STATE HIGHWAY CONSTRUCTION AND MAINTENANCE NOISE VIBRATION GUIDE

Waka Kotahi NZ Transport Agency recognises that noise and vibration associated with road construction and maintenance can be intrusive and disturbing, especially at night. The effective management of noise and vibration is essential to avoid unreasonable effects on communities and individuals. This guide has been produced to inform Waka Kotahi staff, contractors and the public about construction and maintenance noise and vibration. Information is also provided on prediction, management, mitigation and documentation of such noise and vibration.

August 2019, Version 1.1

WAKA KOTAHI NZ TRANSPORT AGENCY

New Zealand Government

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This publication is also available on our website at **www.nzta.govt.nz**

DOCUMENT MANAGEMENT PLAN

1. PURPOSE

This management plan outlines the updating procedures and contact points for the document.

2. DOCUMENT INFORMATION

DOCUMENT NAME	State highway construction and maintenance noise and vibration guide
DOCUMENT NUMBER	SP/M/023
DOCUMENT AVAILABILITY	This document is located in electronic form on the Waka Kotahi website at www.nzta.govt.nz
DOCUMENT OWNER	Greg Haldane
DOCUMENT SPONSOR	Rob Hannaby

3. AMENDMENTS AND REVIEW STRATEGY

All corrective action/improvement requests (CAIRs) suggesting changes will be acknowledged by the document owner.

ACTIVITY	COMMENTS	FREQUENCY
Amendments (minor revisions)	Updates incorporated immediately when they occur.	As required
Review (major revisions)	Amendments fundamentally changing the content or structure of the document will be incorporated as soon as practicable. They may require coordinating with the review team timetable.	Not less than three years
Notification	All users that have subscribed to Technical Advice Notes (http://hip.nzta.govt.nz/tan) will be advised by email of amendments and updates.	Immediately

RECORD OF AMENDMENT

AMENDMENTNUMBER	DESCRIPTION OF CHANGE	EFFECTIVE DATE	UPDATED BY
1.1	Address changes in Waka Kotahi processes and other good practices	August 2019	Greg Haldane

SECTION 1: INTRODUCTION

1 INTRODUCTION

BACKGROUND

The NZ Transport Agency aims to be a good neighbour, taking social and environmental responsibility seriously, including the management of construction and maintenance noise and vibration.

Construction and maintenance activities can produce significant levels of noise and vibration. Adverse effects from high levels of noise and vibration include annoyance and interference with daytime activities such as work, study and domestic living. Other effects include potential sleep disturbance, and long-term health impacts such as increased stress and hypertension. Building damage (both cosmetic and structural) is possible from construction vibration.

This guide applies to the following activities:

- Construction – which for this guide is building new or upgrading existing state highways, and
- Maintenance – which is maintaining the standard of, or repair of existing state highways.

Similar types of equipment and techniques are employed to undertake construction and maintenance works and hence this guide applies to both.

The *State highway environmental and social responsibility plan*[01] provides our approach to implementation of our environmental and social responsibility policy, in relation to the planning, design, operation and maintenance of New Zealand's state highway network.

In accordance with these requirements the plan articulates how Waka Kotahi seeks to responsibly manage human health and nuisance effects. For construction and maintenance activities, that is to be achieved through the processes set out in this guide.

PURPOSE OF THIS DOCUMENT

The purpose of this guide is to provide:

- an understanding of the noise and vibration effects caused by different construction and maintenance techniques
- guidance on how to assess potential adverse effects
- guidance on how to manage noise and vibration from construction and maintenance works.

This guide should assist in:

- applying the *Environmental plan*[01] with respect to construction and maintenance noise and vibration
- managing noise and vibration during construction and maintenance works
- avoiding complaints about noise and vibration as a result of construction and maintenance work.

This guide is consistent with NZS 6803[02] supplemented by additional information on vibration matters from BS 5228-2[03].

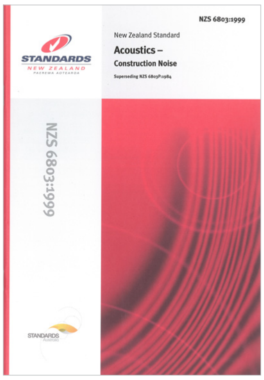
This guide provides both technical acoustics details, as well as wider management issues which are equally important. This guide should help Waka Kotahi **staff**, **consultants** and **contractors** implement good practice management measures on their projects.

Project and maintenance contractors have to manage the risk associated with construction noise and vibration effects, and this guide describes proactive approaches that should address the issue in an efficient manner. The guide is also intended to help the public understand construction and maintenance noise and vibration plus the factors in their management.

This guide shares knowledge from previous projects. The Victoria Park Tunnel project described on the following pages provides an example of excellent management of construction noise and vibration, aided by comprehensive monitoring.

01 Waka Kotahi NZ Transport Agency (2008) *Environmental plan: improving environmental sustainability and public health in New Zealand, version 2.* **www.nzta.govt.nz**

02 Standards New Zealand (1999) *NZS 6803:1999 Acoustics – Construction noise.* **www.standards.co.nz**



03 British Standard (2009) BS 5228-2:2009 *Code of practice for noise and vibration control on construction and open sites - Part 2: Vibration.* **www.bsigroup.com**

Arras Tunnel, Wellington

Victoria Park Tunnel project

CASE STUDY – VICTORIA PARK TUNNEL, AUCKLAND (2009–11)

The Victoria Park Tunnel (VPT) project upgraded 2.2km of State Highway 1, from the Auckland Harbour Bridge to the Wellington Street motorway overbridge, and removed the last remaining bottleneck on the central Auckland motorway system. It comprised a 450m cut and cover tunnel under Victoria Park for three northbound traffic lanes, widening the motorway through St Mary's Bay by one lane in each direction, and refurbishing the Victoria Park viaduct to carry four southbound traffic lanes. The project was delivered by the Victoria Park Alliance comprising the Transport Agency, Fletcher Construction, Beca, Higgins and Parsons Brinckerhoff.

According to Project Manager Andrew Rose from the Alliance, 'As a major infrastructure project with numerous neighbouring residents (some as close as 5m) and with works occurring at weekends and at night, the management of construction noise and vibration was always at the top of the project agenda.'

The project team responded with exemplary management practices, approaching all issues proactively and communicating effectively with neighbours. Examples of good practice on the VPT project include:

- The stakeholder manager provided a single point of contact and responsibility for all issues, and advocated for the community issues on the project management team.
- Consistent and clear communications were given to the community and residents. Signage was erected and updated around the construction site explaining the programme, progress and methods of construction. Flyers were regularly sent out to residents giving construction updates, which included reasons for and dates of future night-time and weekend works.
- Complimentary event tickets were offered to residents during particularly noisy periods of works.
- Works were scheduled in consultation with residents as to whether they preferred Sunday or night works, for example.
- Alternatives to tonal reversing alarms were required on all vehicles operating at night (broadband directional reversing alarms were bulk-purchased by the project).
- Noise measurements were undertaken on significant noise sources before they started operation.
- Site Specific Construction Noise Management Plans (called Schedules in this guide) were prepared for all activities predicted to be above the project noise criteria.
- Regular site noise monitoring of construction activities was carried out to confirm compliance with noise criteria.
- Prior to any night works, the teams were briefed on the behaviours expected of them to minimise all unnecessary noise.
- Project-wide planning ensured noise-intensive activities were undertaken over the same period to minimise the duration of disturbance on residents.
- Complaints were actively investigated and residents kept informed of outcomes.
- The Auckland Council (formerly Auckland City Council) Noise Officer was in close liaison with the project from the start.
- Ongoing feedback was provided to the construction teams on their performance.
- Project key performance indicators were compiled monthly and circulated to alliance board members, as well as within the project team. One of the indicators related specifically to noise, where a comparison was made between night works and the number of complaints.

Community and resident communications

Temporary noise barriers in use at Victoria Park Tunnel

MANAGEMENT PLANS

A procedure was set up within the Construction Noise and Vibration Management Plan to demonstrate compliance with project noise criteria to Auckland Council and, in situations where these could not be met, prove that additional noise mitigation measures were being implemented.

Using the construction noise calculator on the Transport Agency website, noise predictions were undertaken for any construction activity that had the potential to breach the project noise criteria.

A Site Specific Construction Noise Management Plan (SSCNMP) was submitted to the council for activities above the noise criteria. These plans used the Noise Management Schedules as a template (section 5).

Among other things, the SSCNMP contained the mitigation measures proposed, such as the use of temporary noise barriers, localised screening of machinery and smaller plant. Works would not commence until the council approved the SSCNMP.

The SSCNMP procedure developed at VPT ensured responsibility for construction noise management was shared by all of the project team. Prior to any night works being undertaken, the engineer overseeing the works submitted a noise request to the environment manager for review. This ensured that the engineers were considering construction noise impacts when planning night works.

Noise predictions were then undertaken based on the information provided within the noise request and, if required, a SSCNMP was submitted to the council for approval. Each approved noise request was subject to a number of conditions which specified the equipment to be used, hours of work and mitigation measures.

In the first months of the project, a SSCNMP was submitted to the council for approval whenever the predicted levels were above the project noise criteria. Once it was clear to the council that the project team was committed to noise management and the implementation of mitigation measures, this requirement was relaxed. Subsequently, a SSCNMP was only submitted to the council when the predicted levels were 10dB or more above the noise criteria.

Over 100 SSCNMPs were submitted to Auckland Council, and over a 100 more situations were modelled by the project team using the online calculator to be below the threshold for submission of a SSCNMP.

The preferred terminology for a SSCNMP is now a Schedule to the CNVMP.

RESPONSIBILITIES

Construction

Responsibility for construction noise changes throughout a project's life. Figure 1 illustrates some of the key stages. During the planning stage, an acoustics specialist advises the planner of the appropriate noise and vibration criteria, identifies the nearest sensitive neighbouring activities, predicts the construction noise levels and investigates appropriate mitigation, if required. In simple cases, such as where there are no nearby neighbours, this work is not required. The project engineer or construction advisor would supply the indicative construction methodology.

As the construction methodology is confirmed in the design stage, a further assessment of the noise and vibration implications may be required to reassess the impacts and to prepare suitable management plans. In a design and construct contract, the acoustics specialist and environment manager will both be in the contractor's team. Management plans will generally be written collaboratively: the acoustics specialists understands the designation conditions and other technical requirements and best practice (including this guide); and the environment manager understands the contractor's systems and the parent management plans, and has overall responsibility for the implementation of the plan.

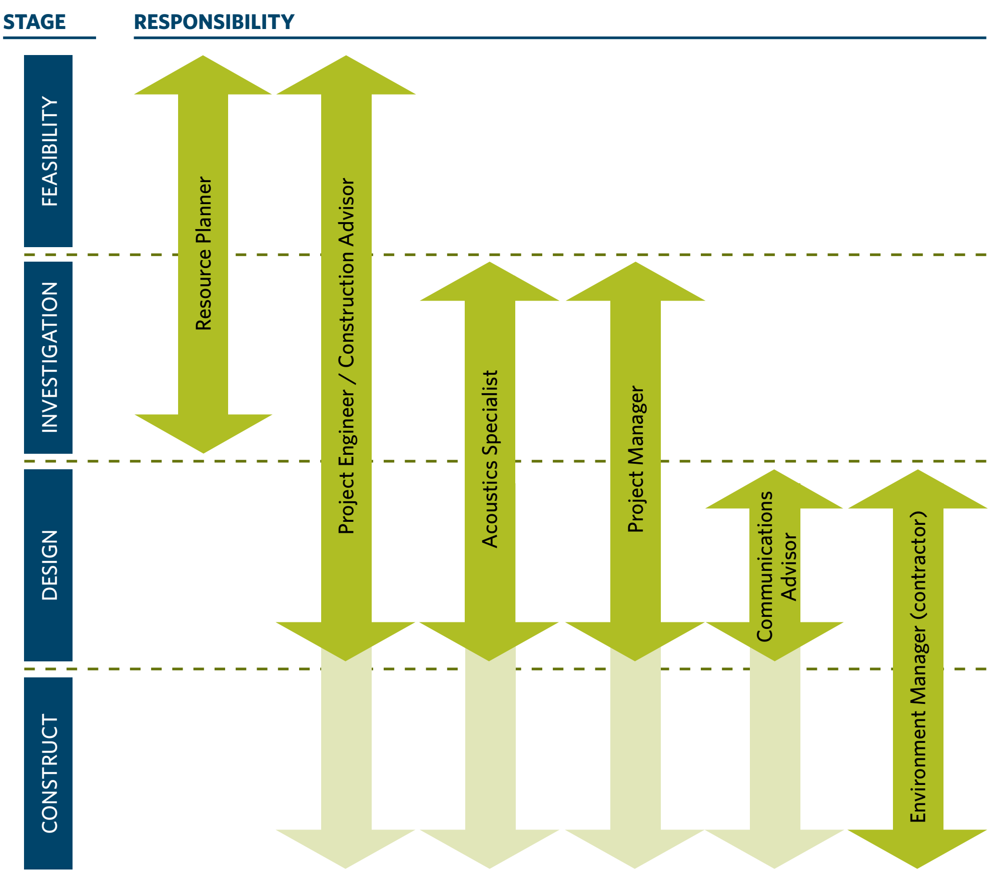
Outside of design and construct contracts, the roles may be filled by personnel from a number of different organisations. The environment manager should always be part of the contractor's team. Acoustics advice may also be required during the build stage to finalise the noise and vibration predictions and mitigation. Because of the workload on larger projects, the environment manager is unlikely to have sufficient time to be proactive on these issues and therefore may require assistance in the form of a dedicated person with the appropriate knowledge and responsibilities.

Maintenance

Responsibility during operation and maintenance lies with the maintenance contractor's environmental manager, followed by team leaders for individual works.

Within this guide reference is made to acoustics specialists with respect to professionals conducting measurement, prediction and assessment of both noise and vibration. Different acoustics specialists may have expertise in only noise and/or vibration, so separate specialists may be required to address noise and vibration issues.

FIGURE 1: RESPONSIBILITIES – CONSTRUCTION



TOOLS

In addition to this guide, a number of tools are available from the Noise and Vibration section of the Highways Information Portal (HIP) (www.nzta.govt.nz) to help manage construction and maintenance noise.

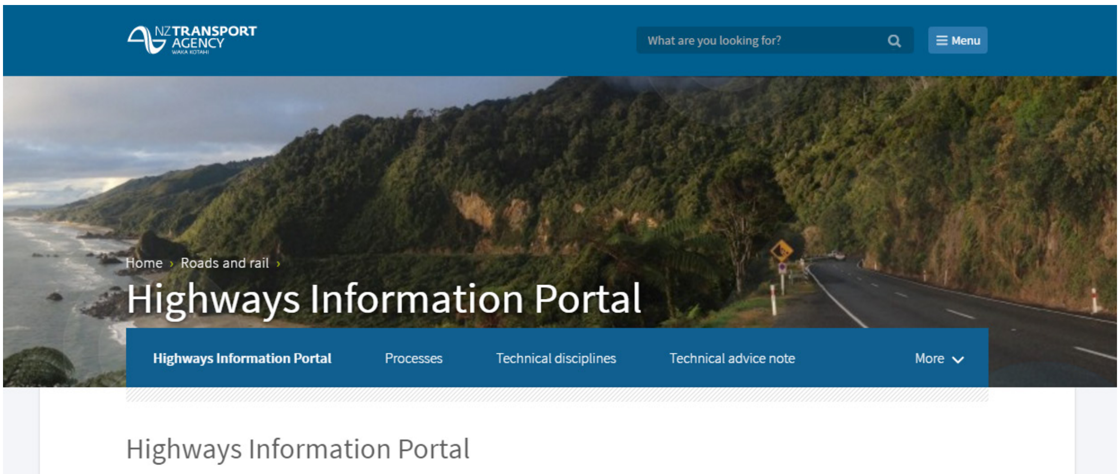
These currently cover noise only and comprise:

- general information
- templates for survey sheets, survey reports, management plans and schedules
- leaflets and posters.

FIGURE 2: TEMPLATES, LEAFLETS AND POSTERS

FIGURE 3: FLYERS

FIGURE 4: ONLINE RESOURCES



NOISE FUNDAMENTALS

The purpose of this section is to outline the basic acoustics principles required to understand the concepts presented in this document.

Sound sources cause changes in air pressure which are detected by our ears and can also be measured by a sound level meter. The pressure changes are expressed in decibels, which is written as 'dB'. The equation for this uses a logarithmic scale and familiar mathematical rules for addition do not apply, eg 55dB + 55dB = 58dB. An increase of 3dB is a doubling of sound energy. However, in the laboratory, a 3dB increase is only just perceptible to the human ear. As a rule-of-thumb a 10dB increase corresponds approximately to a doubling of perceived loudness, eg 60dB sounds twice as loud as 50dB. Some typical noise levels are presented in figure 5.

Road construction and maintenance noise vary considerably, depending on the equipment being used and the distance at which it is being measured. The terrain between the source and the measurement point will also have an effect, particularly if line-of-sight is obstructed, such as by a noise barrier or building.

The difference between the terms 'sound' and 'noise' is subjective, but generally speaking noise is defined as unwanted sound. In this guide the term 'noise' is used to describe the sound/noise produced by construction and maintenance works.

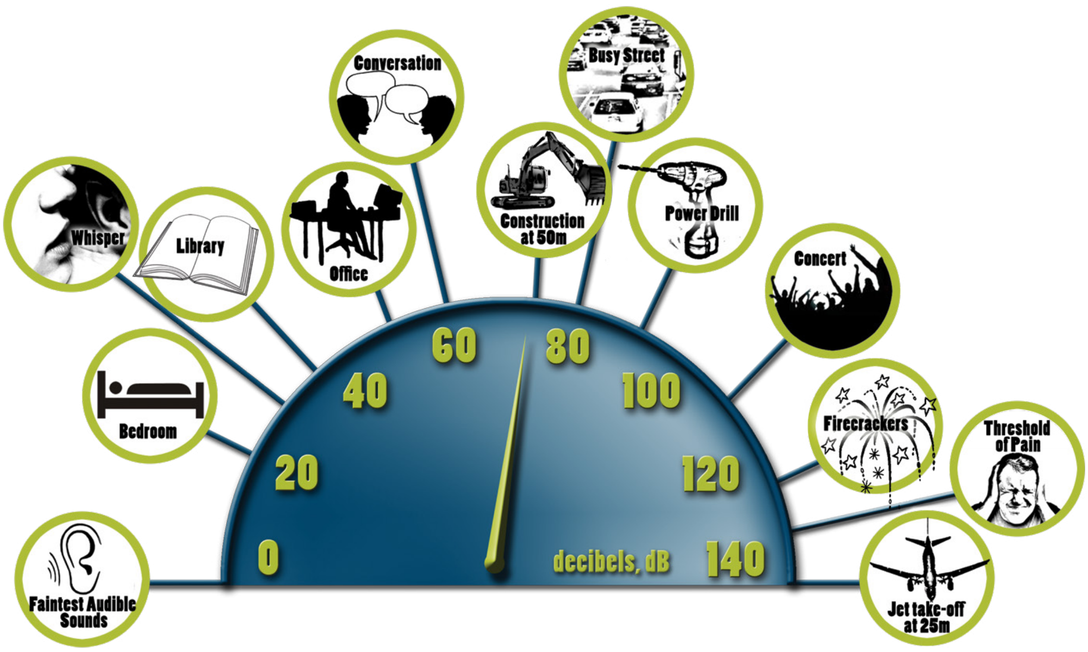
Sound can occur across a whole range of frequencies, from low-frequency rumbles to high-frequency chirps, depending on how fast the air pressure changes are occurring. Where a sound only contains air pressure changes at one distinct frequency, it is described as a 'tone'. Frequency has the units of cycles per second or hertz (Hz).

Measured construction noise levels include all frequencies, but as our hearing is less sensitive to lower frequencies, the measured levels are adjusted to correspond to human hearing. This adjustment is called 'A-weighting' and is identified by the letter A, eg 60dB $L_{Aeq(15\ min)}$. For simplicity within this document, all sound levels are assumed to be A-weighted unless explicitly stated otherwise.

Construction and maintenance noise levels fluctuate and typically are assessed using A-weighted average values identified by 'eq' for 'equivalent' over a set period of 15 minutes, eg $L_{Aeq(15min)}$. Figure 6 provides an illustration of an average level. The $L_{Aeq(15\ min)}$ is obtained from an 'energy' average of the decibel values; this results in a higher value than normal arithmetic averaging. In addition to an average level, the effects of short duration sounds are assessed using a maximum level: L_{AFmax}. The 'maximum' recorded by a sound level meter will depend on the response time of the meter. A sound level meter 'Fast' response is standardised as one-eighth of a second, and is identified by the letter F, eg L_{AFmax}.

Airblast overpressure is an additional acoustic effect caused by blasting, where significant airborne energy is generated at frequencies lower than is typically audible by a human ear, but which can cause subsequent vibrations at audible frequencies within buildings. This is usually quantified in terms of the peak pressure using the linear frequency-weighting: L_{Zpeak}.

FIGURE 5: TYPICAL NOISE LEVELS



Works adjacent residences

FIGURE 6: FLUCTUATING NOISE AND ITS AVERAGE AND MAXIMUM NOISE LEVELS

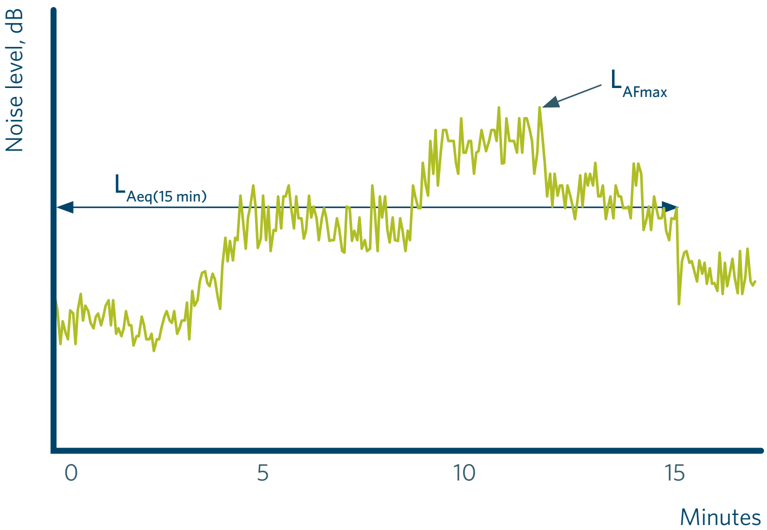
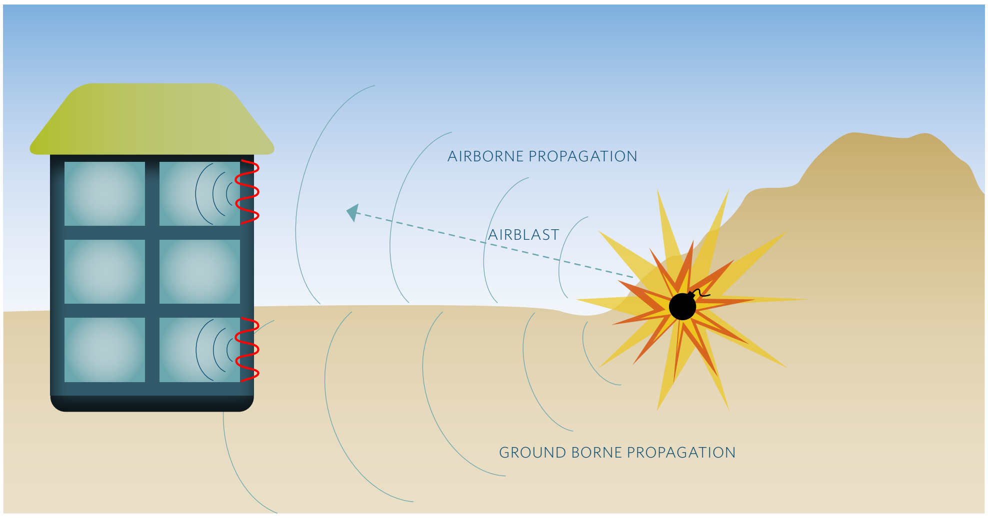


FIGURE 7: VIBRATION AND AIRBLAST PROPAGATION



VIBRATION FUNDAMENTALS

Construction and maintenance equipment can generate vibration as well as noise. This vibration travels through the ground from the worksite and into buildings where, potentially, it can be felt and heard by the occupants. Activities that produce significant vibration include impact and vibratory piling; blasting; surface compaction; drilling or movement of heavy vehicles.

Vibration is described as 'transient' or 'continuous'. Transient vibration is temporarily sustained vibration but which may be frequently repeated. For example, the vibration resulting from impact piling. Continuous vibration is maintained for an indefinite period of time, eg drilling or tunnelling.

Low and medium levels of vibration can be felt and may cause annoyance, particularly at night. Building fittings may also rattle and sensitive equipment may be affected. Higher levels of vibration may cause damage to buildings. Such damage may be cosmetic, such as cracked plaster, or in rare cases structural damage may occur, such as the cracking of floor slabs or foundations.

The perception of vibration often leads to concerns of building damage, but the levels that can be felt are often an order of magnitude below the minimum threshold to cause damage to properties. The effect of the vibration will depend on whether the vibration is continuous or transient.

Local geology will have a significant effect on the transmission of vibration through the ground and therefore the same activity at different locations may well produce different levels of vibration. Furthermore, the type of building construction, including its foundations, will have an effect on the resulting internal vibration.

Vibration can be measured in a number of different ways as displacement, velocity or acceleration. For construction vibration, levels are presented in terms of the peak particle velocity (ppv), in units of millimetres per second (mm/s). This is the instantaneous maximum velocity reached by the vibrating surface as it oscillates about its normal position. The ppv can be quoted individually for one or more of the three orthogonal directions (at right angles) at a measurement point and is known as the 'component ppv'. An alternative method of presenting such measurements is the 'resultant ppv' which combines the velocity of the three directions using a 'square-root of the sum of the squares' (ie a vector addition).

If the vibration in one direction is significantly higher than the other two, the highest component ppv and resultant ppv are similar in level. However, if one direction is not dominant, then the resultant ppv is larger than each of the component ppv. A pseudo resultant is also sometimes used which is a vector addition of the maximum velocity on each of the axes, irrespective of when they occur. Thus the pseudo resultant is an over estimation of the peak level.

Unless otherwise stated, component ppv is used in this guide. The frequency at which the ppv occurs is also usually measured and used in assessments.

The vibration of the floor, walls and ceiling of a building also causes noise to be radiated into a room, known as 'ground borne noise' (figure 9). This is a separate effect to 'airborne noise' which is transmitted through the building structure from a noise source outside. Ground borne noise is typically a low-frequency rumble and it is more noticeable from vibration sources below the ground such as in a tunnel or cutting where the airborne noise is of a low level.

Vibration metrics

Vibration can be measured as acceleration, velocity or displacement and these measurements can be quantified in terms of various metrics or a spectrum, both with and without frequency weightings.

Commonly found vibration metrics include:

- rms acceleration, velocity or displacement - a 'root-mean-squared' average level of the vibration, with or without a frequency weighting
- peak particle velocity (ppv) - the instantaneous maximum velocity reached by the vibrating surface as it oscillates about its normal position. This metric is used by BS 5228-2 and DIN 4150-3[4]
- vibration dose value (VDV) – a 'root-mean-quad' evaluation of the weighted acceleration. The VDV is used in BS 6472[5] and requires specialist instrumentation. An estimation of the VDV using the rms of the weighted acceleration was recommended in earlier versions of BS 6472 but is no longer advised for vibration with time-varying characteristics or for shocks (which includes construction vibration).
- statistical maximum weighted velocity (v95) or acceleration (a95) – the maximum weighted velocity of acceleration that can be expected with 95% probability. As used in the Norwegian Standard NS 8170.

Peak particle velocity is used exclusively throughout this guide to quantify vibration.

4 German Standard DIN 4150-3:1999 *Structural vibration – Effects of vibration on structures.* **www.din.de**

5 BSi (2008) *BS 6472-1 Guide to evaluation of human exposure to vibration in buildings – Vibration sources other than blasting.* **www.bsigroup.com**

FIGURE 8: VIBRATION LEVELS

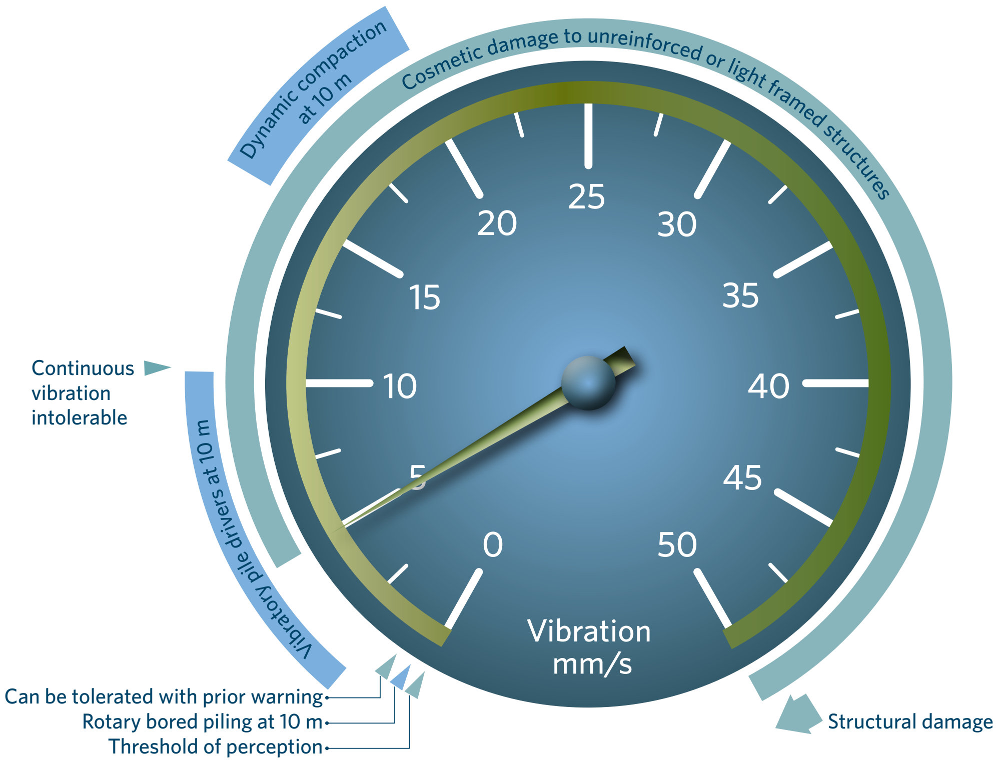


FIGURE 9: VIBRATION PROPAGATION

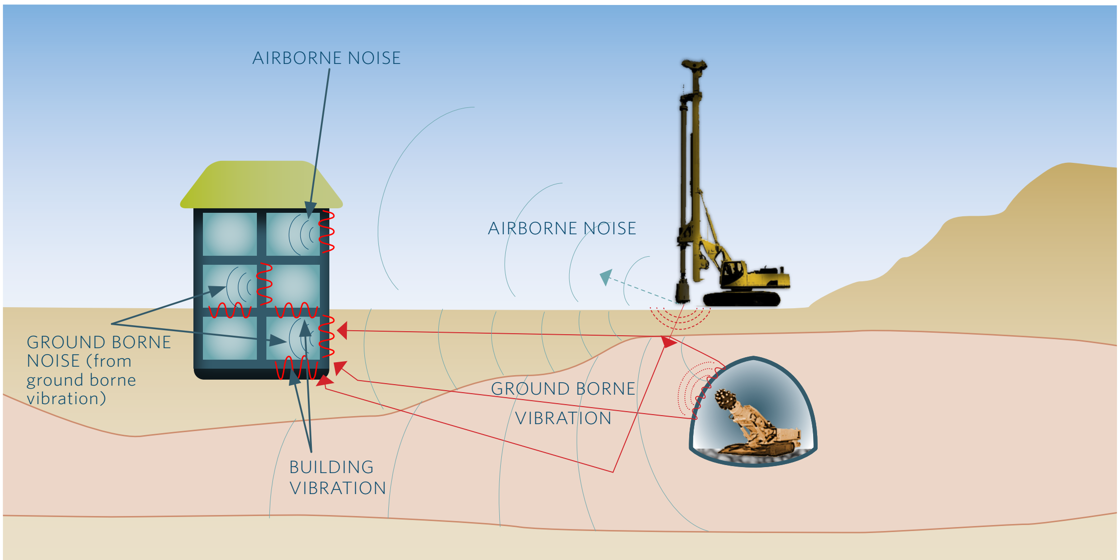
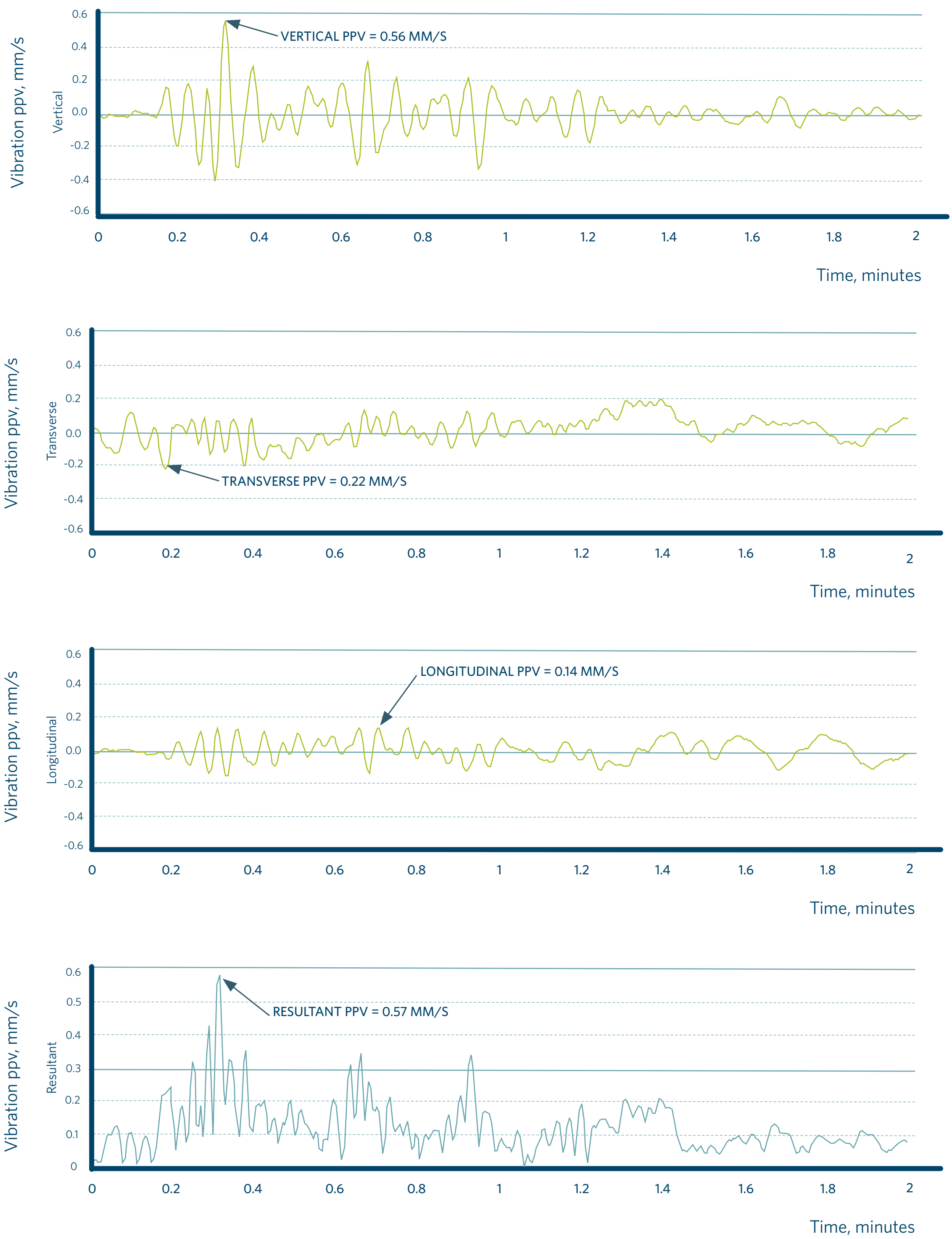


FIGURE 10: MEASUREMENT DIRECTIONS



OTHER GUIDANCE

In addition to the advice provided in this guide, further information about management measures can be found in:

- **British Standard BS 5228 Parts 1[06] and 2**
  These standards address noise (Part 1) and vibration (Part 2). Source data, predictions methodologies, mitigation measures and management are covered within these standards.
- **Australian Standard AS 2436:2010[07]**
  This standard advises on noise and vibration from construction, demolition and maintenance, including the effects on residents adjacent to the works. Information is provided on investigation and identification of sources, control and measurements. Guidance is also given on the effects of noise and vibration for persons working on-site.
- **Australia (QLD), Department of Transport and Main Roads traffic noise management code of practice[08]**
  This document provides a framework for the identification and assessment of noise and vibration impacts from transport infrastructure construction.
- **Australia (VIC) Roads technical guideline[09]**
  This guideline helps those involved in construction and maintenance activities to understand the relevant legislation and suggested working hours applicable to these activities, as well as the key steps involved in noise management, approaches to community engagement, and ways to clearly identify and minimise construction noise.
- **Australia (NSW), Department of Environment and Climate Change guidelines[10,11]**
  Contained in this guide is advice on: identifying and minimising noise and vibration from construction works; applying 'feasible' and 'reasonable' work practices to minimise impacts; recommended standard hours; the assessment and approval stages; reducing time spent dealing with complaints at the project implementation stage; selecting site-specific work practices in order to minimise noise and vibration impacts.
- **United States Federal Transit Administration document[12]**
  This comprehensive document on transit noise and vibration includes a chapter on construction containing typical noise and vibration levels, criteria and mitigation measures.
- **United States Federal Transit Authority's Construction noise handbook[13]**
  This handbook deals exclusively with construction noise and provides more detail than the document above. It includes measurement, prediction, mitigation, stakeholder engagement and noise source data.
- **Dowding's book on construction vibrations[14]**
  This comprehensive text covers the theoretical and practical fundamentals of construction-induced vibrations, including blasting.

06 British Standard (2009) BS 5228-1:2009 *Code of practice for noise and vibration control on construction and open sites - Part 1: Noise.* **www.bsigroup.com**

07 Standards Australia (2010) *AS 2436:2010 Guide to noise and vibration control on construction, demolition and maintenance sites.* **www.standards.org.au**

08 Queensland Government Department of Transport and Main Roads (2016) *Transport noise management code of practice volume 2: construction noise and vibration.* **www.tmr.qld.gov.au**

09 Vicroads (2007) *Technical guidelines: Noise guidelines – Construction and maintenance works.* **www.vicroads.vic.gov.au**

10 Department of Environment and Climate Change NSW (2009) *Interim construction noise guideline.* **www.eps.nsw.gov.au**

11 Australian (NSW) Department of Environment and Conservation, New South Wales (2006) *Assessing vibration: a technical guideline.* **www.eps.nsw.gov.au**

12 Federal Transit Administration (2006) *Transit noise and vibration impact assessment, FTA-VA-90-1003-96.* **www.fta.dot.gov**

13 United States Federal Transit Authority (2006) *Construction noise handbook, FHWA-HEP-06-015.* **www.fhwa.dot.gov**

14 Dowding (2000) *Construction vibrations*, 2nd edition, ISBN 0-9644313-1-9.

SECTION 2: CRITERIA AND LEGISLATION

2 CRITERIA AND LEGISLATION

NOISE

Most construction and maintenance noise, including for roads, is managed in accordance with New Zealand Standard NZS 6803. Like all New Zealand standards, NZS 6803 is voluntary unless specifically mandated in a designation condition or a district plan. General construction noise rules in district plans do not apply to designations. The Transport Agency manages and minimises potentially unreasonable noise effects during state highway construction and maintenance, as far as is practicable, in accordance with this standard.

While this guide and NZS 6803 are focussed on noise from the main construction site, consideration should also be given to off-site effects such as specific construction traffic and general road-traffic on detour routes.

NZS 6803 provides guideline noise criteria for construction and maintenance works (table 1). These criteria set out guidelines as to the noise levels people undertaking construction and maintenance works should try to achieve at neighbouring buildings.

The assessment location is 1m from the building facade and 1.2 - 1.5 m above the relevant floor level figure 11). At this location, noise will be reflected off the facade which increases the measured level. When noise measurements are being undertaken, this increase is included in the noise level for comparison with the noise criteria. When noise levels are being calculated, a correction is required to account for this reflection (see section 4). This is different to how road-traffic noise is assessed under NZS 6806, and most other noise sources under district plan rules.

These criteria and the requirement to manage noise and vibration effects apply to both residential and commercial/industrial neighbours.

For each time period there are two noise criteria:

- an average ($L_{Aeq(15\ min)}$), and
- a maximum (L_{AFmax}).

For typical daytime construction lasting less than 20 weeks, the guideline criteria are 75dB $L_{Aeq(15\ min)}$ and 90dB L_{AFmax}. The $L_{Aeq(15\ min)}$ noise criteria for works lasting less than 20 weeks are also shown graphically in figure 12.

During the day, most people tolerate higher noise levels from temporary activities, compared to permanent activities. Therefore the guideline criteria for temporary work allow for higher noise levels than would be allowed for permanent activities. However, at night the criteria in the standard are similar to those for permanent activities, to prevent sleep disturbance.

Operational road-traffic noise is assessed under NZS 6806 at Protected Premises and Facilities (PPFs), which include residences, schools, marae and parts of hospitals. For construction noise and vibration, the residential criteria should be applied at the same PPFs defined by NZS 6806, during the times they are occupied.

Construction and maintenance at night may result in unavoidable noise levels that exceed the guideline night-time criteria in the standard. Therefore, if such works are necessary and justified at night, the night-time noise criteria set for a project may need to exceed those in the standard. The reasons for this should be clearly recorded, and the effects managed through a Construction Noise and Vibration Management Plan (CNVMP). The Transport Agency should still ensure that alternative night-time noise criteria are both reasonable and practicable. Specific criteria above those in NZS 6803 may also be required for particular daytime activities, particularly where neighbouring houses are immediately adjacent to the works. One situation where it may be reasonable to vary noise criteria (particularly at night) is where there are already elevated ambient noise levels.

In cases where alternative noise criteria are required, Waka Kotahi planners and project managers should consult with the System Design and Delivery team (environment@nzta.govt.nz). Alternative noise criteria should be explicitly allowed for in the designation conditions. Consideration in advance of construction/ maintenance and engagement with the regulatory authority is essential to deliver workable noise criteria, but still appropriately address noise impacts.

FIGURE 11: AIRBORNE NOISE ASSESSMENT LOCATIONS

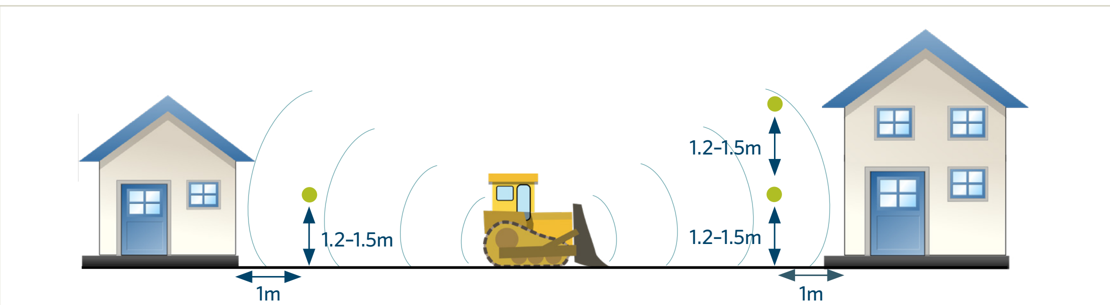


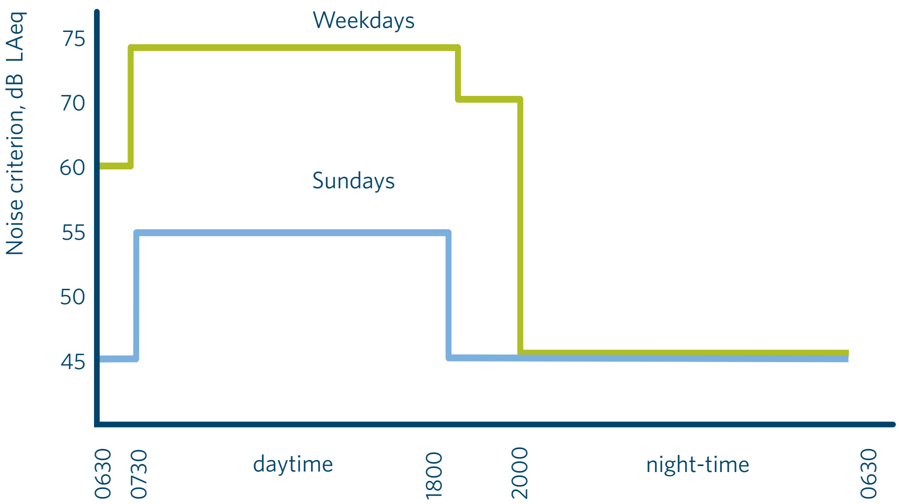
TABLE 1: AIRBORNE NOISE CRITERIA

TIME OF WEEK	TIME PERIOD	DURATION OF WORKS AT A LOCATION					
		Less than 14 days		Less than 20 weeks		More than 20 weeks	
		$L_{Aeq(15\ min)}$	L_{AFmax}	$L_{Aeq(15\ min)}$	L_{AFmax}	$L_{Aeq(15\ min)}$	L_{AFmax}
NOISE CRITERIA AT RESIDENTIAL NEIGHBOURS							
Weekdays	0630-0730	65dB	75dB	60dB	75dB	55dB	75dB
	0730-1800	80dB	95dB	75dB	90dB	70dB	85dB
	1800-2000	75dB	90dB	70dB	85dB	65dB	80dB
	2000-0630	45dB	75dB	45dB	75dB	45dB	75dB
Saturdays	0630-0730	45dB	75dB	45dB	75dB	45dB	75dB
	0730-1800	80dB	95dB	75dB	90dB	70dB	85dB
	1800-2000	45dB	75dB	45dB	75dB	45dB	75dB
	2000-0630	45dB	75dB	45dB	75dB	45dB	75dB
Sundays and public holidays	0630-0730	45dB	75dB	45dB	75dB	45dB	75dB
	0730-1800	55dB	85dB	55dB	85dB	55dB	85dB
	1800-2000	45dB	75dB	45dB	75dB	45dB	75dB
	2000-0630	45dB	75dB	45dB	75dB	45dB	75dB
NOISE CRITERIA AT COMMERCIAL/INDUSTRIAL NEIGHBOURS							
Any day	0730-1800	80dB	-	75dB	-	70dB	-
	1800-0730	85dB	-	80dB	-	75dB	-

Adapted from table 2 and 3 of NZS 6803:1999. © Copyright Standards New Zealand 2016.

NZS 6803 allows some discretion in the appropriate time period for the L_{Aeq} criteria, but for Waka Kotahi projects 15 minutes is recommended as a default value.

FIGURE 12: GUIDELINE RESIDENTIAL NEIGHBOUR CRITERIA FOR CONSTRUCTION LASTING LESS THAN 20 WEEKS



Derived from table 2 of NZS 6803:1999.
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VIBRATION

In the absence of a New Zealand vibration standard, reference is often made to the German Standard DIN 4150-3 or the British Standard BS 5228-2. The British standard includes consideration of effects on people, buildings, building contents and underground services. Part 3 of the German standard only includes effects on buildings.

Annoyance

BS 5228-2 provides the following guidelines to assess the effects of construction vibration on people (table 2). These values apply at the point where the person is located in the building.

Other standards provide information on operational (ie traffic related) vibration criteria, including BS 6472, NS 8170 and ISO 2631 (1989 version). These are different to the criteria presented in table 2 as the characteristics of the vibration are different.

Building damage

In terms of damage to structures, BS 5228-2 and DIN 4150-3 provide guideline values for various types of structure for cosmetic damage from transient and continuous vibration (figure 13). Generally the values apply at the foundation or base of the building on the side facing the source of vibration. Additionally, for continuous vibration, DIN 4150-3 specifies criteria for the horizontal vibration on the top floor.

The guideline values in the two standards are similar, although the German standard is more conservative. The BS 5228-2 criteria for continuous vibration are 50% of the transient criteria shown in figure 13. Based on the guidance from both standards the criteria in table 3 can be used to avoid building damage.

Both BS 5228-2 and DIN 4150-3 have additional provisions such as criteria for historic/sensitive buildings. Appropriate controls for any such buildings within approximately 50 metres of road construction projects should be individually determined. Likewise BS 5228-2 includes criteria for sensitive instruments such as electron microscopes in buildings and underground services which should be assessed case-by-case.

Blasting

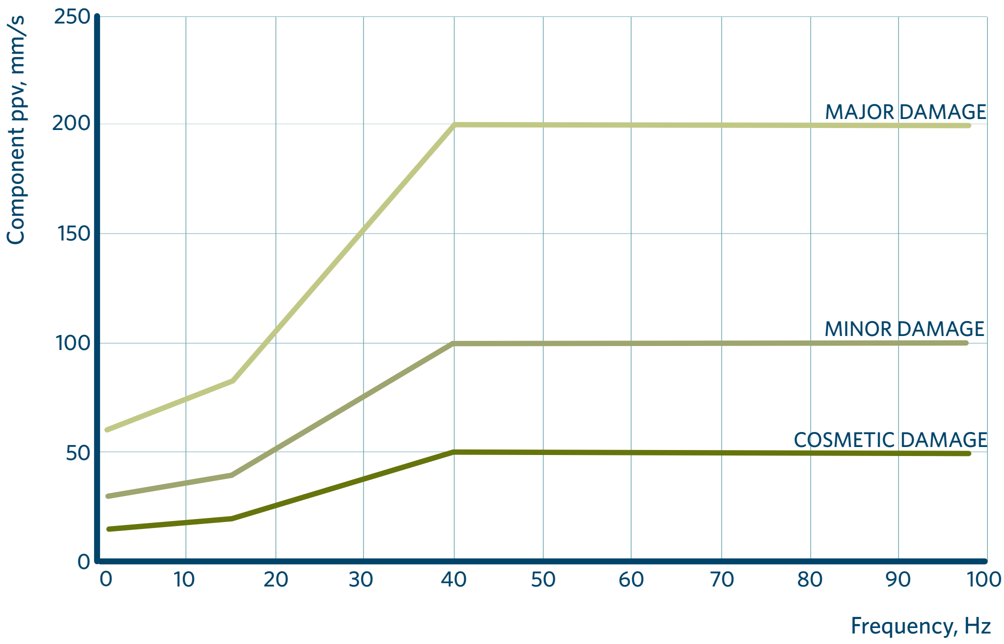
There are no New Zealand standards specifically for blasting noise and vibration, although NZS 6803 does reference Australian Standard AS 2187-2[15], which is commonly used in New Zealand to assess airblast overpressure and blasting vibration. The criteria for building damage from vibration are the same as those discussed above. A higher tolerance is set for human response to blasting vibration. The airblast values apply outside and, in contrast to BS 5228-2 which applies on the foundations, the blasting vibration values apply to the ground outside of buildings.

15 Australian Standard AS 2187-2:2006 *Explosives –Storage and use: Use of explosives.* **www.standards.org.au**

TABLE 2: GUIDE VALUES FOR PERCEPTION FROM BS 5228-2

VIBRATION LEVEL (COMPONENT PPV)	EFFECT
0.14 mm/s	Vibration might be just perceptible in the most sensitive situations for vibration frequencies associated with construction and maintenance. 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.

FIGURE 13: BS 5228-2 TRANSIENT VIBRATION CRITERIA FOR HOUSES



16 NZ Transport Agency (2012) *Technical memorandum – Noise and vibration No. 1 – Construction vibration criteria.* **www.nzta.govt.nz**

Recommended criteria

On the basis of the standards discussed above, the criteria in table 3 can be used to manage the effects of construction vibration and airblast[16]. These are structured as part of a process whereby construction should be managed to comply with the Category A criteria. If measured or predicted vibration and airblast levels exceed the Category A criteria then a suitably qualified expert should be engaged to assess and manage construction vibration and airblast to comply with the Category A criteria as far as practicable.

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

These criteria have been adopted in the model designation conditions prepared by Waka Kotahi.

Measurements to assess vibration levels against the criteria in table 3 should be made in accordance with the advice in section 5.

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

GROUND BORNE NOISE

New Zealand and international standards do not provide criteria for ground borne noise for non-blasting activities. For most construction activities such as piling the airborne noise is dominant and is controlled using NZS 6803, so separate criteria for ground borne noise are not required. However, for tunnelling there is no airborne noise so ground borne noise criteria are needed. The criteria in table 5 (based on the Waterview project) could be used in a management process in the same manner as the vibration criteria.

TABLE 3: CONSTRUCTION VIBRATION CRITERIA

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

* Refer table 4 below

TABLE 4: TABLE B.2 FROM BS 5228-2

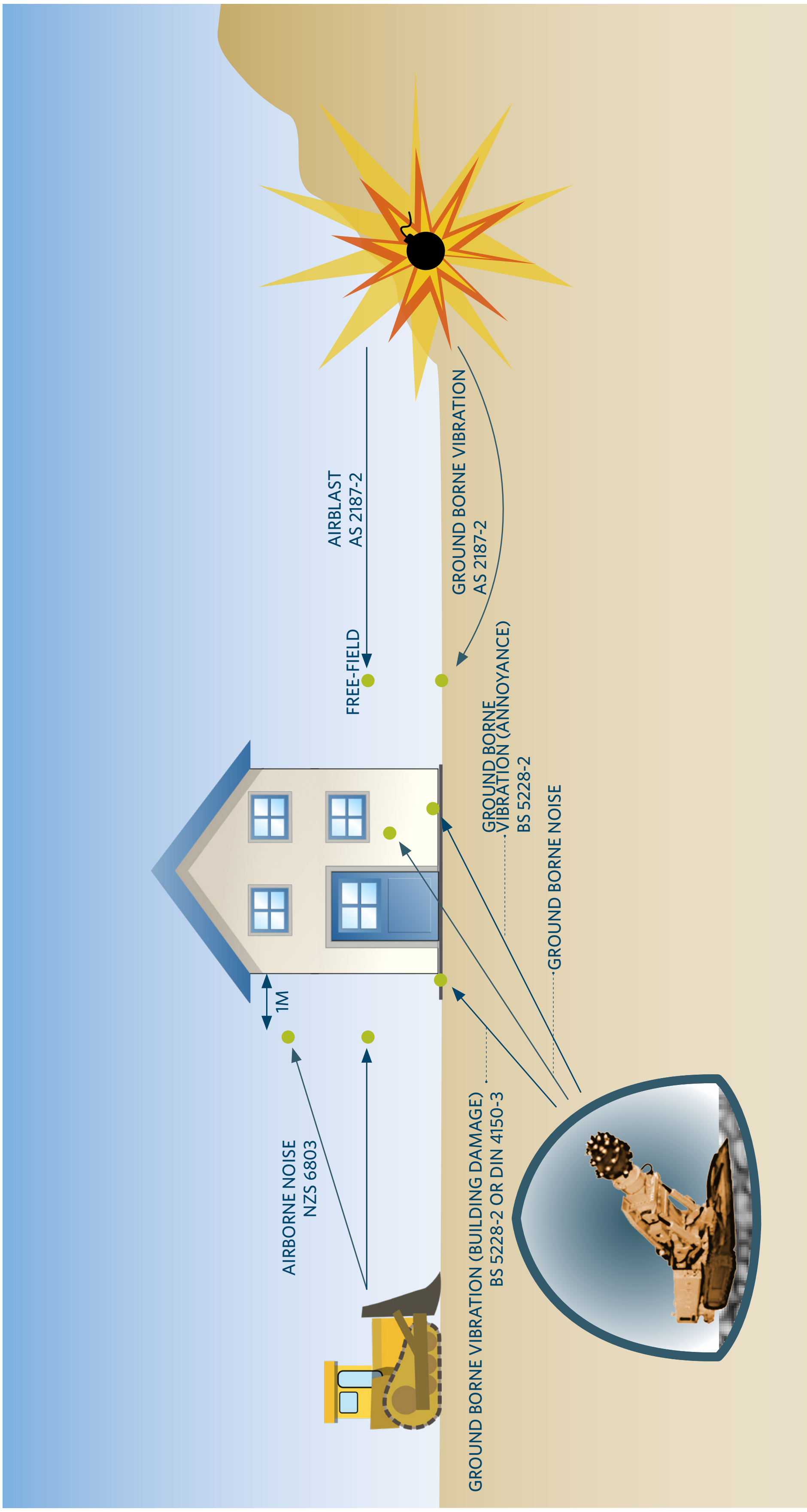
TYPE OF BUILDING	PEAK COMPONENT VELOCITY IN FREQUENCY RANGE OF PREDOMINANT PULSE	
	4 to 15 Hz	**15 Hz and above**
Reinforced or framed structures **Industrial and heavy commercial buildings**	50 mm/s	50 mm/s
Unreinforced or light framed structures **Residential or light commercial buildings**	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above

TABLE 5: GROUND BORNE NOISE CRITERIA

SPACE	TIME	CATEGORY A	CATEGORY B
Bedroom	2000h - 0630h	30 dB $L_{Aeq(15 min)}$	35 dB $L_{Aeq(15 min)}$
Other habitable spaces	0630h – 2000h	35 dB $L_{Aeq(15 min)}$	40 dB $L_{Aeq(15 min)}$

SUMMARY

FIGURE 14: SUMMARY OF APPLICABLE STANDARDS AND MEASUREMENT LOCATIONS



BEST PRACTICABLE OPTION

Under the RMA there is an overarching requirement in section 16(1) to adopt the best practicable option to ensure that the emission of noise and vibration does not exceed a reasonable level. However, where a designation condition (or resource consent) contains a specific construction noise and vibration condition, it is that condition which the person undertaking the project must comply with. Section 17 of the RMA also imposes a duty to avoid, remedy or mitigate adverse effects in general.

The criteria presented in the preceding sections are specifically designed to result in reasonable levels of noise and vibration. However, there may be specific circumstances or types of noise/vibration where compliance with the criteria would not result in a reasonable level. There are also many occasions when it is not practicable for construction activity to achieve the guideline criteria in the standard. In any such circumstances, designation conditions that are consistent with the best practicable option should be adopted.

The RMA defines the best practicable option in this context as:

...the best method for preventing or minimising the adverse effects on the environment having regard, among other things, to—

- **the nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects, and**
- **the financial implications, and the effects on the environment, of that option when compared with other options, and**
- **the current state of technical knowledge and the likelihood that the option can be successfully applied.**

DESIGNATION CONDITIONS

Most road construction works are controlled by the conditions of designations and resource consents. For new designations and consents it is important that conditions are drafted to both protect neighbours and allow practicable road construction methods.

There is often a strong desire for the comfort and certainty of rigid limits in conditions, but in the case of construction noise and vibration this is not appropriate. Sensitivity to construction noise and vibration can vary substantially between buildings and people and it is not possible to detail separate criteria for the often hundreds of different circumstances on a particular project. At a simple level, sensitivity can depend on when different houses are occupied or unoccupied, for example. However, more complex factors include the effectiveness of management measures such as communication and stakeholder engagement.

Significant infrastructure projects could not be built in urban areas if rigid compliance to the guideline noise criteria in NZS 6803 was mandatory.

The aim of conditions for construction activities should be to include criteria as a trigger for certain management actions under a comprehensive framework.

Maintenance activities are not usually subject to noise and vibration controls in designation conditions. Regardless, requirements to follow the good practice described in this guide should be included in Waka Kotahi maintenance contracts.

For prolonged works where a property is subject to exceptionally high construction noise and/or vibration exposure and other project related effects it may be appropriate to consider including the property in the designation and seeking for the crown to purchase it under the Public Works Act 1981 .

If there are historic/vibration sensitive buildings or multi-storey buildings near to the construction works then individual assessment should be made and where appropriate additional vibration criteria should be added to the designation conditions in accordance with DIN 4150/BS 5228.

If there is a history of foundation settlement in the vicinity of the proposed construction works, the model vibration criteria may not be adequate to prevent vibration induced foundation settlement. In such situations, expert advice should be sought from a geotechnical engineer as to what site specific vibration limits should apply. Non-cohesive soils, such as uniformly graded sand or silt, are particularly vulnerable to dynamically induced settlement.

Waka Kotahi uses the online database CSVue (www.csvue.com) for consent management, and this includes details of all existing designation conditions. Contact the System Design and Delivery team (environment@nzta.govt.nz).

Model conditions

Waka Kotahi has prepared model conditions, which have been drafted primarily for high risk projects. To obtain these model conditions, contact the System Design and Delivery team (environment@nzta.govt.nz). Risk in this context is both the risk of works causing annoyance or building damage, and also the related risks of costly mitigation. The level of risk is determined by a screening process.

These model conditions (for high risk projects) are structured around a Construction Noise and Vibration Management Plan.

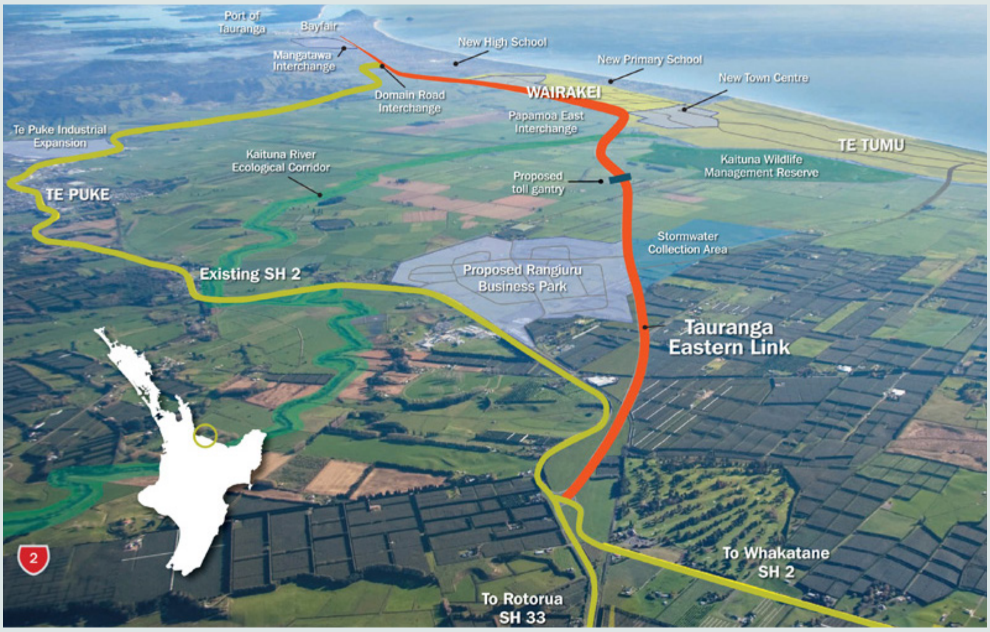
Criteria for blasting have not been included in these conditions as it is not required for the majority of projects.

The key features of these conditions are presented in figure 15.

Note: the construction condition CNV3 cross references one of the operational conditions (ON1-ON14). This cross reference should be checked, particularly if the operational noise conditions are altered.

FIGURE 15: MANAGEMENT PROCESS AND CRITERIA (OUTLINED BY MODEL CONDITIONS)

CONDITION	COMMENTS
Prepare a Construction Noise and Vibration Management Plan (CNVMP) (CNV1/MP1)	The CNVMP provides a framework for the development and implementation of measures to avoid, remedy or mitigate adverse construction noise and vibration effects, and to minimise any exceedance of the criteria.
Prepare schedules for construction activities where noise or vibration is measured or predicted to exceed project criteria, and provide to council at least five working days, where practicable, in advance of the activity proceeding. (CNV2)	A schedule must establish the best practicable option for noise mitigation to be implemented for the construction activity.
Where practicable, mitigation for operational noise should be implemented prior to commencing major construction works that generate noise, which would be attenuated. (CNV3)	The CNVMP must identify which mitigation measures for operational noise would also attenuate construction noise. Where practicable, those measures identified in the CNVMP must be implemented prior to commencing major construction works that generate noise, which would be attenuated.
The long-term construction noise criteria from NZS 6803 must be complied with, as far as practicable. (CNV4)	The long-term construction noise criteria from NZS 6803 must be complied with, as far as practicable.
The Category A construction vibration criteria must be complied with as far as practicable, with further assessment and monitoring required for exceedances (CNV5)	If measured or predicted vibration from construction activities exceeds the Category A criteria, a suitably qualified person must assess and manage construction vibration during those activities. If measured or predicted vibration from construction activities exceeds the Category B criteria those activities must only proceed if vibration effects on affected buildings are assessed, monitored and mitigated by a suitably qualified person.



TEL route

CASE STUDY – TAURANGA EASTERN LINK (2011-2015)

The Tauranga Eastern Link (TEL) is a 23km four-lane highway between Te Maunga and Paengaroa. The first 6km of the route is the widening of an existing two-lane road, and the remaining 17km is a new road. The project includes approximately 2.5 million m^3 of earthworks, 136 culverts and 7 bridges.

The TEL spans three designations which had been established at different times. Each designation is subject to different conditions for construction noise. Generally in such cases consideration should be given to altering the designations to provide a consistent set of conditions. In this instance the differences were not significant and the existing conditions were retained, although the same construction noise management practices were applied throughout the works.

The conditions for construction noise for the TEL illustrate some key issues with many existing construction noise conditions that the Transport Agency is seeking to avoid by promoting use of the model conditions. The difficulties with the conditions are common for many existing designations as well as resource consents and designations for most commercial and industrial activities.

TEL Te Maunga four-laning designation

- The conditions include that construction noise 'shall meet the limits recommended in table 1 of NZS 6803P:1984'. This condition is problematic in that for most road construction works near houses it is not practicable to achieve perfect compliance with the guideline limits in this provisional standard. The 1984 provisional version of NZS 6803 also has a greater emphasis on noise levels than management practices.
- The conditions include restrictions such as 'requiring engines to be fitted with effective exhaust silencers' and 'requiring construction equipment to be kept in good repair'. While these requirements are consistent with good management of construction noise, they are too general as conditions and it is doubtful how they could be enforced. Such issues are better addressed through the CNVMP, which can adapt to the specific effects, activity and location, once the construction methodology is confirmed.
- The conditions also include requirements for communication with neighbours, which again are better addressed by the CNVMP.

TEL Sandhurst Interchange and Tauranga Eastern Arterial designations

Both these designations have similar construction noise conditions, which raise the same issues.

- The conditions require compliance with NZS 6803:1999, but do not specify any noise criteria. This creates the same issues as for the Te Maunga designation above. Furthermore, the 1999 version of the standard is explicit that noise criteria should be stated in conditions rather than simply relying on reference to the standard.
- The conditions require a management plan rather than specifying particular mitigation methods, which is good. However, for the Tauranga Eastern Arterial designation there are no requirements for what the plan should include, which are included in the model conditions.

Bridge beam installation. Waikato Expressway

SECTION 3: WAKA KOTAHI PROCESSES

3 WAKA KOTAHI PROCESSES

INTRODUCTION

Actions are required throughout the lifecycle of a state highway to consider and address construction noise and vibration effects. Different project stages are defined and included in the *Environmental and social responsibility standard*, which are shown in figure 16.

PROJECT DEVELOPMENT

In the Business Case approach, the transportation need is assessed before undertaking detailed analysis of environmental effects such as noise.

This means noise assessments in the early phases are limited to identifying whether noise is a significant issue, and the likely scale of mitigation required. Where different route options are being investigated, construction noise and vibration may be one of many factors to be considered and may form part of a multicriteria analysis.

The consenting strategy will be confirmed during the Detailed Business Case, however the technical assessments required to secure the consents will often not be performed until a decision to construct the project has been made and funding allocated.

CONSENTING

A robust technical assessment is required for obtaining the statutory approvals, however unless the project is through a dense urban area, detailed consideration of construction noise and vibration is generally not warranted.

Critical to getting the right noise and vibration outcome, is obtaining the necessary approvals with appropriate conditions. Waka Kotahi has model conditions that should be used.

As the model conditions explicitly state the objectives and requirements of the construction noise and vibration management plan, a draft plan should not be prepared and submitted with the application.

PROJECT DELIVERY

The Waka Kotahi template for a construction noise and vibration management plan should be used to develop a robust plan consistent with best practice. It should identify significant risk elements, and a process for managing these risks.

However, given that the management of noise should be heavily integrated into project design and communication, it should be modified as appropriate to fit into contractor's systems and other project requirements.

MAINTENANCE STAGES

For maintenance work, the framework for management of noise and vibration should be set for the overall area and for the duration of the maintenance contract in either a CNVMP or a Social and Environmental Management Plan (SEMP), as required by SM030 Z/4. Figure 16 shows the assessment process for individual maintenance activities within that framework.

A Tier 1 assessment is not used for maintenance works, but when planning individual activities the same Tier 2 assessment used for construction projects is applied. This is a simple check that can be carried out quickly without the need for an acoustics specialist.

For some activities and locations a more detailed Tier 3 assessment will be required once all the equipment and procedures are known. The Tier 3 for maintenance works involves the same analysis as for construction works, but does not require preparation of assessment reports, and should instead result in a Schedule.

NOISE ASSESSMENT TIERS

Waka Kotahi has adopted a three-tiered approach to construction noise and vibration assessment, as shown in figure 16. For most projects, detailed assessment of noise and vibration are not appropriate during the investigation stage. Construction noise and vibration can be addressed using standard processes specified in this guide, and detailed assessment is best conducted once a contractor is appointed and specific known activities and equipment can be considered.

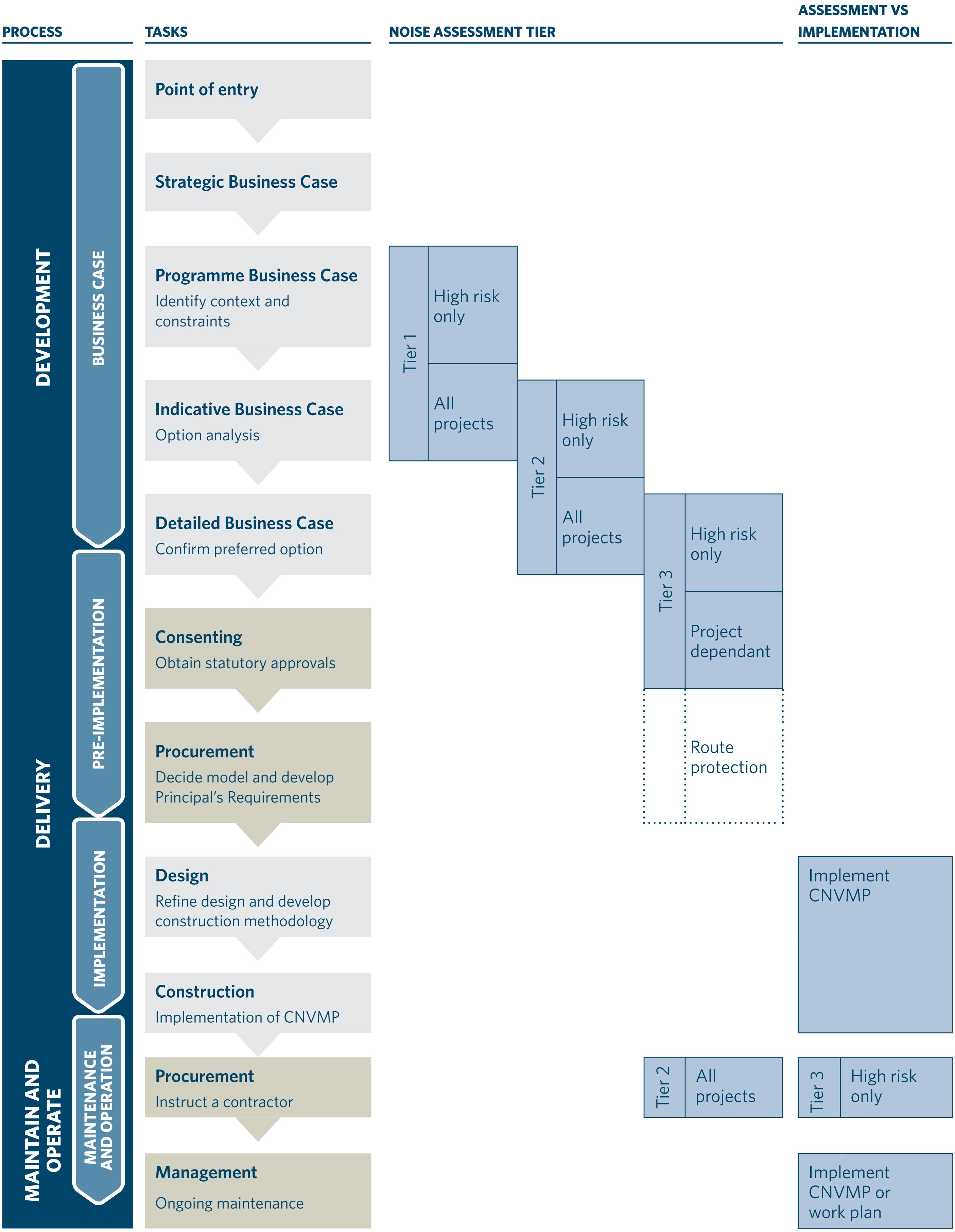
For many projects the tier 1 and 2 assessments can be quickly conducted by project staff without the need for acoustics specialists. Tier 3 assessments are not required on all projects but may require the use of acoustics specialists.

For construction projects, the left side of figure 16 shows Waka Kotahi state highway project stages. The appropriate tier of assessment varies for each stage depending on the 'noise and vibration risk' associated with the project. The risk is determined from the tier 1 assessment. Projects do not always exactly follow the progression of project stages shown in figure 16.

TABLE 6: NOISE TIER SUMMARY

	PURPOSE	OUTPUT
Tier 1	Identify issues / fatal flaws for single or multiple options	Environmental and Social Responsibility Screen
Tier 2	Scale of mitigation and indicative cost	Preliminary Technical Assessment Report
Tier 3	Assessment of effects for RMA approvals	Technical Assessment Report

FIGURE 16: ASSESSMENT PROCESS



TIER 1 – RISK ASSESSMENT

A tier 1 assessment is only required for construction projects (as opposed to maintenance projects) and provides an indication of the 'noise and vibration risk' associated with a project option. Risk in this context is both the risk of works causing annoyance or building damage, and also the related risks of costly mitigation or affecting statutory approvals.

This assessment forms part of the Environment and Social Responsibility (ESR) Screen. This assessment can be completed by a non-specialist.

Consideration should be given to:

- the length of the works, and
- the location and the number of protected premises and facilities (PPFs) within 200m of the proposed alignment.

PPFs are defined in NZS 6806 and include buildings such as houses and schools. Although the definition of PPFs comes from NZS 6806 for operational road-traffic noise rather than NZS 6803 for construction noise, it has been used in this instance to provide consistency and efficiency between the tier 1 assessments for both aspects.

A qualitative review of these two parameters will allow a rating to be developed on a seven point scale from --- to +++ (noting construction will seldom have positive noise or vibration effects).

TIER 2 – PRELIMINARY TECHNICAL ASSESSMENT

A detailed noise and vibration assessment is only required where there are certain construction activities near to PPFs. In other cases, standard management processes can be adopted without the need for a detailed assessment at the consenting stage for construction projects. The purpose of a tier 2 assessment is to screen out those projects and works where detailed assessment is not required. A tier 2 screening assessment is carried out by answering the questions in table 7. Further work in a tier 3 assessment is required if any one of the first group of questions is answered positively, or if three or more of the second group are answered positively.

For maintenance works, the outcome of the tier 2 assessment should be recorded in the work plan for the activity.

At this stage mitigation options should be identified, together with indicative costs for implementation. These should be determined on the basis of professional judgement informed by previous similar projects, rather than detailed acoustics analysis. Consideration should be given to the value-for-money provided by different options.

TABLE 7: TIER 2 ASSESSMENT

Within 20m of a PPF or historic structure:	Is mechanical digging to be undertaken?	Tier 3 required if any questions answered positively
Within 30m of a PPF or historic structure:	Is vibratory piling to be used?	
Within 50m of a PPF:	Is any work to be carried out at the weekend?	
	Is any work to be carried out at night?	
Within 70m of a PPF or historic structure:	Is impact or percussion piling to be used?	
Is blasting required?		
Does the district plan or existing designation conditions require absolute compliance with any construction noise limits?		
Are the works within 100 metres of a PPF?		Tier 3 required if any three questions answered positively
Within 100m of a PPF will there be works for longer than 6 months?		
Is tracked equipment to be used?		
Will there be a batching plant on site?		
Is rock breaking required on site?		
Is fill/cut or bulk materials to be transported via local roads rather than state highways?		
Are there any PPFs with particular sensitivity to noise? (Have complaints been received before at this location?)		
Does the district plan or existing designation conditions set criteria more stringent than NZS 6803:1999?		

TIER 3 – TECHICAL ASSESSMENT

A tier 3 assessment covers the detailed analysis of noise and vibration that may occur at different stages of construction projects and maintenance works, depending on the specific activity and location. For all high-risk projects that require a tier 3 assessment, this assessment will be undertaken by an acoustic specialist. A tier 3 assessment can result in an assessment report for an AEE, a CNVMP or a Schedule.

For a tier 3 assessment of a high-risk construction project (refer to figure 17) the following items of work may require input from an acoustics specialist.

Assessment

- Calculate indicative construction noise and vibration levels.
- Identify relevant designation conditions (CSVue) and criteria. If there are no designation conditions specifying construction noise and vibration criteria, then determine appropriate criteria using the guideline criteria in the relevant standard as a starting point.
- Investigate mitigation options if the noise and vibration criteria are not met without mitigation.
- If it is not practicable to comply with noise and vibration criteria, determine alternative criteria that are practicable and reasonable.
- Produce a construction noise and vibration assessment report.

Design

- Confirm designation conditions (CSVue) and prepare a CNVMP.

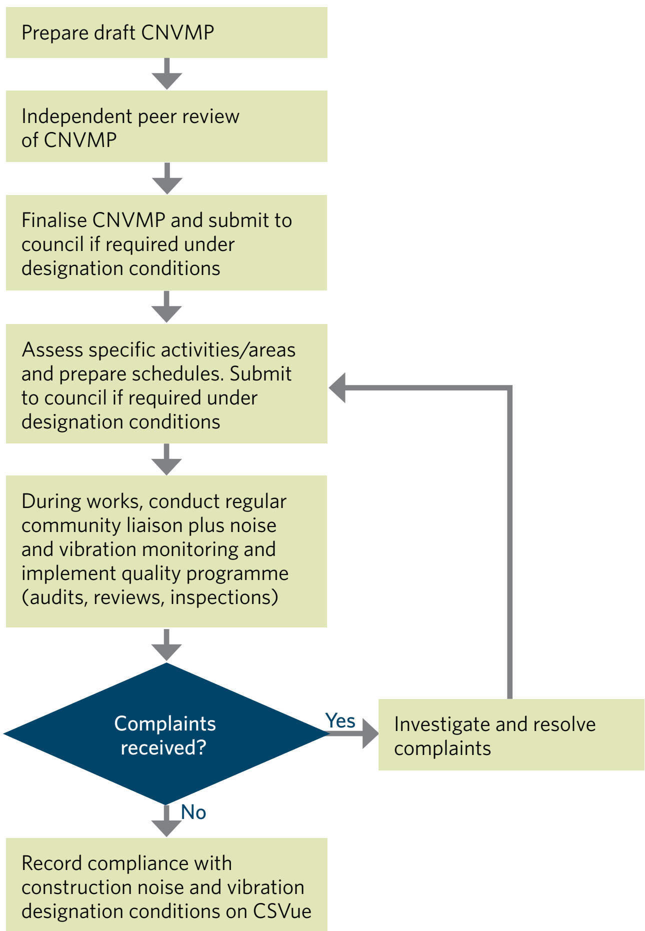
Construct

- Assess specific activities and areas and produce Schedules as required.
- Liaise with the local community and manage complaints.
- Monitor the noise and vibration and implementation of mitigation. Record compliance with any designation conditions on CSVue.

Maintenance

- Assess specific activities and areas and produce Schedules as required.
- Liaise with the local contractor.

FIGURE 17: TIER 3 – DESIGN AND CONSTRUCT STAGES



Tauranga Eastern Link

SECTION 4: PREDICTIONS

4 PREDICTIONS

NOISE CALCULATION

This section introduces basic methods for predicting construction and maintenance noise. It is based on NZS 6803, although in some places the equations have been simplified. The equations in this section form the basis of the web calculator.

This method is usually conservative and experience on some projects is that noise levels measured on site are often several decibels lower than predicted.

For calculations that are more complex than those included in the web calculator, an acoustics specialist will be required.

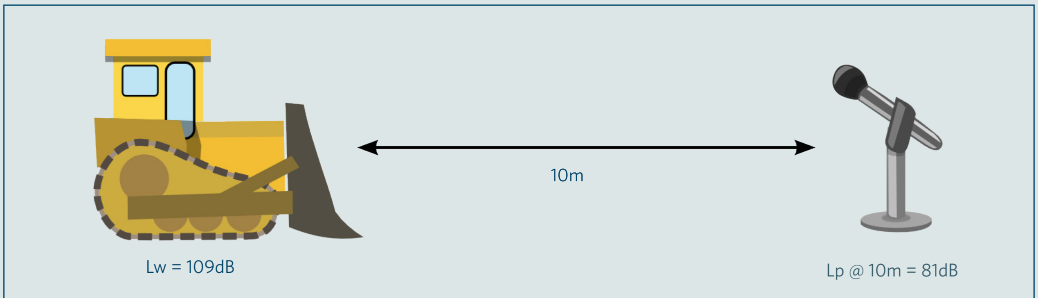
Sound power and sound pressure

Reference data for construction and maintenance equipment and processes are given in BS 5228-1 as sound pressure levels at 10m (Lp_{LW}). Data quoted in other places are sometimes given in an alternative format as a sound power level (LW), often when associated with computer models. Sound power is a physical characteristic of a noise source, which results in different sound pressure levels at different distances from the source. The relationship between the two quantities is shown below.

As can be seen below the sound power level and the sound pressure level at 10m are related by a simple equation (28dB difference). It doesn't matter which quantity is used, providing that subsequent calculations use the corresponding version of the equations.

EQUATION 1: SOUND POWER AND PRESSURE

	SOUND POWER LEVEL (QUANTITY USED IN COMPUTER MODELS)	PROPAGATION (REFERENCE DISTANCE 10M)	SOUND PRESSURE LEVEL AT 10M (QUANTITY GIVEN IN BS 5228-1)
Equation	L_W =	$20\times\log_{10}$(distance) + 8	+ L_P
Example	L_W =	$20\times\log_{10}$(10m) + 8	+ 81



Sound decay with distance

The calculation method describes each item of equipment as a 'point' source and the sound levels decrease 6dB each time the distance from the source doubles ($20\times\log_{10}$(distance)).

At large distances (eg >200m), ground and air absorption can significantly reduce the actual noise levels at receivers, therefore predicted noise levels are generally quite conservative.

Facade levels

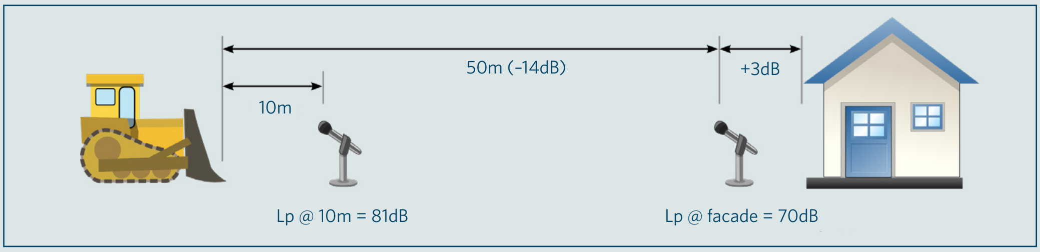
For construction noise, measurements are made at a location 1m from the facade of a building. Consequently, sound is reflected off the facade and results in an increased level being measured.

A 3dB facade correction is required to be included in calculations to allow for this effect

For source data in terms of the sound pressure level at 10m, the facade level at a house at 50m is calculated as follows.

EQUATION 2: DECAY WITH DISTANCE AND FACADE CORRECTIONS

	SOUNDPRESSURELEVEL	DECAYWITHDISTANCE	FACADEREFLECTION	FACADE LEVEL
Equation	L_p at 10m	$-20\times\log_{10}$(distance/10)	+ 3	= L_p at facade
Example	81	$-20\times\log_{10}(50/10)$	+ 3	= L_p at facade
Result	81	-14	+ 3	= 70



Multiple items of equipment

Where there are multiple items of the same equipment, a correction is made to the noise level for one item of equipment to calculate the cumulative sound level. The formula with the example is shown in equation 3.

Sound from multiple items of different equipment is combined by summing the noise levels. Logarithmic addition is used as the noise levels are in decibels. Equation 4 shows this with an example.

EQUATION 3: CORRECTION FOR MULTIPLE ITEMS

	FACADE NOISE LEVEL, ONE ITEM OF EQUIPMENT	NUMBER OF SOURCES CORRECTION	FACADE NOISE LEVEL, ALL ITEMS OF EQUIPMENT
Equation	$L_{p@façade,source\#1}$	$+ 10\times\log_{10}(n)$	= $L_{p@facade,total}$
Example	70	$+ 10\times\log_{10}(4)$	= $L_{p@facade,total}$
Result	70	+6	= 76

EQUATION 4: ADDITION OF MULTIPLE NOISE LEVELS

	SUM OF FACADE NOISE LEVEL OF EACH SOURCE	FACADE NOISE LEVEL, ALL ITEMS OF EQUIPMENT
Equation	$10\times\log_{10}(10^{0.1\times Lp1} + 10^{0.1\times Lp2} + 10^{0.1\times Lp3})$	= L_{ptotal}
Example	$10\times\log_{10}(10^{0.1\times 76} + 10^{0.1\times 69} + 10^{0.1\times 72})$	= L_{ptotal}
Result	$10\times\log_{10}(6.36\times 10^{7})$	= 78

Operating period

NZS 6803 requires assessment of sound levels over a representative period to account for the variable nature of construction and maintenance sound. For road construction and maintenance, 15 minutes is usually adopted, although the period can be between 10 and 60 minutes. If any specific item of equipment is not operating for the full period then the noise level predicted for that item of equipment can be reduced. This is shown in the example below, where a bulldozer is operating for only 9 minutes in the 15-minute period (60% of the time).

Other examples could be power tools such as rattle guns/drills/grinders etc where work is of a short, intermittent nature. Predictions should otherwise generally assume 100% operating time.

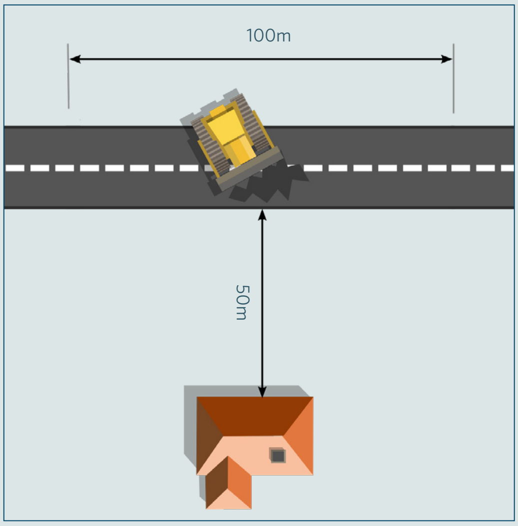
EQUATION 5: CORRECTION FOR INTERMITTENT ACTIVITIES

	PERCENTAGE OPERATING TIME	EQUIPMENT L_P	OPERATING PERIOD CORRECTION	CORRECTED LEVEL
Equation	P	L_P	$+ 10\times\log_{10}(P/100)$	$= L_{P2}$
Example	60%	81	$+ 10\times\log_{10}(60/100)$	$= L_{P2}$
Result		81	- 2.2	= 78.8

Moving sources

BS 5228-1:2009 provides two methods for assessing noise of moving sources. One is for trucks on a haul road and the other is for slow-moving vehicles in a constrained area such as a work site.

Where there is a moving source, the BS 5228-1 data relates to the equipment at the nearest (loudest) point rather than being an average value.



Fast moving sources

For mobile items of plant that pass at intervals (such as earth-moving machinery passing along a haul road), it is possible to predict the sound level at a receiver using the following method.

While a time average noise level is calculated, people will generally observe noise as a series of discrete events.

EQUATION 6: NOISE FROM FAST MOVING SOURCES

	SOUND PRESSURE LEVEL	NUMBER OF VEHICLES	SPEED	DECAY WITH DISTANCE		FAÇADE LEVEL
Equation	Lp at 10m	+10xlog10 (number per hour)	-10xlog10 (speed)	-10xlog10 (distance)	-2	= Lp at facade
Example	80	+10XLOG10(50)	-10XLOG (20)	-10X LOG(100)	-2	

Slow moving sources

Where equipment moves back and forth along a site, an allowance is made for the times when the equipment is further away from the houses and therefore quieter. The following equation simplifies the method from BS 5228-1. The correction factor should be capped at a value of 1.

The correction factor is multiplied by the actual percentage operating time to obtain the effective percentage operating time. For example, for a bulldozer operating 60% of the time, over a distance of 100m and 50m from a house at the nearest point (a distance correction is also applicable but not shown here):

EQUATION 7: MOVING SOURCE CORRECTION FACTOR

	DISTANCE TRAVERSED BY MOVING EQUIPMENT	MINIMUM DISTANCE TO HOUSE	MOVING SOURCE CORRECTION FACTOR
Equation	l_{tr}	d_{min}	$+ 0.07 + 0.6^{(l_{tr}/d_{min})}$
Example	100m	50m	$+ 0.07 + 0.6^{(100/50)}$
Result			= 0.43

EQUATION 8: NOISE FROM SLOW MOVING SOURCE

	EFFECTIVE PERCENTAGE OPERATING TIME	EQUIPMENT L_P	CORRECTION	CORRECTED LEVEL
Equation	P	L_P	$+ 10 \times \log_{10}(P/100)$	$= L_{P2}$
Example	0.43 × 60%	81	$+ 10 \times \log_{10}(0.43 \times 60/100)$	$= L_{P2}$
Result		81	- 5.9	= 75.1

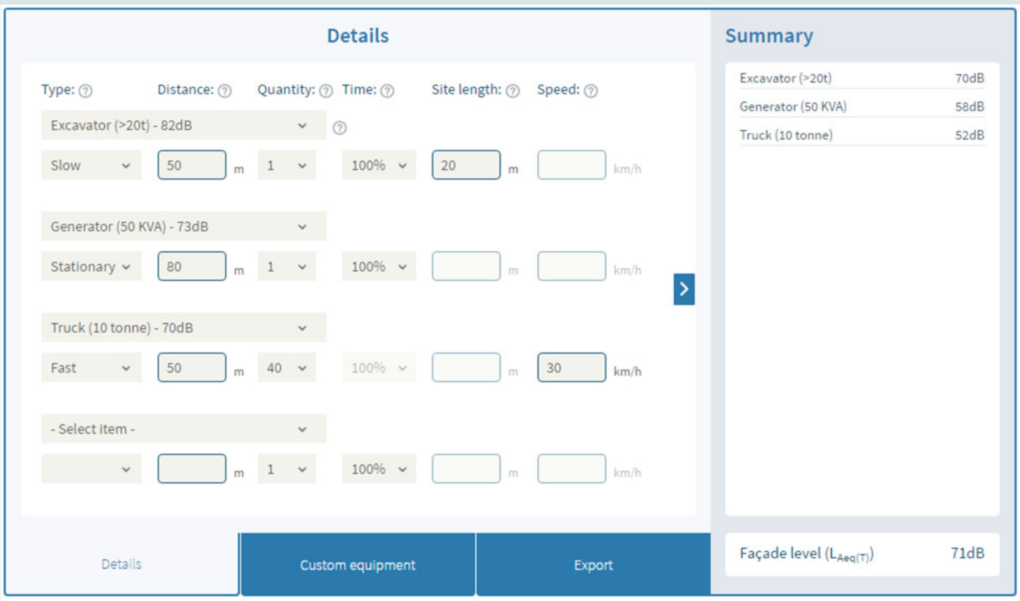
Web noise calculator

A construction and maintenance noise calculator is included on the Highways Information Portal. This calculator provides a method for basic assessment of construction and maintenance noise, based on the methods detailed in the previous pages.

It does not currently include the prediction of vibration.

The calculations are conservative and can be used for simple Tier 3 situations. The calculator is subject to the following limitations:

- The calculator should not be used where distances to receivers exceed 200m.
- Air absorption, ground attenuation, meteorological effects and screening are not included in the main calculations.



Barriers

Barriers and enclosures can be a useful way to prevent noise from reaching nearby buildings. As a rule-of-thumb, when a noise barrier breaks the direct line-of-sight between the source and the receiver, the noise is reduced by approximately 5dB. Increasing the height of the barrier increases the performance, with a theoretical limit of about 20dB. In practice, however, a realistic limit is about 15dB.

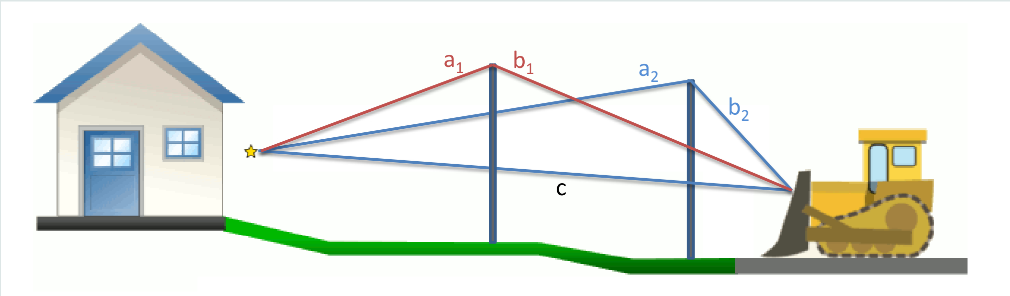
The accurate calculation of barrier performance is a complex process and requires the sound pressure levels at separate frequencies, in addition to the geometry of the receiver in relation to the source and the barrier.

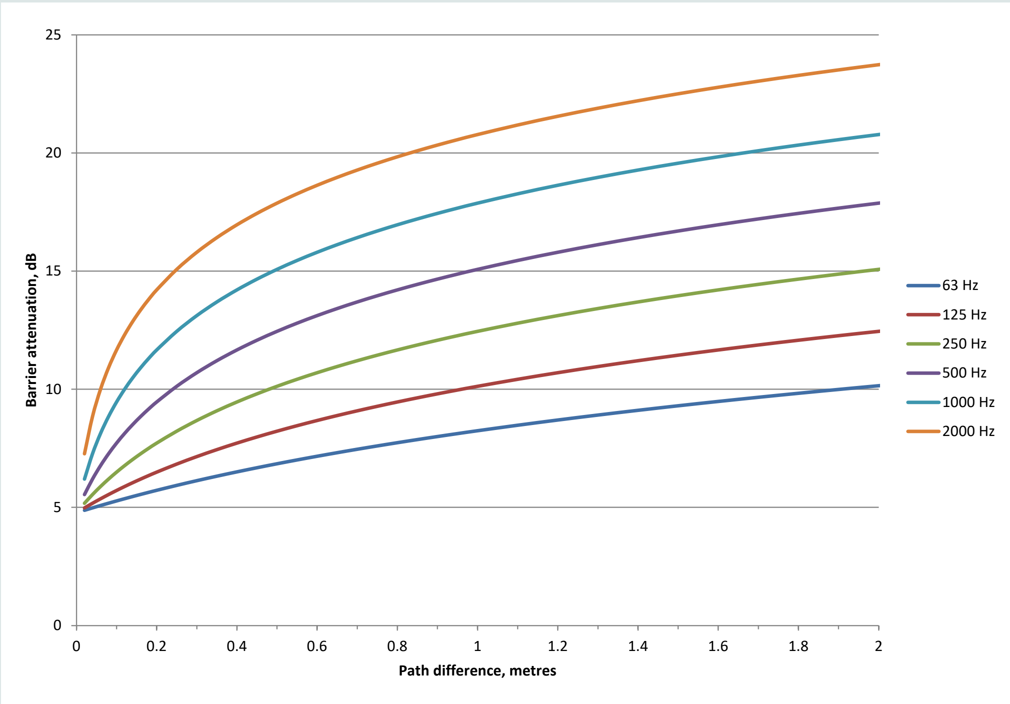
When the receiver is 'hidden' behind the barrier, noise has to travel further as it diffracts over the top edge of the barrier. This extra distance is known as the 'path difference' and is related to the attenuation provided. The concept of path difference explains why barriers are more effective when close to the source (or receiver) than in between.

A further feature of barriers is that they are more effective at reducing noise containing high frequency components than low frequency components. Therefore they may not be as useful for sources containing a high proportion of low frequency noise. This is demonstrated in the figure below, which shows the attenuation in each octave band for increasing path difference.

For the theoretical attenuation to be obtained, the barrier must be sufficiently dense (minimum 10 kg/m^2) and free of gaps. These conditions are readily achieved with permanent barriers, but can prove difficult with portable and temporary barriers.

Further information on barrier performance can be obtained from Annex F of BS 5228-1 and ISO 9613-2:1996[18].

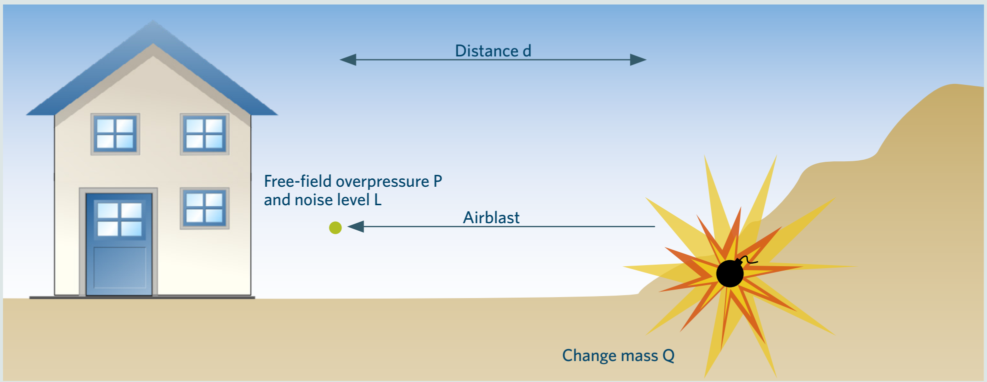




18 International Organization for Standardization (1996) *ISO 9613-2 Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation.* **www.iso.org**

Airblast overpressure and noise

Determining accurate ground borne airblast levels has complexities such as the non-linear blasting process and variability of rock types. In the absence of trial blasts, AS 2187-2 provides empirical relations based on the charge weight and distance to calculate the free-field noise (equations 9 and 10). Figure 18 illustrates the calculated noise levels from a variety of charge sizes.



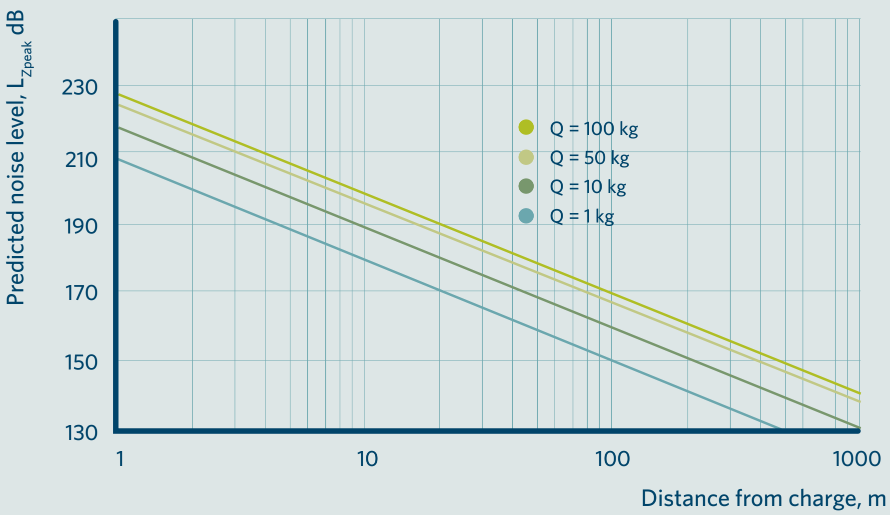
EQUATION 9: AIRBLAST OVERPRESSURE

EQUATION	PARAMETER	DESCRIPTION	UNIT
$P = K_a \left(\frac{d}{Q^{1/3}}\right)^{-1.45}$	P	Overpressure	kPa
	Q	Explosive charge mass	kg
	d	Distance from charge	m
	K_a	Site constant: Unconfined/surface K_a=516 Confined/borehole K_a=10 to 100	$\frac{kg^{2.07}}{m^{0.69}s^2}$

EQUATION 10: AIRBLAST NOISE

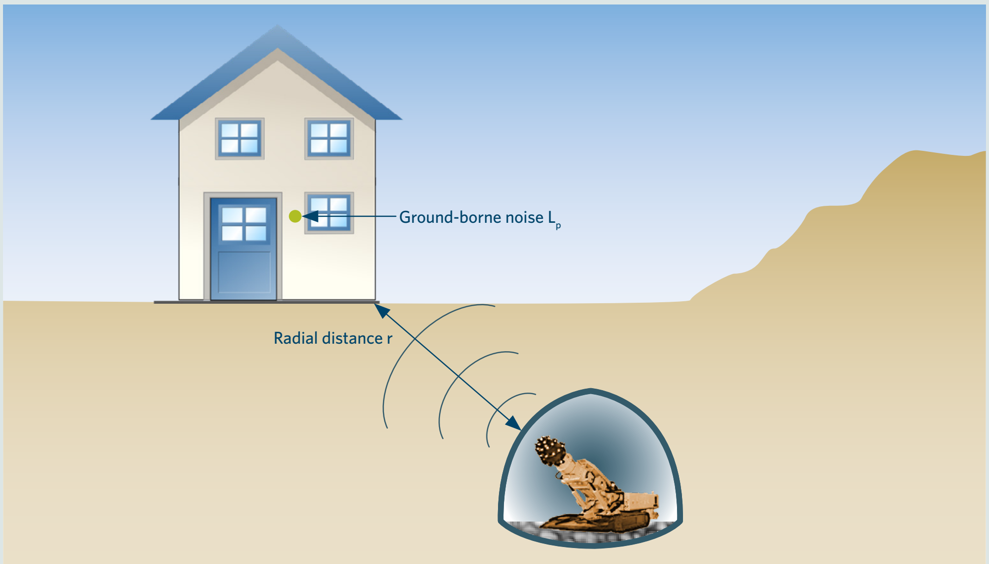
EQUATION	PARAMETER	DESCRIPTION	UNIT
$L = 20 * \log_{10}\left(\frac{P}{2x10^{-8}}\right)$	L	Noise level	dB
	P	Overpressure	kPa

FIGURE 18: PREDICTED AIRBLAST NOISE FOR AN UNCONFINED SURFACE CHARGE



Ground-borne noise from tunnelling

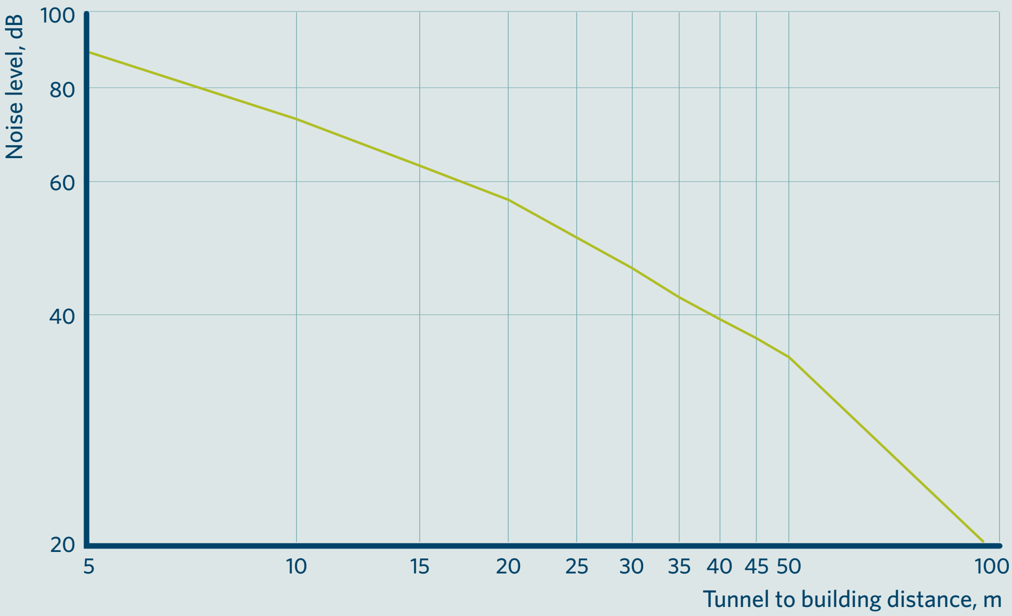
An equation based on empirical data is provided in appendix E of BS 5228-2 to predict the ground-borne noise from tunnel boring operations (equation 11). Noise levels obtained from this equation are shown in figure 19.



EQUATION 11: GROUND-BORNE NOISE

EQUATION	PARAMETER	DESCRIPTION	UNIT
$L_p = 127 - 54 \log_{10} r$	r	Radial distance from tunnel to building 10 < r < 100 m	m
	L_p	Room sound pressure level (A-weighted)	dB

FIGURE 19: PREDICTED GROUND-BORNE NOISE FROM BS 5228-2



NOISE DATA

Ideally, noise data in calculations should be for the specific equipment to be used on site. However, at the assessment stage the equipment has not always been selected, and often data is not available until measurements can be made when equipment arrives on site. Therefore, for initial predictions it is often necessary to use reference noise data.

BS 5228-1 includes reference noise level data for typical construction equipment. These data have been obtained from measurements at construction sites in the United Kingdom on similar types of equipment to that used in New Zealand. The standard also contains historical data from an earlier version, which is reproduced in NZS 6803. Where possible the more recent data should be used as it relates to current equipment types. When using these data it should be remembered that it relates to a specific measurement of a specific item of equipment, so should only be used as a guide.

Manufacturers sometimes provide noise data for their equipment. However, this is generally only for the engine noise and not for the equipment in operation on a site. For example, manufacturers' data would not include noise from material being dropped from a loader's bucket. While equipment engine noise is often dominant, it is better to base predictions on actual measurements of the equipment in operation including all noise sources.

On-site measurements of the operation of the actual equipment should provide the most accurate data. These can be made using a basic sound level meter, typically with a sound pressure measurement at 10m from the equipment. A basic sound level meter does not require frequency analysis capability and can be of class 2 or higher standard. Care should be taken to ensure that the sound being measured is uncontaminated by other noise sources but includes all likely operating conditions of the equipment, in terms of both function and material being worked on. There may well be variability between nominally identical items of equipment and improved data can be obtained by repeating the measurements on other items of the same equipment if available.

BS 5228 NOISE SOURCE LEVELS

The following are examples of some equipment typically used on road construction projects. Included are some typical noise levels for that type of equipment from BS 5228-1, in terms of the LAeq noise level at 10m. As sound decays with distance, lower noise levels will occur at distances greater than 10m.

EXCAVATOR

Idling	52–68dB
Earthworks	69–80dB
Clearing site	70–78dB
Loading lorry	79dB

(BS 5228-1 tables C.2, C.4 and C.5)

GRADER

Earthworks	78–81dB

(BS 5228-1 table C.2)

COMPACTOR

Vibrating	67–77dB

(BS 5228-1 table C.5)

TRUCK

Passing	80dB (L_{Amax})

(BS 5228-1 table C.2)

CRANE

Mobile – idling	60–66dB
Mobile	67–82dB
Tower	76–77dB

(BS 5228-1 table C.2)

SHEET PILING

Vibratory	88dB
Hydraulic jacking	59–63dB
Hydraulic jacking	77–88dB (tubular steel)

(BS 5228-1 table C.3)

BORED PILING

Rotary bored	75–83dB
Continuous flight auger	79–80dB

(BS 5228-1 table C.3)

MILLING

Milling	82dB
Milling – mini	68dB

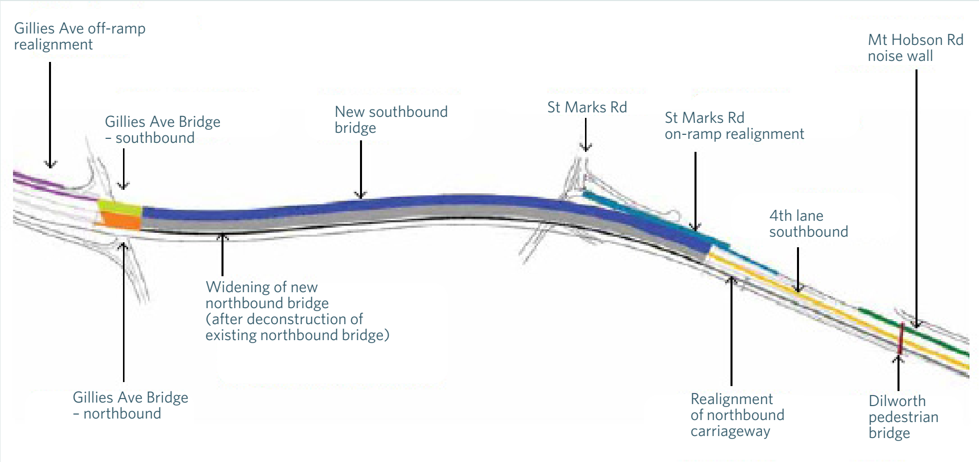
(BS 5228-1 table C.5)

PAVING

Asphalt paver	75–77dB

(BS 5228-1 table C.5)

PROJECT SCHEMATIC



CASE STUDY – NEWMARKET CONNECTION, AUCKLAND (2008–2012)

The Newmarket Connection project was a four-stage replacement of the Newmarket Viaduct (motorway flyover), with a wider, stronger, more sustainable new structure. The project aimed to improve pedestrian links around Newmarket. The project was delivered by the NGA Newmarket Alliance, comprising the Transport Agency, Fulton Hogan, Leighton Contractors, VSL NZ, Beca, URS (now AECOM), Tonkin & Taylor and Boffa Miskell.

Construction noise criteria for the viaduct replacement were specified within the designation conditions for compliance with NZS 6803 at residential properties as close as 20m to the works[19]. Following construction noise complaints received early in the project, additional noise management procedures were instigated, including use of the Transport Noise web calculator (which is now part of the Highways Information Portal).

'A key strategy to achieve consistency in noise management for the project was to use tools and information that were readily available, and version controlled,' stated Simon Paton of the NGA Newmarket Alliance.

To meet these objectives, the project used the Transport Noise website to act as a portal for all relevant noise-related information, particularly the construction noise calculator.

For the majority of the construction equipment used on the project, noise data was measured to provide inputs to the website construction noise calculator. Table 8 presents the sound pressure level at 10m for various construction equipment and activities. These noise data may be useful for initial assessments on other projects where library data from BS 5228-1 is not representative of certain equipment.

19 Northern Gateway Alliance (2008) *Newmarket Viaduct Project Construction Noise and Vibration Management Plan.* **www.nzta.govt.nz**

TABLE 8: MEASURED NOISE SOURCE DATA FROM NEWMARKET CONNECTION PROJECT

EQUIPMENT/ACTIVITY	SOUNDPRESSURELEVEL AT 10M (dB)	EQUIPMENT/ACTIVITY	SOUNDPRESSURELEVEL AT 10M (dB)
Asphalt paver	60-68	Generator	55-71
Bobcat S185	61	Hiab	82
Chainsaw	96	Loader	74
Chainsaw - electric	77	Milling machine	75
Cherry picker	69-79	Bored piling	79-80
Circular saw	81	Power pack	74
Concrete pour/pump	70-75	Reversing alarm	73-75
Crane	49-82	Rockbreaker	79-91
Drilling	66-92	Scissor jack	66
Drum roller	62-79	Streetsweeper	67-83
Dynapac PC/32	61	Wall saw	81-84
Excavator	70-81	Water blasting	75-94
Franner	74	Wire saw	71-75

NOISE MODELLING

Predictions can be made using commercially available noise modelling software packages. These should typically be used for large-scale projects with complicated geometry (terrain and/or barriers) or large numbers of sources and receivers. This type of noise modelling requires an acoustics specialist.

The most common propagation algorithms used in computer modelling are from ISO 9613-2. The basic calculations are similar to those outlined in section 4, but also include air absorption, ground attenuation and terrain screening.

Within the modelling, particular attention should be given to the following:

- **Appropriate equipment sound source data**
  BS 5228-1 provides indicative A-weighted source data. However, increased accuracy is achieved with spectral noise data. Sound pressure levels at 10m can generally be entered directly into the computer model, rather than calculating sound power levels.
- **Moving sources**
  Moving sources can be modelled as multiple point or line sources, or as moving point sources. Consideration should be given to the distance travelled over a 15-minute period. Several scenarios may need to be calculated with sources concentrated in different areas and also distributed along the route. For example, a water truck could be modelled as a line source travelling across a 1km range, with compactors and graders concentrated over a 200m area. Comparison with the simple method described in BS 5228-1 should be performed.
- **Periods of operation for each of the sources**
  Different scenarios should be run with different equipment combinations to reflect the operational variations throughout the day.
- **The type of predicted level (NZS 6803 provides facade noise level limits)**
  Reflective buildings should be included in the model, with receiver points 1m from the building facade. Noise contours should not include a separate facade correction because these are typically inherent in computer models with reflective building surfaces.

Wellington Terrace Tunnel (2011) is an example of where a computer model has been used to predict construction noise (figure 20).

FIGURE 20: PREDICTED CONSTRUCTION NOISE CONTOURS

VIBRATION CALCULATION

In comparison to the prediction of noise, calculating vibration levels is more complex. This is primarily due to the propagation through non-uniform ground plus the coupling between the vibration source and the ground; and between the ground and the building. Because of these factors, vibration results are generally less accurate than those obtained when predicting noise.

Because of the dependence of the level of vibration to local ground conditions, the most accurate method to determine the vibration levels is to undertake a trial using the appropriate equipment at the site. Without such a trial, calculations can be made in advance of the works and confirmed at the start of the works by measurements near to or on any at-risk locations.

A variety of different calculation methods have been developed for construction vibration[20]. To evaluate the most appropriate for this guide, preference has been given to the methods that contain a site specific assessment of the vibration propagation through the ground, either by measurement or by classification of the soil type, thereby minimising the significant factor in the source to receiver path.

The selected calculation methods are described in the following pages:

Method A – Blasting calculation methods from AS 2187-2.

Method B – Piling or compaction methods, combining calculated source data with measured propagation data.

Method C – Empirical equations from BS 5228-2.

Method D - Measured source data combined with a distance correction.

All of these methods predict the vibration on the surface of the ground (known as the 'free-field' vibration). However, the assessment of annoyance and building damage require vibration to be assessed inside the property and on the foundation respectively. Hence, calculation methods to account for the coupling between the ground and the building floor/foundation are described on page 44.

Sensitive PPFs may require more detailed, frequency-dependent assessments which are outside the scope of this guide.

20 NZ Transport Agency (2012) *Ground vibration from road construction, research report 485.* **www.nzta.govt.nz**

RESEARCH REPORT 485

The Waka Kotahi research report 485 on ground vibration summarises a programme of research that commenced in 2005 with the scope of quantifying the levels of ground borne vibration generated during various road construction activities and their attenuation with distance for different New Zealand soil types. The principal objective of the research was to develop a desk-based methodology, validated for New Zealand conditions, for determining separation distances for construction activities to ensure minimal effect on structures and their occupants.

The research involved the following:

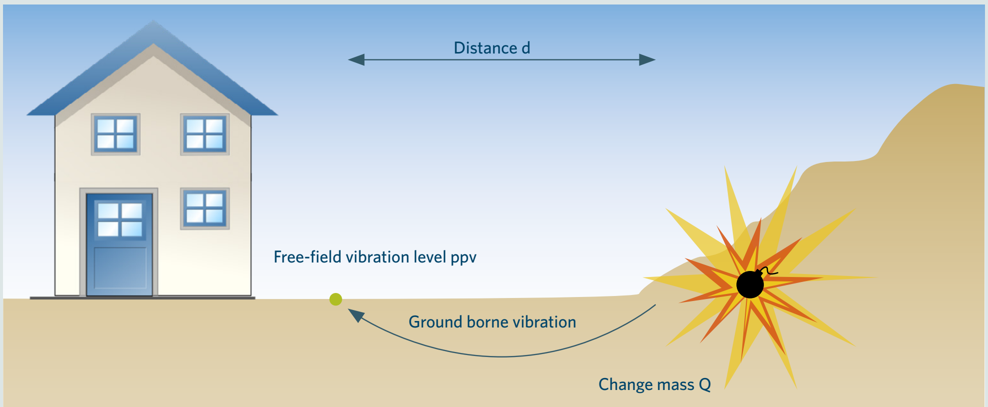
1. A literature review concentrating on the fundamental theory of ground-borne vibrations; measured vibration levels for different types of construction equipment; criteria for assessing vibration levels; and calculation methods.
2. Measurement and analysis of ground-borne vibration data from construction sites throughout New Zealand for representative mechanised construction plant operating on a range of soil types.
3. Investigation into the use of commonly measured geotechnical data (scala penetrometer and falling weight deflectometer) as inputs into the calculation methods.

The results from this report have been included throughout this guide.

In the research report, the measured vibration data is presented as the 'square-root of the sum of squares' (SRSS), otherwise known as the pseudo, or simulated resultant, and is the vector addition of the maximum level of each direction regardless of the time it occurs. Thus this level of vibration will never occur and assessments based on these data will be over-estimates and therefore conservative.

VIBRATION CALCULATION METHOD A – BLASTING VIBRATION

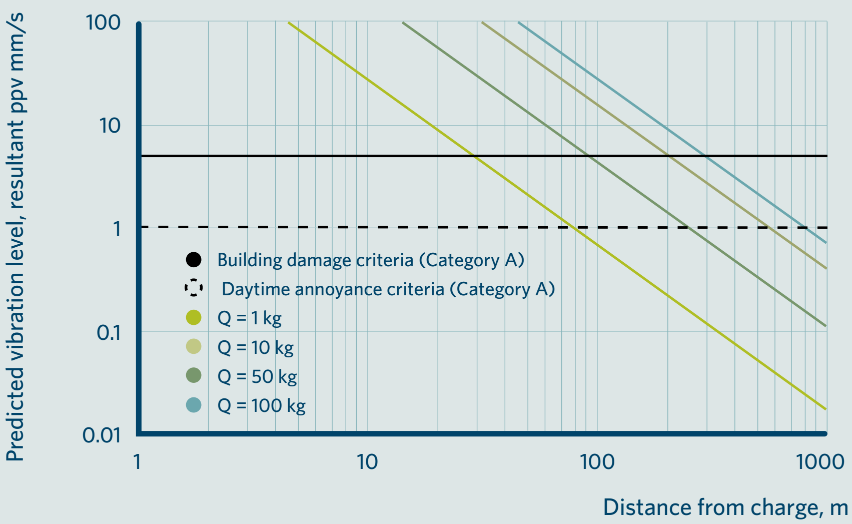
In the absence of trial blasts, AS 2187-222 provides an empirical relation based on the charge weight and distance to calculate the free-field ground borne vibration (equation 12). Figure 21 illustrates the calculated vibration levels from a variety of charge sizes.



EQUATION 12: GROUND VIBRATION FROM BLASTING

EQUATION	PARAMETER	DESCRIPTION	UNIT
$ppv_{res} = 1140 \left(\frac{d}{Q^{1/2}} \right)^{-1.6}$	ppv_{res}	Resultant ppv	mm/s
	Q	Explosive charge mass	kg
	d	Distance from charge	m

FIGURE 21: PREDICTED VIBRATION FROM BLASTING



Foundation and building response

Once the free-field vibration is known, it is often necessary to calculate the vibration levels on building foundations and floors in order to assess building damage and annoyance (section 2). The propagation of vibration from the ground to the building structure depends on many factors, including the coupling between the ground and the foundation; plus the design of the foundations, floors, walls and ceilings and structure.

Generally there is a reduction in vibration from the ground to the foundation and then a further decrease from the foundation into the remainder of the building.

However, resonances in floors can lead to an increase, especially in wood-frame residential structures but also in reinforced concrete slab floors.

Frequency-dependent functions relating the free-field vibration to the foundation and floor vibration have previously been determined[21] and these are simplified as frequency-independent factors in table 9 and 10. The variety in foundation designs has led to a range of factors and these factors can be applied directly to the free-field ppv levels. An example calculation is shown in table 11.

21 US DOT/Transportation Systems Center (1982) *Handbook of Urban Rail Noise and Vibration Control, Report UMTA-MA-06-0099-82-2.*

TABLE 9: FOUNDATION RESPONSE

FOUNDATION TYPE	FACTOR OF VIBRATION ON FOUNDATION RELATIVE TO FREE-FIELD VIBRATION
Slab on grade	1
Single family residential	0.56 to 1
1 and 2 storey residential	0.35 to 0.79
2 to 4 storey masonry building on spread footings	0.22 to 0.56
Large masonry building on piles	0.2 to 0.56

TABLE 10: FLOOR RESPONSE

TYPE	FACTOR
Vibration on floor relative to foundation vibration	0.79 to 0.89 per storey
Vibration on floor relative to floor vibration, due to resonance of wooden or concrete slab floor	2

TABLE 11: EXAMPLE CALCULATION

LOCATION	FACTOR	PPV (MM/S)
Free-field vibration level	-	1.5
Foundation of 2 storey residential building	0.35 to 0.79	0.5 to 1.2
2nd storey floor	0.79 to 0.89 per floor =1.58 to 1.78	0.8 to 2.1
Wooden floor resonance	2	1.6 to 4.2

VIBRATION CALCULATION METHOD B – FALLING WEIGHT DEFLECTOMETER DATA

This method combines predicted energy input into the ground from the equipment with measured propagation through the soil, the latter obtained using a 'falling weight deflectometer' (FWD). Detailed knowledge of the site geology is not required as the soil attenuation characteristics are captured in the measured propagation.

A FWD imparts a load onto the ground by dropping a large weight onto a circular load plate. A load cell mounted on top of the load plate measures the load imparted to the ground and a number of sensors (usually geophones), mounted radially from the load plate, measure the deformation of the ground in response to the load. Waka Kotahi has a comprehensive collection of FWD measurements over the state highway network which are logged in the Road Assessment and Maintenance Management (RAMM) database. This database does not contain the time history FWD data required by this method but this can be supplied by Waka Kotahi on request.

The propagation through the ground is determined from the FWD data by:

1. Calculating the ppv from each of the FWD sensors. For road pavement studies, the FWD data is typically obtained as displacements and therefore the ppv should be obtained from the velocity time histories by differentiating the displacement time history.
2. The scaled distance of each of the sensors is calculated using equation 13.
3. The scaled distances are plotted against the ppv on a log-log plot and a non-linear regression line is fitted to the data of the form of equation 15.
4. A 95% confidence interval is applied to the regression constant b to ensure a conservative prediction (equation 16)

From this propagation characteristic, the ground vibration at a receiver can be calculated from the energy input into the ground by the works:

5. The predicted energy input into the ground for vibratory compaction is: determined by equation 17.

FIGURE 22: FALLING WEIGHT DEFLECTOMETER

EQUATION 13: SCALED DISTANCE

EQUATION		DESCRIPTION	UNIT
$SD = \frac{d}{\sqrt{W}}$	*SD*	Scaled distance	$m/J^{0.5}$
	d	Distance from load plate to sensor	m
	W	Energy imparted by the FWD	J

6. Alternatively, the predicted energy input into the ground for impact piling can be calculated using equation 14.
7. The scaled distance is calculated using equation 13, using the energy input W from step 5 or 6 and the distance d between the source and the receiver.
8. The ppv is calculated using the scaled distance from step 7 using equation 16.

EQUATION 14: FWD ENERGY

EQUATION		DESCRIPTION	UNIT
$W = mgh$	W	Energy imparted by the FWD	J
	m	Drop mass	kg
	g	Acceleration due to gravity (9.81)	m/s^2
	h	Drop height	m

EQUATION 15: REGRESSION LINE

EQUATION		DESCRIPTION	UNIT
$ppv = b(SD)^m$	b	Regression constant	-
	SD	Scaled distance	$m/J^{0.5}$
	m	Regression constant	-

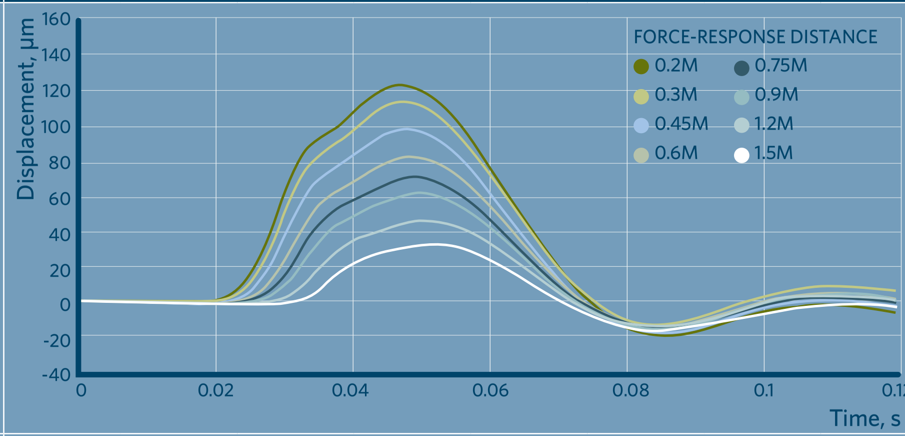
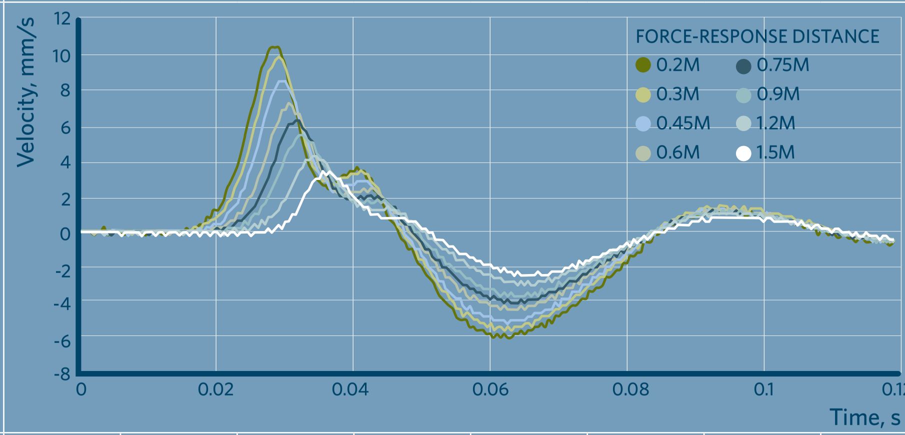
EQUATION 16: REGRESSION LINE WITH 95% CONFIDENCE

EQUATION		DESCRIPTION	UNIT
$ppv = (b + 1.96SE)(SD)^m$	b	Regression constant	-
	SD	Scaled distance	$m/J^{0.5}$
	m	Regression constant	-
	SE	Standard error of the estimation	mm/s

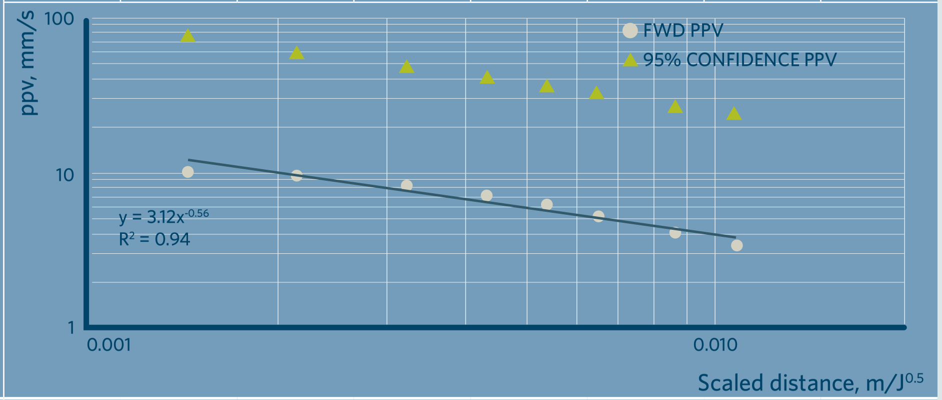
EQUATION 17: VIBRATORY COMPACTION ENERGY

EQUATION		DESCRIPTION	UNIT
$W = DnPA$	W	Energy of compactor	J
	D	Drum diameter	m
	n	Number of blows per unit distance	-
	P	Peak load	N
	A	Peak amplitude	m

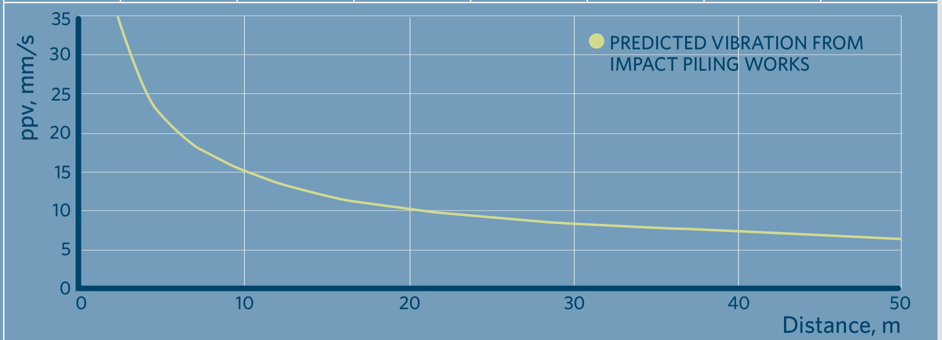
TABLE 12: EXAMPLE – METHOD B PREDICTION USING FWD DATA

STEP	DESCRIPTION	PARAMETER	VARIABLE	UNIT	VALUE(S)							
1	Calculate the ppv for each of the FWD sensors	Time history of FWD displacement data	*t; x*	s; µm								
		Time history of velocity by differentiation of displacement data	*t; x*	s; mm/s								
		Distance from load plate	*d*	m	0.2	0.3	0.45	0.6	0.75	0.9	1.2	1.5
		Peak particle velocity	*ppv*	mm/s	10.4	9.8	8.4	7.2	6.2	5.4	4.2	3.4

STEP	DESCRIPTION	PARAMETER	VARIABLE	UNIT	VALUE(S)							
2	Calculate scaled distances	Drop mass	*m*	kg	4000							
		Acceleration due to gravity	*g*	m/s^2	9.81							
		Drop height	*h*	m	0.5							
		Energy imparted by the FWD (equation 14)	*W*	J	19620							
		Distance from load plate	*d*	m	0.2	0.3	0.45	0.6	0.75	0.9	1.2	1.5
		Scaled distance (equation 13)	*SD*	$m/J^{0.5}$	0.001	0.002	0.003	0.004	0.005	0.006	0.009	0.011
3	Regression line	Regression constant	*m*	mm/s/m	-0.56							
		Regression constant	*b*	mm/s	0.3							
4	95% confidence	Standard error	*SE*		0.84							
		Scaled distance	*SD*	$m/J^{0.5}$	0.001	0.002	0.003	0.004	0.005	0.006	0.009	0.011
		ppv with 95% confidence interval (equation 16)	*ppv*	mm/s^2	77.8	62.0	49.3	42.0	37.0	33.4	28.4	25.1



STEP	DESCRIPTION	PARAMETER	VARIABLE	UNIT	VALUE(S)							
6	Predicted energy into the ground for impact piling	Drop mass	m_{piling}	kg	5000							
		Drop height	h_{piling}	m	3.0							
		Energy (equation 17)	W_{piling}	J	147150							
7	Scaled distance for piling work	Distance to piling work	d_{piling}	m	2	5	10	15	20	25	30	50
		Scaled distance of impact piling (equation 13)	SD_{piling}	m	0.01	0.01	0.03	0.04	0.05	0.07	0.08	0.13
8	Predicted vibration	ppv (equation 16)	ppv_{piling}	mm/s	37.6	22.5	15.2	12.1	10.3	9.1	8.2	6.2



VIBRATION CALCULATION METHOD C – BS 5228-2 EQUATIONS

Equations based on empirical data are provided in appendix E of BS 5228-2 to predict vibration from vibratory dynamic compaction; percussive and vibratory piling; the vibration of stone columns and tunnel boring operations. Note that these methods calculate the resultant ppv (section 1).

For some of the construction methods, the results are in terms of the probability of the predicted ppv levels being exceeded. The equations are reproduced in table 13 and the predicted levels are shown in figure 23.

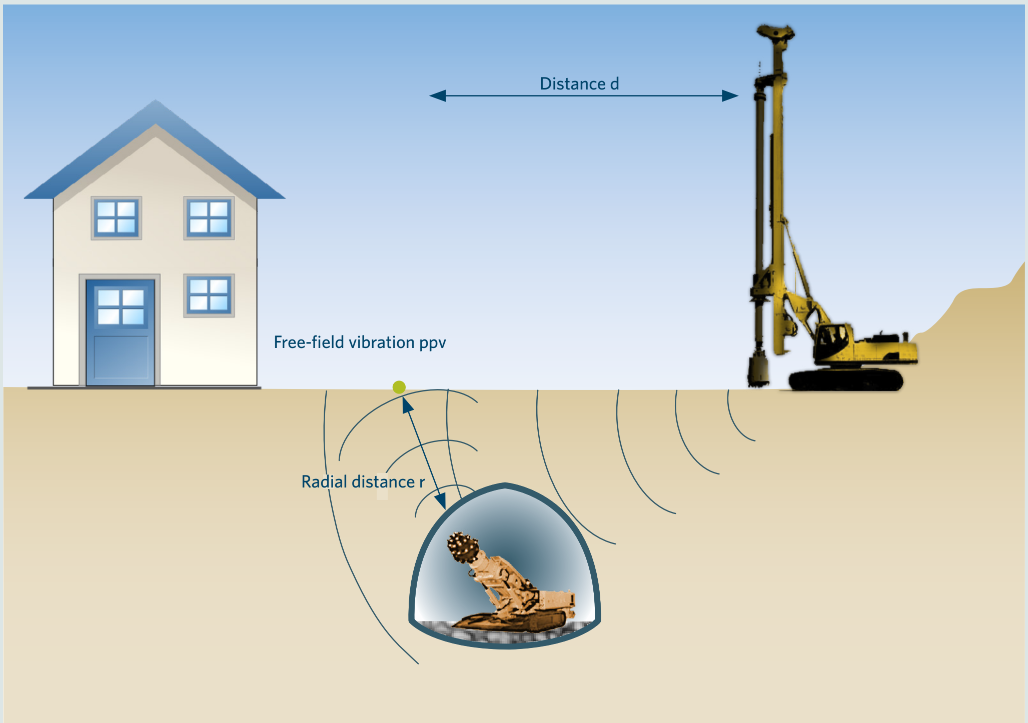


FIGURE 23: PREDICTED VIBRATION FROM BS 5228-2

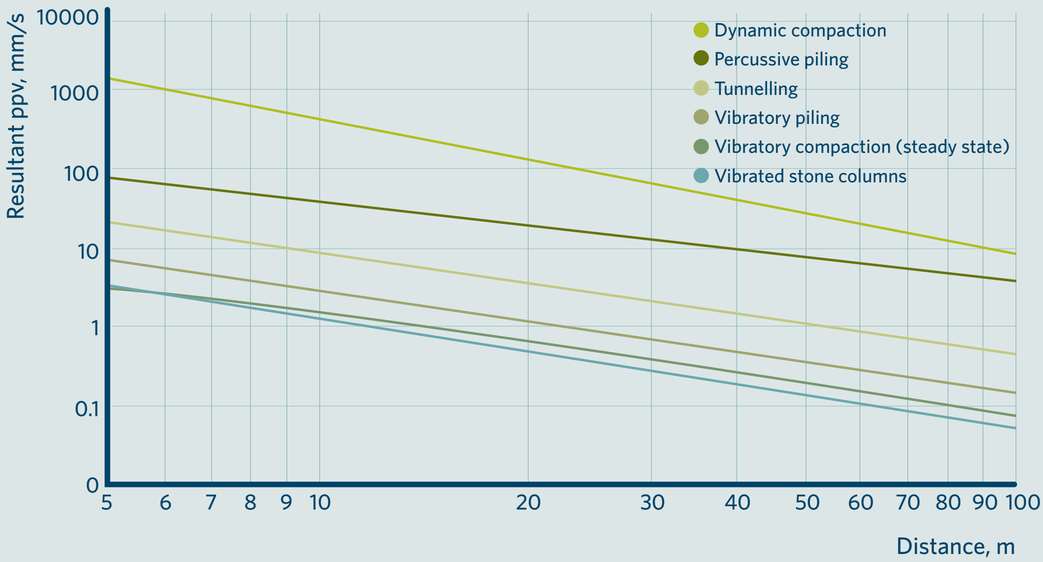


TABLE 13: EMPIRICAL RELATIONSHIPS FROM BS 5228-2

OPERATION	EQUATION	SCALING FACTORS	PROBABILITY OF PREDICTED VALUE BEING EXCEEDED	PARAMETER RANGE
Vibration compaction (steady state)	$ppv_{res} = k_s \sqrt{n_d}\left(\frac{A}{d + w_d}\right)^{1.5}$	$k_s = 75$	50%	$1 \le n_d \le 2$ $0.4 \le A \le 1.72$mm $2 \le d \le 110$m $0.75 \le w_d \le 2.2$m
		$k_s = 143$	33.3%	
		$k_s = 276$	5%	
Vibration compaction (start up and run down)	$ppv_{res} = k_t \sqrt{n_d}\left(\frac{A^{1.5}}{(d + w_d)^{1.3}}\right)$	$k_t = 65$	50%	
		$k_t = 106$	33.3%	
		$k_t = 177$	5%	
Percussive piling	$ppv_{res} \le k_p \left(\frac{\sqrt{W}}{r^{1.3}}\right)$	Depends on soil type, table 4.7	-	$0.75 \le l \le 27$m $1 \le r \le 111$m (where $r^2=l^2+d^2$) $1.5 \le W \le 85$kJ
Vibratory piling	$ppv_{res} = \frac{k_v}{d^{\delta}}$	$k_v = 60$	50%	$1 \le d \le 100$m $1.2 \le W \le 10.7$kJ $\delta = 1.3$ (all operations) $\delta = 1.2$ (start up and run down) $\delta = 1.4$ (steady state operation)
		$k_v = 126$	33.3%	
		$k_v = 266$	5.%	
Dynamic compaction	$ppv_{res} \le 0.037\left(\frac{\sqrt{W_h}}{d}\right)^{1.7}$	-	-	$5 \le d \le 100$m $1.0 \le W_h \le 12$MJ
Vibrated stone columns	$ppv_{res} = \frac{k_c}{d^{1.4}}$	$k_c = 33$	50%	$8 \le d \le 100$m
		$k_c = 44$	33.3%	
		$k_c = 95$	5%	
Tunnelling (tunnel boring machine or roadheader)	$ppv_{res} \le \frac{180}{d^{1.3}}$	-	-	$10 \le d \le 100$m

ppv_{res} – resultant ppv (mm/s) d – distance measured along ground surface (m) r – slope distance from the pile toe (m) where $r^2=l^2+d^2$ l – pile toe depth (m)	A – maximum amplitude of drum (mm) w_d – vibration roller drum width (m) n_d – number of rotating drums k_s & k_v & k_c – scaling factors k_p – scaling factor (table 14)	W – nominal hammer energy (J) W_c – energy per cycle (kJ) W_h – potential energy of a raised damper (J)

TABLE 14: VALUES OF K_p FOR USE IN THE PREDICTIONS OF VIBRATION FROM PERCUSSIVE PILING

PILING TECHNIQUE	ATTENUATION CATEGORY (REFER TO TABLE 15)	k_p
Piles driven to refusal	I, II, III, IV	5
Pile toe being driven through	III Plus fill with large obstructions compared to pile cross-section	3
	I and II	1

VIBRATION CALCULATION METHOD D – DISTANCE CORRECTED MEASURED DATA

In this method, data measured from the same construction activity at another location/project may be used. Corrections to these data should be made to account for any changes in distance and ground condition.

BS 5228-2 provides a large amount of measured data from the UK for this purpose, from a variety of construction equipment. Data measured in New Zealand for typical construction equipment is also available (page 54).

If scala penetrometer results are available, these can be used to calculate the soil attenuation coefficient (equation 18). If site-specific testing has not been performed, the soil classification in table 15 provides an estimate.

Using the scala penetrometer will give a coefficient normalised to 5Hz (α_5). This needs to be converted to the dominant frequency (α_f) using equation 19.

The soil classifications table is broad and will depend on site conditions and the mode of formation of the ground, and no correction is required.

The distance correction is performed using equation 20.

As an example, the vibration levels from three different items of equipment have been calculated at a range of distances for the four attenuation categories and are presented in figures 24 to 26.

EQUATION 18: SOIL ATTENUATION COEFFICIENT AT 5 Hz FROM SCALA PENETROMETER RESULTS

EQUATION	PARAMETER	DESCRIPTION	UNIT
$\alpha_5 = 0.0364e^{-0.411S}$	α_5	soil attenuation coefficient at 5 Hz	1/m
	S	average Scala penetrometer reading	blows/100mm

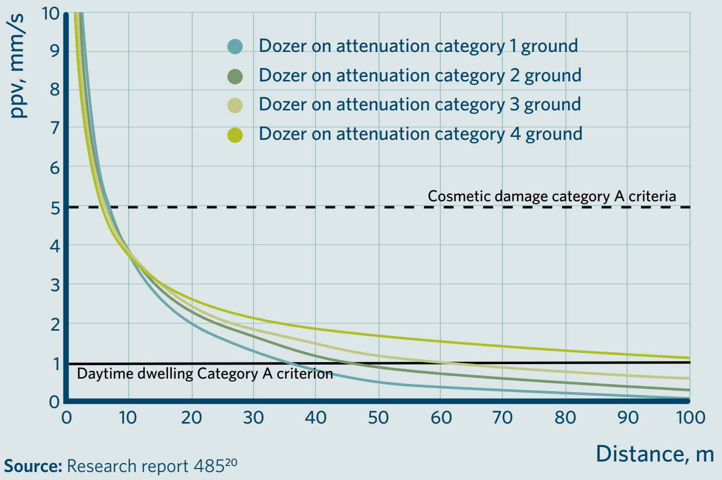
EQUATION 19: SOIL ATTENUATION COEFFICIENT FROM COEFFICIENT AT 5 Hz

EQUATION	PARAMETER	DESCRIPTION	UNIT
$\alpha_f = \dfrac{\alpha_5 f}{5}$	α_f	soil attenuation coefficient	1/m
	α_5	soil attenuation coefficient at 5 Hz	1/m
	S	average Scala penetrometer reading	blows/100mm
	f	dominant frequency of vibration from equipment	Hz

EQUATION 20: VIBRATION AT DISTANCE

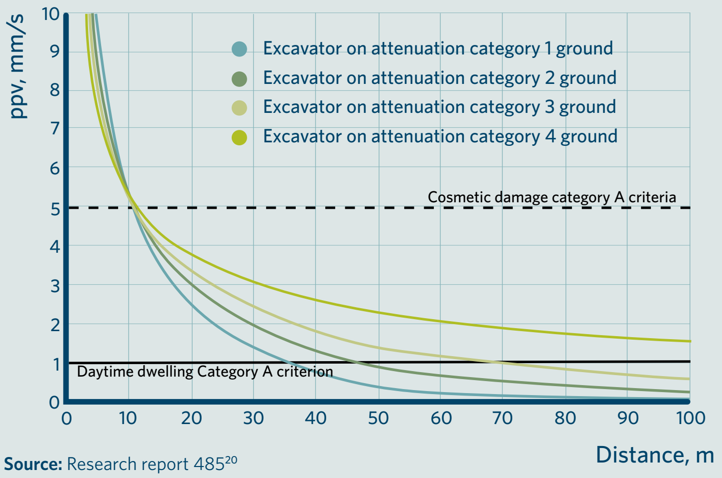
EQUATION	PARAMETER	DESCRIPTION	UNIT
$ppv_2 = ppv_1 \left(\dfrac{10}{d}\right)^{0.5} e^{-\alpha_f (d-10)}$	α_f	soil attenuation coefficient	1/m
	ppv_1	peak particle velocity at 10m	mm/s
	ppv_2	peak particle velocity at distance *r*	mm/s
	d	distance from vibration source	m

FIGURE 24: PREDICTED VIBRATION FROM A KOMATSU D65E DOZER



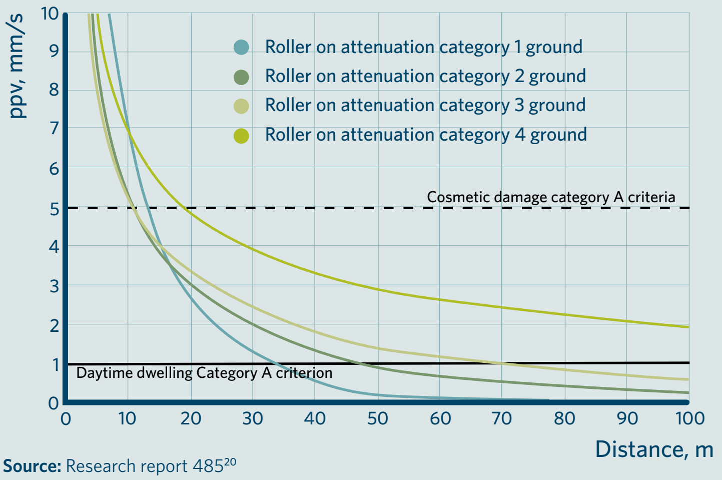
Source: Research report 485[20]

FIGURE 25: PREDICTED VIBRATION FROM A SUMITOMO SH120 EXCAVATOR



Source: Research report 485[20]

FIGURE 26: PREDICTED VIBRATION FROM A HAMM 3410 ROLLER



Source: Research report 485[20]

Note: There are some small differences between the curves presented in this figure and those in research report 485 due to the source data distance used as a starting point for the decay-with-distance calculations.

VIBRATION DATA

On the facing page are examples of some equipment typically used on road construction and maintenance projects, with measured vibration levels in terms of the resultant ppv at 10m, together with the attenuation coefficient and the dominant frequency of the vibration which were also determined from the measurements (see section 4).

The data shows the variability in the vibration levels within a plant type, due to make and model; plus due to the soil on which they are working.

TABLE 15: SOIL ATTENUATION COEFFICIENTS

SOIL CLASSIFICATION		AVERAGE SCALA PENETROMETER READING S (blows/100mm)	SOIL ATTENUATION COEFFICIENT α_f (1/m)
Weak or soft soils (soil penetrates easily); *lossy 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*	I	0.2 - 3.1	0.01 - 0.033
Competent soils (can dig with shovel): *most sands, sandy clays, silty clays, gravel, silts, weathered rock*	II	3.1 - 6.1	0.003 - 0.01
Hard soils (cannot dig with shovel, must use pick to break up): *dense compacted sand, dry consolidated clay, consolidated glacial till, some exposed rock*	III	6.1 - 11.7	0.0003 - 0.003

The soil classifications in this table originate from Dowding and provide a straightforward method of assessing soil type through a qualitative description of consistency and hardness. The New Zealand Soil Classification provides a more detailed system which requires knowledge of the process of the soil formation. For simplicity, a relationship between the two classifications has not been attempted.

PLANT TYPE	ITEM	WEIGHT (TONNE)	SOIL DESCRIPTION	ATTENUATION COEFFICIENT α_f (1/m)	DOMINANT FREQUENCY f (Hz)	RESULTANT ppv[1] at 10m (mm/s)
Dozer 	Komatsu DP31P	7.3	Pumice fill	0.031	12	3.8
	Caterpillar D4H	7.9	Peat	0.073	12	11.9
	Komatsu D65E	20.3	Silty sand	0.009	14	3.8
Excavator 	Komatsu PC60	6.0	Ash	-	21	1.8
	Sumitomo SH120	12.6	Pumice fill	0.061	20	5.4
Grader 	Volvo G726B	16.0	Pumice sand	-	43	0.9
Roller (vibratory and non-vibratory) 	Sakai SW500	4.0	Pumice fill	0.193	50	2.9
	Sakai SW70C	7.1	Dune sand	0.016	53	0.4
	Sakai SW70C	7.1	Silt	0.037	53	0.4
	Bomag BW177D3	7.2	Peat	0.073	28	0.8
	Dynapac CC422HF	10.4	Greywacke fill	0.088	64	1.1
	Caterpillar CB544	10.7	Sandstone	0.07	40	1.1
	Hamm 3410	11.0	Silty sand	0.029	29	7
	Hamm 3414	14.3	Pumice sand	0.012	37	9
	Caterpillar CP663E	16.8	Sandy clay	0.158	28	3.6
	Caterpillar CS663E	17.1	Sandstone	0.012	26	1.8
	Dynapac CA602	18.6	Sandstone	0.046	28	12.4
	Caterpillar 815B	20.8	Sandstone	0.025	13	1.9
	Caterpillar 825C	32.7	Sandstone	0.009	13	0.7
Stabiliser 	Wirtgen WR2000	22.0	Pumice sand	-	36	0.9
Truck 	-	-	Volcanic / sandy loam	0.018	23	-

Note 1: Resultant ppv in terms of the 'square-root of the sum of squares'.

Note 2: Refer to Waka Kotahi **Research Report 485** for details of each measurement site.

SECTION 5: MANAGEMENT

5 MANAGEMENT

PLANS AND SCHEDULES

The most effective method to control construction and maintenance noise and vibration is through proactive management. This includes assessment of all activities and consideration of potential noise and vibration effects and appropriate mitigation.

To ensure that this occurs for all works with a high risk of adverse impact, Waka Kotahi includes a management component within the designation conditions for construction projects or a self-imposed requirement in the contractor procedures manual SM021[22] for either construction projects or maintenance works. This is implemented in management plans and the noise and vibration component is commonly called a Construction Noise and Vibration Management Plan (CNVMP).

For high risk construction projects and maintenance works, the CNVMP will require independent peer review and include a comprehensive risk-based quality assurance/quality control (QA/QC) programme to ensure risks are appropriately managed.

The peer review should be a specific peer review in accordance with the Engineering New Zealand Practice Note 2 and should be completed prior to starting relevant works or submission to any statutory authority.

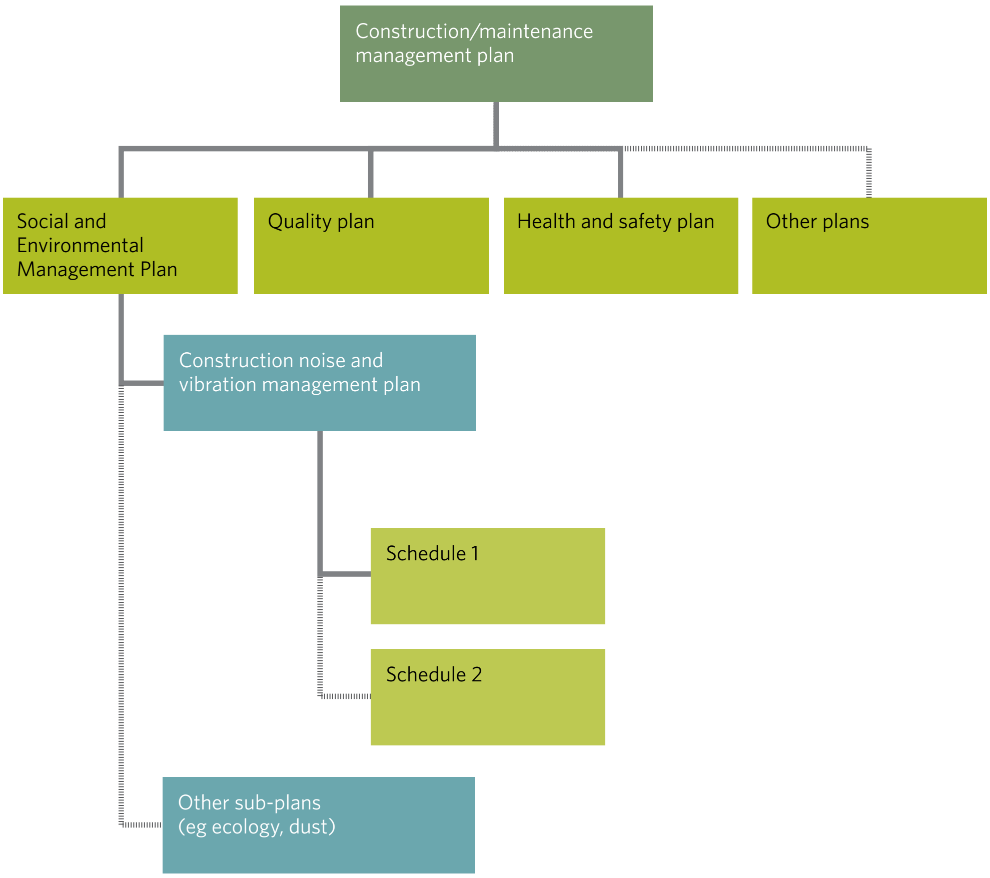
For low and medium risk construction projects and maintenance works the noise and vibration component can be a subsection of a wider Social and Environmental Management Plan (SEMP) rather than being a standalone document.

During the initial planning of works it might not be practical to make a detailed assessment for all high risk activities or locations. In that instance Schedules to the CNVMP, sometimes referred to as 'job noise analyses' or 'site specific plans', detailing the assessment for high risk specific activities or locations, may be added to the CNVMP at a later stage but still prior to each element of work starting.

For maintenance works, there should be a single CNVMP for the maintenance contract as a whole, with specific schedules for the locations and types of works, as required. A Schedule is important even for short duration works and works where physical mitigation is known not to be practicable, as it will highlight the need for enhanced communications.

22 Waka Kotahi NZ Transport Agency (2017) *Contract procedures manual (SM021), version 2.*

FIGURE 27: KEY DOCUMENTS IN THE MANAGEMENT OF CONSTRUCTION AND MAINTENANCE NOISE AND VIBRATION



COMMUNICATIONS

Effective stakeholder engagement is a critical part of managing construction and maintenance noise and vibration. Stakeholder engagement can have a greater bearing on acceptance of the works and complaints than the actual noise and vibration levels. Neighbours who understand what, when and why the works are happening are often able to adjust their activities accordingly and are generally more tolerant of construction noise and vibration.

Where practicable, works should also be scheduled to avoid noisy or vibration producing activities at any specific times identified as particularly sensitive through stakeholder engagement, accepting there is a balance between avoidance of sensitive times and the overall duration of the works. Examples include school exams or community events.

As a key stakeholder, liaising and collaborating with the territorial local authorities (TLA) is important.

Stakeholder engagement for construction and maintenance noise and vibration should be integrated with the wider project requirements, following the project communications plan and the Transport Agency' *Public engagement guidelines*[23]. In general, neighbours should be informed at least one week before work starts and any local issues should be identified. For larger projects, stakeholder engagement should commence during the planning stages. Residents can be informed about work using a variety of means, including personal visits, letter drops, community meetings, newspaper and radio advertising, site signboards, posters and notices on websites. Where work continues for long periods, regular updates are important.

23 Waka Kotahi NZ Transport Agency (2016) *Public engagement guidelines.* **www.nzta.govt.nz**

Information provided should include the:

- reason for the works
- reason for the construction methodology proposed
- overall timeframe and timing of specific noisy or vibration producing activities
- reason for any night or weekend works
- expected noise and/or vibration effects.

All communications should include contact names and phone numbers. In particular:

- the name and phone number of a Transport Agency staff member
- the name and phone number of a person located on the construction site who is able to take immediate action.

Examples of flyers and letter drops are provided on the Transport Noise website for:

- night works
- construction activities
- road closure
- public briefings/meetings.

MITIGATION

Mitigation measures should be properly planned and implemented in a structured hierarchy depending on the extent of predicted effects. In general, the hierarchy should be in the order of:

- managing times of activities to avoid night works and other sensitive times
- liaising with neighbours so they can work around specific activities
- selecting equipment and methodologies to restrict noise
- using screening/enclosure/barriers
- offering neighbours temporary relocation
- for long duration works, treating neighbouring buildings.

FIGURE 28: FLYER EXAMPLES

STAFF

- Include construction and maintenance noise management as part of site induction procedures and within SSCNMPs/schedules as part of mitigation.
- Implement an incentive scheme to prevent shouting and swearing.
- Communicate using the radio/phone.
- Hold regular toolbox/tailgate noise management briefings and start-up briefings prior to any night works.

EQUIPMENT

- Adopt quieter techniques and processes.
- Select low-noise equipment.
- Only use required power and size of equipment.
- Fit engine exhausts with silencers.
- Operate equipment in a quiet and efficient manner.
- Do not leave equipment idling unnecessarily.
- Regularly inspect and maintain equipment.
- Place tools and equipment on the ground – do not drop.
- Cover surfaces with resilient material where tools/ equipment are placed.
- Do not drag equipment on the ground.
- Avoid striking bare metal with tools.
- Locally screen power tools.
- Keep blades sharp.
- Clamp materials when cutting.

VEHICLES

- Fit engine exhausts with silencers.
- Use non-tonal reversing alarms mandatory for night works on urban projects..
- Avoid slamming doors.
- Minimise speed and engine revs.
- Turn down stereos.
- Minimise the use of horns.
- Turn engines off when stationary for extended periods of time.
- Place bedding layer or resilient liner in truck trays.
- Use rubber seals around tailgates.
- Keep site roads well maintained and avoid steep gradients, where practicable.

DELIVERIES

- Use designated routes and access points for deliveries, where practicable avoiding local roads (especially at night).
- Provide a working area for efficient unloading of deliveries.
- Avoid delivery trucks waiting around the site.
- Limit night-time deliveries in residential areas.
- Combine loads to reduce the number of deliveries.

Mobile acoustic cutting booth

CASE STUDY – TILE CUTTING BOOTH, QUEEN STREET, AUCKLAND

Specific screening around noisy items of equipment can be used to reduce the noise. A mobile acoustic cutting booth has been successfully used in Auckland.

NOISE PROPAGATION

- Locate fixed plant away from neighbouring houses and other noise-sensitive properties.
- Install operational traffic noise barriers (eg fences, walls or earth berms) at an early stage so that they also provide benefit for construction noise, and maintain any existing barriers.
- Install temporary barriers/hoardings to screen construction and maintenance noise.
- Locate site buildings and material stockpiles to screen works from neighbours.
- Install localised enclosures or screening of equipment.
- Keep enclosure panels/doors closed.

SCHEDULING

- Where practicable, limit working hours in residential areas to weekday and Saturday daytimes.
- In commercial/industrial areas, impacts may be minimised by conducting work outside normal working hours.
- Identify any particularly sensitive times for activities such as schools, and where practicable avoid nearby works during those times. Works near schools may be best at weekends or holidays.
- If working at night in residential areas, where practicable perform noisiest work during less sensitive times, such as prior to 2300 h.
- Provide respite periods by limiting the number of consecutive nights worked near residences.
- Where practicable, avoid conflicts with community events.

NEIGHBOURING BUILDINGS

If, following a hierarchy of mitigation options (such as that presented at the beginning of this section), reasonable noise levels cannot be achieved by any other practicable means, then the following should be considered:

- Offer residents temporary relocation during works exceeding reasonable noise criteria.
- Provide mechanical ventilation so that windows can remain closed.
- Upgrade the building envelope to provide greater sound insulation (typically, the windows are the weakest path that should be upgraded first).

ADDITIONAL MEASURES FOR SPECIFIC EQUIPMENT

- Excavators, bulldozers, loaders, bobcats:
  - Grease tracks regularly (keep grease in cab); and if possible, use wheeled equipment.
- Cranes and hiabs:
  - Use straps rather than chains where practical.
- Generators:
  - Use centralised generators; and use mains electricity.
- Diamond coring drills:
  - Use thermic lance as an alternative.
- Saw cutting:
  - Use hydraulic saw or wire cutter.
- Milling machines:
  - Heat asphalt before milling.
- Concrete mixer:
  - Do not let aggregates fall from excessive height; and do not hammer the drum.

VIBRATION

For the mitigation of vibration, the following advice can be followed:

- Operate vibration-generating equipment as far away from vibration-sensitive sites as possible.
- Phase construction stages so vibration-generating activities do not occur at the same time. Unlike noise, the total vibration level produced could be significantly less when each vibration source operates separately.
- Avoid impact pile-driving and vibratory rollers where possible in vibration-sensitive areas. Drilled piles, hydraulic press-in piles or a sonic vibratory pile driver cause lower vibration levels than impact pile-driving, although geological conditions may restrict the use of these alternatives. Additionally, sustained vibration at a fixed frequency may be more noticeable to nearby residents and cause a resonant response of building components.
- Select demolition methods not involving impact, where possible. For example, sawing bridge decks into sections that can be loaded onto trucks results in lower vibration levels than impact demolition by pavement breakers; and milling generates lower vibration levels than excavation using clam shell or chisel drops.
- In some instances a cut-off trench can be used as a vibration barrier if located close to the source.

Temporary noise barriers

Broadband reversing alarm

CASE STUDY – MANDATING THE USE OF BROADBAND REVERSING ALARMS

Since 2009, Waka Kotahi has made the use of broadband reversing alarms on vehicles working at night mandatory on some urban projects, including the Victoria Park Tunnel and Newmarket Viaduct.

To implement this, the projects' alliance teams procured broadband reversing alarms for contractors to fit to their vehicles. Also, one of the larger contractors separately purchased and fitted broadband alarms to all their vehicles.

Broadband reversing alarms direct the noise in a specific direction and have a less 'harsh' sound. It is generally a straightforward process to exchange these two types of alarms.

No health and safety issues arose from the use of the broadband alarms on these projects, and when standing behind vehicles the alarms appeared subjectively to be at least as loud as traditional beepers.

Residents expressed a clear preference for the broadband alarms.

For projects requiring the use of broadband alarms the biggest challenge has been ensuring that all subcontractors have alarms fitted, including trucks visiting the site on a one-off basis. Tight controls are required to ensure all subcontractors adhere to reversing alarm requirements.

All contractors are responsible for ensuring the reversing alarms on their vehicles are of an appropriate specification to ensure a safe working environment. As a guide, the following reversing alarm requirements are likely to be appropriate on most Transport Agency projects:

- broadband
- directional
- automatic level adjustment over a range of approximately 20dB
- maximum rated level approximately 97dB.

This guideline is appropriate for medium vehicles on typical urban sites. A higher or lower rated level may be appropriate for other vehicles and sites.

Reversing alarms require two wires to be connected. In many cases, they are a standard size, allowing them to be directly swapped with the alarm originally supplied with a vehicle. As broadband alarms produce a 'beam' with the loudest noise in one particular direction, it is important that the alarms are fitted with an unimpeded view facing backwards from the vehicle. Alarms should always be fitted by a suitably qualified technician.

TRAINING

All personnel involved in construction and maintenance noise management are required to have appropriate training.

For staff undertaking construction and maintenance noise surveys this training should include the following:

- site health and safety procedures
- basic acoustic concepts and units
- construction and maintenance noise sources
- factors affecting sound propagation
- mitigation options
- survey procedures
- equipment operation
- equipment calibration
- meteorological constraints
- residual sound constraints
- data analysis/interpretation.

These topics will be covered in an Transport Agency eLearning package.

CONDITION SURVEYS

Building condition surveys before and after works should be used to determine whether any cosmetic or structural damage has occurred to neighbouring buildings as a result of construction vibration. Any damage caused by construction vibration should be repaired by Waka Kotahi. Surveys before the works are important as many houses already have cracked walls, which could be incorrectly attributed to construction vibration. Therefore, as a precautionary measure, surveys should be made for all properties where construction vibration is predicted to exceed the Category A criteria for building damage.

Prior to works commencing, properties should be identified that are at risk of damage based on predicted levels. These should be inspected to determine the pre-works existing condition.

Depending on the severity of the predicted vibration, measurements of the actual vibration from key sources may be undertaken at the start of the works. This information can then be used to establish the requirement for ongoing condition surveys as the works progress.

Following the completion of the works, a final condition survey should be undertaken.

Specialist surveyors should be employed to conduct building condition surveys and their reports both before and after construction should contain as a minimum:

- Building address and location.
- A description of the building condition and any cosmetic and/or structural damage.
- Sketches and photographs showing the location and extent of any damage.
- Verification of the report by the surveyor and building owner.

DIVERSIONS

Where construction or maintenance work requires the road to be closed either partially or completely, temporary diversions are used to maintain traffic flows. Depending on the routing of the diversion, the extra traffic may be a significant addition to the existing traffic on the diversion route and in this case, the traffic noise levels along the route will increase. Additional noise, particularly at night, has the potential to cause annoyance to and complaints from local residents.

The noise from the extra traffic on a diversion route can be predicted using standard calculation methods and will depend on the volumes of the existing and extra traffic including number of trucks. Deliveries to and from the work site may also use these routes and therefore should be included in the calculation. An acoustics specialist will be needed to undertake such calculations.

The management of the noise from the diverted traffic should be included in the CNVMP. Similar effects also occur on haul roads, the noise from which should also be assessed.

CASE STUDY – VIBRATION

As part of the Grafton Gully Project (2002-03), a new rail bridge was constructed to allow the realignment of a busy intersection. Temporary piles were required for the bridge construction, prior to the completed structure being ‘slided’ into place.

Initially, a fixed-frequency vibratory piling method was used. However, this resulted in the excitation of a resonance in the ground and adjacent residential properties. Complaints quickly followed and the contractor sought an appropriate solution.

The work was completed without any further complaints by the use of a variable frequency piling head, set at an appropriate frequency which avoided generating the resonances.

NIGHT WORKS

Night works can cause the greatest disturbance to residents and should generally be avoided. However, a significant amount of state highway upgrading or maintenance works in urban areas cannot be carried out during daytime hours due to high traffic flows and lack of suitable detours. Some specific construction processes for new roads, such as some concrete pours, are required to be continuous and therefore also require night works. This section provides guidance on how to identify when it is necessary to undertake works at night and additional controls that may be required. Further advice is available from Auckland Council[24].

Night works are more likely to be required for upgrading or maintenance of existing roads than construction of new roads. Maintenance works can be classified into two groups: routine and periodic maintenance. Routine maintenance generally occurs during the day, although occasionally night works are necessary. Periodic maintenance such as resurfacing is more likely to require night works. Asphalt surfacing work is one of the most significant night-time maintenance noise issues, particularly if the existing surface requires milling to remove it first.

Roads with traffic volumes greater than 35,000 vpd AADT are classified as 'high volume' and minimising delays becomes difficult. If there is no suitable way to limit traffic disruption and delay during the day then night works may be required. Other factors to consider include the method of works/closure, possible detours, predicted noise levels, timeframe for works, and safety aspects.

Night-time road construction and maintenance works are necessary if:

- congestion prevents daytime maintenance (information about congestion is available from the network manager), or
- the window of opportunity for daytime works is too short (this depends on: the nature of the works, ie type, duration, safety issues, etc; congestion; site and traffic characteristics), or
- the construction process is continuous (such as some concrete pours).

Before confirming that night works are required, it should be evaluated:

- What options are available to avoid working at night?
- If there are options, are these technically and economically feasible?

Robust consideration of these questions is required to justify night works. It is important that this evaluation process takes into account all the affected stakeholders both locally and regionally.

Criteria

As discussed in section 2, the recommended guideline criteria for temporary construction and maintenance activity are higher than for permanent activities on the basis that people generally tolerate short term disturbance. However, at night the guideline criteria are similar to those for permanent activities, to prevent sleep disturbance.

Predictions should be made to determine what noise and vibration levels are practicable to achieve for night works. For most works the guideline noise criteria in NZS 6803 are not achievable at night. However, if night works are justified, and enhanced management and communication procedures are implemented, then it is generally reasonable for construction and maintenance noise and vibration to exceed the NZS 6803 recommended guidelines. Alternative criteria that are reasonable and practicable should be adopted.

Night-time criteria for vibration are included in this guide. Where practically possible, the vibration from night-time works should be managed to comply with the Category A criteria. If the vibration is predicted to exceed this level, then, as for noise, enhanced management and communication procedures should be implemented.

Where alternate criteria are proposed, these should be agreed between Waka Kotahi and the regulatory authority (council). Once agreed the criteria adopted should be recorded in the CNVMP. If agreement cannot be reached then advice should be sought from the System Design and Delivery team (environment@nzta.govt.nz).

Mitigation

For most night works, enhanced noise and vibration management measures are required, although this depends on the scale of the project and the number of stakeholders potentially affected. For example, if the area around night works is uninhabited then there is unlikely to be any noise or vibration effect and therefore no additional management or mitigation should be required. However, night works in the middle of a residential area require careful management. A proactive approach is usually the most effective way for a contractor to manage the risk associated with potential noise effects.

The main noise effect of undertaking road construction and maintenance at night is sleep disturbance. Where practicable, works should be programmed so that all noisy work is undertaken earlier in the night to avoid sleep disturbance.

For night works in particular, people tend not to be disturbed so much by the lower frequency continuous noise from machine engines, but do get disturbed by noises such as reversing beepers, whistling, banging tailgates or shouting.

If mitigation of noise from night works requires the installation of temporary barriers or similar, this can reduce the available working time and thus time for this installation and removal must be included in the programming.

In addition to standard good construction and maintenance noise management, when conducting night works it may be necessary to:

- increase the frequency of communications with stakeholders
- conduct regular noise and vibration monitoring to ensure adopted noise criteria are achieved
- if unreasonable noise and vibration levels cannot be avoided, offer temporary relocation to neighbours.

24 Auckland City Council (2007) *Code of practice for managing road maintenance noise.*

Left: Monitoring locations

Right: Site location

CASE STUDY – TERRACE TUNNEL, WELLINGTON (2010–11)

The Terrace Tunnel project involved upgrading: fire and life safety systems; ventilation; drainage and earthquake resilience, to extend the working life of the tunnel. An alliance of Waka Kotahi, AECOM, Leighton Contractors and SKM undertook the works.

To minimise the disruption to traffic, the majority of the works were undertaken at night with the potential to cause adverse noise at the residential properties located adjacent to the ends of the tunnel. As such, noise was proactively managed from the beginning of the project and a comprehensive Project Construction Noise and Vibration Management Plan was produced using the Transport Agency template.

Andrew Mitchell, acoustics engineer for the Alliance explains the noise management used on this project:

'Project noise targets (based upon section 7.2.6 of NZS 6803 – 'background plus 10dB') were agreed with the Wellington City Council. To monitor compliance with noise targets, members of the environment team were trained in the use of sound level meters. Fortnightly noise monitoring was undertaken of construction activities, as well as when a new phase of works began. Monitoring details and results were recorded on the noise survey sheet. Subsequently, a survey report was produced using the template and distributed to the relevant project staff. Any exceedances of the noise targets were recorded on the project risk register and discussed with site supervisors to ensure mitigation measures were implemented to reduce noise levels. In some circumstances, work stopped when the noise targets were exceeded and restarted only when a solution was found. One solution was simply to move metal waste skips from a lay-by near to a residential property into the tunnel, thus screening the noise when the skips were filled.'

COMPLAINTS

The specific complaint process for each project should be detailed in the CNVMP or the wider SEMP. In some regions, a central contact is used for receiving complaints from maintenance works. Otherwise, such complaints should be addressed in the same manner as those from construction projects.

Good practice in handling complaints includes the following:

- Provide a readily accessible contact point, for example, on high-risk projects through a 24-hour toll-free information and complaints line. During works a contact should be available who is located on site and able to take immediate action.
- Give complaints a fair hearing, including looking at the issue from their point of view.
- Have a documented complaints process, including an escalation procedure so that if a complainant is not satisfied there is a clear path to follow.
- Call back as soon as possible to keep people informed of action to be taken to address noise and/or vibration problems. Call back at night-time only if requested by the complainant to avoid further disturbance.
- Quickly respond to complaints, with complaint-handling staff having both a good knowledge of the project and ready access to information.
- Implement all feasible and reasonable measures to address the source of complaint.
- Keep a register of any complaints

By populating a national complaint register, the Transport Agency can identify common causes of complaint and seek to avoid repeat incidences on other projects.

CASE STUDY – NEWMARKET CONNECTION, AUCKLAND (2008–2012)

As part of the Newmarket Connection Project, an additional southbound lane on SH1 was constructed between Newmarket Viaduct and Green Lane. Being adjacent to the existing state highway, the works were undertaken in a high noise environment with a large proportion of the work carried out at night. However, it was also within a residential area, with some buildings as close as 5m to the works. According to Ronnie Salunga of Waka Kotahi, 'This project was an example of very good customer care. Understanding the needs of the affected residents from a very early stage; working with them to introduce innovative solutions to satisfy their concerns; and keeping them fully informed on a regular basis of everything that was happening or about to happen was the key to successful stakeholder management.'

Prior to night-time or noisy works, letters were distributed to affected residents in addition to the bi-monthly newsletter. These letters included the what, when and why details of the works, with the aim to prepare people for any construction noise and vibration effects. Reassurance was also given that noise and vibration monitoring was being undertaken. Often the letters were followed up with a personal visit, giving residents a direct opportunity to discuss any concerns. Generally people appreciated the information and therefore were more accepting of the work.

Those at home both day and night, such as home workers, were particularly affected by the night works and, in one street of 100 residents, two households were relocated at their request during night work at certain times during the project.

The effectiveness of the proactive approach was evident in an instance of piling works. The project communications manager visited all of the properties in the adjoining area prior to the start of the piling. The only complaint received was from the one property where the occupants weren't available at the time of the visit.

MONITORING

Noise and vibration monitoring is not needed for all projects, and the specific requirements should be identified in the CNVMP (for high risk works) or the SEMP (for low and medium risk works). In particular, where the noise risk is low (section 3), monitoring might not be required. When monitoring is necessary, the requirements for conducting construction noise measurements are provided in NZS 6801:2008[25], NZS 6802:2008[26] and NZS 6803. For vibration measurements, reference should be made to BS 5228-2 and DIN 4150-3. For additional guidance on measurement techniques, reference can be made to BS 6472-1 in relation to human annoyance and ISO 4866:2010[27] for building damage.

The following provides some additional practical guidance, but does not reproduce the full requirements of these standards. All personnel involved in monitoring should have appropriate training. Tools and templates relating to monitoring are available on the Transport Agency website.

SURVEY PLANNING

- Liaise with the site manager and obtain the construction and maintenance schedule. Choose a time(s) for the survey during representative activities.
- If conducting night-time monitoring, visit the site in daylight first.
- Arrange access to make measurements outside neighbouring buildings.
- Print survey sheets and a high-resolution aerial photograph of the works and the nearest neighbours.
- Check the equipment and calibration records.
- Check the weather forecast.
- Take photographs of measurement position and activity during measurements.
- Detail all of the matters listed in this section on the survey sheets.

NOISE MEASUREMENTS

- Take measurements 1m from the most exposed facade of occupied neighbouring buildings.
- Take measurements 1.2–1.5m above the floor levels of interest.
- If the above location is not practicable then a location should be used either closer to the works or possibly inside the neighbouring building. Applicable corrections are given in NZS 6801 and NZS 6803.
- Sound level meter/analyser should be self-supported (on a tripod) and not hand-held.
- If there is a choice of several neighbouring buildings at a similar distance from the works, the position least affected by other noise sources (such as traffic) should be used.
- Record locations of any reflecting surfaces (such as walls) near to the measurement position.

There are generally two methods of conducting measurements:

1. Take several 15-minute samples of representative construction/maintenance activity (NZS 6803 allows some discretion in the appropriate time period, but for Transport Agency projects 15 minutes is recommended as a default value), or
2. Take short (approximately 5 to 30 seconds) measurements of specific events.

The first approach is preferable as it allows a direct comparison with construction/maintenance noise criteria. However, contamination by fluctuating residual sound (such as sporadic road-traffic) often means that the second approach is required. In this instance it is then necessary to conduct detailed analysis after the survey to calculate the effective construction/maintenance noise level over 15 minutes. Procedures for this are provided in NZS 6801 and NZS 6802. Even using the first approach of taking 15-minute samples, it may often be necessary to take a separate measurement of the residual sound and subtract.

The equipment required to monitor noise is specified in NZS 6801, which requires a Class 2 (or better) sound level meter. These can be bought or hired by a project, or contractors can be employed to undertake measurements with their own meters.

VIBRATION

- For the assessment of building damage, vibration measurements are made on the building foundation, at the side of the building that is nearest to the vibration source. This can either be on an external wall just above ground height or on an internal basement wall. Applicable measurement locations for assessing against DIN4150-3 criteria are given in DIN 45669-2.
- Typically measurements are made in three orthogonal directions (at right angles to each other), with one axis orientated towards the longest building edge and one in the vertical orientation. The orientation of the axes should be recorded on the survey sheet.
- When annoyance is to be assessed, measurement should be made at the location where the highest level of annoyance occurs. One of the measurement directions should be orientated with the head-foot axis of the person subjected to the vibration. If the person is standing or seated, then this axis will be vertical. For a sleeping person, this axis will be horizontal. For multi-storey buildings measurements should also be taken on the highest internal floor.
- For all of these measurements, the transducers should be rigidly attached to the structure, either using direct fastening (screwing into a drilled and tapped hole or clamping); adhesive or weighted with a sandbag (for low vibration levels).

To quantify a ppv, measurements are required when the source of the vibration is producing the highest levels of vibration. The operating condition at which

25 Standards New Zealand (2008) *NZS 6801:2008 Acoustics – Measurement of environmental sound.* **www.standards.co.nz**

26 Standards New Zealand (2008) *NZS 6802:2008 Acoustics – Environmental noise.* **www.standards.co.nz**

27 International Standards Organisation (2010) *ISO 4866 Mechanical vibration and shock. Vibration of fixed structures – Guidelines for the measurement of vibrations and evaluation of their effects on structures.* **www.iso.org**

this occurs depends upon the type of equipment and may correspond to maximum speed, highest revs or greatest force. In most cases, the highest level of vibration occurs when the source is nearest to the measurement location. The length of measurement should be long enough to capture the highest level of vibration, which may be only a few seconds. A number of measurements of the highest level should be made to ensure repeatability.

Due to the variability of vibration levels measured from a consistent source, a statistical approach to the reporting of the results is often used. This is typically in the form of a confidence level, e.g. 95%, which means that 5% of a measurement sample will be above the reported result. In this manner, there will be more certainty in compliance with a vibration criterion by removing some of the uncertainty in the measured results.

Equipment to measure vibration is available for a project to hire or buy but often acoustics specialists can provide a measurement service. Typically, the equipment has three transducers that measure acceleration or velocity in three orthogonal directions, with in-built processing to produce the required metric, e.g. the ppv level. Accelerometer transducers are used to measure acceleration, whilst geophones measure velocity. Both types of transducer can be used but differ in the frequency range over which the data is valid; robustness and cost.

UNMANNED LOGGING EQUIPMENT

Some projects may require noise and/or vibration to be monitored continuously or for long periods of time, due to the nature of the works or to comply with a designation condition. Attended measurements over such periods would be expensive and in most instances not be practicable.

In these cases, unattended noise and vibration loggers are used. Typically these will record noise and vibration levels at a fixed time interval. Short intervals can be used to quantify the noise from short-term events (eg 1 minute) and subsequent processing can be used to combine these short intervals into the required sample length (typically 15 minutes). Short intervals allow spurious data points to be removed from the average. Typically intervals of 1 second are used to quantify the ppv of vibration.

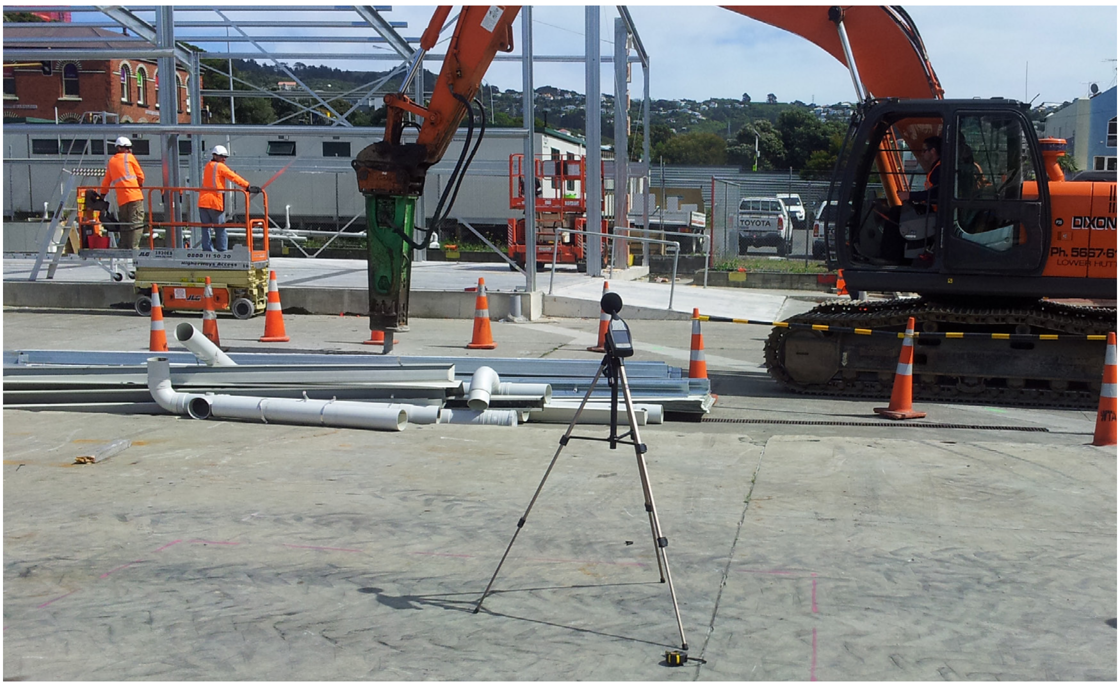
The levels from unattended monitoring should also be used with caution, as it will often be difficult to identify the source of the noise or vibration, giving erroneous results if high levels are recorded by sources not directly associated with the works. Obtaining site activity records will assist in identifying any spikes in measured noise or vibration. Careful location of the equipment will minimise this effect, for example: shielding a logger from the noise generated by an adjacent industrial source.

Meteorological conditions should also be quantified during noise monitoring over long periods of time, particularly when measuring noise at long distances from the source, as wind direction and speed can affect the noise propagation significantly.

Modern equipment allows high levels of noise or vibration to trigger the recording of audio samples, which can be subsequently used to assist with source identification. Remote access is also available to check on operation and download results. Data storage, power requirements and security must also be considered.

REPORTING

- On site, fill in all parts of the survey sheets.
- If required, prepare a formal report for the project team and/or consenting authority, referencing the designation conditions (CSVue).



DOCUMENTATION

PROJECT DATABASE

All projects should have a comprehensive construction noise and vibration records system, which, depending on the level of risk, will include: management plans; management schedules; quality records (audits, inspections, peer reviews) calculations; monitoring results and complaints records. This should preferably be in electronic form.

The following sections detail the key information that should be saved within a specific database for construction noise and vibration issues. The information is required for compliance with relevant standards and good practice. In some instances resource consent or designation conditions may require additional information to be recorded.

COMMUNICATION AND COMPLAINT REGISTER

A record should be kept of all contacts, communication and liaison with neighbours regarding construction noise. This should include:

- date of contact
- people involved
- brief summary of the discussions held.

For complaints this should include:

- time, date and location
- complainant name and contact number
- description of noise/vibration/equipment reported
- immediate action taken to address complaint, including timeframe
- investigation and corrective actions taken, including timeframes
- follow-up check, including timeframe
- details of complaint closure.

There may be communication and complaint registers as part of project-wide systems for other issues as well as noise. In that instance the CNVMP should contain a reference to the location of the central registers.

CONSTRUCTION NOISE AND VIBRATION MANAGEMENT PLAN

The CNVMP, or alternatively a section included in the SEMP, should detail consultant and contractor obligations during construction and maintenance, and should include:

- applicable noise and vibration criteria
- consent/designation condition requirements
- identification of the most affected houses and other sensitive locations where noise and/or vibration limits apply
- description of the works, anticipated equipment/processes and durations
- assessment of construction noise and vibration levels
- appropriate mitigation measures to be implemented
- quality programme (schedule of inspections, audits and reviews of plan and plan implementation)
- monitoring and reporting requirements
- staff training/awareness programme
- procedures for maintaining contact with stakeholders and managing complaints
- contact numbers for key construction staff, staff responsible for assessment and council officers, including at least one Waka Kotahi staff member.

If any of these details are not available when first preparing the CNVMP then it should be updated when the information becomes available.

SCHEDULES

A schedule to the CNVMP provides a specific assessment of an activity and/or location and should include details such as:

- activity location, start and finish dates, and times
- the nearest neighbours to the activity
- a location plan
- predictions and mitigation for the activity
- communication with neighbours
- location, times and type of monitoring

Templates for a management plan and schedule are available on the Waka Kotahi website.

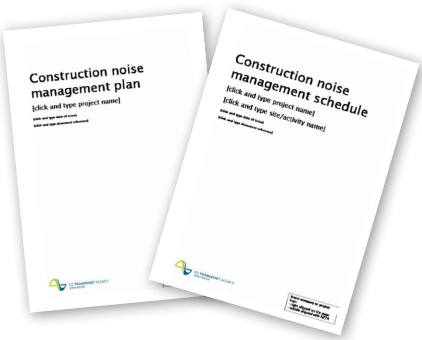
MONITORING REGISTER

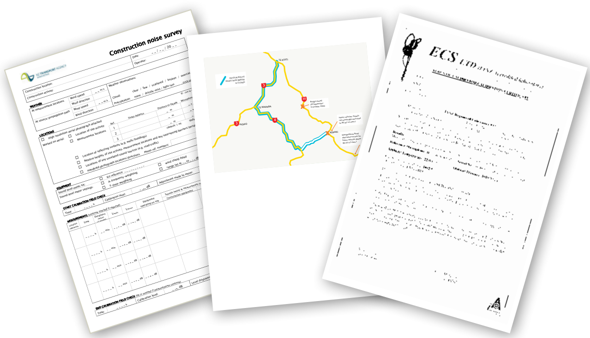
All details relating to noise and vibration monitoring should be stored in the construction noise and vibration database, including the following:

- Site survey sheets and associated aerial photographs.
- Site survey summary sheet.
- The key elements to be observed and entered into the survey sheet, and then recorded, are:
  - date
  - time (measurement start time)
  - construction location
  - construction activity
  - measurement location street address
  - measurement duration (minutes)
  - noise metrics, eg $L_{Aeq(t)}$, L_{AFmax}
  - vibration metrics, eg ppv.
- Survey reports (both internal reports and reports submitted to council).
- Survey and equipment operating procedures.
- Current and past equipment kit details and calibration summary:

  Rather than record equipment details during each survey, the requirements of NZS 6801 can be achieved by maintaining an accurate register of equipment kits in the construction noise database. It is therefore important that all previous equipment data is retained. For each measurement kit the equipment summary should include:
  - sound level meter type, serial number and last calibration date and certificate reference
  - microphone type, serial number and last calibration date and certificate reference (this often forms part of the sound level meter calibration)
  - field calibrator type, serial number and last calibration date and certificate reference
  - wind shield type
  - tripod type
  - wind meter type
  - copies of calibration certificates.

A similar equipment summary for vibration equipment could also be used.





CASE STUDY – VIBRATION MEASUREMENTS

The case study on page 3 describes the good practice carried out on the Victoria Park Tunnel (VPT) project in terms of the noise and vibration management, a proactive approach and communicating effectively with neighbours. This case study describes the vibration monitoring carried out during that project as part of the overall management system. Monitoring was required to verify compliance with a designation condition which referenced vibration criteria in DIN 4150-3.

Between January 2010 and October 2011, 204 vibration measurements were undertaken by the project staff and consultants, and results compiled into a register. The monitoring was mainly proactive measurements (198), with a small number of measurements in response to complaints about vibration (6). Proactive measurements were typically taken at the start of a construction activity that was envisaged to produce significant levels of vibration near to a receiver sensitive to building damage or human annoyance.

A combination of manned and unmanned measurements was used. The vibration was measured in three directions with transducers typically clamped to a vertical structure or held in place on a horizontal surface using a sandbag. The two photos in figure 29 show appropriate mounting positions, measuring vibration near or on the foundation of a structure to assess building damage. For the assessment of human response, the transducers would be typically mounted on an internal floor.

Some of the measurements for the VPT project did not use appropriate measurement locations. The example shown in figure 30 will not measure vibration comparable with the guideline values in DIN 4150 as this arrangement measures the response of the specific wall rather than the foundation of the building.

In order to assess the potential for building damage according to the DIN 4150-3 guidelines, the frequency of the ppv is also required, as the effect of vibration on structures is frequency dependent. Where recorded in the register, Figure 31 presents the vibration level against frequency. The DIN 4150-3 guideline levels are also included for comparison.

FIGURE 29: TRANSDUCER MOUNTING METHODS USED ON THE VPT PROJECT

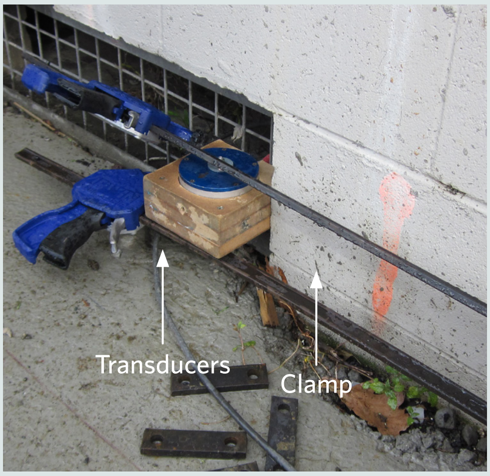


FIGURE 30: INCORRECT TRANSDUCER LOCATION

LESSONS LEARNT

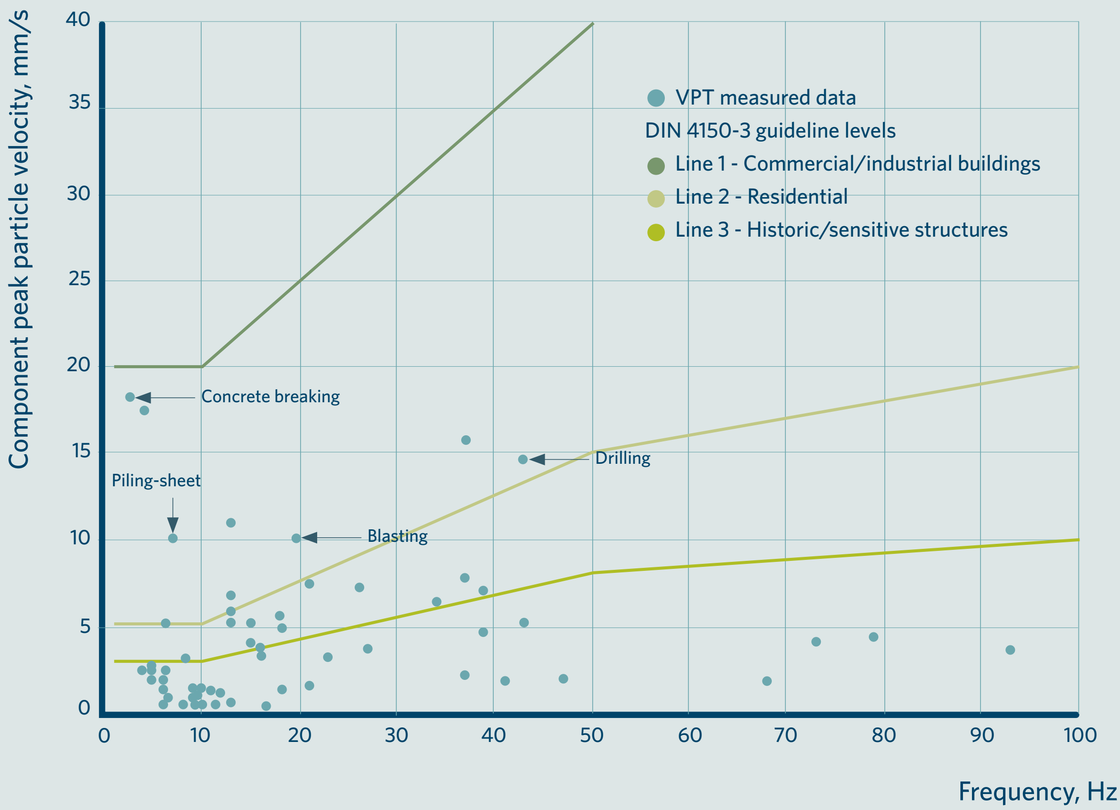
From review of the monitoring records, the following improvements to the vibration measurement methodology have been identified which should be implemented for future projects:

- The location of the measuring transducers should be determined by the effect to be assessed (see section 2):
  - Human response/annoyance – at the location where the vibration is felt, eg on an internal floor
  - Building damage – on the building foundation.

If access prevents the use of these locations, then measurements can be made elsewhere with the appropriate corrections applied for the foundation and building response (table 9 and 10).

- The frequency of the ppv should be recorded as the response of a human and a building, and the corresponding criteria, are frequency dependent.
- If unmanned measurements are to be used, the transducers must be in a location where the effects of erroneous vibration sources is minimised. Such sources may include intentional or unintentional knocking of the transducers by site workers or the public.
- The source of vibration during each measurement should be determined. This may be difficult where there is lots of construction activity occurring at the same time. Temporarily stopping and restarting individual activities can assist in the identification of the source.
- Consistent terminology and data entries should be made in the vibration register to assist with comprehension and subsequent analysis.

FIGURE 31: VIBRATION LEVELS MEASURED ON VPT PROJECT



SECTION 6: GLOSSARY

6 GLOSSARY

GLOSSARY

A-WEIGHTING	Human hearing is less sensitive at very low and very high frequencies. Noise measurements capture all frequencies and therefore need to be adjusted to correspond to human hearing. This adjustment is called 'A-weighting'.
AIRBLAST OVERPRESSURE	Airblast overpressure is an acoustic effect caused by blasting where significant airborne energy is generated at frequencies lower than is typically audible by a human ear but which can cause subsequent vibrations at audible frequencies within buildings.
AIRBORNE NOISE	Noise inside or outside a building caused by sound propagated through the air.
ALTERED ROAD	An existing road that is subject to alterations of the horizontal or vertical alignment which meets the criteria in section 1.5 of NZS 6806, including certain sound level thresholds.
AS	Australian Standard.
BARRIER	A structure that is placed between a noise source and a receiver to reduce the noise. In this guide, 'barrier' refers to both wall type structures and berms/bunds.
BEST PRACTICABLE OPTION (BPO)	The best method for preventing or minimising the adverse effects on the environment, having regard, among other things, to: - the nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects, and - the financial implications, and the effects on the environment, of that option when compared with other options, and - the current state of technical knowledge and the likelihood that the option can be successfully applied.
BLASTING	The breaking-up of rock or other hard material by the use of explosives.
BROADBAND	A broadband source emits noise or vibration at a wide range of frequencies.
CNVMP	Construction Noise and Vibration Management Plan. A document detailing the obligations towards noise and vibration of the NZTA and its consultants and contractors.
COMPACTION	The consolidation of material during construction of a road or structure. This is often carried out using a heavy weight and/or vibration of the material.
COMPONENT PPV	The ppv for one measurement direction. See also resultant ppv.
CONDITION SURVEY	The inspection of a structure by a qualified engineer to assess the current state. Where construction work is likely to produce significant vibration, before and after condition surveys are used to gauge cosmetic or structural damage.
CONDITIONS	Conditions placed on a resource consent (pursuant to section 108 of the RMA) or on a designation (pursuant to subsection 171(2)(c) or subsection 149P(4)(b) of the RMA).
CONTINUOUS VIBRATION	Vibration that is maintained for an indefinite period of time.
COSMETIC DAMAGE	The formation or growth of hairline cracks on plaster or drywall surfaces and in the mortar joints of a brick/concrete block construction.
DECIBEL (dB)	A unit of measurement on a logarithmic scale which describes the magnitude of sound pressure with respect to a reference value (20 μPa).
DIRECTIONAL	Some sound sources can produce different sound levels at the same distance from the source, depending on direction. These sources are known as 'directional sources'.

DISTANCE CORRECTION	As sound propagates away from a source, the sound level reduces. A distance correction is the amount of reduction in sound level.
EXISTING ROAD	A formed legal road existing at the time when road-traffic noise effects of a new or altered road are assessed in accordance with NZS 6806.
FACADE	The outside of an external wall of a building. A +3dB difference is often used between the facade noise level (building present) and the free-field noise level (no building). This difference is known as the 'facade correction'.
FREE-FIELD	Description of a location which is at least 3.5m from any significant sound-reflecting surface other than the ground.
GROUND BORNE NOISE	Noise inside a building caused by vibration of the building structure due to vibration through the ground from an external vibration source.
GROUND BORNE VIBRATION	Vibration inside or outside a building due to vibration through the ground from an external vibration source.
HERTZ	Unit of frequency, used for both sound and vibration.
$L_{Aeq(15min)}$	The A-weighted time-average sound level over a 15-minute period, measured in units of decibels (dB).
L_{AFmax}	The maximum A-weighted noise level with a 1/8 second or 'Fast' time constant (indicated by a 'F'), measured in units of decibels (dB).
LOGARITHMIC	Logarithmic scales reduce wide-ranging quantities to smaller scales. For example, the decibel is a logarithmic unit quantifying sound pressure.
L_{Zpeak}	The peak un-weighted (indicated by a 'Z') noise level with no time constant, measured in units of decibels (dB).
MOVING SOURCE	A noise source that does not stay in one place. In terms of construction noise and vibration, an example of a moving source would be a truck delivering material.
NEW ROAD	Any road which is to be constructed where no previously formed legal road existed. This includes the formation of a previously unformed legal road.
NOISE	Noise may be considered as sound that serves little or no purpose for the exposed persons and is commonly described as 'unwanted sound'.
NOISE AND VIBRATION RISK	The risk of works causing annoyance and/or building damage, and also the related risks of costly mitigation or affecting statutory approvals.
NZTA	Waka Kotahi NZ Transport Agency. The crown entity responsible for, amongst other functions, the management and maintenance of the state highway network.
PERCEPTILE	Noticeable by humans.
PILING	A column of wood or steel or concrete that is driven into the ground to provide support for a structure. Piles can be driven by impact, vibration or rotating.
PPV	Peak particle velocity. This is the instantaneous maximum velocity reached by the vibrating surface as it oscillates about its normal position.
RESULTANT PPV	The combination of the velocity of three orthogonal directions using a 'root-mean-squared' summation.

PROTECTED PREMISES AND FACILITIES (PPFS)	Spaces in buildings used for: • residential activities • marae • overnight medical care • teaching (and sleeping) in educational facilities • playgrounds that are part of educational facilities that are within 20m of buildings used for teaching purposes.
PSEUDO RESULTANT	A 'square-root of the sum of squares' (SRSS) of 2 or more vibration levels on orthogonal axes. Otherwise known as the 'simulated resultant'. It is the vector addition of the maximum level of each direction regardless of the time it occurs. Thus this level of vibration will never occur and assessments based on these data will be over-estimates and therefore conservative.
RMA	Resource Management Act 1991.
SCHEDULE TO CNVMS	Also known as a Site Specific Construction Noise Management Plan (SSCNMP) or job noise analysis. A specific noise and vibration assessment of an activity and/or location.
SIMULATED RESULTANT	See pseudo resultant
SOUND	Sound (pressure) levels are an objective measure of changes in pressure levels that may be heard by humans. Unwanted sound can be considered as noise.
SPECTRA/ SPECTRAL DATA	A graph/table of sound or vibration level versus frequency.
SOUND PRESSURE	The local pressure deviation from the ambient (average or equilibrium) atmospheric pressure caused by a sound wave.
SOUND POWER	A measure of the energy of a sound source per time unit. Sound power is neither room dependent nor distance dependent. Sound power is only attributed to the sound source.
TIME CONSTANT	During a noise measurement, a sound level meter averages the rapidly varying signal from the microphone into a slow-moving signal that allows the sound level to be 'read' by the operator. The time over which this average is calculated is the 'time constant' and originally corresponded to the speed at which the damped needle moved on an analogue sound level meter. The calculations made on modern digital meters replicate this effect with the same time constants. Typical time constants are 'Slow' of 1 second duration (often denoted 'S') or 'Fast' of 1/8 second duration ('F').
TRANSIENT VIBRATION	Transient vibration is temporarily sustained vibration but which may be frequently repeated. For example, the vibration resulting from impact piling.
VIBRATION	Vibration is a periodic motion about a normal position. In this guide, vibration refers to the movement in the ground ('ground borne vibration') or in a structure.

FURTHER INFORMATION

This document is available on our website
www.nzta.govt.nz

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WAKA KOTAHI NZ TRANSPORT AGENCY

New Zealand Government

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