16 Ground Vibration

Overview
This Chapter provides a summary of the potential and actual vibration effects from the construction and then the operation of the Project. The primary vibration concerns are the potential for damage to buildings, underground services and the human response to vibration. The effects of construction vibration relate to the use of machinery and movement of heavy vehicles, which can cause ground borne vibration.

The potential vibration effects from the operation of the Project relate to vehicles using the new realigned roads and the bridge and is therefore, related to the quality of the road surface and the speed of traffic.

All potential vibration effects from the operation of the Project would be such that no specific mitigation is considered necessary.

Vibration levels generated by construction are typically higher than those from operation but would be temporary and of a limited duration within any location. The assessment has considered the type of machinery that could be used, the potential combinations of their use, the location of those works and the anticipated duration of works. The potential vibration effects of these on nearby properties have been considered. A key effect is expected from the use of machinery to lay road pavement, but it is noted that this activity occurs on the existing road network as of right and is programmed to occur on SH1 in the next 3 years. Therefore, the effects of this type of activity would be very similar to those of the construction of the Project.

Overall, methods to manage and control construction related vibration effects are outlined in the draft CNVMP and appropriate standards specified. A detailed construction methodology will be developed mindful of these standards and those methods will enable vibration effects to be appropriately managed through the CNVMP.

In summary, vibration effects resulting from the construction and operation of the Project have been identified and addressed within the proposed Project design development. Furthermore, vibrations generated during the construction phase can be suitably mitigated in accordance with the CNVMP.
16.1 Introduction

An assessment of the actual and potential vibration effects of the construction and then the operation Project is detailed in Technical Report 8: *Assessment of Ground Vibration Effects* in Volume 3 of the lodged documents.

The assessment has quantified the level of vibration created by current traffic flows and predicts the levels of vibration that can be expected once the Project is in place (given anticipated traffic volumes in 2021 and 2031).

Ground vibration effects have been assessed by reference to international standards that specify when vibration effects on human comfort, buildings and underground services are material. As there is no single New Zealand or international standard that provides guidance on all relevant aspects of ground vibration measurement and assessment, multiple standards have been used in the assessment. Table 16-1 provides a summary of these.

Table 16-1 Summary of relevant vibration standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>Reason used in the assessment</th>
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<tbody>
<tr>
<td>Norwegian Standard NS 8176.E:2005</td>
<td>Guidance on human responses to traffic-induced vibration levels</td>
</tr>
<tr>
<td>British Standard, BS 5228.2, 2009</td>
<td>Guidance on human responses to vibration levels and describing the effect for each level, and for the assessment of ground vibration effects on buildings and services</td>
</tr>
<tr>
<td>International Standard ISO 8041:2005</td>
<td>Guideline for measurement instrumentation</td>
</tr>
<tr>
<td>International Standard ISO 4866:2010</td>
<td>Guidelines for the measurement of vibration and evaluation of their effects on structures</td>
</tr>
<tr>
<td>German standard DIN 4150-3 (1999)</td>
<td>Guidelines for the assessment of ground vibration on buildings and services</td>
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This Chapter also assesses likely vibration effects from construction based on the construction methodology provided in Appendix A to the CEMP (Volume 4) and summarised in Part B, Chapter 4 of the AEE.

16.2 Existing Ground Vibration Environment

The soils in the Basin Reserve area comprise of weak or soft soils in the valley floor area (at Kent and Cambridge Terraces) and competent soils on the ridges of the
valley floor at Buckle Street and Paterson Street. Therefore, the area with the most potential for vibration issues is at the valley floor area of Kent and Cambridge Terraces. This is because soft soil has a lower stiffness resulting in higher ground vibrations.

To determine the existing ground vibration levels, measurements were taken at seven sites around the Project Area using Colibrys Si-flex SF3000L tri-axial accelerometers interfaced to an IOtech LogBook/360 data acquisition system. The vibration measurements conformed to the International Standard ISO 8041:2005; Human response to vibration – measuring instrumentation and ISO 4866:2010 Mechanical vibration and shock – Vibration of fixed structures – Guidelines for the measurement of vibration and evaluation of their effects on structures.

Transverse, longitudinal (radial) and vertical components of vibration were measured at the following sites:

- S1a and S1b – Corner of Ellice Street and Kent Terrace (repeated in this location);
- S2 – Ellice Street;
- S3 – Paterson Street, northern side;
- S4 – Paterson Street, southern side;
- S5 – Buckle Street Crèche;
- S6 – Tory Street; and
- S7 – Interislander Ferry terminal car park under a load bearing bridge pier (similar comparison environment to the building under the bridge at Kent Terrace/Ellice Street).

Traffic induced vibrations from both SH1 and local roads were measured to determine the range of vibration levels nearby buildings and occupants presently experience. In relation to the effects on human comfort, the results showed that the vibration levels range between the threshold where vibrations can be perceived (0.3mm/s PPV) and the threshold that would likely cause complaint (1mm/s PPV).

The results showed that the majority of the ground vibrations occur in the 0.1 to 0.3 mm/s PPV range with only a handful of recordings above 0.4mm/s PPV and only one incident recording 0.9mm/s PPV. The highest magnitude vibrations were measured 2m to 4m from the road edge wherever heavy commercial vehicles and buses were able to travel at the speed limit of 50kmh such as along Paterson Street and Buckle Street (including near the Crèche).

The Norwegian Standard NS 8176.E:2005 indicates that approximately 6% of people would be highly annoyed with 0.3mm/s PPV which is the most consistent level of vibration found in the results. The remaining majority (approximately 94%) of the general population may perceive the vibration and not experience levels of discomfort.
The lowest vibration magnitude that may cause damage to a structure is 2.5mm/s PPV. No recordings reached this magnitude.

Overall, the existing ground vibrations that are induced by traffic flows at the Basin Reserve are perceptible but do not cause complaint and do not have a detrimental effect on nearby buildings or structures. These low level traffic induced vibrations from SH1 are considered acceptable as they are within internationally recognised guidelines for human comfort and building damage.

16.3 Assessment of Effects on Ground Vibration during operation

16.3.1 Human Comfort

Traffic induced vibration effects on human comfort arising during operation of the Project have been assessed using two methodologies:

- For measured vibration levels, Norwegian Standard NS 8176.E:2005 “Vibration and shock: Measurement of vibration in buildings from land based transport and guidance to evaluation of its effects on human beings” has been applied as it provides a method for determining the number of people who will respond to a particular magnitude of vibration; and

- For predicted vibration levels, British Standard, BS 5228.2,2009, “Code of practice for noise and vibration control on construction and open sites – part 2: Vibration,” has been applied as it enables the consequences of predicted PPV value levels in terms of human perception and disturbance to be readily understood. This standard gives guidance for human responses to different vibration levels and describing the effect for each level. 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 8Hz eliminating any frequency dependency effects.

The British standard guidelines indicate that for lower levels of vibration the effects ‘might be just perceptible’ while at higher levels of vibration, the effects are ‘likely to be intolerable for any more than a very brief exposure’.

As ground vibration levels decrease with distance from the vibration source, particular attention was focussed where the Project brought traffic closer to existing buildings. The only building affected in this way was St Joseph’s Church. On the basis of actual vibration measurements of SH1 traffic in the vicinity of Paterson Street made at distances ranging from 2m to 20m from the kerb edge, occupants of St Joseph’s Church are expected to be exposed to only low level traffic vibrations of about 0.3 mm/s PPV. Therefore, they are unlikely to perceive any significant change from the existing situation.
For the other buildings bordering the Project, occupants would experience traffic-induced vibration levels the same as at present. This is because the distance between the buildings and SH1 remain essentially the same or increase.

Therefore, the operational ground vibration levels with the Project in place will have no more effect than currently being experienced.

For the proposed building under the bridge, traffic-induced vibrations of the order of 0.4 to 0.8 mm/s PPV would be transmitted via the bridge piers, resulting in about 30% to 50% of occupants showing some form of annoyance ranging from slightly annoyed to highly annoyed. Therefore, some means of isolating the building from these traffic-induced vibrations is desirable. A condition of consent is proposed that requires detailed design to take this aspect into consideration.

### 16.3.2 Buildings

The assessment of ground vibration effects to buildings has been carried out in accordance with German standard DIN 4150-3 (1999) “Structural vibration – Part 3: Effects of vibration on structures”. The standard recognises the difference between the structure of residential, historic buildings and commercial buildings (with commercial buildings being able to withstand higher vibration levels).

The assessment of traffic-induced vibrations considered all the different soils types in the Project Area and determined that the magnitude of the vibrations would range between 0.3 mm/s PPV and 0.5 mm/s. Such vibration levels are well below the threshold level of 2.5 mm/s PPV in DIN 4150-3 for the onset of minor building damage i.e. enlargement of existing cracks, formation of cracks in plastered surfaces.

Overall, the anticipated levels of ground vibration being induced by traffic flows in the Project Area would have no adverse effects on nearby buildings.

The proposed building under the bridge at the corner of Kent Terrace and Ellice Street will be exposed to higher levels of traffic-induced vibrations than other buildings on account of a bridge pier being located within its footprint. Therefore, the design and treatment of this building will require a higher standard of building detailing to mitigate traffic-induced vibrations transmitted to the building via a bridge pier. This may for example involve inclusion of base isolation in the building design, which will afford the required performance. As explained above, a condition of consent will require this to be taken into consideration during the detailed design stages.

### 16.3.3 Buried Pipework/Underground Services

The assessment of traffic-induced ground vibrations on buried pipework has been carried out in accordance with German Standard DIN 4150-3 (1999) “Structural vibration – Part 3: Effects of vibration on structures.” The standard recognises
differences in vibration sensitivity of different pipe material with plastic and masonry pipes tolerating lower vibration levels than steel pipes.

The minimum guideline value given in DIN 4150-3 for evaluating the effects of long-term vibration on buried pipework is 25 mm/s PPV as measured on the pipe. Based on measured maximum traffic-induced vibration levels and soil attenuation factors, this guideline value would not be exceeded even if the pipework was a very small distance (less than 0.6 m) beneath the road surface.

Therefore, buried pipework would not be adversely affected by the Project once it becomes operational as there would be no worsening of existing traffic-induced vibration levels.

16.4 Assessment of Effects on Ground Vibration during Construction

There will be the potential for short term adverse vibration effects arising from construction activity related to bridge piling and ground compaction associated with retaining walls and road realignments. The vibration levels are insufficient to cause damage to buildings but may be disturbing to building occupants. However, this disturbance is likely to be acceptable if proven vibration management methods are applied by the Constructor.

To assist the Constructor in selecting appropriate construction methods that would minimise these adverse vibration effects, sandbag drop tests were performed to determine predictor curves for each soil type in the Project Area. These predictor curves allow reliable estimates for impact related construction activities such as pile driving and dynamic compaction through the use of vibrating rollers.

16.4.1 Bore piling

The estimated vibration levels have been calculated for the buildings closest to the bore piling operations for the construction of the bridge. These buildings are (distances provided are the shortest distances from the proposed location of bore piling to the fascia of the building):

- the Crèche, 18 Buckle Street (50m from the bore piling);
- R.A. Vance Stand, Basin Reserve (22m);
- Grandstand apartments, 80 – 82 Kent Terrace (16m);
- St. Joseph’s Church, 156 Brougham Street (54m);
- residential apartment building, 9 Dufferin Street (54m);
- Regional Wines and Spirits, 15 Ellice Street (24m main bridge and 6m pedestrian/cycle ramp).; and
- two-storey residential building, 21 Ellice Street (28m main bridge and 18m pedestrian/cycle ramp).

Regional Wines and Spirits and the residential building at 21 Ellice Street are located in the proximity of where the pedestrian/cycling ramp is detached from the main bridge structure, thereby being close to both the piers of the main bridge and the piers of the pedestrian/cycling ramp.

The buildings estimated to experience the highest vibration levels during construction of the bridge piles are Regional Wines & Spirits (3.4-14 mm/s PPV), the Grandstand Apartments (1.1-4.5 mm/s PPV), 21 Ellice Street (1.6-3.7 mm/s PPV) and the R.A. Vance Stand (0.7-2.6 mm/s PPV).

It is noted that the CS Dempster Gate will be relocated in advance of the piling work. As a result it will be 200 m away from the construction activity and therefore the magnitude of construction related vibrations will be too small to cause any damage to the Gate.

### 16.4.2 Road Surfacing

There are a number of buildings located within 5m of the road edge that are expected to experience perceptible vibrations during road surfacing on Paterson Street and Dufferin Street. These are specifically, the St Mark’s classroom building on Paterson Street, St Joseph’s Church, St Mark’s Church Hall, and the residential building at 11 Dufferin Street.

However, road resurfacing works occur on the existing SH 1 and on local roads as a permitted activity and entail the same construction machinery. The next resurface works are programmed to occur over the next 3 years (2014-2017) if this Project does not proceed and would result in similar levels of vibration effects.

### 16.4.3 Underground services/Buried Pipework

Piling activity in weaker soils at Kent Terrace and Cambridge Terrace would take place in close proximity to where there is a concentration of buried pipework, including gas and water mains and stormwater and sewer lines. This pipework is typically at a depth of 0.6m or more below the road surface. The closest radial distance from piling activity to a major buried pipeline is about 5m. Therefore, the maximum vibration levels these service pipes are likely to be subjected to is 4 mm/s PPV (lower bound) and 16 mm/s (upper bound).

With reference to British Standard BS 5228-2:2009, “Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration,” the maximum level of intermittent or transient vibration to which underground services should be subjected to is 30 mm/s PPV. This guideline value is deemed to be applicable to most metal and reinforced concrete service pipes. Therefore, direct dynamic stresses in the service pipes caused by ground vibrations generated by bore piling.

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operations would be easily tolerated if the underground services are in good condition.

If the services are old or dilapidated the British Standard indicates that a maximum level of intermittent or transient vibration of 15 mm/s PPV should be applied. The upper bound estimate of vibration from piling work would exceed this limit, and therefore action is required to mitigate such potential effects (see section 16.5 below).

There is also some potential for failure from distortion due to the vibrations causing settlement of the ground surrounding the service pipes. However, this is considered to be extremely unlikely as:

- In creating the borehole, the drilling method produces little vibration and so there is little disturbance of the surrounding soil provided the correct drilling technology is selected, there is little disturbance of the surrounding soil;
- The steel casing will be driven into very weak soil strata. As limited energy will be required to drive the casing, vibration levels in the proximity of the underground services and at the ground surface should be comparatively low magnitude and insufficient to cause settlement.

### 16.4.4 Construction effects associated with the northern gateway building

If piling to support the foundation slab of the northern gateway building in the Basin Reserve is required, it will most likely involve bored and cased piles because of the soft nature of the soil and close proximity of the RA Vance Stand and the historic Waitangi Stream culvert.

It is considered that the only building that could be affected is the RA Vance Stand. The lower-bound vibration level at the RA Vance Stand will be below the 20 mm/s PPV DIN 4150-3:1999 damage threshold for short-term vibration of commercial buildings. However, at the upper-bound estimate of 47 mm/s PPV, the frequency of the vibratory hammer used to drive the steel casing into the ground will have to be at least 85 Hz to prevent cosmetic damage. Therefore, care will have to be taken if a vibratory hammer is used to prevent cosmetic damage from occurring to the RA Vance Stand.

An analysis has been undertaken of the potential effects of the construction of the northern gateway building on the Grandstand Apartments. This has considered the 65m option as well as alternatives of 45m and 55m. The effect of reducing the proposed building length from 65m to 45m is to increase the separation distance to the Grandstand Apartments, from 41 m to 46 m. This would result in the upper bound vibration level decreasing from 0.5 mm/s PPV to 0.4 mm/s PPV. This upper-bound value of 0.5 mm/s PPV is just above the perception threshold of 0.3 mm/s PPV but below the complaint threshold of 1 mm/s PPV. Therefore, no more than
minor effects are expected if the 65m building option and these effects would diminish if the shorter length options were to be pursued.

For the northern gateway building, particular care will also need to be taken with respect to the location of the piles and piling technique for the 55 m and 65 m options to ensure that the historic Waitangi Stream culvert is subjected to vibration levels that will not result in adverse effects.

16.5 Measures to avoid remedy or mitigate actual or potential adverse effects of ground vibration

16.5.1 Operational Effects

The assessment of effects has concluded that the level of ground vibration created by the operation of the Project will have no adverse effects on the level of human comfort, on nearby buildings or on buried pipework. Therefore no mitigation is required in relation to operational vibration effects generally.

In the case of St Joseph’s Church which will be closer to the roadway than is considered ideal at 4.18 m, the proposed road surface and speed limits will serve to mitigate potential adverse vibration effects.

16.5.2 Construction Effects

Physical works during construction have the potential to induce occurrences of ground vibration in the higher magnitude levels. These are likely to occur during the bridge piling and for the construction of the bridge abutments.

These effects are temporary and in any event are able to be managed using standard industry practice. The types of methods available to manage these types of effects are outlined in the draft Construction Noise and Vibration Management Plan (CNVMP) in Volume 4 of these documents and provides performance standards relied on for this assessment. The draft management plan would be finalised by the constructor and will inform the chosen construction methodology. Use of management plans in this way provides a transparent and resilient process for managing effects. Provided that works are undertaken in accordance with the CNVMP then construction vibration effects would be minor.

In relation to the potential impacts on underground services it is proposed that all old and/or dilapidated services will be identified prior to works commencing. Monitoring of vibration sources relevant to these services will be undertaken to ensure that measured vibrations are less than 10 mm/s PPV. If this level is exceeded then the service will be relocated further away from the piling work.
Finally in relation to the potential effects of the construction of the northern gateway building in the Basin Reserve, it is proposed that a condition survey be undertaken on the RA Vance Stand (and also the players pavilion for the 65m option) pre and post construction so that if any damage occurs from construction it can be identified and rectified. It is also recommended that if either the 55 m or 65 m option of the northern gateway building is to be built, piling technologies that cause minimal vibration, such as screw piling or steel reinforced concrete piles with the casings oscillated into the ground, be used so that the historic Waitangi Stream Culvert is not subjected to vibration levels that are potentially damaging to brickwork.