When construction equipment is being evaluated for its ability to cause structural damage at a particular residence, the relevant standard that shall be used is as listed in line 2 of table 1 of German Standard DIN 4150 3:1999. The criteria are as listed below:

Type of Structure	**Vibration Thresholds for Structural Damage, PPV (mm/s)**				
	Short-Term				**Long-Term**
	At Foundation			**Uppermost Floor**	**Uppermost Floor**
	0 to 10 Hz	**10 to 50 Hz**	**50 to 100 Hz**	**All Frequencies**	**All Frequencies**
Commercial /industrial	20	20 to 40	40 to 50	40	10
Residential	5	5 to 15	15 to 20	15	5
Sensitive/Historic	3	3 to 8	8 to 10	8	2.5

Note: When a range of velocities is given, the limit increases linearly over the frequency range.

9 Conclusions and Recommendations

An assessment of vibration effects regarding the construction and operation of the Ashburton second urban bridge project, which utilised both measurements of traffic induced vibrations along the proposed route and application of predictor equations has identified:

1. The existing environment along the proposed route is exposed to low level traffic-induced vibrations. These vibrations are considered to be acceptable as they are within recognised guidelines for human comfort applied internationally. The Ashburton second urban bridge project, once operational will not result in any worsening of existing traffic-induced vibration levels but will increase the number of occurrences of vibration events that occur during the course of a 16 hour daytime.
2. Vibration effects from the operation of the Asburton second urban bridge project are such that no specific mitigation is considered necessary, provided the volume of heavy goods vehicle traffic is less than 700 HGV's per day.
3. Should heavy goods vehicle traffic exceed 700 HGV's per day, more attention to road roughness management will be required to ensure that the average road roughness is about 25% less than at present so adverse comment can be avoided.
4. It is understood that the new road will be surfaced with a bituminous mix surface, either asphaltic concrete or open graded porous asphalt (OGPA). Also, Chalmers Avenue, which is presently surfaced with chipseal, will be progressively sealed with bituminous mix as sections of the chipseal surface come up for resealing. As bituminous mix surfaces provide a considerably smoother riding surface than chipseal surfaces because of their ability to smooth out corrugations in the underlying surface layer, a reduction in the average 100m lane roughness of 25% or more over that at present should be able to be easily achieved.
5. Vibration levels generated by construction are likely to be higher than those from operation but would be temporary and of a limited duration.
6. There is potential for adverse effects from construction but these can be appropriately mitigated through a Construction Vibration Management Plan as the mitigation measures relate to selection of equipment and processes and the location and operation of the equipment.
7. Specifically, pile operations associated with construction of the bridge piers may cause damage to nearby buildings and underground services if separation distances are insufficient for the piling technique employed.
8. Also, for the greenfield road construction between the west bank of the Ashburton River and Grahams Road, the separation distance between the designation and neighbouring residential properties is too short to ensure the structural damage threshold of 3 mm/s PPV is not exceeded at 7 residential properties, with the most at risk being 64 Wilkins Rd and 119 Grove St. Therefore, the Construction Vibration Management Plan must ensure that the selection and operation of mechanised construction equipment to be used on the project complies with draft State Highway Construction and Maintenance Noise and Vibration Guide (NZTA, 2012).
9. Between now and when construction of the Ashburton second urban bridge (ASUB) project commences, houses can by right be built right up to the designation boundary in both the Residential C and Residential D Zones. The exception is where the designation boundary

utilises existing property boundaries through the Residential D Zone, in which case a house could be built up to 6 m from the designation boundary. These separation distances are less than the estimated 7 m required to ensure the structural damage threshold of 5 mm/s PPV for new residential buildings is not exceeded.

10. The three recommended options for minimising Ashburton District Council's exposure to claims for damage caused by construction of the ASUB project to houses that may be built in the interim period before the construction commences are:

    a. Extend both sides of the designation boundary by 7 m.

    b. Impose a performance condition on the designation to manage vibrations in accordance with the draft State Highway Construction and Maintenance Noise and Vibration Guide (NZTA, 2012). Furthermore, when assessing the potential of construction equipment to cause structural damage to neighbouring dwellings before being brought on to site, the criteria that should be applied to the measured vibrations is as listed in line 2 of table 1 of the German Standard DIN 4150-3:1999. These measurements should be made at a distance from source that corresponds to the minimum distance between where the equipment is expected to operate within the designation and the foundations of the bordering dwellings.

    c. Construct the Grahams Road to Johnstone Street section of the proposed road before any subdivision development occurs within the Residential C Zone. This is not considered necessary for the Residential D zone due to the larger allotment sizes (even at 4,000m^2 assuming reticulated sewage is available) providing greater flexibility for landowners to site a dwelling away from the proposed designation boundary.

11. The recommended minimum separation distances between source and receiver for operational vibrations of 8 m (for avoiding disturbing building occupants) and for piling operations of 42 m (for avoiding structural damage) can be readily accommodated within the existing designation boundary.

Therefore, it is concluded that:

1. By imposing conditions on the proposed designation, construction vibration can be managed to ensure adverse effects on both existing and future dwellings will be minor.
2. Vibration effects resulting from the operation of the second bridge and local feeder roads are likely to be of such a nature that no specific mitigation is considered necessary.

10 References

Amick, H. (1999) *A Frequency-Dependent Soil Propagation Model*. Presented at SPIE Conference on Current Developments in Vibration Control for Optomechanical Systems, Denver, Colorado, July 20, 1999. Retrieved from http://www.vulcanhammer.net/geotechnical/Amick-SPIE99.pdf

British Standard, BS 5228.2:2009. Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration.

British Standard, BS 6472-1:2008. Guide to evaluation of human exposure to vibration in buildings – Part 1: Vibration sources other than blasting.

British Standard, BS 7385:Part2:1993. Evaluation and measurement for vibration in buildings, Part 2. Guide to damage levels from ground-borne vibration.

Cenek, P.D., Sutherland, A.J. and McIver, I.R.(2012) Ground Vibration from Road Construction, NZ Transport Agency Research Report 485, downloadable from: http://www.nzta.govt.nz/resources/research/reports/485/index.html

Dowding, C.H. (2000) Construction Vibrations. Second Edition. ISBN 0-99644313-1-9. Prentice Hall Engineering/Science/Mathematics, Upper Saddle River, NJ.

German Standard, DIN 4150-3:1999. Structural Vibration – Part 3: Effects of vibration on structures.

Hanson, C.E., Towers, D.A. and Meister, L. D. (2006) Transit Noise and Vibration Impact Assessment. Report FTA-VA-90-1003-06, Office of Planning and Environment, Federal Transit Administration.

Hunaidi, O. (2000) Traffic Vibrations in Buildings. Construction Technology Update No. 39. Institute for Research in Construction, National Research Council of Canada. ISSN 1206-1220.

Norwegian Standard NS 8176.E:2005 Second Edition Vibration and Shock. Measurement of vibration in buildings from landbased transport and guidance to evaluation of its effects on human beings, Standards, Norway, 2005. English translation version, 2006.

NZS/ISO 2631-2:1989(E) Evaluation of Human Exposure to Whole-Body Vibration – Part 2: Continuous and Shock-Induced Vibration in Buildings (1 to 80 Hz).

NZTA (2012). Draft State Highway Construction and Maintenance Noise and Vibration Guide, downloadable from: http://acoustics.nzta.govt.nz/management/construction

Opus International Consultants Ltd
20 Moorhouse Avenue
PO Box 1482, Christchurch Mail Centre,
Christchurch 8140
New Zealand

t: +64 3 363 5400
f: +64 3 365 7858
w: www.opus.co.nz