Grey Lynn Tunnel

Watercare Services Limited

Vibration Assessment of Grey Lynn Tunnel and Tawariki Street Shafts

Revision No. 3

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Distribution

To: Karyn Sinclair
Jacobs New Zealand Limited

From: Victor Romero
McMillen Jacobs Associates

Prepared By: William CB Gates, PhD, PE (WA)
McMillen Jacobs Associates

Reviewed By: Victor Romero
McMillen Jacobs Associates

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Executive Summary

The purpose of this report is to assess potential vibration impacts associated with the construction of the Grey Lynn Tunnel and Tawariki Street Shafts. The report has been prepared by McMillen Jacobs Associates for Watercare Services Ltd (Watercare). Watercare is proposing to construct a wastewater interceptor from Western Springs to Tawariki Street, Grey Lynn (Grey Lynn Tunnel). The Tawariki St shafts includes the main shaft that the Grey Lynn Tunnel connects to and a secondary shaft to enable the connection of future sewers. The Grey Lynn Tunnel will connect to the Central Interceptor at Western Springs via the Western Springs shaft site.

The Grey Lynn Tunnel will be excavated using an earth pressure balance (EPB) tunnel boring machine (TBM), which will be the primary source of vibration for tunnel construction. The Tawariki Street Shafts and near-surface sewer collection chambers will be constructed using conventional mechanical equipment (e.g. CAT 330 medium hydraulics excavator or similar). Shaft walls will be supported with either secant piles, sheet piles, ring beams with lagging, steel liner plate, precast segmental rings, caisson or similar installed by pile boring drilling rig or vibratory hammer.

This report assesses the potential construction vibration effects associated with the Grey Lynn Tunnel and shaft construction in accordance with the relevant Auckland Unitary Plan (Operative in Part) (AUP (OP)) rules (2016) and German Industrial Standard (DIN) 4150-3 (1999): Structural vibration – Part 3: Effects of vibration on structures. For human response, the report follows vibration guidelines that are outlined in the British Standard (BS) 5228-2:2009: Human Response.

The U.S. Federal Transit Administration (2006) method was used to assess vibration from various construction activities. This standard method has been adopted as a standard approach by various agencies and governments in the United States and has been adopted by a number of overseas jurisdictions, including Australia (Melbourne Metro, 2016), and elsewhere, to quantitatively assess vibration from construction activities.

There are no commercial and industrial buildings, listed historical structures or sensitive structures (such as laboratories or healthcare facilities with instruments and/or diagnostic equipment) along the alignment of the Grey Lynn Tunnel. Vibration levels during construction of the Grey Lynn Tunnel and Tawariki Street Shafts are predicted to be within limits and guidelines outlined in the AUP (OP) rules, DIN 4150-3, and BS 5228-2. The results of our assessment are tabulated in this report. This report recommends establishing seismograph monitoring stations at key receivers (identified under monitoring) along the Grey Lynn Tunnel alignment and at the Tawariki Street Shafts to record both background vibration and vibrations during construction to verify compliance with the guidelines outlined in this report. In addition, this report provides standard recommended and suggested methods to mitigate construction vibration, if required. The recommended methods are good practice for all construction sites. The suggested methods are additional means to mitigate construction impacts as needed.

This report provides an outline for the vibration sections of Construction Noise and Vibration Management Plan (CNVMP) identifying the minimum standards to be complied with during the construction of the Grey Lynn Tunnel and Tawariki Street Shaft. The CNVMP will be prepared by the construction contractor. The purpose of the CNVMP is to minimise the vibration effects on health and limit discomfort to people as well as minimise the risk of damage to structures.

1.0 Introduction

1.1 Project Description

Watercare Services Limited ("Watercare") is the water and wastewater service provider for Auckland. Watercare is proposing to construct a wastewater interceptor from Tawariki Street, Grey Lynn to Western Springs ("Grey Lynn Tunnel"). The Grey Lynn Tunnel will connect to the Central Interceptor at Western Springs.

1.2 Project Overview

The Grey Lynn Tunnel involves the elements shown in the drawings and outlined in more detail in the reports which form part of the application. These elements are summarised as follows.

1.2.1 Grey Lynn Tunnel

The Grey Lynn Tunnel involves construction, operation and maintenance of a 1.6km gravity tunnel from Western Springs to Tawariki Street, Grey Lynn with a 4.5m internal diameter, at an approximate depth of between 15 to 62m below ground surface, depending on local topography. The tunnel will be constructed northwards from Western Springs using a Tunnel Boring Machine ("TBM"). The Grey Lynn Tunnel will connect to the Central Interceptor at Western Springs via the Western Springs shaft site.

1.2.2 Tawariki Street Shaft Site

The Grey Lynn Tunnel also involves construction, operation and maintenance of two shafts and associated structures at Tawariki Street, Grey Lynn ("Tawariki Street Shaft Site").

The Tawariki Street Shaft Site will be located at 44-48 Tawariki Street where the majority of the construction works will take place. Construction works will also take place within the road reserve at the eastern end of Tawariki Street and a small area of school land (St Paul's College) bordering the end of Tawariki Street (approximately 150m2).

The Tawariki Street Shaft Site will involve the following components:

1.2.2.1 Main Shaft

- A 25m deep shaft, with an internal diameter of approximately 10.8m, to drop flow from the existing sewers into the Grey Lynn Tunnel;
- Diversion of the Tawariki Local Sewer to a chamber to the north of the shaft. This chamber will be approximately 12m long, 5m wide and 5m deep below ground, and will connect to the shaft via a trenched sewer;
- Diversion of the Orakei Main Sewer to a chamber to the south of the shaft. This chamber will be approximately 10m long, 5m wide and 11m deep below ground;
- Construction of a stub pipe on the western edge of the shaft to enable future connections (that are not part of this proposal) from the CSO network;
- Construction of a grit trap within the property at 48 Tawariki St to replace the existing grit trap located within the Tawariki Street road reserve. The replacement grit trap will be approximately 16m long, 5m wide and 13m deep below ground;
- Permanent retaining of the bank at the end of Tawariki Street to enable the construction of the chamber for the Orakei Main Sewer. The area of the bank requiring retaining will be approximately 44m long, 3m wide and 2m high; and
- An above ground plant and ventilation building that is approximately 14m long, 6m wide and 4m high. An air vent in a form of a stack will be incorporated into the plant and ventilation building

and discharge air vertically via a roof vent. The vent stack will be designed with a flange to allow future extension of up to 8m in total height and approximately 1m in diameter in the unexpected event of odour issues.

1.2.2.2 Tawariki Connection Sewer Shaft – Secondary Shaft

A secondary shaft will be constructed at the Tawariki Street Shaft Site to enable the connection of future sewers (that are not part of this proposal) from the Combined Sewers Overflows ("CSO") network. This will involve the following components:

- A 25m deep drop shaft with an internal diameter of approximately 10.2m; and
- A sewer pipe constructed by pipe-jacking to connect the secondary shaft to the main shaft.

1.3 Construction Timeframe

The construction works for the main shaft, chambers and tunnel will occur at the same time as works for the Central Interceptor. Construction will be up to 2 ½ years total duration. The construction of the main shaft and chambers is estimated to take approximately 12 months initially, followed by a hiatus of several months waiting for the TBM to arrive at Tawariki Street Shaft Site. This will be followed by approximately 9 months of activity to remove the TBM and complete the internal structure of the main shaft.

The secondary shaft will be constructed in conjunction with the future sewers at a later date but (subject to need) within a 10-year period following construction of the main shaft and tunnel. The construction period for the secondary shaft and future sewer connections is estimated to be up to 2 years total duration.

1.4 Assessment

This report provides technical input to supplement the Assessment of Environmental Effects (AEE) Report addressing the effects of vibrations from construction of the Grey Lynn Tunnel and Tawariki Street Shafts in Tawariki Street. Construction vibration effects associated with the Grey Lynn Tunnel and Tawariki Street Shafts are assessed in accordance with the AUP (OP) rules (2016) and (DIN) 4150-3 (1999). For human response, the report follows vibration guidelines in BS 5228-2:2009: Human Response.

This report has been developed based on input from the following:

- Briefing and site walk of the project area by the Grey Lynn Tunnel project team.
- Review of concept designs for Grey Lynn Tunnel and Tawariki Street Shafts, including construction methodology and layouts.
- Review of geotechnical information and assessment of ground conditions for excavation of the tunnel and shafts.
- Discussions with the project team to identify anticipated construction equipment and methods.
- Review of vibration source levels for various construction equipment and methods to evaluate the vibration.
- Review of vibration standards and guidelines and development of assessment criteria.
- Identification of structures and sensitive receivers along the tunnel alignment.
- Assessment of likely effects on receivers including effects of distance from vibration sources.
- Discussions with the project team regarding anticipated programme for the works.
- Assessment of mitigation measures (as needed).
- Outline of Construction Noise and Vibration Management Plan for construction.

2.0 Existing Conditions

2.1 Geology and Construction Ground Conditions

A geotechnical investigation has been conducted for the Grey Lynn Tunnel alignment and Tawariki Street Shaft site, which is summarised in an addendum to the project Geotechnical Factual Report (Jacobs/AECOM/McMillen Jacobs Associates 2018). The Grey Lynn Tunnel will transect rock units of the Waitemata Group (Miocene) and specifically the East Coast Bay Formation (ECBF) to the junction with the bottom of the Tawariki Street shafts. From the surface, the shafts will be excavated through units of the Tauranga Group (TG) and the upper weathered rock units of the Waitemata Group (RS) and into the ECBF rock.

The rock units of the ECBF have been characterised as moderately weathered to unweathered rock. The lithology of the ECBF has been characterised by alternating strata of very weak to weak (3.0–9.5 MPa), graded, bedded, silty, muddy sandstones and laminated mudstones. The upper weathered rock units of the RS consist of very stiff to hard, residually to highly weathered cohesive soil (silt and clay) and dense to very dense, residually to highly weathered sand. The undifferentiated TG consists of soft to firm cohesive clays, silts and loose to medium dense sands.

2.2 Existing Structures and Utilities

2.2.1 Existing Structures

The alignment of the Grey Lynn Tunnel is primarily through residential areas. There are no major existing commercial or industrial structures. The largest structures near the Tunnel alignment appear to be the Church of Jesus Christ of Latter-Day Saints (LDS) near the junction of Surrey Crescent and Old Mill Road (at approximately Chainage 233350) and the government offices for the Ministry of Social Development at junction of Surrey Crescent and Richmond Road (at approximately Chainage 23775). The Grey Lynn Tunnel will pass approximately 58 m directly beneath the LDS church. At the Ministry of Social Development, the Tunnel alignment will be about 100 m northwest and 55 m below grade with diagonal offset of about 115 m. In both areas, the Grey Lynn Tunnel will transect very weak to weak, moderately weathered to weathered units of the ECBF rock, which will attenuate TBM vibrations.

At the Tawariki Street Shaft site, the closest residence (42 Tawariki St) is approximately 15 m from the shafts. The residences across the street (35, 37, 39, and 41 Tawariki St) are approximately 20 m to 40 m from the shafts. The shafts will be excavated through the undifferentiated TG, upper weathered rock units of the RS and into the very weak to weak, moderately weathered to weathered units of the ECBF rock, all of which will attenuate vibration.

2.2.2 Utilities

The utilities generally follow streets, consisting of buried power lines, water lines and sewer lines. We have assumed the utilities cross very weak and highly weathered units of the undifferentiated TG and upper weathered rock units of the RS, all of which will attenuate vibration.

3.0 Construction Methodology and Sources of Vibration

The methods of construction and the types of equipment utilised determine the level of vibration generated. The following sections discuss the anticipated methods of construction for the two main components of the Grey Lynn Tunnel and Tawariki Street Shafts and the equipment required with regards to vibration impacts.

3.1 Grey Lynn Tunnel

The Grey Lynn Tunnel is approximately 1.6 km in length with an internal diameter of 4.5 m. The depth of overburden above the Tunnel may be as shallow as 15 m near the valleys and over 60 m in the uplands. The Tunnel will be excavated using an earth pressure balance (EPB) TBM. The TBM will be a primary source of vibration. An EPB TBM is a mechanised tunnelling method in which the excavated material is used to support the tunnel face while it is being plasticised using foams, polymers and other additives to make it transportable and impermeable. The spoils are admitted into the TBM via a screw conveyor arrangement, which allows the pressure at the face of the TBM to remain balanced without the use of slurry. Vibration source levels and spectral characteristics are dependent on the machine type, machine size, and ground conditions through which the tunnelling will occur.

TBM require transport of people, materials, and equipment into and out of the machine. Transport methods could include rolling stock, conveyors, or rubber-tired vehicles. Steel wheeled vehicles on rails will have a higher vibration source level than rubber-tired vehicles. The engine pulling the train may create a significant vibration source. In addition, vibration typically occurs at the juncture of the rails or at areas where there are voids beneath the rail resulting in bumps when a car goes over them.

3.2 Tawariki Street Shafts and Near-Surface Chambers

The Tawariki Street Shafts and near-surface sewer collection chambers will be constructed using an excavator with rippers. Because of the softer deposits, construction of the shaft walls will be supported with either secant piles, typically installed using a pile boring drilling rig, or sheet pile retention rings, installed by pile boring vibratory hammer.

Alternatively, sheet piles may be installed to support the shaft walls and the near-surface chambers, instead of secant piles or sheet pile retention rings. Vibratory hammers are widely used to drive and extract sheet piles. However, pile-driving is one of the greatest sources of vibration associated with equipment used during construction of a project.

Because of the soft, weak upper weathered rock units of the RS rock and weathered units of the ECBF rock, the Tawariki Street Shafts and near-surface chambers will likely be excavated using either a 320 or 330 excavator with an attached ripper.

4.0 Guideline Targets for Construction Vibration

Construction vibration effects associated with the Grey Lynn Tunnel and Tawariki Street Shafts are assessed in accordance with the AUP (OP) rules and DIN 4150-3 (2016). For human response, the report follows vibration guidelines outlined in BS 5228-2:2009.

4.1 Effects of Vibration on Structures

4.1.1 AUP(OP): Building Damage

Standard E25.6.30 Vibration of the AUP (OP) (2016) sets out requirements relating to construction vibration activities that address building damage and comfort to occupants. Standard E25.6.30 provides that construction activities must be controlled to ensure vibration does not exceed the following limits:

1. The limits outlined in DIN 4150-3 (1999) when measured in accordance with that standard on any structure not on the same site, and
2. The limits outlined in Table 1 in any axis when measured in the corner of the floor of the storey of interest for multi-storey buildings or within 500 mm of ground level at the foundation of a single-story building.

Table 1: Vibration Limits in Buildings (AUP (OP)Table E25.6.30.1)

Receiver	Period	Peak Particle Velocity (PPV) Limit (mm/sec)
Occupied activity sensitive to noise or vibration	Night-time 10 pm to 7 am	0.3
	Daytime 7 am to 10 pm	2.0
Other occupied buildings	At all times	2.0

According to Standard E25.6.30, works generating vibration for three days or less between the hours of 7 am and 6 pm may exceed the limits reproduced in Table 1 above, but must comply with a limit of 5 mm/sec peak particle velocity (PPV) in any axis when measured in the corner of the floor of the storey of interest for multi-storey buildings or within 500 mm of ground level at the foundation of a single storey building. Additional requirements to meet this standard are:

1. All occupied buildings within 50 m from of the extent the works generating vibration must be advised in writing no less than three days prior to the vibration-generating works commencing; and
2. The written advice must include details of the location of the works, the duration of the works, a phone number for complaints, and the name of the site manager.

4.1.2 DIN 4150-3 (1999)

4.1.2.1 Damage to Structures

DIN 4150-3 contains vibration limits for buildings that, when complied with, “will not result in damage that will have an adverse effect on the structure’s serviceability”. Table 2 outlines the limits from DIN 4150-3. Different criteria are provided for “short-term” or transient vibration sources such as blasting and pile driving and “long-term” or continuous vibration sources such as vibro-compaction or sheet piling. In addition to providing the guidelines summarised in Table 2, Clause 5.1 of DIN 4150-3 notes that a vibration level greater than the DIN criteria does not necessarily result in building damage.

Table 2: Vibration velocity guideline values for peak particle velocity (PPV) for structures (DIN 4150-3)

Category of Structure	Short-Term Vibration				Long-Term Vibration[b]
	PPV (mm/sec) at Foundation Frequency of:			PPV at Horizontal Plane of Highest Floor at All Frequencies (mm/sec)	PPV at Horizontal Plane of Highest Floor (mm/sec)
	1 Hz to 10 Hz	10 Hz to 50 Hz	50 Hz to 100 Hz[a]		
Commercial/Industrial	20	20 to 40	40 to 50	40	10
Residential/School	5	5 to 15	15 to 20	15	5
Historic or sensitive structures	3	3 to 8	8 to 10	8	2.5

a) At frequencies above 100 Hz, the values in this column may be used as minimum values.
b) Standard defines short-term vibration as “vibration which does not occur often enough to cause structural fatigue, and which does not produce resonance in the structure being evaluated”. Long-term is defined as all other vibration types not covered by the short-term definition.

As reflected in Table 2, the vibration guidelines in DIN 4150-3 include three categories of building structures with increasing levels of protection. The significant margins displayed in Table 2 and Figure 1 reflect higher level of protection provided by this standard to residential structures (Category 2) compared to commercial structures (Category 1). Similarly, a higher level of protection is provided to sensitive structures to include but not limited to laboratories or healthcare facilities with instruments and/or diagnostic equipment (Category 3).

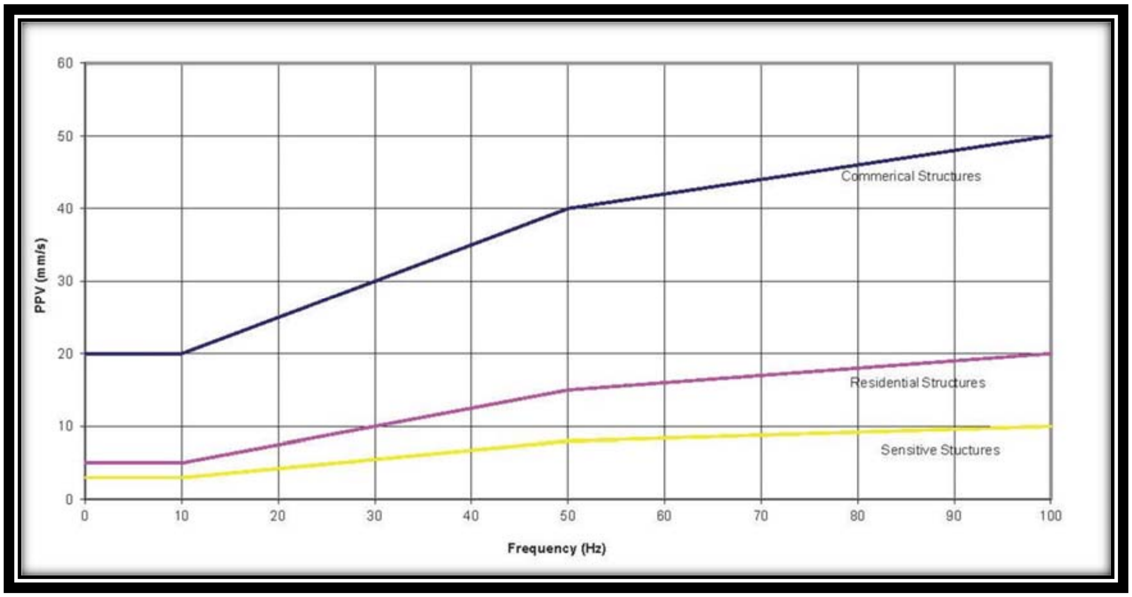

Figure 1: Baseline curves representing short-term vibration effects on structures in relation to recorded data (Marshal Day Acoustics 2010).

Category 3 in Table 1 outlines guidelines for vibration velocity values attendant to short-term vibration effects on historical and sensitive structures and equipment. There are no sensitive or historical structures on the Heritage New Zealand list that are on the Grey Lynn Tunnel alignment. Moreover, there are no hospitals, laboratories, or research institutions on the Tunnel alignment that employ sensitive equipment such as MRI machines or microscopes that are highly sensitive to vibration. As such, vibration criteria used in this assessment are based on Category 2 structures because there limited commercial and industrial structures on the alignment.

4.1.2.1.1 Damage to Utilities

There is no guideline for vibration limits for utilities and services listed in the AUP (OP) or DIN 4150-3. However, a rule-of-thumb for long-term vibrations on utility structures is to limit the PPV to 20 mm/sec at all frequencies. This guideline was used for the Melbourne Metro Rail Project (Melbourne Metro 2016) and is utilised in this assessment, as there was no other apparent guidance established for utilities in New Zealand.

4.2 Human Response Standard

4.2.1 BS 5228-2:2009 – Human Response

Appendix B.2 of BS 5228-2:2009 provides guidance for people's expectations and responses to construction vibration. Table 3 summarises the vibration criteria from this standard. Comparing these criteria to those by DIN 4150-3, as summarised in Table 2, it appears that people are likely to complain at vibration levels significantly below those that cause building and structural damage. Moreover, construction activities generate vibration at a wide range of frequencies, and peoples' sensitivity to the higher frequencies in this range exacerbates their perception of the potential for building damage.

Table 3: Criteria for human response to construction vibration (BS 5228-2:2009, Annex B)

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

5.0 Construction Vibration Assessment Methods

Vibration source levels and spectral characteristics are dependent on machine type and size and the ground conditions in which the construction occurs. Operation of construction equipment causes ground vibrations recorded as peak particle velocity (PPV) that spread through the ground and diminish in strength with distance. Structures founded on soil or rock near the construction site respond to these vibrations, with varying results ranging from no perceptible effects at the lowest levels, low rumbling sounds and perceptible vibration at moderate levels, and slight damage at the highest levels. Strong competent rock such as basalt tends to transmit ground vibration with ease. However, weak weathered rock and soil tend to attenuate the ground vibration within a relatively short distance.

The FTA (2006) method outlines a method to assess vibration from various construction activities in various ground conditions. This method has been adopted as a standard approach by various agencies and governments in the United States, such as Caltrans (2013), by overseas jurisdictions, such as Australia (Melbourne Metro 2016), and elsewhere to quantitatively assess vibration from construction activities. As part of this study, the FTA measured ground vibration source levels as PPV for various types of construction equipment in a multitude of ground conditions (rock and soil) and developed a regression curve comparing distance in metres from the vibration source to PPV in mm/sec.

Table 4 is a summary of the vibration source levels for various machines and other vibration sources compiled from FTA research (2006), Melbourne Metro (2016), and Caltrans (2013). The PPV produced by each piece of equipment is normalised at 7.6 m.

5.1 Vibration Assessment Steps

To conduct the vibration assessment, FTA (2006) recommends the following steps:

- Select equipment and associated source levels at the reference distance of 7.6 m listed on Table 4
- Use the following propagation equation to assess the ground vibrations as PPV:

$$PPV_{equip} = PPV_{ref}\left(\frac{7.6m}{D}\right)^{1.5}$$

Where:

PPV $_{(equip)}$ is the PPV in mm/sec of the equipment adjusted for distance;

PPV $_{(ref)}$ is the reference vibration level in mm/sec of the equipment in

Table 4;

D is the distance in metres from the equipment to the receiver at the structure.

Compare estimated results to vibration criteria tabulated in Table 1, Table 2, and Table 3.

- Note: Assessing construction vibration is an inexact science, computed vibration results are estimates and may vary slightly by a few mm/sec based on machine type and size and the ground conditions in which the construction occurs.

Table 4: Vibration source levels for construction equipment (modified from FTA 2006, Table 12-2; Melbourne Metro 2016)

Equipment		PPV at 7.6 m (mm/sec)	Reference Comments
Pile Driver (impact)	Upper range	38.6	FTA
	Typical	16.4	FTA
Pile Driver (Sonic)	Upper range	18.7	FTA
	Typical	4.3	FTA
Pile driver (vibratory)		16.5	Caltrans
Vibratory roller		5.3	FTA
Clam shovel drop (slurry wall)		5.1	FTA
EPB TBM		4.3	Melbourne Metro
20t excavator & hydraulic rock breaker		4.7	Melbourne Metro
12–15t excavator & hydraulic rock breaker		3.3	Melbourne Metro
7t excavator & hydraulic rock breaker		2.4	Melbourne Metro
Hoe ram		2.3	FTA
Large bulldozer		2.3	FTA
Caisson drilling (auger)		2.3	FTA
Crane, wheel-mounted with outriggers, 450t		2.3	Based on similar data
Excavator with ripper		1.3	Melbourne Metro
Hydromill (slurry wall)	In soil	0.2	FTA
	In rock	0.4	FTA
Piling drilling (bored)		1.0	BS 5228-2
Loaded trucks & traffic		1.9	FTA
Crane, track-mounted, 120t		1.9	Based on similar data
Fixed plant		1.9	Melbourne Metro
Jackhammer		0.9	FTA
Small bulldozer		0.1	FTA

6.0 Construction Vibration Estimates

6.1 Grey Lynn Tunnel

6.1.1 TBM: EPB

Overburden (OB) above the Grey Lynn Tunnel ranges from about 17 m where it runs under Sackville Street, Chainage 24300 to over 58 m (and ranges from 15 to 62m when applying a vertical envelope of -2m/+2m). The Tunnel will be excavated using an EPB TBM. The frequency spectra for TBM range between 16 and 80 Hz (Melbourne Metro 2016). We have assumed the vibration source level for the EPB is 4.3 mm/sec at 7.6 m (Table 4). Using the propagation equation in Section 5.1, we can predict the following ground vibrations along the Grey Lynn Tunnel alignment due to operation of the EPB TBM.

- Daycare facility at 38 Sackville Street, near Chainage 24,300: 17.9 m OB ~1.19 mm/sec.
- Sackville Reserve at 36 Sackville Street, near Chainage 24,300: 17.3 m OB ~1.25 mm/sec.
- Residential house at 34 Sackville Street, near Chainage 24,300: 17.5 m OB ~1.23 mm/sec.

- Residential house at 32 Sackville Street, near Chainage 24,300: 18.9 m OB ~1.10 mm/sec.
- Residential house at 2/30 Sackville Street, near Chainage 24,300: 20.0 m OB ~1.00 mm/sec.
- Residential house at 30 Sackville Street, near Chainage 24,300: 20.0 m OB ~1.00 mm/sec.
- Residential house at 39 Tawariki Street, near Chainage 24,600: 20.5 m OB ~0.97 mm/sec.
- Residential house at 37 Tawariki Street, near Chainage 24,600: 20.4 m OB ~0.98 mm/sec.
- Old stream valley (Paleo Valley) near Chainage 24250 (length ± 50 m): 20 m OB ~1.00 mm/sec.
- LDS church near Chainage 23350: 58 m OB ~0.20 mm/sec.
- Government offices near Chainage 23775: 115 m OB ~0.07 mm/sec.
- For all utilities at all frequencies assume a buffer of 3 m offset around the tunnel periphery to maintain a PPV of < 20 mm/sec.

Based on our assessment, the predicted ground vibrations generated from the EPB TBM are just above the suggested vibration limits outlined by the AUP (OP) for night-time operations between 10:00 PM and 7:00 AM (see Table 1). Similarly, the predicted ground vibrations and frequency spectra are below the suggested guidelines in DIN 4150-3 (see Table 2) for structures in the following categories: commercial and industrial, residential and schools, and historic or sensitive structures. Referencing Table 3, vibrations from the EPB TBM along the alignment where the overburden is less than 17 (15m at worst case scenario) may be just perceptible. However, these low-level vibrations are considered acceptable provided that prior warning and an explanation of the drilling operations is provided to residents. A procedure for this prior warning and explanation of the vibrations from the drilling operations will be included in the CNVMP.

6.1.2 Rolling Stock and Conveyors

The same conditions for the OB apply for the rolling stock and conveyors in the Tunnel. We have assumed that rolling stock will be on rubber-tired vehicles and the vibration source level for heavy vehicle travel and conveyors is 1.9 mm/sec at 7.6 m (Table 4). Using the propagation equation in Section 5.1, we can predict the following ground vibrations along the Tunnel alignment due to rolling stock and conveyors.

- Daycare facility at 38 Sackville Street, near Chainage 24,300: 17.9 m OB ~0.53 mm/sec.
- Sackville Reserve at 36 Sackville Street, near Chainage 24,300: 17.3 m OB ~0.55 mm/sec.
- Residential house at 34 Sackville Street, near Chainage 24,300: 17.5 m OB ~0.54 mm/sec.
- Residential house at 32 Sackville Street, near Chainage 24,300: 18.9 m OB ~0.48 mm/sec.
- Residential house at 2/30 Sackville Street, near Chainage 24,300: 20.0 m OB ~0.45 mm/sec.
- Residential house at 30 Sackville Street, near Chainage 24,300: 20.0 m OB ~0.45 mm/sec.
- Residential house at 39 Tawariki Street, near Chainage 24,600: 20.5 m OB ~0.43 mm/sec.
- Residential house at 37 Tawariki Street, near Chainage 24,600: 20.4 m OB ~0.43 mm/sec.
- Old stream valley near Chainage 24250 (length ± 50 m): 20 m OB ~0.45 mm/sec.
- LDS church near Chainage 23350: 58 m OB ~0.10 mm/sec.
- Government offices near Chainage 23775: 115 m OB ~0.03 mm/sec.

Based on our assessment, the predicted ground vibrations generated from the rolling stock fall below the suggested vibration limits outlined by the AUP (OP) (see Table 1) and DIN 4150-3 (see Table 2) for structures in the following categories: commercial and industrial, residential and schools, and historic or sensitive structures. In addition, the expected vibration levels may be just perceptible in areas where the OB is less than 17 in thickness (See Table 3).

6.2 Tawariki Street Shafts and Near-Surface Chambers

At the Tawariki Street Shaft area, the closest residence (42 Tawariki Street) is about 15 m from the shafts. Residences 44, 46 and 48 on Tawariki Street were excluded from this assessment as they are within the Tawariki Street Shaft construction site. The residences across the street (35, 37, 39, and 41 Tawariki Street) are about 20 m to 40 m from the shafts. The shafts will be excavated through the undifferentiated TG, upper weathered rock units of RS and into the very weak to weak, moderately weathered to weathered units of the ECBF rock, all of which will attenuate vibration. In addition, the near-surface chambers or vaults will probably be excavated in very weak and highly weathered undifferentiated TG.

6.2.1 Cranes: 120t and 450t Crane

To support construction of the Tawariki Street Shafts, up to two cranes may be required on site at any one time. The crane for the shaft construction will be a typical crawler crane, which is a 120 t crane, 7x5 m footprint with extended belts. The crane for the TBM recovery will be a 450 t crane, 16x9 m footprint with extended outriggers.

The nearest horizontal distance from a shaft to the residence at Tawariki Street is about 15 m. The vibration source level for the 120 t crane is about 1.9 mm/sec at 7.6 m (Table 4). Using the propagation equation in Section 5.1, we can predict the ground vibrations as PPV of 0.67 mm/sec at the closest residence (42 Tawariki Street).

Similarly, the vibration source level for 450 t crane is about 2.3 mm/sec at 7.6 m (Table 4). Using the propagation equation in Section 5.1, we can predict the ground vibrations as PPV of 0.82 mm/sec at the closest residence at 42 Tawariki Street.

Based on our assessment, the predicted ground vibrations of 0.67 mm/sec and 0.82 mm/sec generated from the 120 t crane and/or the 450 t crane are within limits for DIN 4150-3 (see Table 2). However, the vibrations are slightly above the suggested vibration limits outlined by the AUP (OP) (see Table 1) for the residential structure near 42 Tawariki Street for night-time hours of 10 pm to 7 am; and, the expected vibration levels may exceed the recommended criteria for human response to construction vibration as presented in Table 3. In both cases the vibrations may exceed the recommended guidelines by 0.37 mm/sec and 0.52 mm/sec and might be just perceptible to the residents in the vicinity of 35, 37, 39 and 42 Tawariki Street. However, these low-level vibrations are considered acceptable provided that prior warning and explanation of the construction operations are provided to the residents. A procedure for this prior warning and explanation of the vibrations from the shaft construction operations will be included in the CNVMP. Moreover, excavation of the shafts will not occur during the night-time hours of 10 pm to 7 am

6.2.2 Excavators: 320 or 330 Excavator with Ripper

The Tawariki Street Shafts and near-surface chambers will be excavated with a 320 or 330 excavator with a ripper. The nearest horizontal distance to the residence at Tawariki Street is about 15 m. The vibration source level for an excavator with a ripper is 1.3 mm/sec at 7.6 m (Table 4). Using the propagation equation in Section 5.1, we can predict the ground vibrations as PPV of 0.47 mm/sec at the closest residence, 42 Tawariki Street.

Based on our assessment, the predicted ground vibrations of 0.47 mm/sec generated from the 320 or 330 excavators with a ripper are within limits for DIN 4150-3 (see Table 2). However, the vibrations are slightly above the suggested vibration limits outlined by the AUP (OP) (see Table 1) for residential structures for night-time hours of 10 pm to 7 am; and, the expected vibration levels may exceed the recommended criteria for human response to construction vibration as presented in Table 3. In both cases the vibrations may exceed the recommended guidelines by 0.17 mm/sec and might be just perceptible to the residents in the vicinity 42 Tawariki Street. Vibrations at residential areas 35, 37, 39 and 46 Tawariki Street are expected to be below 0.3 mm/sec. However, these low-level vibrations are considered acceptable provided that prior warning and explanation of the construction operations are provided to the residents. A procedure for this prior warning and explanation of the vibrations from the shaft construction operations will be included in the CNVMP. Moreover, excavation of the shafts will not occur during the night-time hours of 10 pm to 7 am.

6.2.3 Secant Pile Drill Rigs

Secant piles may be installed to support the shaft walls and the near-surface chambers. The secant piles would typically be installed using a pile boring drilling rig. The vibration source level as PPV at 7.6 m is approximately 1.0 mm/sec for boring pilling drill rigs (Table 4). Using the propagation equation in Section 5.1, we can predict the ground vibrations as PPV of 0.36 mm/sec at the closest residence, 42 Tawariki Street.

Based on our assessment, the predicted ground vibrations of 0.36 mm/sec generated from the pile boring drilling rig in the residences near the shafts are within limits for DIN 4150-3 (see Table 2). However, the vibrations are slightly above the suggested vibration limits outlined by the AUP (OP) (see Table 1) for the residential structure near 42 Tawariki Street for night-time 10 pm to 7 am; and, the expected vibration levels may exceed the recommended criteria for human response to construction vibration as presented in Table 3. In both cases the vibrations may exceed the recommended guidelines by 0.06 mm/sec and might be just perceptible to the residents. Vibrations at residential areas 35, 37, 39 and 46 Tawariki Street are expected to be below 0.3 mm/sec. Moreover, these low-level vibrations are considered acceptable provided that prior warning and explanation of the construction operations are provided to the residents. A procedure for this prior warning and explanation of the vibrations from the shaft construction operations will be included in the CNVMP. Furthermore, installation of the secant piles for shoring will not occur during the night-time hours of 10 pm to 7 am.

6.2.4 Sheet Piles Vibratory Hammer

Alternatively, sheet piles may be installed to support the shaft walls and the near-surface chambers using a vibratory hammer. Pile-driving is one of the greatest sources of vibration associated with equipment used during construction of a project. According to literature research, the frequency spectra for the vibratory hammer range is between 20 and 50 Hz (DFI) and the typical vibration source level as PPV at 7.6 m is approximately 16.51 mm/sec for vibratory pile drivers (Table 4). Using the propagation equation in Section 5.1, we can predict the ground vibrations as PPV of 5.95 mm/sec at the closest residence, 42 Tawariki Street.

Based on our assessment, the predicted ground vibrations of 5.95 mm/sec and frequency spectra of 20 to 50 Hz generated from the vibratory hammer around the shafts for expected short-term vibrations fall below the limits based on DIN 4150-3 (see Table 2) for the nearest residence (about 15 m) at 42 Tawariki Street around the shafts. However, for the same residence, the long-term PPV may be exceeded by 0.95 mm/sec. Vibrations at residential areas 35, 37, 39 and 46 Tawariki Street are expected to be below 3.9 mm/sec and within limits. On the other hand, the vibrations may exceed the suggested vibration limits outlined by the AUP (OP) (see Table 1) by at most 5.65 mm/sec near 42 Tawariki Street and about 3.6 mm/sec near residences 35, 37, 39 and 46 Tawariki Street. Referring to Table 3, vibrations from the vibratory hammer exceeding the guidance near the shafts will be perceptible and residents may complain. It should be noted that these low-level vibrations are considered acceptable provided that prior warning and explanation of the construction operations are provided to the residents. A procedure for this prior warning and explanation of the vibrations from the shaft construction operations will be included in the CNVMP. Furthermore, installation of the sheet pile shoring (if chosen) will not occur during the night-time hours of 10 pm to 7 am.

6.2.5 Utilities

For utilities, we have assumed either:

- An in situ earthen buffer between the utility and the secant pile or sheet pile wall of at least 7 m at all frequencies to maintain PPV below 20 mm/sec; or
- Utilities within site boundaries will be connected (e.g. sanitary and storm sewers) into the chambers/drop shafts, or will be temporarily diverted and replaced (e.g. potable water).

6.3 Summary of Construction Vibration Estimates

In general, we expect construction of the Grey Lynn Tunnel will comply with vibration limit guidelines in the AUP (OP), DIN 4150-3, and BS 5228-2 (as outlined in Tables 1, 2, and 3, respectively). Vibrations from the TBM may be just above the suggested vibration limits outlined by the AUP (OP) for night-time operations between 10 pm and 7 am (see Table 1). In addition, vibrations may be at or exceed the BS 5228-2 guidelines (see Table 3) and may be just perceptible. However, these low-level vibrations are considered acceptable and can be tolerated provided that prior warning and explanation of the drilling operations are provided to the residents.

Use of 120t to support construction of the Tawariki Street Shafts, and use of a 450t crane for TBM retrieval, will comply with vibration limit guidelines of DIN 4150-3 (Table 2). However, because of the proximity of the residential structure at 42 Tawariki Street (15 m from a shaft) and 35, 37, 39 and 41 Tawariki Street, vibrations may exceed guidelines AUP (OP) (Table 1) for night-time hours 10 pm to 7 am and the BS 5228-2 guidelines (see Table 3) where vibrations may be just perceptible. However, these low-level vibrations are considered acceptable and could be tolerated provided that prior warning and explanation of the drilling operations was provided to the residents. Moreover, excavation and shoring of the shafts will not occur during the night-time hours of 10 pm to 7 am, therefore there is no effect. Similarly, TBM retrieval could be limited to day-time hours.

Excavation of the Tawariki Street Shafts using 320 or 330 excavators with a ripper and installation of shoring using a secant pile drilling rig will comply with vibration limit guidelines of DIN 4150-3 (Table 2). However, because of the proximity of the residential structure at 42 Tawariki Street (15 m from a shaft), vibrations will exceed guidelines AUP (OP) (Table 1) for night-time hours 10 pm to 7 am and the BS 5228-2 guidelines (see Table 3) where vibrations may be just perceptible. Vibrations at residential areas at 35, 37, 39 and 46 Tawariki Street are expected to be within limits. It should be noted that these low-level vibrations are considered acceptable and can be tolerated provided that prior warning and explanation of the drilling operations are provided to the residents. Moreover, excavation and shoring of the shafts will not occur during the night-time hours of 10 pm to 7 am, therefore there is no effect.

If the contractor elects to install sheet pile shoring with a vibratory hammer, short-term vibrations fall below the limits based on DIN 4150-3 (see Table 2) for residence at 42 Tawariki Street about 15 m from the shafts, but the long-term vibrations may be exceeded. In addition, vibrations will exceed guidelines AUP (OP) (Table 1) for night-time hours 10 pm to 7 am, including residential areas at 35, 37, 39 and 46 Tawariki Street. Referring to Table 3, vibrations from the vibratory hammer exceeding the guidance near the shafts will be perceptible and residents may complain. However, these low-level vibrations could be acceptable provided that prior warning and explanation of the construction operations was provided to the residents. Furthermore, shoring of the shafts with sheet piles will not occur during the night-time hours of 10 pm to 7 am.

7.0 Mitigation Options

The following are recommended and suggested methods to mitigate construction vibration. The recommended methods are good practice for all construction sites. The suggested methods are additional means to mitigate construction methods as needed.

7.1 Recommended Mitigation Options

- Communicate with adjacent residents along the Grey Lynn Tunnel alignment specifically at Sackville Street (residences 30, 2/30, 32, 34, and 38) and residences 35, 37, 39, 41 and 42 around the Tawariki Street Shaft site about the different vibrations and what to expect.
- Manage construction hours as follows:
  - Tunnelling activities – 24 hours a day, 7 days a week will occur for all tunnelling activities;
  - Shaft site construction activities – 7 am to 6 pm Monday to Friday, 8 am to 6 pm Saturday; and
  - Truck movements – 7 am to 6 pm Monday to Friday, 8 am to 6 pm Saturday.
- Conduct pre-condition surveys at the LDS Church on Surrey Crescent Street, the government buildings near Richmond Road and residences at 30,2/30, 32, 34, 38 Sackville Street along the alignment and residences 35, 37, 39, 41 and 42 Tawariki Street at the shaft site.
- Enact a warning procedure when construction vibration will occur.
- Use alternative design, construction methods, and equipment to mitigate construction vibration. For instance, for support of the shaft walls install secant piles with a pile drilling rig as opposed to installing sheet piles with a vibratory hammer, where the geologic conditions permit.
- Ensure ground vibrations are kept below 20 mm/sec at all frequencies at utilities lines adjacent to the work site by maintaining an in-situ buffer of earth of about 3 m between the tunnel work and utility and 7 m between the shaft work and utility.
- Institute a good maintenance program for construction equipment and vehicles to minimise vibration.

7.2 Suggested Mitigation Options (if required)

- Isolate vibration source, such as installing cushions below the rails at vibration points or using rubber-tired vehicles to transport rolling stock to and from the EPB TBM.
- Construct a vibration attenuation barrier between source and receiver.
- Consider, where mitigation is not feasible, possible temporary relocation of residents during activities that are close to the affected structures.
- Modify affected building structures to change the response characteristics by, for example, installing bracing to modify building response frequency.
- Isolate very sensitive equipment by use of, for example, airbags or floating slabs.

8.0 Consideration of Sensitive Receivers and Potential for Damage to Neighbouring Properties

We have conducted an initial assessment of the potential vibrations during construction operations along the Grey Lynn Tunnel and Tawariki Street Shafts. Our assessment included review of the likely construction methods, the levels of vibration that they will generate, and estimation of the distances at which vibration levels will exceed the proposed limits for both structural damage and sensitive receivers.

Section 6.0 summarises the construction activity and attendant vibration for the expected equipment. The summary was based on vibration source levels for each piece of equipment and the general distance from the source to the receiver.

Based on our initial assessment, there are no commercial or industrial structures within the alignment of the Grey Lynn Tunnel. Moreover, there are no historical structures listed as New Zealand Heritage structures or sensitive structures and equipment on the alignment and there is sufficient OB to attenuate the vibrations. Three residential structures within Tawariki Street Shaft Site will be removed. In short, the risk for damage from construction vibration near the Grey Lynn Tunnel alignment and the Tawariki Street shafts is low. The construction vibrations may be perceptible to residents but should not cause disturbance, especially if residents are notified and informed on the construction methods. Moreover, we do not expect that vibrations will exceed 20 mm/sec at buried utilities along the tunnel alignment and at the shafts. Overall, the risk of damage is less than minor.

In general, any effects of vibration on the structures along the alignment and in the vicinity of the shafts can be managed by control of construction means and methods to limit vibration levels at the source. To minimize vibration complaints and affects to residential structures, excavation and shoring of the shafts should not occur during the night-time hours of 10 pm to 7 am. If necessary, other mitigation measures may also be considered, as discussed in Section 7.0.

9.0 Construction Noise and Vibration Management Plan

A CNVMP identifying the minimum standards to be complied with during the construction of the Grey Lynn Tunnel and Tawariki Street Shafts shall be prepared by the contractor. The purpose of the CNVMP is to minimise the vibration effects on health and limit discomfort to people as well as minimise the risk of damage to structures.

We recommend the CNVMP include the following items in the document:

- Vibration guidance criteria as outlined in the AUP (OP) (Table 1) and DIN 4150-3 (Table 2), and the criteria for human response as outlined in BS 5228-2 (Table 3) for the Grey Lynn Tunnel and Tawariki Street Shafts.
- Notification requirements and information to be provided to the community. The AUP (OP) requires the following:
  - Post signage notification with construction schedule at key locations within 50 m of the works generating vibration advising public on when vibration-generating works will commence; and
  - The written notification must include details of the location of the works, the duration of the works, a phone number for complaints and the name of the site manager.
- Consider a ground vibration PPV of 20 mm/sec at all frequencies for excavation next to utility lines; maintain an in-situ buffer of earth of about 3 m between the utilities along the tunnel alignment work and 7 m at the shafts between the works and the utilities.
- Manage construction hours as follows:
  - Tunnelling activities – 24 hours a day, 7 days a week will occur for all tunnelling activities;
  - Shaft site construction activities – 7 am to 6 pm Monday to Friday, 8 am to 6 pm Saturday; and

    - Truck movements – 7 am to 6 pm Monday to Friday, 8 am to 6 pm Saturday.
- List of equipment that is likely to generate significant levels of vibration.
- Requirements for vibration monitoring including trials for establishing attenuation characteristics and the associated statistical parameters for design of safe operating distances.
- Requirements for condition (dilapidation) surveys on potentially affected structures (such as residential structures adjacent to the shafts) prior to, during, and after completion of the works.
- Requirements for background vibration monitoring in advance of the project.
- Reporting requirements including response flow chart identifying actions and reporting protocols if vibrations exceed the criteria.
- Roles and responsibilities of key personnel on site including contact details.
- Construction operator training procedures for activities likely to generate significant levels of vibration.
- Construction vibration mitigation options.
- Recording system for receiving and handling of complaints.

10.0 References

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