Technical Report 18

Assessment of Vibration Effects

NZ TRANSPORT AGENCY
WAKA KOTAHI

MacKays to Peka Peka Expressway

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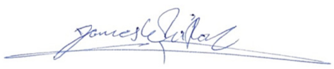
Prepared by	James Whitlock (Marshall Day Acoustics)		8 August 2011
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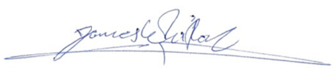
Approved by	James Whitlock		20 August 2011
on behalf of	Marshall Day Acoustics		

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Executive Summary

This report provides an assessment of vibration effects for the construction and operation of the MacKays to Peka Peka Expressway Project.

It contains a review of relevant international vibration standards for building damage and human response, as there are no relevant New Zealand standards on these subjects. Project criteria adopting the most relevant standards have been recommended.

Construction vibration effects have been assessed through on-site measurement of identified machinery, as well as the review of data from relevant standards and previous measurements. This data has been analysed and processed to establish risk contours for identified receivers along the proposed Expressway.

Predictions of construction vibration levels indicate there is a degree of risk that the Project criteria may be exceeded in every Sector of the Project, and Sector 2 contains the highest number of potentially affected parties. A Construction Noise and Vibration Management Plan (CNVMP) is recommended as the management tool to ameliorate this risk. The document will outline the methodology for assessing, managing and mitigating the Project construction vibration effects.

Operation vibration effects have been assessed through site measurements of heavy vehicle movements, and discussion with residents. The critical factor for generation of vibration has been identified as road surface quality. The operation vibration effects of the Project are predicted to be negligible, provided the road surface of the proposed Expressway is maintained in accordance with NZTA standard policy.

1. Introduction

This assessment of vibration effects addresses, as part of the AEE, the vibration effects of both construction and operation of the MacKays to Peka Peka Expressway Project (the Project). These two aspects involve different vibration sources, sensitivities and effects. This assessment has been based on information, plans and methodologies provided to Marshall Day Acoustics (MDA) by the MacKays to Peka Peka Project team.

This Plan refers to the Project team as carrying out works on behalf of and as contracted by the NZTA. The NZTA is the requiring authority and the consent holder.

A Glossary of Terms is attached in Appendix 18.A.

1.1. Construction phase

The construction phase is the more crucial of the two phases as vibration levels produced by construction activities are typically higher, and therefore more likely to be detected by a greater number of receivers (especially residential), which may result in complaint. Construction vibration by nature is a temporary or short-term activity and will be of limited duration for any one receiver as it is a mobile construction site. As such there is generally a higher tolerance to vibration during the construction period.

The level of human perception for vibration is at least an order of magnitude below the limit for building damage risk (refer vibration criteria in Appendix 18.B). This means that adverse human reaction to construction vibration – borne out of residents' concerns over building damage – can often be expressed for activities generating vibration levels which readily comply with the building damage thresholds.

The construction criteria (refer Section 4.3.1) address both the human response and building damage risk effects in an approach which, it is noted, forms the basis of NZTA construction vibration policy, currently under development.

The construction phase must be carefully managed by the Project construction teams, and controlled and verified through the use of management tools such as the Construction Noise and Vibration Management Plan (CNVMP). The key vibration sources for the construction phase are anticipated to be:

- Vibratory rollers for base course and road surfacing
- Excavators working close to property boundaries
- Motor scrapers levelling the alignment
- Off-road fill transport
- Vibroreplacement and vibro-hammer piling of H-piles for bridge abutments and retaining

The risk of vibration effects is most likely in Sector 2 of the Project (refer to Part D, Chapter 7, Volume 2 of the AEE for the Project sector diagram), where operations are undertaken in close proximity to areas of medium-density housing between Kāpiti Road and Mazengarb Road.

1.2. Operation phase

The Project's operation phase contains much less risk of adverse effects than the construction phase because the vibration levels generated by even heavy traffic are significantly less than those generated by construction activities. During the operation phase, more focus is given to human perception because any vibration effects will be ongoing and will continue indefinitely, as opposed to construction, which has a limited timeframe.

An existing ambient vibration survey quantifying the current situation (refer Section 2) involved measurements of existing vibration levels in a number of dwellings alongside the proposed Expressway alignment and the existing SH1 route.

2. Existing Environment

2.1. Ground conditions

Ground conditions are a crucial consideration in this vibration assessment because the type of soil between source and receiver affects the vibration level at the receiver. Vibration energy travels faster and with less distance attenuation in hard, or densely compacted ground such as rock or dry consolidated clay than it does in softer or more aerated ground.

There are two predominant ground types in the vicinity of the Proposed Expressway: sand and peat. Refer to the Assessment of Ground Settlement Effects (Technical Report 35, Volume 3). Peaty soil is classed as soft ground and has some unique vibration properties. Sandy soil can be classed as soft or competent depending on its level of compaction (Hassan, 2006).

Buildings on soft ground

Buildings constructed on soft ground must have foundations designed to ensure that the structure is not compromised should the ground beneath it settle over time. It is understood that this has been a problem for older dwellings built in the Kāpiti Coast District where differential settlement under buildings has resulted in effects such as slumping, cracking of concrete and separation of dwellings from patios, driveways etc.

Generally these effects are addressed either by piled foundations that extend to a depth or stratum where the ground composition is sufficient to support the weight of the building, or by excavating the soft ground and replacing it with a compacted building platform, typically sand.

Technical Report 35, Volume 3, contains a review of buildings 50m either side of the Proposed Expressway for sensitivity to settlement.

The same considerations must be made in the proposed Expressway design to avoid cracking and unevenness in the road surface over time, which would generate vibration when driven over by heavy traffic. It is understood the proposed construction is to include a combination of excavation and replacement of peat with sand, and/or pre-loading of peat with a sand-gravel mix (minimum depth 1.5 metres). The design tolerance for road settlement is understood to be 40mm per 10 metres road length (refer to Technical Report 35, Volume 3).

The question of whether or not there will be adverse effects during the operation phase relies heavily on the road surface being smooth and even, and it is understood that the design achieves this.

Vibration propagation in peat

Peat is a soft soil made up of partially decayed vegetation. When dry it is soft and springy underfoot, highly aerated and porous, and when wet it readily becomes boggy with a high level of water retention.

As a medium for vibration it is highly variable, depending on the level of water content. In the region of the proposed Expressway the water table is high and the peat is typically saturated, so much of the vibration assessment involves saturated peat.

Vibration measurements were made during the 'peat trial' works undertaken by the Project construction and geotechnical experts. These measurements were conducted specifically to obtain vibration profile data in the specific saturated peat soil type relevant to the proposed Expressway. The findings and application of data from these measurements are contained in Section 5.5.1, and added to vibration data sourced from reference documents, refer Section 5.5.3.

The results show that significant ground vibrations from construction can be generated in peat, particularly in the horizontal axes by the weight-shift of machinery, however the attenuation profile is consistent with that of soft soil, or competent soil at low frequencies (Hassan, 2006) i.e. vibration reduces with distance more than it does in hard soils or rock.

2.2. Ambient vibration surveys

The full ambient vibration assessment is contained in Technical Report 19, Volume 3.

Survey details

A programme of ambient vibration level surveys and resident questionnaires was undertaken involving 13 dwellings: 9 adjacent to the proposed Expressway route, and 4 adjacent to the existing SH1 route in areas of peaty soil (considered to be representative of the peat around the Project area).

Data from the 9 sites near the proposed Expressway alignment provides existing baseline vibration levels and subjective comments against which the operation vibration effects of the Project can be assessed. Data from the 4 'existing SH1 sites' was obtained to measure vibration levels (and the opinion of residents) in dwellings close to a high-traffic route in an area of peaty soil.

Identifying the ambient vibration level

Vibration in a dwelling structure can be generated by a range of sources, including (but not limited to):

- Occupant activities: walking, closing doors, dropping objects, stereo use etc.
- Equipment: fridges, freezers, heaters, pumps etc.

- Environmental factors: traffic, rainfall, earthquakes etc.

The primary source of interest in the ambient survey is traffic, so measures have been taken to isolate this data.

At each site, vibration measurements were undertaken simultaneously on the dwelling structure and the ground. This isolates those peaks which did not originate in the ground, and therefore are not generated by traffic. These data were removed. Then the effects of rainfall and earthquakes were addressed also, by sourcing data on these events and removing these periods from the vibration data. The arithmetic average of the remaining data represents the ambient vibration level, or the 'mean uncontaminated dwelling PPV' (refer to Appendix 18.A).

Survey results

(a) Dwellings adjacent to the Project alignment

The results from measurements at these 9 sites show that the ambient vibration environment due to existing traffic is low i.e. the mean uncontaminated dwelling PPV values did not exceed the residential perception threshold (defined in BS 5228-2:2009 as 0.3 mm/s PPV) at any site. Furthermore, most residents felt no traffic vibration in their homes and those that did were not disturbed by it.

Traffic vibration levels were often well below the vibration levels induced by activities of the occupants themselves. Nevertheless, comments from the occupants did not reflect any disturbance from these peaks, most notably at 28 Puriri Road which showed frequent and consistent high-level peaks within the dwelling. This indicates that residents can become accustomed to moderately high levels of dwelling vibration provided the source or character of the vibration is identifiable and not unexpected.

(b) Dwellings adjacent to the existing SH1 route

Vibration data measured at the 4 sites adjacent to the existing SH1 route were noticeably higher, with more frequent peaks above the threshold of perception.

The occupants of these buildings could readily feel vibrations from traffic and trains but were generally not disturbed by them, having become somewhat habituated. It follows that the same habituation would take place for residents adjacent to the proposed Expressway, however the vibration effects of the Project are expected to be better controlled by virtue of a better quality road surface.

3. Methodology

The methodology for assessing the vibration effects of this Project was divided into nine broad steps:

- Visiting the alignment to establish an understanding of the Project, identifying affected parties (in terms of their proximity to the proposed Expressway) and familiarisation with the ground conditions in the area
- Reviewing the applicability of vibration standards (if any) currently applied by Kāpiti Coast District Council, and standards used in similar projects, to vibration performance standards
- Attending public fora to discuss any concerns relating to vibration which residents may have, and to outline the approach to assessing and mitigating the effects
- Establishing, through site-measurement, the current ambient vibration conditions for receivers who may in future be affected by operation vibration from the Project, and receivers who live adjacent to the existing SH1 route
- Identifying those Project construction activities likely to generate significant vibration levels, and sourcing data for these activities through on-site measurement, historical measurements, and reference literature
- Reviewing objective data and subjective surveys of human response to heavy traffic and relating these to the proposed Expressway
- Analysing the collected vibration data and using prediction models (incorporating distance and ground attenuation effects) to calculate a risk contour for dwellings during the construction and operation of the proposed Expressway
- Identifying any sensitive receivers within the risk contours and assessing the effects on these receivers
- Outlining management tools and mitigation options for any receivers subject to vibration levels which exceed the Project criteria

4. Vibration performance standards

The scale and significance of this Project demands the adoption of practical and accepted vibration criteria to assess environmental vibration effects.

Two aspects of vibration effects are considered: the potential for damage to buildings, and the human response to vibration. Both of these effects must be considered for each of the construction and operation phases of the Project, however the risk of each effect differs by phase.

The risk of building damage exists only during the construction phase because operation vibration from proposed Expressway traffic is well below building damage thresholds (Watts, 1988). The risk of human perception issues (e.g. discomfort, sleep disturbance, loss of amenity) is most significant in the operation phase because of the ongoing nature of vibration from the completed proposed Expressway.

Whilst vibration levels produced by construction will be higher than for operation of the completed proposed Expressway, the construction phase has a finite timeframe and with effective management (through the implementation of management plans etc), the effects can be avoided and/or mitigated. Moreover, the most common concern of receivers during construction is damage to their buildings which is addressed by the building damage criteria.

The Project construction vibration criteria (Section 4.3.1) address both the human response and building damage risk aspects of the construction phase.

4.1. Review of vibration standards

There are no current New Zealand standards specifically relating to construction or traffic vibration. There is, however, a precedent for adopting selected international vibration standards which are either referenced by statutory or policy documents (i.e. district plans, NZTA policy) or have been successfully implemented in other large projects.

The relevant vibration standards are outlined in Appendix 18.B, and listed as references.

4.2. Other reference documents

Draft NZTA vibration guide

The author of this report has been involved in an NZTA working group to develop a vibration guide for the construction of roading projects.

The progressive criteria approach from the NZ Road Noise Standard NZS 6806:2010 *"Acoustics – Road-traffic noise – New and altered roads"* has been adopted for the guide, insofar as there are two distinct categories which are applied in sequence, depending on the situation.

This guide is a work in progress, and its proposed criteria are included below:

> *"**Guide to assessing vibration effects for State highway asset improvement projects***
>
> *Construction vibration and airblast shall be managed in accordance with the Category A criteria in Table C2.*
>
> *If measured or predicted vibration and airblast levels exceed the Category A criteria then a suitably qualified expert shall be engaged to assess and manage construction vibration and airblast to comply with the Category A criteria as far as practicable.*
>
> *If construction vibration exceeds the Category B criteria then construction activity shall only proceed if approved by the [territorial authority] and if there is continuous monitoring of*

vibration levels and effects on those buildings at risk of exceeding the Category B criteria, by suitably qualified experts.

Measurements of construction vibration and airblast shall be in accordance with:

a) *ISO 4866:2010 "Mechanical vibration and shock - Vibration of fixed structures - Guidelines for the measurement of vibrations and evaluation of their effects on structures"; and*

b) *AS 2187-2:2006 "Explosives – Storage and use – Part 2: Use of explosives".*

Table C2 Construction vibration and airblast criteria

Receiver	*Details*	*Category A*	*Category B*
Occupied dwellings	*Night-time 2000h - 0630h (transient vibration)*	*0.3 mm/s PPV*	*1 mm/s PPV*
	Daytime 0630h - 2000h	*1 mm/s PPV*	*5 mm/s PPV*
Other occupied buildings	*Daytime 0630h - 2000h*	*2 mm/s PPV*	*5 mm/s PPV*
All occupied buildings	*Daytime blasting – vibration* *– airblast*	*5 mm/s PPV* *120 dB L_{ZPeak}*[2]*	*10 mm/s PPV* *-*
All other buildings	*Vibration – transient (including blasting)*	*5 mm/s PPV*	*BS 5228-2*[2] Table B.2*
	*Vibration – continuous***		*BS 5228-2*[1] 50% of Table B.2 values*
	Airblast	*-*	*133 dB L_{ZPeak}*[2]*

*[1] *BS 5228-2:2009 "Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration"*

*[2] *'dB L_{ZPeak}' is the current terminology for peak decibels Linear or 'dBL'. The reference sound pressure is 20 µPa.*

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 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 above 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."*

Resource Management Act

Under the provisions of the Resource Management Act (RMA) there is a duty to adopt the best practicable option to ensure that the noise from any development does not exceed a reasonable level. Note that the definition of noise in the RMA includes vibration.

Specifically, Sections 16 and 17 reference 'noise' effects as follows.

Section 16 states that *"every occupier of land (including any coastal marine area), and every person carrying out an activity, shall adopt the best practicable option to ensure that the emission of noise from that land or water does not exceed a reasonable level"*.

Section 17 states that *"every person has a duty to avoid, remedy, or mitigate any adverse effect on the environment arising from an activity, whether or not the activity is in accordance with a rule in a plan, a resource consent or relevant sections of the RMA"*.

Local government planning documents

The Kāpiti Coast District Plan contains no criteria, nor reference to standards relating to construction or traffic vibration. Vibration is addressed only in relation to 'home occupations' where it is included as one of the matters 'over which council reserves control'.

Similarly, neither the Greater Wellington Regional Council nor the Wellington City District Council has produced statutory publications containing vibration criteria.

NZTA Environmental Plan

Section 2.12 of the NZTA Environmental Plan addresses vibration effects of State highways, and the construction and maintenance thereof. It recommends methods for assessing and addressing vibration effects, with references to NZTA Planning Policy Manual (SP/M/001) and State Highway Control Manual (SM012).

Of particular note are the Environmental Plan's references to the following vibration standards in the 'toolkit', the latter two of which are adopted for use in this Project:

- NZ/ISO 2631-2:1989
- AS 2670-2:1990
- DIN 4150-3:1999
- NS 8176.E:2005

The NZ/ISO Standard is no longer valid, as it was withdrawn by Standards New Zealand in 2005, following a 2003 revision of the original ISO Standard (ISO 2631-2:1989) which removed all assessment criteria. The AS Standard is identical to these standards, so is eliminated by association.

National Environmental Standards

Whilst there is no National Environmental Standard (NES) to control noise and vibration from construction works or traffic operation, it is noted that the NES for Electricity Transmission Activities contains reference to DIN 4150-3:1999 in clause 37.3, in relation to vibration control of construction activities relating to existing transmission lines.

4.3. Project criteria

Construction vibration criteria

There will be two distinct effects of construction vibration – human response and building damage risk – and each is assessed by different criteria.

The draft NZTA vibration guide (refer Section 4.2.1) forms the basis for the Project construction vibration criteria. The draft guide adopts criteria from DIN 4150-3:1999 and BS 5228-2:2009 (refer Appendix 18.B) in a management-based framework designed to address both human response and building damage effects. The guide applies to both construction vibration and airblast from blasting, so has been reduced and revised as appropriate to form the Project construction criteria, as follows:

Category A: adopts criteria from British Standard BS 5228-2:2009 and is designed to practically address the human response effects in dwellings during the daytime and night-time periods, and offices during the daytime. For other building types, and offices during the night-time (i.e. unoccupied), the policy reverts to the residential building damage criterion from German Standard DIN 4150-3:1999.

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

Category B: is generally designed to protect buildings against damage and adopts criteria from DIN 4150-3:1999 and BS 5228-2:2009, but retains a higher degree of night-time protection for occupied dwellings at night using human response criteria of BS 5228-2:2009.

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

Table 4.3.1 is a reduced version of Table C2 from the draft policy (refer Section 4.2.1), with aspects not relevant to the Project removed, and some clarification of terms added.

Table 4.3.1 Project construction vibration criteria

Receiver	Details	Category A	Category B
Occupied dwellings	Night-time 2000h - 0630h	0.3 mm/s PPV	1 mm/s PPV
	Daytime 0630h - 2000h	1 mm/s PPV	5 mm/s PPV
Other occupied buildings*	Daytime 0630h - 2000h	2 mm/s PPV	5 mm/s PPV
All other buildings	Vibration – continuous**	5 mm/s PPV	50% of Line 2 values in Table B.2 of BS 5228-2:2009

* 'Other occupied buildings' is intended to include daytime workplaces such as offices, community centres etc., not industrial buildings. Schools, hospitals, rest homes etc. would fall under the occupied dwellings category.

** This line addresses 'continuous' or 'long-term' vibration (as opposed to 'transient' or 'short-term' vibration – refer Appendix 18.B.1 for definitions) as there is no construction machinery proposed which produces transient vibration. The 50% modifier to values in Table B.2 of BS 5228-2:2009 is recommended in that Standard for continuous vibration sources.

These criteria are to be implemented through the CNVMP, for example through liaison with potentially-affected receivers to discuss how Category A relates to vibration perception and which machinery may produce perceivable vibration levels. Education on how vibration is perceivable at levels well below where building damage may occur is also a key message to convey.

Operation vibration criteria

The standard adopted for operation vibration of this Project is Norwegian Standard NS 8176.E:2005 *"Vibration and Shock – Measurement of vibration in buildings from land based transport and guidance to evaluation of its effects on human beings"*.

It specifically addresses transportation vibration, is referenced in the NZTA Environmental Plan, and has been adopted in other large New Zealand roading projects such as Waterview Connection and Transmission Gully. The velocity performance criteria are given in Table 4.3.2 below. The Standard contains both acceleration and velocity criteria. The velocity criteria have been adopted for ease of measurement, and consistency with the parameters in other vibration standards relating to the Project.

Table 4.3.2: Human response criteria for transport sources in NS 8176.E:2005

Type of vibration value	Class A	Class B	Class C	Class D
Statistical maximum value for weighted velocity, $v_{w,95}$ (mm/s)*	0.1	0.15	0.3	0.6

* $v_{w,95}$ = value exceeded for 5% of events (equivalent to L_{05} in noise terminology)

The majority of residences along the Project alignment would be categorised as Class C receivers, according to the Standard's classification (refer Appendix 18.B). Class C corresponds to the "recommended limit value for vibration in new residential buildings and in connection with the planning and building of new transport infrastructures" (NS 8176.E:2005) and that "about 15% of the affected persons in Class C dwellings can be expected to be disturbed by vibration."

Class C is considered to be the most appropriate criterion for the following reasons:

- It is recommended by the Standard for the planning and building of new transport infrastructures
- The vibration velocity in the Class B criterion (i.e. more stringent) is 0.15 mm/s which (notwithstanding the statistical spread) is close to the limit of perceptibility stated in BS 5228-2:2009 (refer Appendix 18.B.4). Imperceptibility is considered to be an excessive (and impractical) requirement
- The Class D criterion is lenient, and does not necessarily represent the best practicable option. The Standard states "An attempt should be made to meet Class C requirements, but Class D can be used when the cost-benefit considerations make it unreasonable to require Class C

A discussion of the Class C criterion and its correlation with annoyance ratings is included in Appendix 18.B.5.

It is noted that Appendix 18.C of the Standard addresses the combined effects of noise and vibration, including reradiated noise – i.e. vibration energy in the dwelling structure that manifests itself as a 'rattle or hum' and is heard rather than felt. It states that "no method has been found anywhere in the world for the measurement or evaluation of the total annoyance when combined effects are included".

In terms of the relationship between the two effects, it states that "vibration is perceived to be more disturbing when it occurs simultaneously with noise", but (intuitively) if the magnitude of one is perceptually higher, then that will dominate the annoyance

Note that compliance with the Norwegian criteria would also ensure compliance with the less stringent building damage criteria in DIN 4150-3:1999.

5. Construction Vibration

This section of the assessment addresses the vibration effects of the Project's construction phase. Both phases of the Project involve different vibration sources, sensitivities and effects. The construction phase is expected to generate the highest vibration levels, due to the heavy machinery used for earthworks and other activities.

The following sections identify the key construction activities, sensitive receivers, prediction of construction vibration levels, and the accuracy of these predictions. This assessment informs the processes and response management for the works in conjunction with the CNVMP.

5.1. Key construction vibration issues

The construction phase will involve the use of heavy machinery operating for periods in relatively close proximity to vibration sensitive receivers. Night-time construction may be required in certain areas, however the use of high-vibration machinery at night is not anticipated.

Table 5.1 below shows the vibration generating activities which are proposed in each Project Sector. The risk of adverse construction vibration effects from these activities is described in detail in Section 5.6.

Table 5.1: Key Construction Vibration Issues

Sector	Vibration source(s)	Locations of closest receivers
1	Vibro-hammer piling and vibroreplacement for bridge construction at Raumati Road Excavators for cut and fill operations Motor scrapers for levelling of the alignment Off-road fill transport Vibratory rollers and wheeled loaders for basecourse and sealing of the proposed Expressway and ancillary roads	Raumati Road, Leinster Avenue, Main Road (SH1), Conifer Court, Matai Road, Raumati Road
2	Excavators for cut and fill operations Motor scrapers for levelling of the alignment Off-road fill transport Vibratory rollers and wheeled loaders for basecourse and sealing of the proposed Expressway and ancillary roads	Quadrant Heights, Datum Way, Observation Place, Milne Drive, Kāpiti Road, Greenwood Place, Elder Grove, Cypress Grove, Spackman Crescent, Makarini Street, Palmer Court, Oxford Court, St James Court, Chilton Drive, Ratanui Road, Mazengarb Road
3	Excavators for cut and fill operations Motor scrapers for levelling of the alignment Off-road fill transport Vibratory rollers and wheeled loaders for basecourse and sealing of the proposed Expressway and ancillary roads	Kauri Road, Te Moana Road, Puriri Road

Sector	Vibration source(s)	Locations of closest receivers
4	Excavators for cut and fill operations Motor scrapers for levelling of the alignment Off-road fill transport Vibratory rollers and wheeled loaders for basecourse and sealing of the proposed Expressway and ancillary roads	Peka Peka Road, Te Kowhai Road

Other construction machinery and activities in addition to those listed in Table 5.1, such as pumps, generators etc. may produce some ground vibration also. However, experience has shown that adverse effects (particularly human response) are most likely to arise from the activities outlined in Table 5.1.

It is noted that the use of excavators for standard cut and fill operations is not typically associated with high vibration levels. However on soft ground such as peat, jerky movements such as quick changes of direction and shaking the bucket attachment can generate high vibration levels in the horizontal axes. This was confirmed through site measurements at the peat trials - refer Section 5.5.1. Using the excavator to compact sand (by patting with the bucket attachment) was also found to generate quite high levels.

Whilst these operations are only problematic on peat (and therefore present during initial works only), it is considered that issues can be avoided with sufficient operator training and use of alternative methods e.g. adding a plastic or other low friction lining to the excavator buckets to reduce the need for shaking, and using the weight of the machinery rather than banging the ground to compact mounds of sand or other fill materials.

There is the possibility that even low-level vibration in dwellings could result in breakage of crockery, ornaments, or pictures to fall of walls etc, but this risk depends on how well these items are secured. For example, there wouldn't be sufficient vibration to cause items to 'jump' off a shelf but if the shelf was not level they could, over time, slowly creep over the edge. Communication with residents is the key here, with suggestions that any valuables are secured during periods of high vibration.

With careful management and liaison with affected parties and implementation of the best practicable option, as per the CNVMP, vibration effects of Project construction activities can generally be controlled and or mitigated.

5.2. Construction timeframe

The overall construction timeframe for the entire Project is expected to be four years. This will comprise of the following activities:

- Preload and surcharge of peat areas (Sectors 1, 3 and 4): 3 years

- Kāpiti Road to Te Moana Road (Sectors 2 and 3): 3 years
- Southern Tie-in south of Poplar Ave (Sectors 1 and 2): 3 years
- Northern Tie-in at Peka Peka Beach Road (Sector 4): 3 years

No significant vibration-inducing machinery is proposed for use at night-time.

5.3. Construction Noise and Vibration Management Plan (CNVMP)

The Construction Noise and Vibration Management Plan (CNVMP) will form part of a comprehensive suite of environmental controls within the Construction Environmental Management Plan (CEMP) for the construction phase of the Project.

The CNVMP addresses the potential construction noise and vibration effects associated with the construction of the Project and identifies the standards that must be complied with (i.e. the Project criteria, refer Section 4.2) as well as best practicable options for noise and vibration management.

It is intended as a framework for the development of particular control practices and procedures to minimise effects on health and safety and to reduce the impact on the environment. It should be updated throughout the course of the Project to reflect material changes to construction techniques or the natural environment.

A CNVMP has been developed for this Project (refer to Appendix F of the CEMP, Volume 4).

An outline of the recommended CNVMP contents is summarised below:

- The construction noise and vibration project criteria
- Hours of operation, including times and days when high-vibration machinery would be used
- List of machinery to be used
- Requirements for vibration measurements of relevant machinery prior to construction or during their first operation, to confirm risk contours
- Requirements for building condition surveys of critical dwellings prior to and after completion of construction works, and during the works if required
- Requirements for identifying any existing infrastructure assets (services, roads etc) which may be at risk of vibration induced damage during construction
- Roles and responsibilities of personnel on site
- Construction operator training procedures, particularly regarding the use of excavators
- Construction noise and vibration monitoring and reporting requirements
- Mitigation options, including alternative strategies where full compliance with the Project Criteria cannot be achieved
- Management schedules containing site specific information
- Methods for receiving and handling complaints about construction noise and vibration (the draft CNVMP (CEMP Appendix F, Volume 4) also presents this as a flow diagram)

- Procedure for managing vibration damage to existing services such as roads and underground pipelines

5.4. Sensitive receivers

As discussed in Section 1.1, the primary consideration relating to construction vibration effects is that of building damage. The vast majority of buildings adjacent to the Project construction footprint are dwellings, so the assessment focuses primarily on these receivers. Some buildings may themselves be vibration-sensitive due, for instance, to foundation on peat. This issue is to be managed and controlled by the CNVMP.

Notwithstanding this, the effect of vibration on building occupants is also assessed. Buildings whose occupants are generally considered to be sensitive to construction vibration effects include residences, schools, offices, churches, rest homes, historic structures, hospitals and buildings which may contain vibration-sensitive equipment such as scientific or medical laboratories.

The criteria for human response to construction are in Category A of the Project criteria, and are based on BS 5228-2:2009. For temporary construction activities, higher vibration levels will generally be tolerated – if sensitive receivers are well informed of construction activities and consider that the construction operation is well controlled and managed (i.e. through the CNVMP) – because their concern over potential damage to their building can be mitigated.

Waahi Tapu Area

Between approximately chainage 10900m and 11100m, the proposed Expressway passes on the west side of the Maketu tree and to the east of the Urupa. These are understood to be burial grounds and there has been some concern over the vibration disturbance of the remains in these locations during the construction phase.

Neither the author nor the Project's Archaeological Expert are aware of any suitable performance standards nor collected data to assess the effects of vibration on buried remains (refer to Technical Report 9, Volume 3). However, the issue may be approached with the following considerations:

- The soft ground in these areas (particularly the areas of saturated peat) will serve to envelop and protect any buried remains in a liquid suspension
- Attempting to quantify or observe any effects on buried remains (e.g. through digging or uncovering) would likely generate more disturbance than any vibration effects
- Liaison with the Takamore Trust during the construction phase is essential, to ensure any concerns over this issue are addressed
- The issue can be managed through the CNVMP

5.5. Vibration prediction

The following sections describe the procedure for predicting vibration levels from construction activities. The outcomes of these predictions are given in Section 5.6, in terms of the risk of each activity exceeding the Project criteria at identified receivers.

Peat trials

Measurements of construction equipment were undertaken at 155 Greenhill Road, Peka Peka on 31st May, 1st June and 3rd June 2011. The purpose was to measure actual machinery proposed for use in the Project construction undertaking works in peaty soils.

Measurements were undertaken using two Instantel Minimate seismographic loggers[1] each with two tri-axial geophones (fixed to the ground with groundspikes and sandbags or buried in the ground) in a linear array extending out from the vibration source. The following operations were measured:

- 21 tonne excavator digging and filling in saturated peat soil
- 21 tonne excavator patting sand with bucket attachment(for testing purposes only)
- 21 tonne excavator shaking its bucket (for testing purposes only)
- 28 tonne wheeled dozer driving back and forth, spreading and compacting sand
- 14 tonne vibrating roller compacting sand

The measured levels have been processed and the regression curves are given in Appendix 18.C.

There were two important observations made during the peat trial measurements.

The first is that when the excavator was working in peat, the primary vibration source was the ‘wobble’ of the machine when rotating or shaking its bucket. The ground was so soft that the ground-bucket interaction generated virtually no vibration at all.

The two excavator measurements undertaken ‘for testing purposes only’ involved the excavator making exaggerated movements specifically to generate the maximum vibration possible. As noted in Section 5.1, use of excavators in this manner is not expected (and should specifically be avoided) when working on site.

The second observation was that the vibrations measured in peat were usefully attenuated when the machines were working in sand, presumably because the sand’s mass provides an inertia base and there is an impedance barrier at the sand-peat interface.

[1] 1) Instantel Minimate Pro6 (S/N MP12633) with 2 tri-axial geophones (S/N SD12580, SD12581)
2) Instantel Minimate Plus (S/N BE9167) with 2 tri-axial geophones (S/N BG8325, BG8326)

These observations facilitate development of some best-practice management techniques in the CNVMP to minimise unnecessary vibration during the construction period.

Neither motor scrapers nor off-road trucks were available for testing in the peat trials. Typical motor scraper operation is similar to that of an excavator and wheeled loader so their data is used to represent this source. Similarly, wheeled loader data can be reasonably used to represent off-road trucks.

Prediction methodology

The basic prediction model for vibration propagation with distance is:

$$PPV = K(D/E^{1/2})^{-n} \quad \text{--- (1)}$$

Where:

K = the ground transmission constant (for a given ground type)

D = Distance from source to receiver

E = Energy of source

n = empirical constant based on a number of factors such as the geology, ground profile, frequency of transmitted wave, predominant waveform. The value of n is obtained from regression analysis and for the peat trials had a value between 0.5 and 1.5.

For a given vibration source, it may be assumed that the energy delivered into the ground is constant (over a sufficient timescale), therefore the equation reduces to:

$$PPV = K \cdot D^{-n} \quad \text{--- (2)}$$

This prediction method is elaborated in Hassan, 2006 (refer to References) which, unlike many other methods, contains frequency-dependant ground attenuation formulae. This method yields slightly more conservative results than other texts such as Gutowsky & Dym (1976) and Nelson (1987) so is considered preferable in effects assessments.

This same vibration prediction methodology was utilised in the Waterview Connection Project.

Vibration source data

Vibration data for high-vibration construction machinery has been obtained from two references including:

- Site-specific measurements at the ‘peat trials’ undertaken by the Project construction and geotechnical teams at Greenhill Road

- British Standard BS 5228-2:2009, Annex C (piling only)

The peat trial measurements provide the most ideal source as they are site specific, including the actual ground type and equipment to be used on the Project.

All data (measured and acquired) with a sample size of more than 6 measurements have been assembled, and regression analysis has been undertaken to establish propagation trends. The datasets from BS 5228-2:2009 display a huge variance due to equipment type, soil conditions and measurement location, however there is insufficient information provided to allow filtering, so all available data has been used in the regression analysis.

The regression curves (refer Appendix 18.C) enable ‘risk contours’ to be established by examining the distance that corresponds to a peak particle velocity of 5 mm/s, (being project criterion for residential building damage).

To ensure conservative estimates of risk contour, a safety factor of 2 (as recommended by Hunt et al., 2010) has been added to the regression curves until such time as on-site testing can be undertaken to refine the prediction model.

Section 5.6 gives the predicted risk contour for each item of high-vibration machinery, and the corresponding buildings along the proposed Expressway alignment at risk of exceeding the Project construction criterion.

Prediction accuracy

Vibration prediction is less reliable than noise prediction. The primary difficulty is being able to accurately model ground conditions that are non-homogeneous and complex in three-dimensions, and consequently difficult to quantify on site.

As discussed in Section 5.5.3, vibration prediction models are purported by Hunt et al., (2010) to only achieve accuracy to within ± 100% at best (i.e. doubling or halving).

With regards to ground type, the peat trial measurement data is ideal because it was obtained in ground conditions relevant to the project. The attenuation profiles measured in the peat trials are consistent with the values for ‘soft soils’ contained in Hassan (2006), except at low frequencies (i.e. below 15 Hz) where it acts more like a ‘competent soil’.

The vibration data sourced from other MDA measurements and BS 5228-2:2009 involves a range of sources, ground types and measurement locations which cannot all be practicably normalized. In any case, the Project involves soft and competent soils (i.e. peat and sand respectively) so data measured in consolidated and hard soils make for conservative predictions.

Additional variables include, but are not limited to, machine type (and consequently the energy delivered into the ground), operating mode, operator skill, the presence of submerged solid objects (e.g. boulders), measurement technique and apparatus accuracy.

The CNVMP should require that the first instance of each high-vibration machineis accompanied by vibration measurements, as appropriate, to assess compliance with the Project criteria, and build up a site-specific profile of risk contours for each operation.

Transmission of ground vibration into buildings

The transmission efficiency of vibration from the ground into buildings is dependent on the soil type and characteristics of the building foundations. Nelson (1987) notes four basic building foundation types: slab-on-grade, spread footings, piles founded on earth and piles supported by rock.

This is a crucial aspect for this Project because peat does not provide stable soil conditions for building. Any dwelling not founded on a more stable base than peat (i.e. a suitable sand building platform or piles which extend down to a layer of sand) is at risk of differential settlement which may lead to building or property damage. For any such dwellings, vibration from construction works may accelerate settlement and cause damage. This is not a vibration issue as such, rather a structural issue brought about by a geotechnical issue, which is exacerbated by vibration.

The vast majority of residential dwellings adjacent to the proposed Expressway are understood to be either slab-on-grade, or piles founded on earth (sand, not peat). Nelson states that the coupling loss for slab-on-grade construction is zero and the coupling losses for pile foundations (labelled as single family residences) are as shown in Table 5.5.5 below:

Table 5.5.5: Coupling losses for vibration into buildings, from Nelson (1987)

	Frequency (Hz)					
	16	31.5	63	125	250	500
Corresponding multiplication factor for PPV value	0.6	0.6	0.6	0.6	0.7	0.9

This trend is supported in the Assessment of Ground Settlement Effects Report (Technical Report 35, Volume 3) i.e. that dwellings with piles in sand are less susceptible to damage than those with a concrete slab on sand, which are less susceptible than any with foundations in peat.

For the assessment of effects however, it is pragmatic to assume the coupling loss is zero, so the predictions in Section 5.6 below conservatively assume no attenuation due to transmission into buildings. This does not preclude the potential for vibration-induced settlement for any dwellings which may have foundations in peat.

5.6. Risk assessment criteria

The assessment of vibration effects is based on a 'risk assessment' of construction activities. The risk assessment requires a threshold, above which effects are to be considered potentially significant. The most pragmatic threshold is the residential building damage criterion from DIN 4150-3:1999, as it is widely utilised for this purpose and addresses the most common concern of residents during the construction period.

Therefore the risk assessment criterion is 5 mm/s PPV, measured on the foundation of any residential building.

It should be noted that exceedance of this criterion only increases the risk, it does not imply certainty that building damage will occur. BS 5228-2:2009 sets limits as high as 50 mm/s at certain frequencies, before building damage is considered to be a concern.

It is well known that DIN 4150-3:1999 is a conservative Standard, designed to avoid *all* damage to buildings i.e. even superficial damage like cracking in plaster. Significantly greater limits would be applied for damage to structural foundations.

Notwithstanding this, the CNVMP should contain the Project criteria from Table 4.3.1 in full, so that the full range of potential vibration effects of the Project construction are considered and subsequently managed.

5.7. Risk of construction vibration effects by sector

The following Sections 5.7.1 – 5.7.4 outline the identified high-vibration machinery to be used in each Project Sector with a list of 'risk contours', which indicate the distance at which each vibration source is expected to comply with the risk assessment criterion of 5 mm/s PPV (refer Section 4.3.1).

The closest receivers to each vibration source have been identified and categorised as high or medium risk of exceeding the criterion, according to the following definitions:

- High Risk – Dwellings where vibration levels are likely to exceed the risk assessment criteria. This does not necessarily imply damage to the building structure, but these are the receivers subject to the highest vibration levels.
- Medium Risk – These dwellings are close to the risk contour and some construction activities may produce vibration levels close to the risk assessment criteria, with possible intermittent exceedance
- Others – No significant risk.

These risk levels also inform the community liaison process in the CNVMP.

The distances from the construction footprint to receivers were scaled off aerial photographs provided by the Project team. A visual judgement was made on which buildings are residences (as opposed to garages, carports etc). The dwellings that are proposed to be removed as part of the Project are excluded from the tables in Sections 5.7.1 – 5.7.4.

In addition, a set of construction risk diagrams (aerial maps with 'cloud markings' to indicate these areas) has been developed, refer Appendix 18.D.

As discussed previously, these predictions are not accurate enough to establish control lines and the tables below are primarily intended to inform the construction contractor of 'hotspots' where particular care is required. As recommended in the CNVMP, data from on-site vibration measurements should be used to refine the risk contours and risk levels.

Note that the receivers given in the following Sections are property addresses so, unless specified otherwise, any ancillary buildings on those sites (i.e. garages, sheds etc.) may be subject to some vibration risk, albeit reduced because they do not generally have plasterwork or delicate paintwork.

Also, there are a number of residential swimming pools on properties adjacent to the Project alignment. These are not covered by the risk assessment criterion however the risk of damage to the pool structure is noted, particularly for those directly adjacent to the boundary. This issue should be addressed in the CNVMP.

Sector 1: Raumati South

Table 5.7.1: Risk assessment for construction activities in Sector 1

Source	Risk contour (m)	Risk level	At risk receivers
Piling: Vibro-hammer or cast-in-place methods only	19m	Med	90 Raumati Road
Vibratory rollers	16m	High	106, 107, 108, 112 Leinster Avenue 240 Main Road (front house) 10, 12 Conifer Court 110 Raumati Road
		Med	105 [+garage] Leinster Avenue 2 eastern-most dwellings of 260 Main Road subdivision (Shalom village) 218B Matai Road 90 Raumati Road
Excavators (digging and tracking) Wheeled loaders Motor scrapers Off-road trucks	8m	High	106, 107, 112 Leinster Avenue 240 Main Road (front house) 12 Conifer Court
		Med	105 [garage] 108 Leinster Avenue 10 Conifer Court 218B Matai Road 90, 110 Raumati Road

Sector 2: Raumati/Paraparaumu

Table 5.7.2: Risk assessment for construction activities in Sector 2

Source	Risk contour (m)	Risk level	At risk receivers
Vibratory rollers	16m	High	29, 39, 41 Quadrant Heights 21, 23, 24, 26 Observation Place 51, 55, 59 Milne Drive 84, 86, 88, 90, 92, 94 Kāpiti Road 13, 15, 15A, 17, 18 Greenwood Place 7, 8, 8A, 9, 9A Elder Grove 14B, 16B, 22, 24, 28B Cypress Grove 15, 33, 35, 37B Spackman Crescent 63A, 63B, 65–93 (odd numbers only), 97B, 99B, 105, 107 Makarini Street 6B, 8, 8B, 10, 14, 16, 18A, 18B, 24 Palmer Court 4, 6, 8, 10, 12 Oxford Court 9 [+pool], 11, 15, 24 St James Court 20, 22, 37B, 41 [pool], 45 Chilton Drive 345, 353 Mazengarb Road
		Med	45, 47 Quadrant Heights 17 Datum Way 15, 27 Observation Place 5 Elder Grove garage 18 [garage], 20B [+garage], 26, 28A Cypress Grove 17, 21, 25 [+garage], 27 [+garage], 29, 31, 37A Spackman Crescent 95, 97A Makarini Street 2/24, 3/24, 26-34 & 42-50 (even numbers only) Cheltenham Drive 12 Palmer Court 37A Chilton Drive

Source	Risk contour (m)	Risk level	At risk receivers
Excavators (digging and tracking) Wheeled loaders Motor scrapers Off-road trucks	8m	High	29 Quadrant Heights 21, 23, 24, 26 Observation Place 51, 55, 59 Milne Drive 84, 86, 88, 90, 92, 94 Kāpiti Road 13, 15, 15A, 17, 18 Greenwood Place 7, 8A, 9, 9A Elder Grove 14B, 16B, 28B Cypress Grove 35, 37B Spackman Crescent 63A, 63B, 77, 97B, 99B, 105, 107 Makarini Street 6B, 8B, 18A, 18B Palmer Court 4, 6, 8, 10, 12 Oxford Court 9 [+pool], 11, 15 St James Court 20, 22 Chilton Drive 60A Ratanui Road
		Med	39, 41 Quadrant Heights 8 Elder Grove 18 [garage], 20B [garage], 22, 24 Cypress Grove 15, 25 [garage], 27 [garage], 33 Spackman Crescent 65–75 & 79-93 (odd numbers only), 97B, 99B, 105, 107 Makarini Street 8, 10, 14, 16 Palmer Court 24 St James Court 37B, 41 [pool], 45 Chilton Drive

It is noted that the proposed Expressway construction envelope is very close to a number of commercial premises in Milne Drive, Kāpiti Road, Sheffield Street and Manchester Street.

The vibration damage criteria for commercial premises are significantly higher than for residences, however due care and management will be required because of the proximity. Vibration criteria for these buildings are contained in the Project criteria, refer Table 4.3.1.

Sector 3: Otaihanga/Waikanae

Table 5.7.3: Risk assessment for construction activities in Sector 3

Source	Risk contour (m)	Risk level	At risk receivers
Vibratory rollers	16m	High	18 [+pool], 20, 23 Kauri Road
		Med	131 Otaihanga Road 25A Kauri Road (El Rancho building)
Excavators (digging and tracking) Wheeled loaders Motor scrapers Off-road trucks	8m	High	18 [pool], 23 Kauri Road 145, 190B Te Moana Road
		Med	150 Otaihanga Road 49, 61 Killalea Place 18 Kauri Road 31, 53 Puriri Road 145A, 164 (two dwellings) Te Moana Road

Sector 4: Waikanae North

Table 5.7.4: Risk assessment for construction activities in Sector 4

Source	Risk contour (m)	Risk level	At risk receivers
Vibratory rollers	16m	High	31 Peka Peka Road
		Med	20 Peka Peka Road
Excavators (digging and tracking) Wheeled loaders Motor scrapers Off-road trucks	8m	High	20, 31 Peka Peka Road
		Med	27 Te Kowhai Road

5.8. Assessment of construction effects

The effects of construction vibration involve large variables, predominantly with regard to different construction methods, vibration source energies, variable ground types, the behaviour of vibration waves through this inhomogeneous medium, and the foundation type of a receiver.

The significant vibration sources and most sensitive receivers for each Sector have been predicted, and conservative calculations of risk contour distances have been undertaken.

These results are provisional however, and must be refined and supported by site-specific measurements once construction begins, as recommended in the CNVMP. For crucial activities such excavating, vibratory compacting and pile driving, measurements of the initial works are recommended.

As the repository of on-site measurements increases, the risk categories can be refined and improved controls can be achieved.

The initial predictions indicate that in all Sectors there is the likelihood that the risk assessment criteria will be exceeded by construction activity. Tables 5.7.1 – 5.7.4 above outline the risk level associated with activities proposed for each Sector, and identify the sensitive receivers that would be affected by such activities. Sector 2 contains the highest number of at-risk receivers, by a significant margin.

There are not known to be any vibration sensitive or multi-storey buildings near the proposed Expressway, however building damage due to foundation settlement is a real risk particularly for any dwellings with foundations on peat. It is anticipated that this effect would be handled on a case-by-case basis through the management procedures in the CNVMP.

Note that construction vibration may be felt at locations further from the proposed Expressway than listed in Tables 5.7.1 – 5.7.4. These effects can be managed by the Category A Project criteria through the CNVMP.

The draft CNVMP (CEMP Appendix F, Volume 4) sets out the Project criteria for control of construction activities, reiterates the risk analysis from Section 5.6, and provides details on mitigation measures that must be adopted throughout the entire Project construction.

The issue of re-radiated noise (refer Section 4.3.2) is not addressed in any known standard. The magnitude varies considerably from structure to structure due to the complexity of building junctions and variance in building materials. It is anticipated that this effect would be handled on a case-by-case basis through the complaint management procedures in the CNVMP.

In summary, vibration from construction activities is expected to comply with the Project criteria for the majority of receivers along the proposed Expressway alignment. Where there is a risk of exceedance, measurements of the identified high-vibration machinery should be undertaken prior to construction to refine the risk contours. All remaining at risk receivers shall be protected by adopting best practicable options for the construction phase, in conjunction with liaison and monitoring implemented through the CNVMP to control and mitigate any effects.

6. Operation Vibration

This section of the assessment addresses the operational vibration effects of the Project. That is, the vibration from traffic – in particular, heavy vehicles - using the new proposed Expressway once completed.

6.1. Key operation vibration issues

The main anticipated vibration issue from the completed proposed Expressway would be from heavy vehicle movements (e.g. trucks with a gross weight above 3,500kg[2]) passing over imperfections in the road surface.

Previous measurements of truck movements undertaken adjacent to a relatively new and smooth quality road surface (OGPA) (refer Section 6.3) showed that if there are no significant imperfections, there is no significant vibration.

Therefore, the question of whether or not there will be adverse effects during the operation phase relies heavily on the quality of the road surface. The assessment tool for operational vibration is Norwegian Standard NS 8176.E:2005, which is included in the Project criteria.

The proposed Expressway is understood to be predominantly OGPA, except at the northern end from chainage 15100 to the northern tie-in, which will be chip seal (refer to Technical Report 15, Volume 3). There is a difference in roughness between these surfaces, but the effect of this on vibration production is minor compared to that of bumps and dips. The most common vibration issue arises when repairs, particularly backfilled trenches, are carried out poorly.

Road surface maintenance is a policy issue for both pavement types, and there is an existing NZTA framework to ensure the pavement of the proposed Expressway does not degrade below a certain level of roughness. In New Zealand this roughness is categorised using the National Association of Australian State Road Authorities (NAASRA) method which uses a surface profiling machine to evaluate the state of the road surface. It is understood that State highways will generally be resurfaced for roads with NAASRA counts greater than 70 counts/km[3].

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[2] This vehicle weight is stated in Norwegian Standard NS 8176.E:2005

[3] NZTA Network Operations Technical Memorandum No. TNZ TM 7003 v1 “Roughness Requirements for Finished Pavement Construction”, 2006.

There are no anticipated building damage effects in the operation phase.

6.2. Sensitive receivers

The sensitive receivers for the operation phase of the Project are the same for the construction phase outlined in Section 5.4, i.e. residences, however the focus is shifted from effects on building structure to effects on human comfort, which may include annoyance, sleep disturbance etc.

6.3. Operation vibration levels

The assessment of vibration effects for the operation phase is based on four site measurements of heavy vehicle movements, as follows:

1. On the living room floor of 174 Main Road, Raumati South, 36m from the existing SH1 route (18th July 2011). The road surface is well worn chip seal
2. On the bathroom floor of 158A Main Road, Raumati South, 15 metres from the existing SH1 route (11th July 2011). The road surface is well worn chip seal
3. On the ground, 10m from the SH20 Mt Roskill alignment, Auckland (5th March 2010). At the time of measurement, the OGPA road surface was 10 months old, with a NAASRA count of 25 counts/km.
4. On the ground, 25m from Quarry Road, Drury, Auckland (13th January 2010). The road surface was dilapidated chip seal

Sites 1 and 2 provide vibration data for heavy vehicles on a well-used road surface in peaty soil similar to the proposed Expressway geology, whilst sites 3 and 4 provide data for heavy vehicles for the extremes of new and dilapidated road surfaces in competent soil (which is equivalent to compacted sand according to Hassan (2006)).

The measurements were undertaken generally in accordance with Norwegian Standard NS 8176.E:2005 which also contains the vibration criteria for the operation phase, refer Section 4.3.2. The measurement results are shown in Table 6.3. Note that the $v_{w,95}$ values are not peak velocities, and involve RMS (root-mean-square) averaging and slow time-weighting. They cannot, therefore, be compared directly with the measured dwelling data in the existing ambient survey (refer Section 2.2).

Table 6.3: Heavy vehicle measurements adjacent to two State Highways, classified according to NS 8176.E:2005

Location		Measurement Position	No. of heavy vehicles measured	Statistical weighted velocity $v_{w,95}$ (mm/s)	Dwelling Class
1	174 Main Rd, Raumati South	Living room floor 34m to road edge	22	0.06	A
2	158A Main Rd, Raumati South	Bathroom floor 15m to road edge	6*	0.09	A
3	SH 20 Mt Roskill, Auckland	On ground 10m to road edge	17	0.01	A
4	Quarry Road, Drury, Auckland	On ground 25m to road edge	15	0.18	C

* Note that 6 truck passes is less than the 15 required by the Standard, so the $v_{w,95}$ for this dataset is indicative only.

The Project criterion for operation vibration is a maximum $v_{w,95}$ of 0.3 mm/s (refer 0), so these measurements all comply with the criteria.

For the measurements adjacent to the existing SH1, vibrations from truck passes were not discernible by the technician undertaking the tests. This is at odds with the comments received from the occupiers of these buildings, but is in line with the measured levels and the corresponding descriptions of human response in NS 8176.E:2005.

A calculation of the effect of ground type and distance has been undertaken using the method in Hassan (2006) (refer Section 5.5.2) to identify compliance distances associated with truck movements in ground conditions relating to the Project.

This calculation indicates that, for worn chip seal roads the Project criterion of $v_{w,95}$ 0.3 mm/s would be exceeded for distances less than approximately 15 metres from the road edge. There are no dwellings this close to the proposed Expressway edge (the garage of 18 Greenwood Place is 13 metres, but is not a habitable space).

For a newly sealed OGPA pavement, the risk contour is less than 2 metres from the road edge which clearly outlines the importance of road surface maintenance. There are no receivers this close to the proposed Expressway edge and at the closest dwelling (51 Milne Drive) the vibration would be expected to be less than 0.05 mm/s (around 6% percent chance of disturbance, according to NS 8176.E:2005). The effect on all other receivers along the route would be less than this.

6.4. Assessment of operation effects

An assessment of vibration effects from the operation phase of the Project has been undertaken in the following manner:

- Measurement of heavy vehicle movements on various road surface and ground types (including peat), according to the NS 8176.E:2005 Standard
- Assessment of the effect of ground type and distance on these measurements to establish the minimum risk contour for a new and dilapidated road surface

The operation effects of vibration from the proposed Expressway are expected to be negligible (i.e. very unlikely to cause annoyance), provided the proposed Expressway road surface is monitored and maintained in accordance with the NZTA policy for road roughness. This policy is the primary mitigation tool, and the best practicable option for avoiding and mitigating operational vibration effects.

This does not imply that residents adjacent to the proposed Expressway will not feel traffic vibration (there is a small likelihood that the closest receivers may be affected), rather the vibrations will be at a level deemed by the most appropriate Standard for human response to traffic vibration to be acceptable. Vibration monitoring may be undertaken on a case-by-case basis if complaints of traffic vibration are received.

In summary, the operation vibration effects are predicted to be negligible provided the road surface of the proposed Expressway is maintained according to NZTA policy.

7. Summary and Conclusions

A detailed assessment of construction and operation vibration effects has been undertaken for the MacKays to Peka Peka Expressway Project. The assessment has identified and quantified potential vibration risks associated with construction activities and the likelihood of ongoing effects from traffic vibration during operation.

The assessment of effects draws on data obtained through on-site measurements of existing vibration environments, construction activities and heavy vehicle movements with supplementary information obtained through the review and implementation of historical vibration measurements and the use of empirical prediction models.

The Project criteria for the construction phase address both building damage and human response, and are based on the draft policy of an NZTA working group in which the author of this report is involved. The criterion for the risk assessment is based on conservative building damage criteria, because this is the primary concern of residents during construction.

It is anticipated that the Project's most significant vibration effects are likely to come from the use of vibrating rollers in Sector 2 between Kāpiti and Mazengarb Roads, because of the close proximity to a large number of residences.

Predictions of construction vibration levels indicate that the risk assessment may be exceeded in every Sector of the Project. The development of a Construction Noise and Vibration Management Plan (CNVMP) is recommended as the tool to ameliorate this risk, and should outline the methodology for implementing the full Project criteria and assessing, managing and mitigating the Project construction effects.

The assessment of human response to vibration, which is most relevant to operation effects once the Project is complete, is based on measurements in accordance with the Norwegian Standard NS 8176.E:2005. The operation vibration effects are predicted to be negligible, provided the road surface of the new proposed Expressway is maintained in accordance with NZTA standard policy.

These assessments lead to the following recommendations:

- A Construction Noise and Vibration Management Plan (CNVMP) should be developed, with contents in accordance with Section 5.3 of this assessment. A CNVMP has been developed – refer to Appendix F of the CEMP, Volume 4
- The Project construction must be measured and assessed in accordance with the standards contained in the Project criteria – refer Section 4.3.1
- The road surface of the new proposed Expressway must be maintained in accordance with NZTA standard policy, in order to avoid vibration issues from heavy traffic

Overall, it is considered that the MacKays to Peka Peka Expressway Project can be constructed and operated such that adverse vibration effects can generally be avoided, remedied or mitigated using best practicable options to achieve compliance with the Project criteria.

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Appendix 18.A

Glossary of Terms

Appendix 18.A – Glossary of Terms

Ambient vibration	The existing vibration at a given receiver location. Includes any and all vibration sources in the vicinity of the receiver i.e. traffic vibration for houses adjacent to existing roads
BS 5228-2:2009	British Standard BS 5228-2:2009 "Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration". This is the standard adopted for this Project to assess human response to construction
DIN 4150-3:1999	German Standard DIN 4150-3:1999 "Structural Vibration – Part 3: Effects of vibration on structures". This standard is generally adopted in NZ to assess building damage.
PPV	Peak Particle Velocity, measured in mm/s. This is the standard metric for assessing construction vibration levels.
Risk contour	The closest distance to a vibration source at which a measurement would be expected to comply with the risk assessment criteria

Appendix 18.B

Vibration Standards

Appendix 18.B – Vibration Standards

B.1 DIN 4150-3:1999

The use of German Standard DIN 4150-3:1999 *"Structural vibration – Part 3: Effects of vibration on structures"* is widespread in New Zealand and it has a history of successful implementation in projects involving construction activities[4].

The Standard adopts the Peak Particle Velocity (PPV) metric and gives guideline values which, "when complied with, will not result in damage that will have an adverse effect on the structure's serviceability."

The guideline values are different depending on the vibration source, and are separated on the basis of short-term and long-term vibration. The standard defines short-term vibration as "vibration which does not occur often enough to cause structural fatigue and which does not produce resonance in the structure being evaluated". Long-term vibration is defined as all other types of vibration not covered by the definition of short-term vibration.

Pragmatically, the short-term vibration definition applies to activities which follow the form of a single shock followed by a period of rest such as blasting, drop hammer pile-driving (i.e. non-vibratory), dynamic consolidation etc. All other construction activities (including the majority of those proposed for this Project) would be categorised as long-term.

Traffic may be categorised as either, depending on the nature of the vibration i.e. vibration from consistent (but rough) road surface may be long-term, whereas a road with a bump in the pavement may generate a short-term vibration event.

The criteria for short-term and long-term vibration activities, as received by different building types, are summarised in Table B.1 below which is a combination of Tables 1 and 3 of the Standard:

[4] Waterview Connection, State Highway 20 Avondale, Vic Park Tunnel, State Highway 18 Greenhithe, Northern Busway, Auckland War Memorial Museum

Table B.1: Summary of Building Damage criteria in DIN 4150-3:1999

Type of structure	Short-term vibration				Long-term vibration
	PPV at the foundation at a frequency of			PPV at horizontal plane of highest floor (mm/s)	PPV at horizontal plane of highest floor (mm/s)
	1 - 10Hz (mm/s)	10 - 50 Hz (mm/s)	50 - 100 Hz (mm/s)		
Commercial/Industrial	20	20 – 40	40 – 50	40	10
Residential/School	5	5 – 15	15 – 20	15	5
Historic or sensitive structures	3	3 – 8	8 – 10	8	2.5

The standard also contains criteria for buried pipework of different materials and the effects of vibration on floor serviceability, as well as guidelines for measurement of vibration in buildings i.e. placement and orientation of the transducers.

It should be noted that these criteria are designed to avoid *all* damage to buildings i.e. even superficial damage like cracking in plaster. Significantly greater limits would be applied for damage to structural foundations.

B.2 BS 6472-1:2008

The British Standard BS 6472-1:2008 *"Guide to evaluation of human exposure to vibration in buildings – Part 1: Vibration sources other than blasting"* is not widely adopted in New Zealand, but has advantages in the assessment of operational vibration effects due to its dose-response metric Vibration Dose Value (VDV).

VDV is calculated from the frequency-weighted vibration acceleration (weighted according to the W_b or W_d curves for vertical and horizontal acceleration respectively), which is integrated over the day or night time period. Table 1 of the Standard contains VDV ranges which may result in adverse comment in residential buildings, and is copied in Table B.2 below:

Table B.2 Vibration dose value ranges which might result in various probabilities of adverse comment within residential buildings

Place and time	Low probability of adverse comment $ms^{-1.75}$	Adverse comment possible $ms^{-1.75}$	Adverse comment probable $ms^{-1.75}$
Residential buildings 16 h day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8 h night	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

NOTE For offices and workshops, multiplying factors of 2 and 4 respectively should be applied to the above vibration dose value ranges for a 16 h day."

There is however some controversy surrounding the use and usability of VDV. Its calculation method is complex and results in values with the rather maladroit units of $ms^{-1.75}$. Additionally, for continuous vibration (such as motorway traffic), the "estimated VDV" metric eVDV is recommended in place of VDV. The correlation between VDV and eVDV for the same data set is variable, and relies heavily on the event period used in the calculation.

The Institute of Acoustics (UK) has undertaken comparison studies of the two parameters, and concludes that eVDV is generally a reliable estimate of VDV provided the crest factors for transient signals are calculated correctly, and that the constant 1.4 in the eVDV equation is not necessarily correct and should be derived for a given signal (e.g. a value of 1.11 should be used for a sinusoidal signal) (Greer et al, 2005).

This Standard is not known to have been adopted in New Zealand.

B.3 BS 7385-2:1993

The second part of the BS 7385 series – BS 7385-2:1993 *"Evaluation and measurement for vibration in buildings – Part 2. Guide to damage levels from groundborne vibration"* sets vibration limits for building structures based on an extensive review of international case histories. The introduction states that despite the large number of UK case studies involved in the review, "very few cases of vibration-induced damage were found".

The criteria, also in PPV, are contained in Table 1 of the Standard, which is copied in Table B.3 below:

Table B.3 – Transient vibration guide values for cosmetic damage in BS 7385-2:1993

Line	Type of building	Peak component particle velocity in frequency range of predominant pulse	
		4 Hz to 15 Hz	15 Hz and above
1	Reinforced or framed structures Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structures Residential or light commercial type 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

NOTE 1. Values referred to are at the base of the building (see 6.3)

NOTE 2. For line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded.

These criteria relate predominantly to transient vibration, and the standard suggests that the criteria "may need to be reduced by up to 50%", especially at low frequencies. Notwithstanding this, the criteria are 3 to 10 times higher (i.e. less stringent) than those in DIN 4150-3:1999.

Note that there is no consideration for historic or sensitive structures in the above table. This is addressed in Section 7.5.2 which states:

> *"7.5.2 Important buildings*
>
> *Important buildings which are difficult to repair may require special consideration on a case-by-case basis. A building of historical value should not (unless it is structurally unsound) be assumed to be more sensitive."*

Note that 'peak component particle velocity' refers to the maximum PPV of the three orthogonal axes (longitudinal, transverse or vertical), also known as peak vector sum (PVS).

This approach to historic structures is quite different to that of the DIN 4150-3:1999 Standard which is less definitive with its definition of such buildings and more stringent in its criteria.

B.4 BS 5228-2:2009

The British Standard BS 5228-2:2009 *"Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration"* is a comprehensive and voluminous standard covering many aspects of prediction, measurement, assessment and control of vibration from construction works.

In terms of vibration criteria, this Standard contains references to, and reiterates the criteria from BS 6472 (human response) and BS 7385 (building damage), which are described in Sections 2.6, 2.7 and 4.2, 4.3 respectively).

However Annex B of the Standard addresses human response to construction vibration and suggests that BS 6472 may not be appropriate. It states:

> *"BS 6472, as stated, provides guidance on human response to vibration in buildings. Whilst the assessment of the response to vibration in BS 6472 is based on the VDV and weighted acceleration, for construction it is considered more appropriate to provide guidance in terms of the PPV, since this parameter is likely to be more routinely measured based on the more usual concern over potential building damage. Furthermore, since many of the empirical vibration predictors yield a result in terms of PPV, it is necessary to understand what the consequences might be of any predicted levels in terms of human perception and disturbance."*

Some guidance is given in Table B.2 of the Standard, reproduced in Table B.4 below:

Table B.4 Guidance on the effects of vibration levels in BS 5228-2:2009

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

The use of PPV is a pragmatic approach to construction vibration assessment and the criteria in Table B.1 are considered suitable for assessment of human response to construction vibration effects. Furthermore, the criteria have a reasonable correlation with DIN 4150-3:1999 in terms of the level of concern expected with regard to building damage.

It is noted that the primary issue relating to construction vibration is damage to buildings and although people may become concerned at levels above 1 mm/s PPV, in the context of a project, this effect can be managed through communication with concerned residents and other mitigation strategies outlined in project specific construction management plans.

B.5 NS 8176.E:2005

The Norwegian Standard NS 8176.E:2005 *"Vibration and shock – Measurement of vibration in buildings from landbased transport and guidance to evaluation of its effects on human beings"* specifically addresses vibration effects from rail and road traffic. It purports to have been developed to fill a requirement for a transport-specific vibration standard, stating in its introduction that the recommended limits in ISO 2631-2 (presumably the 1989 version) "are not adequate for vibration from transport".

It is referenced in the NZTA Environmental Plan and has been successfully adopted in a number of large roading projects.[5]

The NS Standard outlines the requirements for measuring equipment, and outlines a measurement procedure which requires a minimum of 15 single 'passings' of a heavy vehicle (i.e. train, tram or heavy road vehicles (gross weight greater than 3500 kg)). The maximum velocity values v_i of each of these passings is recorded with a slow time-weighting in 1/3 octaves between 0.5Hz and 160 Hz. There is provision for acceleration values also, however the application is identical so for the purposes of this description, velocity will be used.

The values for each pass are weighted according to the W_m weighting curve[6], and the mean and standard deviation of the 15 passings is calculated. The mean and standard deviation are then combined (assuming a log-normal distribution) to provide a statistical maximum value $v_{w,95}$. Specification of the statistical maximum value implies that there is about 5% probability for a randomly selected passing vehicle to give a higher vibration value[7].

---

[5] Waterview Connection, Transmission Gully, SH1 North Shore Busway, Esmonde Rd Interchange, SH16 Western Ring Route - Henderson Creek to Waimumu Bridge.

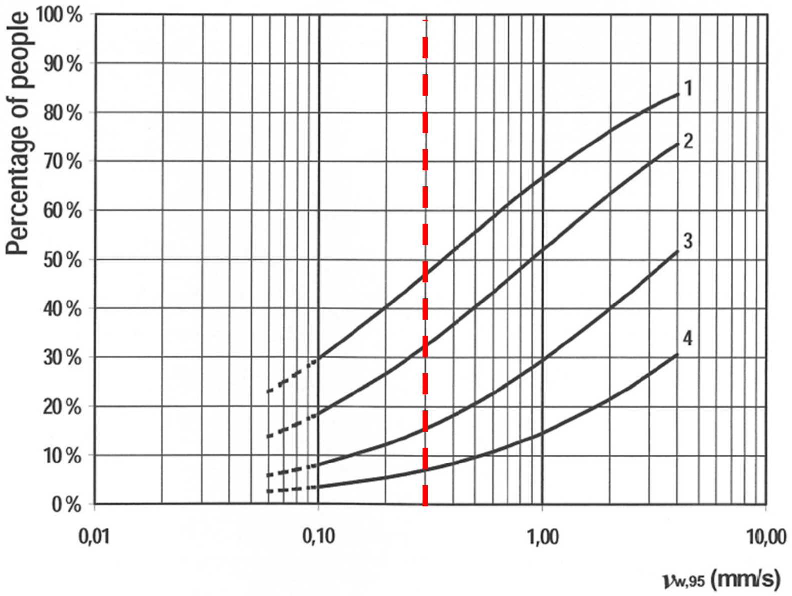
[6] The W_m weighting curve is defined in ISO 2631-2:2003

[7] Note that this is of a similar nature to the percentile levels adopted in NZ for noise but would be expressed as an L_{05} i.e. the percentile is inverted

Appendix A of the Standard contains exposure-effect curves for annoyance and disturbance which look at the relationship between measured $v_{w,95}$ levels and percentage of people affected. The studies were conducted in fourteen areas of Norway, with residents' reactions to vibration from road traffic, railways, underground and trams.

This is a useful resource that can assist in predicting and quantifying vibration effects. It is similar to Shultz curves (Shultz, 1978) for noise but may not have been as thoroughly tested to determine the veracity of the curves.

The percentage annoyed graph – Figure A.1 from the Standard is reproduced below:



Key

1 Perceives vibration
2 Highly, moderately and slightly annoyed of vibration
3 Highly and moderately annoyed of vibration
4 Highly annoyed of vibration

Figure A.1 – The percentage of persons with various degrees of annoyance due to vibration in dwellings, plotted against calculated statistical maximum values for weighted velocity, $v_{w,95}$ in mm/s

This graph clearly shows that annoyance increases proportionally with vibration velocity. The differentiation between curves 2, 3 and 4 are somewhat esoteric as there is no guidance as to the definitions of 'highly', 'highly and moderately', and 'highly, moderately and slightly' annoyed.

Notwithstanding this, the notes in Sections B.3.3 and B.3.4 of the Standard (relating to the Class C and Class D ratings (see overleaf)) most closely resemble Curve 3 - highly and moderately annoyed of vibration.

The results of these studies have then been analysed and processed by Standards Norway, together with evaluations of cost-benefit ratio and noise annoyance classifications, to develop a classification rating for residential building vibration. The intention has been to make a comparable classification with noise. Appendix B of the Standard gives details of this classification. The four classes of dwelling and corresponding statistical maximum values are as follows:

"B.3 Guidance vibration classes

The statistical maximum value for weighted velocity (or acceleration) shall not exceed the limits specified in Table B.1

B.3.1 Class A: Corresponds to very good vibration conditions, where people will only perceive vibration as an exception.

NOTE: Persons in Class A dwellings will normally not be expected to notice vibration

B.3.2 Class B: Corresponds to relatively good vibration conditions.

NOTE: Persons in Class B dwellings can be expected to be disturbed by vibration to some extent

B.3.3 Class C: Corresponds to the recommended limit value for vibration in new residential buildings and in connection with the planning and building of new transport infrastructures.

NOTE: About 15% of the affected persons in Class C dwellings can be expected to be disturbed by vibration.

B.3.4 Class D: Corresponds to vibration conditions that ought to be achieved in existing residential buildings.

NOTE: About 25% of persons can be expected to be disturbed by vibration in class D dwellings. An attempt should be made to meet class C requirements, but Class D can be used when the cost-benefit considerations make it unreasonable to require class C."

Table B.1 in the Standard is copied in Table B.5 below:

Table B.5 Guidance classification of swellings with the upper limits for the statistical maximum value for weighted velocity $v_{w,95}$ or acceleration $a_{w,95}$.

Type of vibration value	*Class A*	*Class B*	*Class C*	*Class D*
Statistical maximum value for weighted velocity, $v_{w,95}$ (mm/s)	*0.1*	*0.15*	*0.3*	*0.6*
Statistical maximum value for weighted acceleration, $a_{w,95}$ (mm/s^2)	*3.6*	*5.4*	*11*	*21*

It is noted that Class C relates to about 15% of receivers being disturbed by vibration and Class D relates to about 25%.

As discussed previously, it is assumed that in this instance 'disturbed' equates to 'highly and moderately annoyed'. This is to say that for a Class C rating, 85% (i.e. a significant majority) of receivers would not be disturbed by vibrations of this magnitude, which is considered an acceptable benchmark.

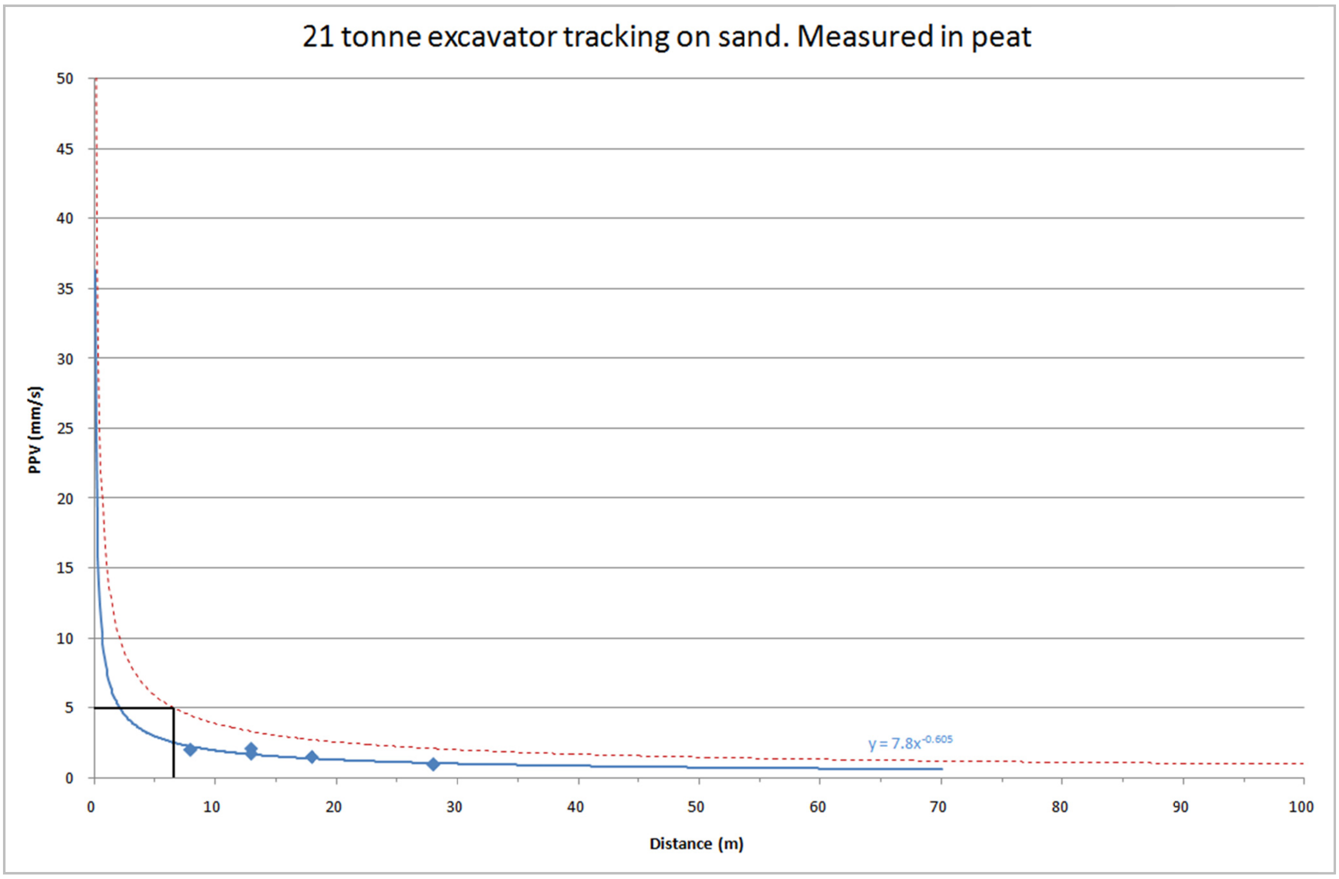
It is also noted that Scandinavian countries are generally recognised for maintaining a high living-standard, so it is considered that the survey outcomes may be relatively conservative in terms of residents' responses to environmental vibration effects.

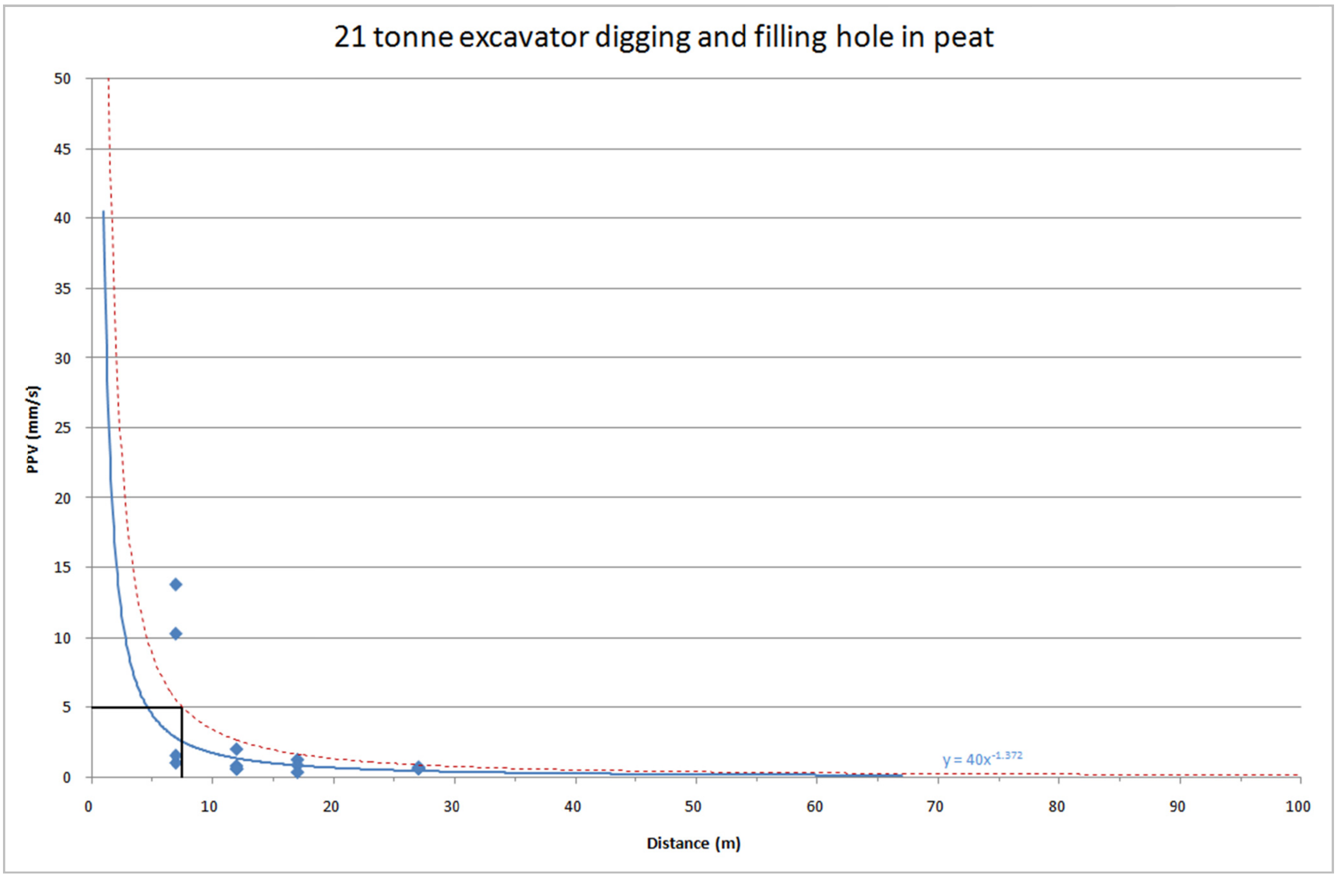
Appendix 18.C

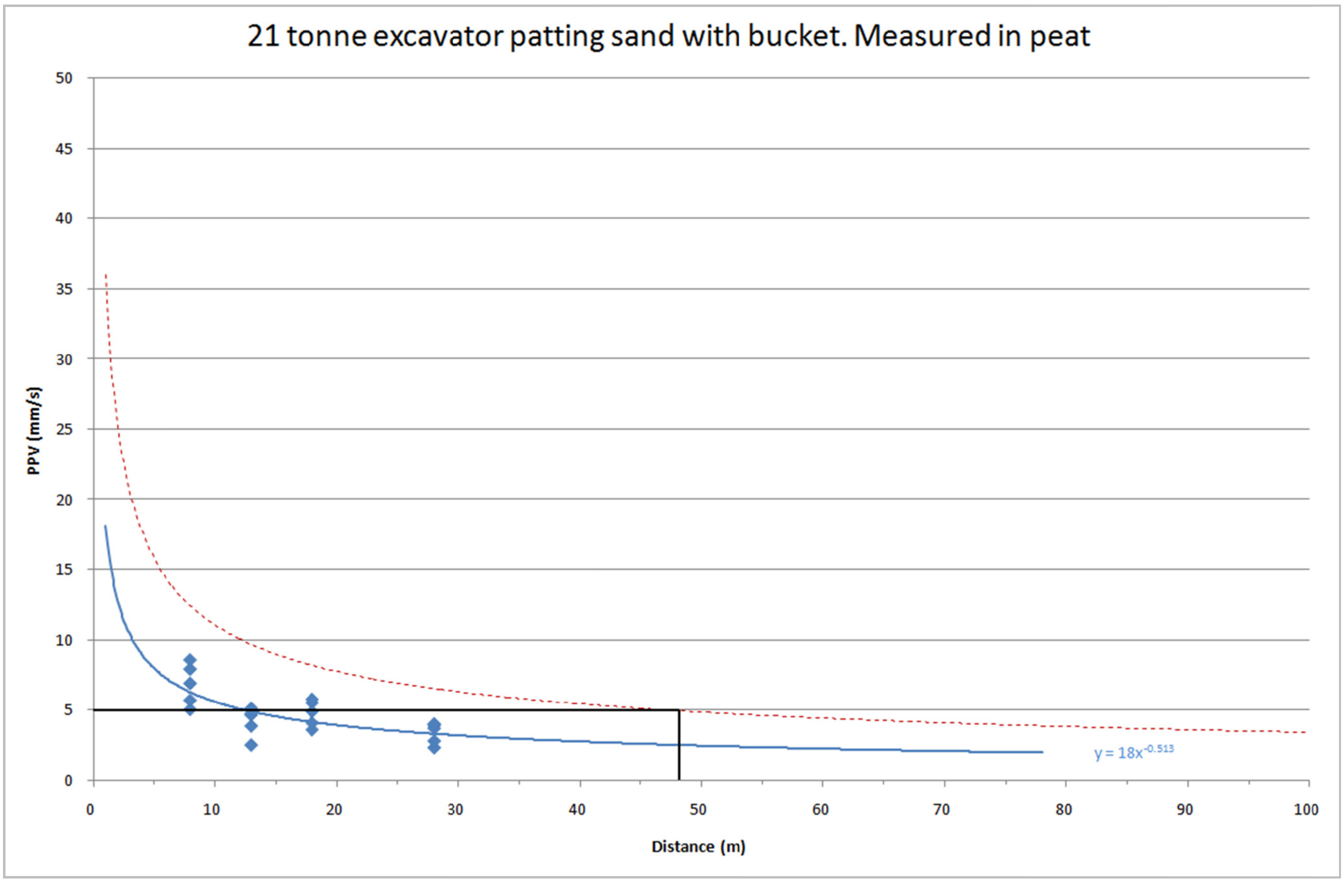
Regression curves of construction machinery

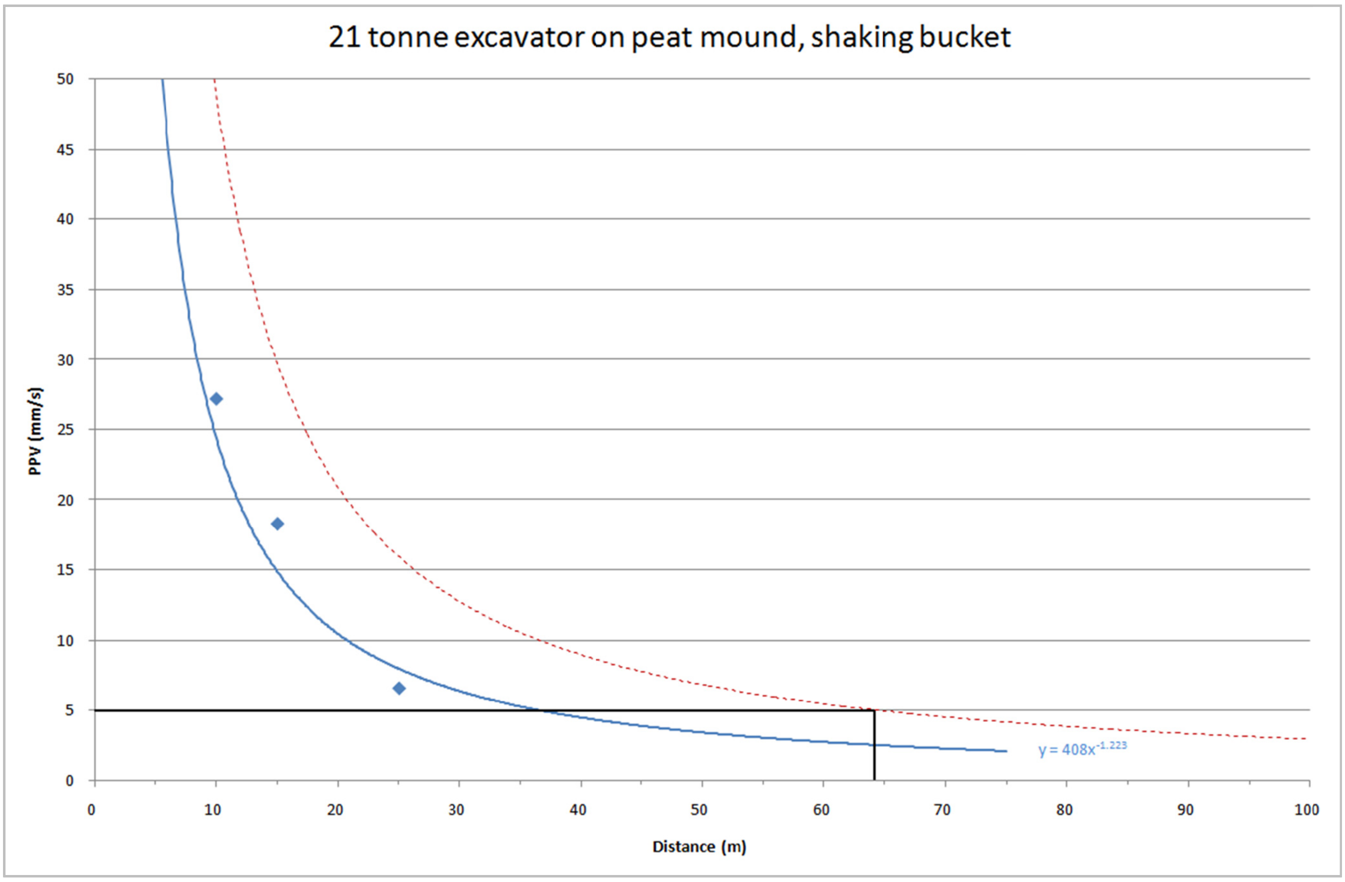
Appendix 18.C – Regression curves of construction machinery

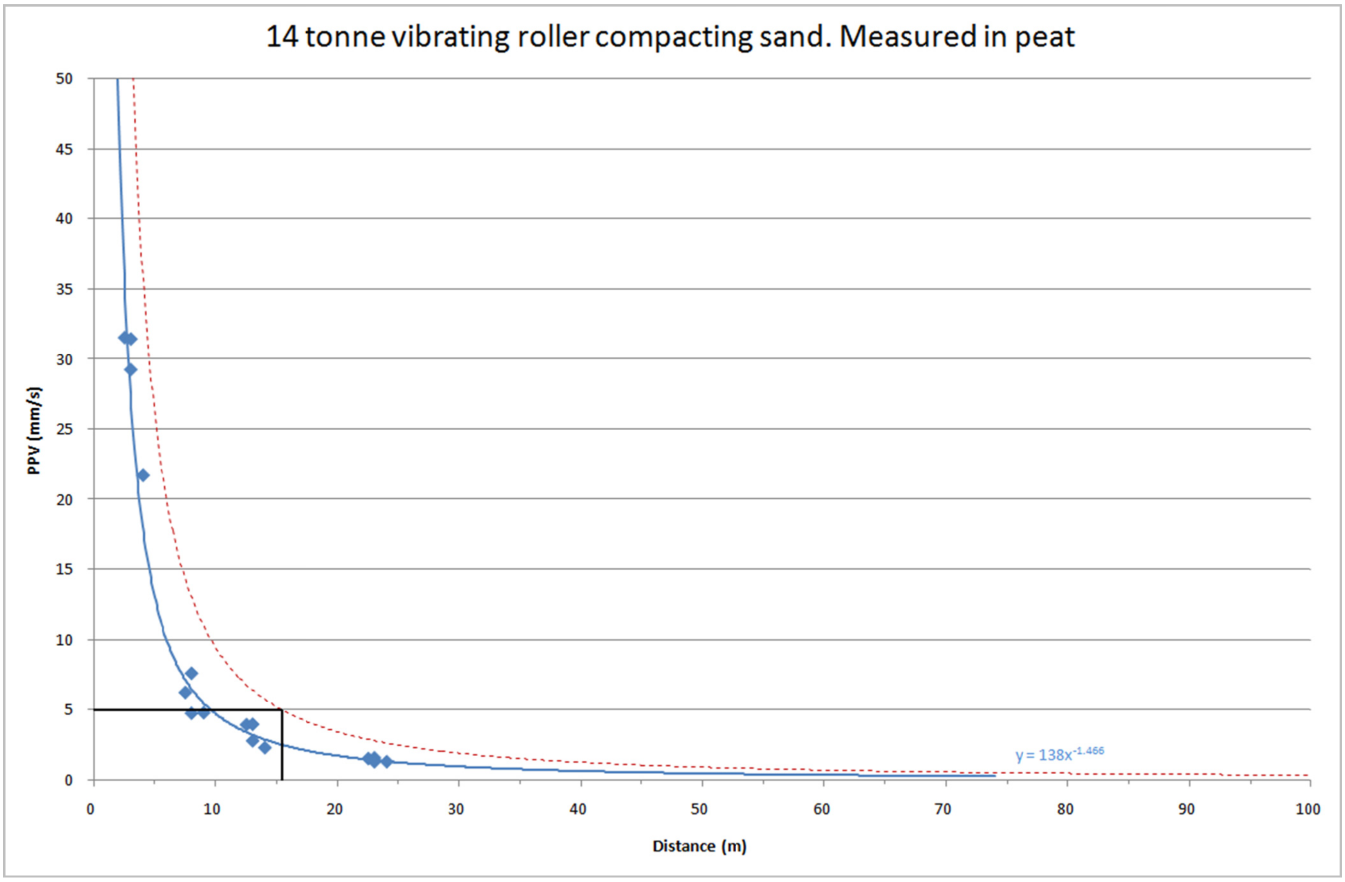
Regression line of collected data .... +100% safety factor

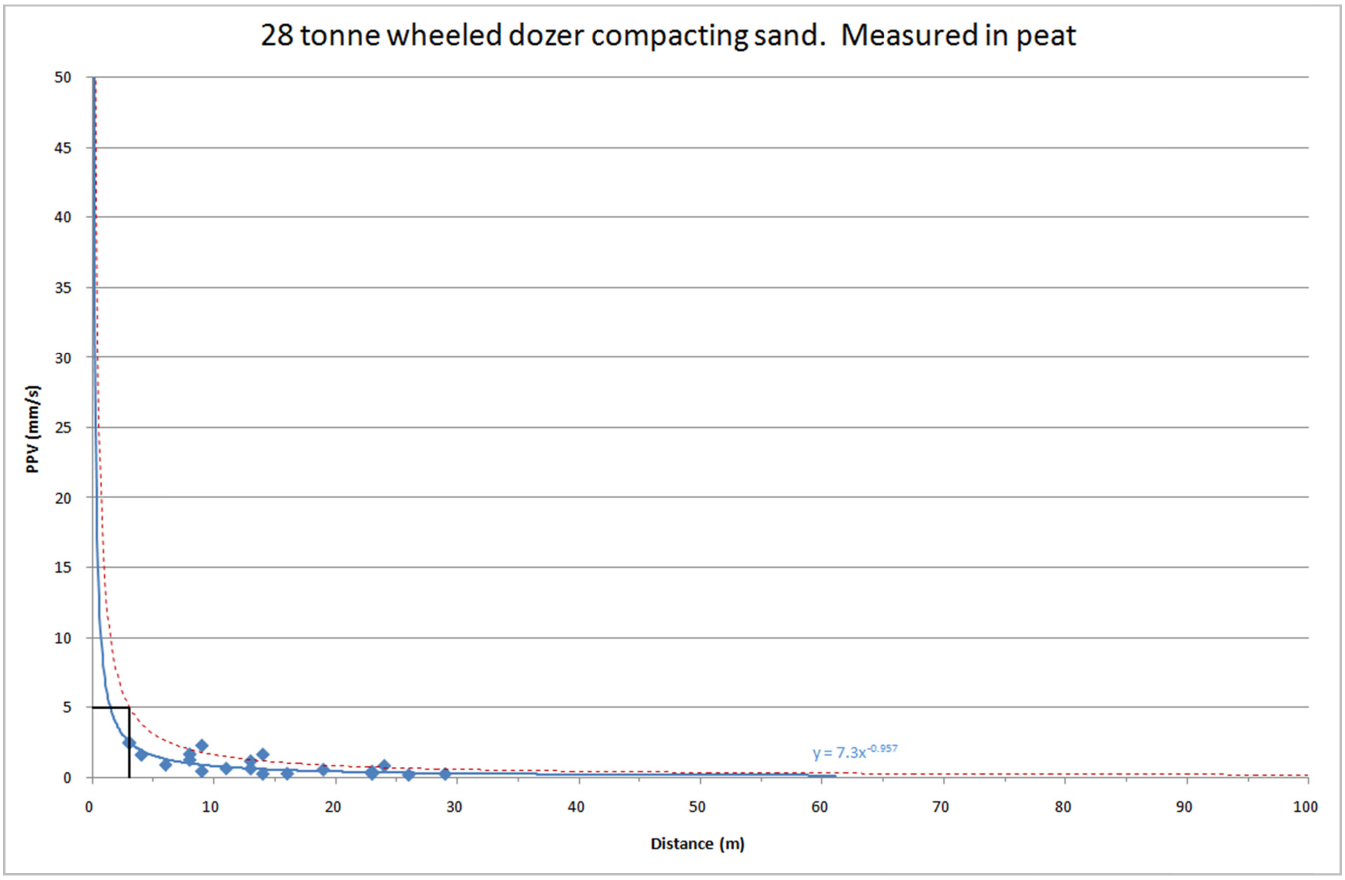


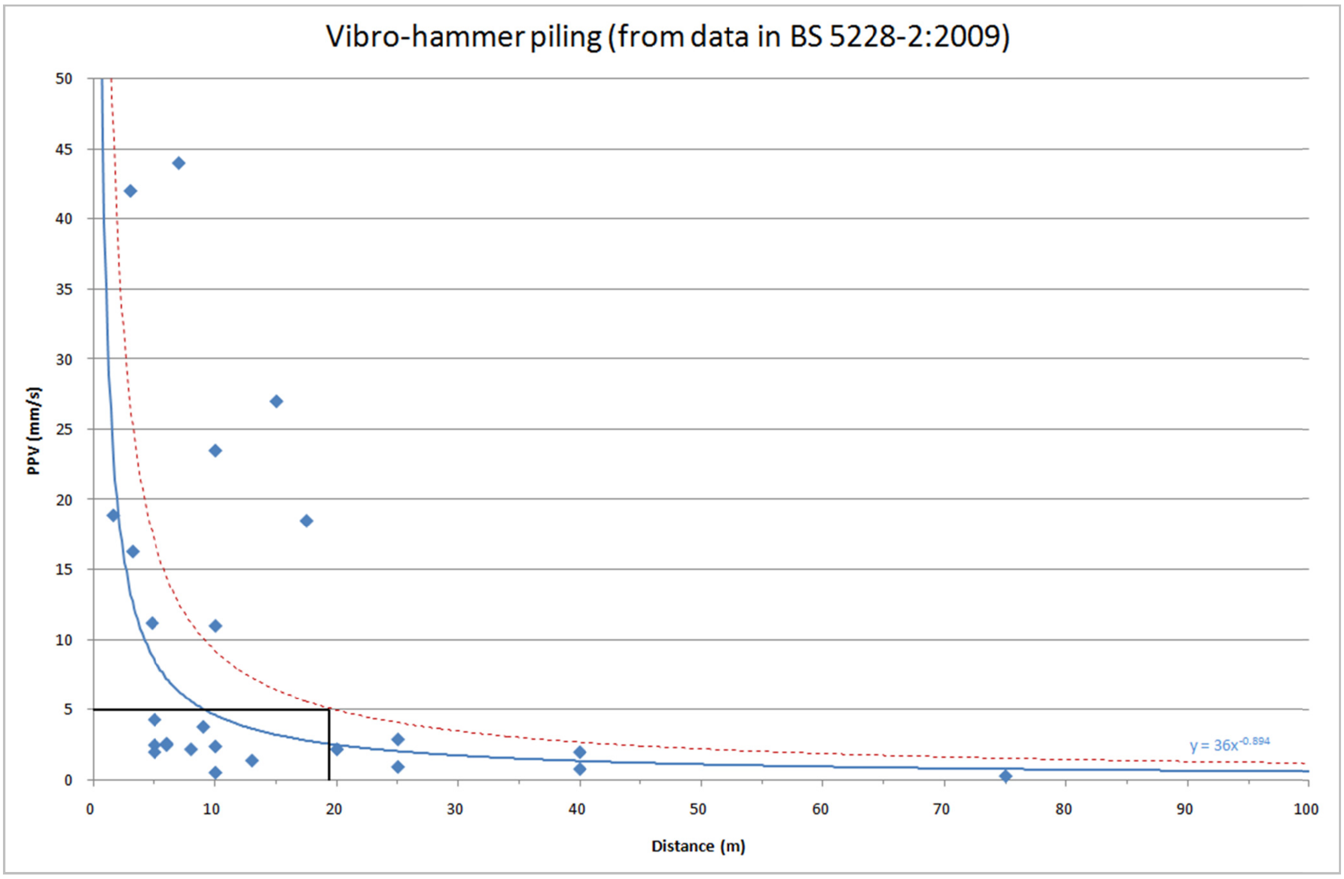



21 tonne excavator patting sand with bucket. Measured in peat
PPV (mm/s)
Distance (m)
y = 18x^-0.513
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100


21 tonne excavator on peat mound, shaking bucket
PPV (mm/s)
Distance (m)
y = 408x^-1.223
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100


14 tonne vibrating roller compacting sand. Measured in peat
PPV (mm/s)
50
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Distance (m)
y = 138x^-1.466


28 tonne wheeled dozer compacting sand. Measured in peat
PPV (mm/s)
50
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Distance (m)
y = 7.3x^-0.957


Vibro-hammer piling (from data in BS 5228-2:2009)
PPV (mm/s)
Distance (m)
y = 36x^-0.894
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100

Appendix 18.D

Construction risk diagrams

Appendix 18.D – Construction risk diagrams

Aerial maps with ‘cloud markings’ to indicate areas which are at risk of exceeding the risk assessment criteria are located in:

Appendix 18.D, Technical Report Appendices, Report 18, Volume 5