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Tēnā koutou katoa,

I'm not sure how the rest of the country feels about this summer, but up here in Auckland it was not the summer we were hoping for. However, in between all the flooding and cyclones my family and I managed to get in a bit of sailing and a couple of solid camping trips. My heart goes out to those that were affected by the weather across the country.

I'm hoping that everyone is keeping busy enough with the widespread talk of an impending recession. Consultants and designers are always amongst the first to feel these effects when projects go on hold, with a lag of six month or more before the remainder of the construction industry catches on. Strangely, some acousticians are always busy, no matter what the economic climate.

We have a NZ Building Code G6 interpretation guideline coming out shortly through the Association of Australasian Acoustical Consultants (AAAC), co-authored by ASNZ members from Marshall Day, Acoustic Engineering Services and Norman Disney & Young, with input and feedback from a range of other contributors as well. The aim of the guideline is to improve acoustic quality in apartments and townhouses and clarify were the NZBC applies and where it does not. Work is also planned for several other AAAC guidelines which are specific to the New Zealand market.

To further enhance our ASNZ Council, I am pleased to announce that Mathew Legg has been reconfirmed as a member of the Council. Thanks for your contributions to the ASNZ to date, and we look forward to more from you.

The Council is encouraging growth of the ASNZ by improving our web and social media presence, led by Victoria Rastelli. We have made updates to the Society's LinkedIn page, and have planned content being uploaded regularly, but are always looking for more contributions from our members. Feel free to get in touch if you would like to share a post about anything in the field of acoustics.

The ASNZ Council has also been reviewing a new app which will look to replace the old ASNZ Cafe and Restaurant Acoustic Index (CRAI) with a more modern user experience. Further details on this will be announced soon.

Lunch Bunches are continuing this year, with good attendance so far in person at the University of Auckland-hosted events and online via Zoom. The most recent event was presented by yours truly, which was somewhat nerve wracking – you know you're in trouble when the academics start asking the tricky questions! Watch out for James's emails for information on these upcoming educational events.

Ngā mihi,

Tim Beresford
President of the Acoustical Society of New Zealand

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Kia ora and welcome to the first issue of New Zealand Acoustics for 2023.

This issue is a Special Edition (SE) journal focusing on construction noise in New Zealand. The paper entitled "Construction Noise and Vibration: Current Practice and Application: A New Zealand Perspective" aims to first and foremost be a teaching resource on construction noise and vibration for stakeholders and laypersons.

The paper also aims to start a conversation asking the question "does the current New Zealand construction standard NZS 6803:1999 remain fit for purpose, and what, if any, amendments are needed and how should this revision be carried out?" In preparing the paper we attempted to speak to a wide range of stakeholders and consultants to gain feedback and perspective.

A paper on construction noise reform is also presented which focuses on construction noise reform with specific review of construction noise assessments, costs and the RMA consenting process. We thoroughly encourage you to read both papers.

We both look forward to publishing and promoting New Zealand acoustics and its achievements for the coming year.

Lindsay Hannah & Wyatt Page
Principal Editors

FEATURES

Construction Noise and Vibration Current Practice and Application: A New Zealand Perspective

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An original peer-reviewed contribution

1 Purpose

The World Health Organization (WHO) considers environmental noise as one of the biggest challenges to the quality of life and human health. Construction noise is a growing environmental concern with respect to acoustic amenity and health effects. In New Zealand, *NZS 6803:1999 Acoustics – Construction Noise*, is the main acoustic standard adopted for the assessment and management of construction noise. The standard is now well over 20 years old. The standard seeks to find a balance between the needs of the construction industry and setting reasonable community expectations and limits on construction noise. While our cities and towns continue to grow, a critical balance is required between ongoing developmental needs and ensuring noise effects on our communities are suitably managed to a reasonable level. The required balance between growth and management is a continuing challenge for stakeholders, which includes engineers, architects, local authorities, government agencies, contractors, site operators, developers, environmental health officers, and planners.

This paper has two aims, first and foremost is to be a teaching resource on construction noise for stakeholders and laypersons. The second is to answer the question, does the current New Zealand construction standard NZS 6803:1999 remain fit for purpose, and what, if any, amendments are needed and how should this revision be carried out?

2 Construction work and site - A Definition

The nature of construction activities and a construction site are both well defined in both the Construction Contracts Act 2002 and NZS 6803:1999.

The Construction Contracts Act (Section 6) defines construction work as any of the following:

(a) the construction, erection, installation, carrying out, alteration, repair, restoration, renewal, maintenance, extension, demolition, removal, or dismantling of any building, erection, edifice, or structure forming, or to form, part of land (whether permanent or not and whether constructed wholly or partly on, above, or below ground level):

(b) the construction, erection, installation, carrying out, alteration, repair, restoration, renewal, maintenance, extension, demolition, removal, or dismantling of any works forming, or to form, part of land; including—

- (i) any road, motorway, aircraft runway, wharf, docks, harbour works, railway, cableway, or tramway:
- (ii) any canal, inland waterway, pipeline, reservoir, aqueduct, water main, well, or sewer:
- (iii) any electricity, water, gas, or telephone reticulation:
- (iv) any telecommunication apparatus or industrial plant:
- (v) any installation for the purposes of land drainage or coast protection:

(c) the installation in any building or structure of fittings forming, or to form, part of land; including heating, lighting, air conditioning, ventilation, power supply, drainage, sanitation, water supply or fire protection, security, and communications systems:

(d) the alteration, repair, maintenance, extension, demolition, or dismantling of the systems mentioned in paragraph (c):

(e) the external or internal cleaning of buildings and structures, so far as it is carried out in the course of their construction, erection, alteration, repair, restoration, or extension:

(f) any operation that forms an integral part of, or is preparatory to or is for rendering complete, work of the kind referred to in paragraphs (a) to (d); including—

- (i) site clearance, earthmoving, excavation, tunnelling, and boring; and
- (ii) laying foundations; and
- (iii) erecting, maintaining, or dismantling scaffolding or cranes; and
- (iv) prefabricating customised components of any building or structure, whether carried out on the construction site or elsewhere; and
- (v) site restoration, landscaping, and the provision of roadways and other access works:

(g) the painting or decorating of the internal or external surfaces of any building or structure.

The Construction Contracts Act notes construction work does not include the following:

(a) drilling for or extracting oil or natural gas: (b) extracting (whether by underground or surface working) minerals, including tunnelling or boring, or constructing underground works, for that purpose.

And defines a construction site as:

(b) the land on which the claimant has been carrying out construction work under the relevant construction contract: (b) in relation to related services, the land or premises that are the subject of the contract

Section 3.1 'definitions' of NZS 6803:1999 Acoustics – Construction Noise, defines construction work as:

Any work in connection with the construction, erection, installation, carrying out, repair, maintenance, cleaning, painting, renewal, removal, alteration, dismantling, or demolition of:

(a) Any building, erection, edifice, structure, wall, fence or chimney, whether constructed wholly or partly above or below ground level;

(b) Any road, motorway, harbour or foreshore works, railway, cableway, tramway, canal, or aerodrome;

(c) Any drainage, irrigation, or river control work;

(d) Any electricity, water, gas, or telecommunications reticulation;

(e) Any bridge, viaduct, dam, reservoir, earthworks, pipeline, aqueduct, culvert, drive, shaft, tunnel, or reclamation; or

(f) Any scaffolding.

In NZS 6803:1999, construction work includes:

(a) any work in connection with any excavation, site preparation, or preparatory work, carried out for the purpose of any construction work; and

(b) the use of any plant, tools, gear, or materials for the purpose of any construction work; and

(c) any construction work carried out underwater, including work on ships, wrecks, buoys, rafts, and obstructions to navigation; and

(d) any inspection or other work carried out for the purpose of ascertaining whether construction work should be carried out.


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Remarkables Primary School

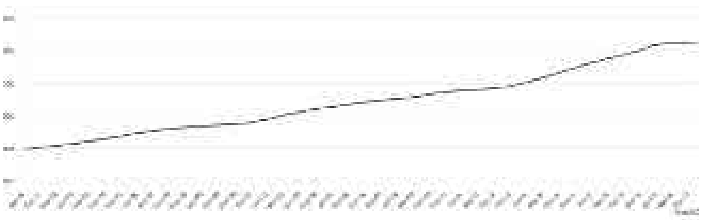

Forte Health

3 Trends in population and building consents

'Stats NZ' are New Zealand's official data agency who collect information on people and organisations through censuses and surveys. Data provided by Stats NZ states that New Zealand is projected to have close to 2.3 million households in New Zealand by the year 2043, this is an increase of nearly half a million increasing from 1.8 million in 2018. Stats NZ notes that the number of households is expected to grow on average by 0.9% a year over this 25-year projection period.

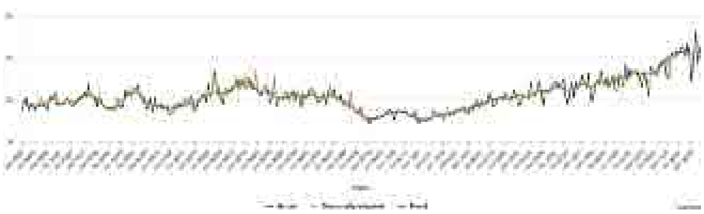
Figure 1 illustrates the growth of New Zealand's population over a 30-year period between March 1991 to March 2022.

Figure 1. New Zealand's population March 1991 to March 2022[1]



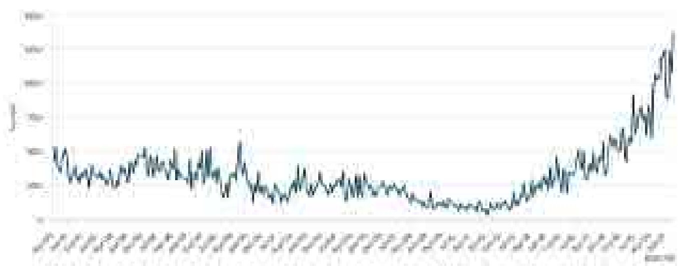
As our population grows, additional houses, dwellings, and apartments are required, as is the supporting infrastructure. The following graph provides consented number of new dwellings over 27 years from January 1995 to May 2022. Stats NZ defines a dwelling as *"any building or structure - or its parts - that is used, or intended to be used, for human habitation"*. **Figure 2** illustrates new dwellings consented January 1995 to May 2022.

Figure 2. New dwellings consented January 1995 to May 2022 [1]



In addition to the above data for new dwellings, consents for multi-unit homes, including townhouses, apartments, and flats, have also increased steadily over recent years. Figure 3 illustrates new townhouses, flats, and units over a 31-year period between April 1990 and May 2021. Note there has been a steady growth of consents from around 2012 to present.

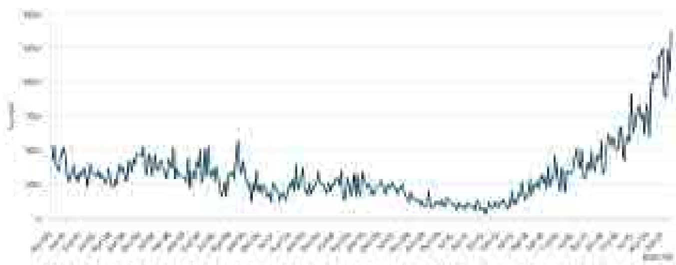
Figure 3. New townhouses, flats, and units April 1990 to May 2021[1]



The above data shows general trends in consents and population as a function of time.

Figure 4 shows new homes per 1000 residents from March 1966 to February 2021. In this data set growth for the year ended February 2021 was 7.8%, compared to the highest number of new homes consented prior to this being 13.4% in the year ended December 1973.

Figure 4. New homes per 1000 residents March 1966 to February 2021 [1]



Stats NZ report that the number of new homes consented per 1,000 residents has been increasing since the early 2010's. Following the global financial crisis (GFC, 2007-2009), the number of new homes consented for every 1,000 people living in New Zealand has increased year on year. Although the number of new homes consented per 1,000 residents is significantly less than figures seen in the 1970's. The average home has changed since then with respect to several factors, including floor plan square area as well as the requirements of the end users. Stats New Zealand report at its lowest point in 1975, the average home was around 107m2. Homes have on average become bigger since then, leading to an increase in the total floor area added per 1,000 residents, while the number of new homes remained relatively flat. As can be seen in Figure 4, there has been a steady increase of new homes consented (per 1000 residents) year on year since 2012.

The data set illustrates general trends in New Zealand's population and consenting of homes. A key takeaway is as our population continues to grow, so does consented buildings in the residential and commercial sector. It should also be noted that it is not just residential development that is needed, there are many other examples that require ongoing development, the aged care sector being just one of these. As development increases for all sectors, so do the requirements for supporting infrastructure. This may include anything from local development of roading, infrastructure for water, power, and telecommunication services, to schools and community facilities such as hospitals. All of these involve construction noise being produced as part of their development.

New Zealand's urban areas hold about 86% of our population and experience approximately 99% of our population growth. Regardless of who may or may not be affected by construction noise or vibration, noise which includes noise from construction activity has and will continue to receive increasing recognition as one of our critical environmental noise pollution problems, especially as our populations grow and becomes more urbanised with higher density housing in the main centres.

4 Trends in construction noise complaints

The world's current population at the end of November 2022 was approximately 8 billion, and the population is forecast to reach nearly 10 billion by 2050. New Zealand's population is around 5 million, with approximately 1.5 million people living in Auckland followed by approximately 400,000 persons living in both Wellington and Christchurch, the largest major cities. Currently,

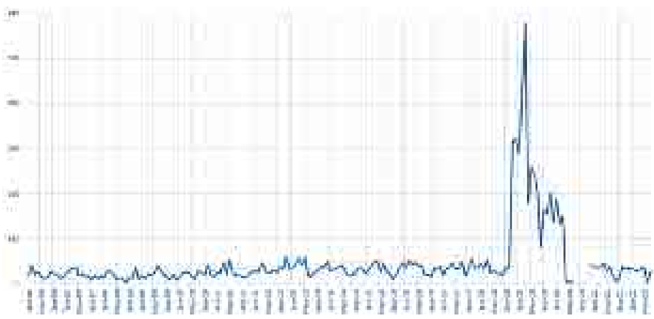
[1] *Source Statistic New Zealand (stats.govt.nz)*

Wellington has a population growth rate of about 0.5% and the Wellington City Council (WCC) Urban Growth Plan states that the city's projected population growth will result in the need for over 20,000 additional residential dwellings by 2043 (over 700 new homes on average per year).

Complaints received due to construction noise or vibration are not related to one single factor. Increased population growth, density, mental health, attitudes, technology, and lifestyle are just some of the examples relating to 'triggers' for construction noise complaints. Anecdotally, there has been an increase in construction noise complaints as more people adopt a 'hybrid work model', where they work partly from home and partly in an office. Traditionally, prior to the Covid 19 Pandemic, we generally only worked from the office. With the hybrid work model, in certain cases noise complaints are starting to arise from perceived 'incompatibility', for example, someone working from home complains about the construction work being conducted on a site next door. These complaints are not necessarily from the absolute level, but the fact that construction noise can at certain times be louder compared to the surrounding soundscape and background sounds in any given area. Such noise levels and related activity were present before the Covid 19 Pandemic, however, the people did not work from home and thus were not subject to sound exposure from this activity.

Available data from Wellington City Council (WCC) shows that there have been over 5000 separate construction-based noise complaints received over the last 5 years. These are complaints via the excessive noise provisions of the Resource Management Act 1991, to the WCC call centre, and does not include complaints received by other methods, such as directly to officers or via communication channels such as email, or social media. Taking account of these other channels, the complaints would be significantly greater. In 2018 (prior to Covid 19) there was a total of over 6000 complaints (for all noise sources), this reduced to just over 5000 in 2020 and increased dramatically to over 7000 in 2021. Construction complaints (noise or vibration) generally range between 250 and 500 between 2006 and 2018 prior to the Covid 19 Pandemic. However, in 2019, the total number of construction complaints was 2878, which was about 50% of the total complaints received in that year. Construction noise complaints in 2020 fell to 528 and fell again in 2021 to 372. This fall was a general function of the Covid-19 landscape, with a host of activities being delayed, interrupted, or stopped altogether. The percentage of construction complaints to the total noise complaints ranges from 5% to 10% in any year from 2006 to the present (with the outlier of 2019 as noted above, being about 50%). **Figure 5** shows the total number of construction complaints as a function of each month from 2006 to 2021.

Figure 5. Total number of construction complaints for Wellington District as a function of year from 2006 to 2021 [2]



5 Construction noise - Some basic theory

All sound is produced by mechanical vibrations propagated as a wave motion in air or other media. Sound from construction noise in its *mechanics* is no different from sound in everyday life, however, the nature and scale are different with respect to sound level, character, and nature, which evokes physiological responses in the ear and auditory pathways that are perceived and interpreted by the listener. Physiological acoustics deals with the transduction of sound energy to sensation through the peripheral auditory system, where it I encoded and transmitted by the auditory nerve to the brain. Sound may be termed 'noise' when it is unwanted and results in adverse effects on health and wellbeing, or reduction of amenity value. Construction noise can be defined as noise emitted and received from any construction work.

The most common unit used to describe sound is the decibel (dB), which involves taking the air pressure (Pa) change as a ratio to a reference pressure of 20 μPa and putting it on a logarithmic scale, producing the sound pressure level (L_p). Because this is a nonlinear scale, one can't simply add the numbers together to get the correct result. **Figure 6** illustrates adding sound *pressure* levels together. Each time the sound energy doubles, the sound pressure level increases by only 3 dB.

[2] *Wellington City Council Acoustic Team Specialist Advice and Compliance 2022*

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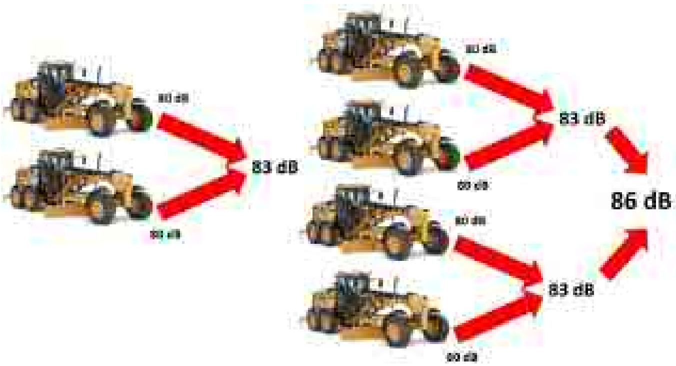
Figure 6. Sound levels and doubling of sound energy [(3)]



The frequency of the sound is the rate at which these oscillations occur and is measured in cycles per second, or Hertz (Hz). The response of human hearing varies with frequency and so commonly an 'A-weighting filter' is used on the sound level meter to approximate this response. Historically this was indicated using dBA (A -frequency weighted decibels), but because there are many ways (*descriptors*) to measure sound, this notation is no longer used in standards as it is ambiguous. A 10 dB increase in sound pressure level using A-weighting (L_{pA}) is commonly accepted as being perceived as a doubling of the loudness, such that 70 dB sounds twice as loud as 60 dB. A 3 dB increase is generally only just perceptible to the human ear in outdoor spaces. A sound source can also be described in terms of its sound power (unit of W) which results in a sound pressure (unit of Pa) at a certain distance from a source. This is commonly put on a decibel scale resulting in the sound power level (L_W or L_{WA} if A- weighted) but its reference is 10^{-12} W, not 20 µPa as for sound pressure level. The sound power level is absolute, it does not vary with distance from the source or the acoustic environment.

As sound propagates away from a sound source, the sound pressure level generally decreases as the sound spreads out. It may be higher in one direction than another. For example, directly in front of a plant's exhaust outlet as opposed to the opposite side of the machine. Other factors that result in the sound pressure level decreasing are commonly lumped into a single term called 'excess attenuation' which includes the effect of barriers, ground reflection, air absorption and other effects. In simple terms, the conversion between sound power level and sound pressure level should consider geometrical spreading, the directivity of the source, as well as other propagation effects. A basic formula for the sound pressure level (L_p) from a source is as follows:

$$L_P = L_W + DI_M - A_E \qquad \text{(Eq 1)}$$

Where:

L_W is the sound power level of the source (dB)

DI_M is the directivity index of the sound source in a particular direction

A_E is all attenuation along the transmission path (dB) – a function of various factors such as temperature, humidity, frequency, wind speed, direction, ground absorption and other effects.

Other adjustments such as topography and structures can be made with respect to additional attenuation measures to take account of barriers, such as acoustic fences, intervening buildings or terrain features (earth bunds for example). The duration of the percentage of operating time is another factor that should be included.

When directivity and excess attenuation are set to zero, the relationship between sound pressure level and sound power level at a distance R (m) from the source, may be described in the far field (far enough away so that the sound source is considered to be a point source) as:

$$L_{pA} = L_{WA} - 10\log_{10}(4\pi R^2) \text{ for spherical spreading (Eq 2)}$$

$$L_{pA} = L_{WA} - 10\log_{10}(2\pi R^2) \text{ for hemispherical spreading (source located on the ground)} \qquad \text{(Eq 3)}$$

The above **equation 3** would apply to flat open sites, and simplifies to:

$$L_{pA} = L_{WA} - 20\log_{10} R - 8 \qquad \text{(Eq 4)}$$

Using the above equation 4, the sound pressure level decreases by 6 dB for a doubling of distance (R) from the sound source. Assuming there is no other sound-reflecting surfaces nearby, this represents a worse case. **Figure 7** illustrates sound pressure level reduction with distance, applying formula from equation 4. In this case, the typical plant sound power level is 112 dB (construction plant levels or group levels could be much high than this) and in this example it is not until 20m away does the level drop to the common compliance value 75 dB L_{Aeq}.

Figure 7. Sound level (L_{Aeq}) reduction (6 dB per doubling of distance (point source)) as function of distance from source [(3)]

It is worth noting that if there are multiple similar sound sources operating in a line, the reduction with a doubling of distance from the line source is only 3 dB.

The takeaway from the above for a single source is that without sufficient mitigation measures, large buffer distances are required to reduce levels at receiver sites to an acceptable level. In many cases even with sufficient mitigation measures and buffer distances, the levels at receiver sites can produce high sound pressure levels.

When modelling construction noise, the above is overly simplistic as it presents sound pressure levels as simply a function of distance for a single source at a single point in time. However, for real sites, the modelling of construction noise can be, and generally is, complex, for a host of reasons. It is common for a construction site to have numerous fluctuations and activities within the construction area or site, which utilise various processes and various types of machinery of different sizes, ages, and condition. The sound power of individual machinery fluctuates with the activity being carried out and even the experience and attitude of the machine operator can also affect the sound pressure levels. In other cases, sound pressure levels from certain plant items such as fixed mechanical plant (such as generators, pumps, and idling machinery), may be considered steady-state or quasi-steady state in nature. Noise from most machinery has descriptive characteristics, such as tonality, impulsive, modulating, low frequency, intermittent, and so forth. Modelling noise from construction can be challenging and is rarely straightforward.

There are many sources of publications and databases on construction equipment noise levels at both source (sound power level) and set reference distances (sound pressure level), this includes the NZS 6803:1999 Acoustics – Construction Noise and BS 5228-1 2009 Code of practice for noise and vibration control on construction and open sites. Part 1 - Noise, others include:

- The Department of Environment Food and Rural Affairs in the United Kingdom published L_{Aeq} and L_{AFmax} sound pressure levels in 2008 (DEFRA www.gov.uk);
- The US Federal Highway Administration (FHWA) published

[3] *L, Hannah. Page, W 2023*

L_{AFmax} sound pressure levels in 2006 ((highways.dot.gov);

- The European Commission (2000) issued Directive 2000/14/EC (amended by Directive 2005/88/EC) on equipment sound power levels (see https://www.ec.europa.eu/info/index_en); and
- The Department of Energy and Infrastructure in South Australia published *Infrastructure Works at Night – Operational Instruction 21.7* in 2007 (www.dit.sa.gov.au).

Table 1 shows the sound pressure levels at 10 m distance from a typical construction plant, a 40t tracked excavator (223kW). The sound power level for this excavator is about 108 dB L_{WA} and as can be seen, the sound pressure levels in octave frequency bands are not uniform. There is a significant frequency peak at 125 Hz, typical for large machinery of this type.

Table 1. Example of sound pressure levels for common construction plant - 40t tracked excavator[3]

Equipment	Sound pressure level (dB) in the octave frequency band (Hz)								L_{Aeq}
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	@10m (dB)
40t tracked Excavator 223kW	77	86	75	75	71	69	64	55	77

Table C.2 in Appendix C of NZS 6803:1999 provides the sound pressure levels at 10 m and sound power level for common equipment. However, the standard does not provide octave (or third octave) sound pressure levels, which are generally required in terms of acoustic design with respect to noise mitigation and modelling.

Adopting an acoustic model, albeit a basic one, through to modelling with specialist acoustic software, the predictions can only be accurate when input information is accurate. For example, an under-estimate of the sound power of plant will result in an under-estimate of the sound pressure levels. The input information must also be current for the machinery in use and may need to consider the age of the machinery. Simply adopting reference levels from a standard database must be used with caution.

6 Underwater construction noise - Some basic theory

Most construction assessments and literature with respect to construction noise focus on activities taking place on land, however, acknowledgment of underwater construction noise effects on the health and wellbeing of marine life should be recognised as an important and developing area. Expert literature such as that published by United States Department of Commerce National Oceanic and Atmospheric Administration (NOAA) states that many marine organisms rely on their ability to hear for their survival. Sound is a highly efficient means of communication underwater and is the primary way that many marine species gather and understand information about their environment. Many aquatic animals use sound vocalisation to find prey, locate mates and offspring, avoid predators, guide their navigation, and locate habitat, as well as to listen and communicate with each other.

If not suitably managed, anthropogenic (human-made) underwater noise, including from temporary construction activity, can negatively impact ocean animals and their ecosystems. High levels of noise can reduce the ability of animals to communicate with potential mates, other group members, their offspring, or feeding partners. Noise can also reduce an ocean animal's ability to hear environmental cues that are vital for survival, including those keys to avoiding predators, finding food, and navigating to preferred habitats. Effects can include Temporary Threshold Shift (TTS) which is the temporary loss of hearing because of exposure to sound over time or Permanent Threshold Shift (PTS) which is the permanent loss of hearing caused by some kind of acoustic or trauma (PTS is irreversible). NOAA guidelines provide details of marine mammal hearing range and onset threshold for PTS.

There are currently no New Zealand standards for underwater noise effects, including any from construction underwater. NOAA has published guidance for assessing sound on marine mammals. The NOAA Guidelines identify the received levels above at which individual marine mammals are predicted to experience changes in hearing sensitivity, either temporary or permanent. The guidelines also provide guidance on assessment descriptors. As with effects on land, underwater sound will vary depending upon the process, nature, scale, and activity for example with piling the levels will vary as a function of the pile size, driving energy, and a number of other factors including water depth, pile length, and sea and seabed conditions. A dominant source of underwater sound from construction includes blasting, dredging, or the installation of piles using vibration (vibro) and impact (driven) piling techniques.

The hearing of marine mammals is not the same as humans, with marine mammals typically hearing over a wider range of frequencies and with a different sensitivity. It is therefore important to understand how an animal’s hearing varies over the entire frequency range in order to assess the effects of sound on marine mammals. In the case of underwater sound, the reference is taken as 1 μPa (whereas airborne sound the reference pressure is 20 μPa). Thus, to convert from a sound pressure level referenced to 20 μPa to one referenced to 1 μPa, a factor of 20 log (20/1) or 26 dB must be added to the former quantity. In terms of levels, 60 dB re 20 μPa is the same as 86 dB re 1 μPa. The hearing response curves for fish, humans, and marine mammals, also varies. The noise assessment of marine life, including construction noise is a growing area and is itself an area studied by an expert in underwater acoustics and related fields.

There are a host of noise descriptors used in underwater acoustics. Using piling noise as an example, this is not continuous, sound energy will occur as a series of impulses. Each impulse produces a maximum instantaneous peak sound pressure level which can be expressed as either a peak-to-peak level or zero-to-peak. Peak sound levels (L_{peak}) can be defined as peak-to-peak levels being the maximum instantaneous sound pressure level, measured in units of decibels (dB). The total sound energy of each impulse is expressed as the sound exposure level single strike, SEL_{ss}. This is the sound exposure level of a single event, compressed into a unit period (one second), measured in decibels (dB). The cumulative sound energy (SEL_{cum}) is the total sound exposure level of multiple events and is typically assessed over a 24-hour day.

The SEL_{cum} will vary depending upon the number of strikes and the duration of piling. The following formula can be used to calculate the cumulative sound energy:

$$SEL_{cum} = SEL_{ss} + 10 * \log_{10} (\text{number of strikes}) \qquad \text{(Eq 5)}$$

There a various mitigation measures for underwater noise such as: 1) reducing noise generated at the source, 2) use of acoustic barriers (for example to reduce the radiated noise), and 3) adopting measures to control, protect or deter marine life out of or away from critical areas (providing buffer zones). Monitoring underwater noise is also a key management method.

7 Construction vibration - Some basic theory

Construction vibration (on land) is a separate issue from construction noise, and is treated separately with respect to measurement, assessment, monitoring, and management. Vibration literature recognizes repeatedly that people are far more sensitive to vibration perception than structures are to vibration damage. Vibrations, even of very low magnitude, can be perceptible to people and can interfere with the satisfactory conduct of certain activities. For example, delicate procedures in hospital operating theatres or the use of very sensitive laboratory weighing equipment. Sensitivity to vibration at different times of the day is more complex than sensitivity to noise. The sensitivity of the human body to vibration varies according to the direction and frequency of the vibration. If a person is active and moving, they are generally less sensitive to vibration.

It is important to understand that the prediction of vibration is deemed 'less reliable' than airborne noise predictions. The modelling of vibration is usually less accurate due to factors such as ground conditions, which are often non-homogeneous and complex in three-dimensions, making it difficult to quantify vibration pathways with accuracy and certainty. As with any modelling, conducting a peer review or cross-check of modelling against empirically derived relationships such as those contained in *BS 5228-2:2009 Code of practice for noise and vibration control on construction and open sites Part 2: Vibration*, is recommended.

Construction vibration and the related science are well documented, with vibration being the passage of mechanical energy that oscillates about the average position of the particles or molecules which make up the material, item, or structure. A vibration must travel is some physical material. In real-world materials, vibration waves often look different, both in shape and intensity, along the three different possible directions of movement or axis (up-down (vertical), back-forth (longitudinal), side-side (horizontal). With respect to construction vibration, the medium of travel is generally the ground (or underwater). Ground vibration will either be natural, for example, earthquakes, or human-made, for example from construction equipment, blasting, or event traffic movements from vehicles (generally heavies).

Damage to structures and buildings from construction ground vibration can occur by three basic types of interaction. Section 3 ('Terms and definitions') of DIN 4150-3 2016 Structural vibration – Part 3: Effects of vibration on structures (see section 12.1), defines damage due to vibration as *"any permanent consequence of an action that reduces the serviceability of a structure or one of its components"*. The first vibration interaction is the direct interface of the ground vibration with the structure. If a vibration has high enough intensity (energy) and lasts for a long enough duration, this can potentially damage, even though its frequency composition does not directly "excite" the natural vibration frequencies ('resonant frequencies') of the structure.

The second interaction with ground vibration is that of ground vibrations with frequencies that overlap the natural vibration frequencies of the structure, those which are *"in resonance"* with the structure. Such resonant interactions are self-reinforcing in the structure, growing with each passing wave. Therefore, resonant vibrations are potentially damaging (if they last long enough).

The third and final interaction with ground vibration is when ground vibration can cause damage by bringing about settling of the soil around the structure, and the corresponding settling of the structure's foundation. Ground settling effects are often indicated by cracks in the soil around the structure or shifting of soil around structural supports, with possible damage to support structures such as concrete slabs or foundations. Vibration can produce damage without noticeable settling, through the resonant and non-resonant interactions.

Ground liquefaction is another type of vibration effect that is worth mentioning. Liquefaction is when sand or silt below the groundwater level suddenly loses all its bearing capacity because of dynamic mechanical effects. This would generally occur during earthquakes and the process can lead to damage as serious as the collapse of buildings. The construction vibration level produced when compliant with vibration standards, normally lies well below the vibration magnitudes which occur during major earthquakes, thus these effects are only to be expected under very unfavourable circumstances.

There are a host of parameters that will determine the final intensity of vibration received at the location. These include the energy per blow or cycle, the distance between source and receiver, ground conditions, soil–structure interaction, construction of the structure, and the location of measurement location (soil surface, building foundation, or internal structural element of the building). The typical frequency range for environmental construction ground vibration is between 1 to 200 Hz.

Wood-frame buildings, such as typical residential structures found in New Zealand, are more easily excited by ground vibration due to their lightweight construction. In contrast, large masonry buildings with spread footings and foundations, have a much lower response to ground vibration.

A common prediction model for vibration peak particle velocity (PPV in mm/s) propagation with distance is:

$$PPV = K\,(D/E^{½})^{-n} \qquad \text{(Eq 6)}$$

Where: K is ground transmission constant (for a given ground type)

D is distance from source to receiver (m)

E is energy of source (J)

n is empirical constant based on several factors such as the geology, ground profile, frequency of transmitted wave, predominant waveform.

The value of n is obtained from regression analysis and is generally between 0.5 and 1.5. A value of 1.5 is used for competent soils, which include most sands, sandy clays, silty clays, gravel, silts, weathered rock. A value of 1.1 is used for hard soils, which include dense compacted sand, dry consolidated clay, consolidated glacial till, some exposed rock (cannot dig with a shovel, need a pick to break up).

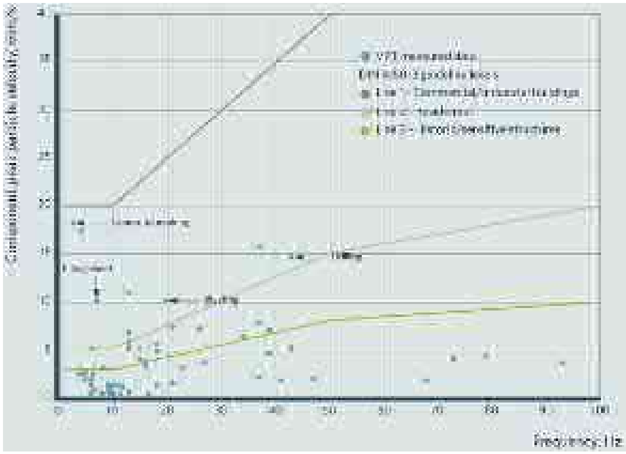
For a given vibration source, it may be assumed that the energy delivered into the ground is constant (over a sufficient timescale), therefore equation 6 reduces to

$$PPV = K\,D\text{-}n \qquad \text{(Eq 7)}$$

Unlike airborne construction noise, which can require significant buffer distances to achieve compliance with the construction criteria, vibration intensity generally reduces quickly with buffer distance such that short buffer distances in the region of 10 m to 50 m are sufficient.

Figure 8 illustrates the measured vibration levels (PPV) as a function of frequency from a host of construction activities on the Victoria Park Tunnel (Auckland, New Zealand). For four particular activities, the level is above the guidance values for residential locations.

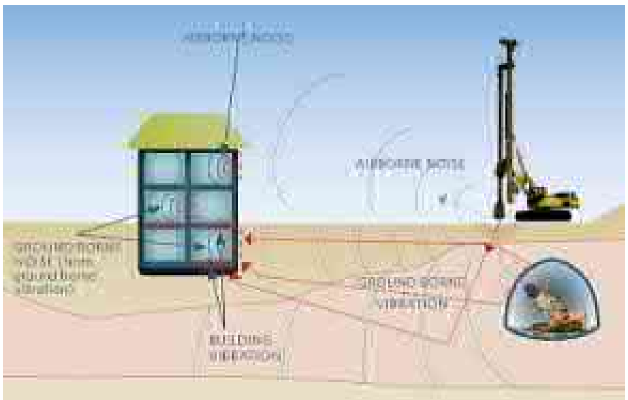
Figure 8. Measured vibration levels as function of frequency [4]



8 Construction noise transmission

Sound energy travels from a source to receiver through a medium such as air, water, and solid objects (such as the ground or built structure). Section 5 discussed sound propagating as a wave motion in air, which in acoustic modelling can generally be well defined as a 'homogeneous' medium. There are however other mediums for construction energy to propagate between source and receivers, some common transmission paths for construction energy are discussed in the following sections and are illustrated in **Figure 9.**

Figure 9. Construction noise sources - airbone and ground borne [4]



8.1 Airborne Noise

Airborne noise is construction noise that travels through the air. Airborne noise happens when energy causes the air in the surroundings to compress. This compression makes some regions of the air have a higher pressure. It is then followed by rarefaction, where the lower pressure occurs in the other regions. This compression-rarefaction pattern moves away from the energy source at the speed of sound as longitudinal waves. Airborne construction noise is generally measured and assessed nationally and internationally using the noise descriptors, $L_{Aeq(t)}$ (the A-weighted equivalent level over the integration time period t) and L_{AFmax} (the maximum A-weighted, F time-weighted level over a time period).

8.2 Ground-borne regenerated noise

Ground-borne noise means audible noise caused by the vibration of elements of a structure. Ground-borne noise is also referred to as 're-radiated noise', 'structure-borne noise', 'solid-borne noise' or 'regenerated noise'. Ground-borne construction noise is a separate matter to airborne noise. The vibration of structures causes noise to be radiated into a room. Ground-borne noise originates as vibration and propagates between the source and receiver, generally, the medium is through the ground and/or building structural elements, for example, construction plant is located underground, rather than through just the air. What is critical with ground-borne construction noise is the levels are generally only 'relevant' or audible when source levels are very high, thus resulting in audible airborne noise levels at the source. Ground-borne noise may be caused by plant, such as tunnel-boring machines. Ground-borne levels related to vibration velocity levels of the radiating surfaces can be estimated using the following formulas:

$$L_{pA} = L_v - k \qquad \text{(Eq 8)}$$

Where: L_{pA} is sound pressure level (dB re 20μPa)

L_v is spatially averaged vibration velocity level (in dB relative 1 x 10-6 mm/s)

k is a room or space constant for the receiving space (dB)

Ground-borne noise caused by plant, such as tunnel boring machines, can be estimated using the following formula:

$$L_{pA} = 127 - 54 \log_{10} r \qquad \text{(Eq 9)}$$

Where: LpA room sound pressure level (dB)

r is the radial distance from tunnel to building (m) for $10 < r < 100$ m

The New Zealand standard for construction noise, NZS 6803:1999, does not cover ground-borne noise. The Australian *EPA Interim Construction Noise Guideline (ICNG) 2009* recommended the following levels for ground-borne noise levels to protect the amenity and sleep of people when they are at home:

- Evening (6.00pm to 10.00pm) Internal 40 dB $L_{Aeq\ (15\ min)}$
- Night-time (10.00pm to 7.00am) Internal 35 dB $L_{Aeq\ (15\ min)}$

8.3 Airblast noise and Over-pressure

Airblast noise is another type of construction noise and can be described as the pressure wave that radiates out from the blasting area of an explosion hence 'noise' from explosives or 'blasting' is often described as 'airblast' noise. Airblast overpressure is the energy transmitted from the blast within the atmosphere in the form of pressure waves. As these waves pass a given position, the pressure of the air rises very rapidly then falls more slowly then returns to the ambient value after several oscillations. The pressure wave consists of both audible (noise) and inaudible (concussion – typically infrasound) energy.

[4] *Source NZ Transport Agency State highway construction and maintenance noise and vibration guide. August 2019. V1.1*

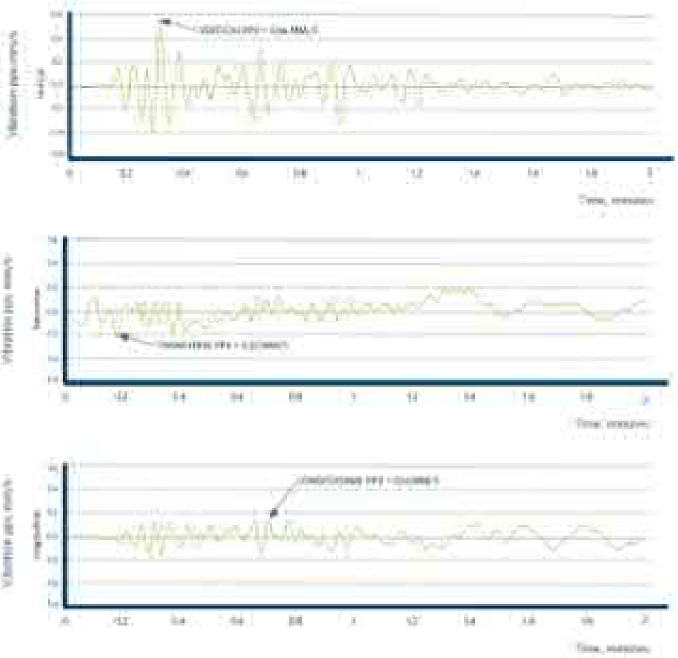
The maximum excess pressure in this wave is known as the peak overpressure. It is typically measured and assessed using the L_{Zpeak} (dB) descriptor, which is the Z-weighted peak sound pressure level. The difference in duration between blasting and construction vibrations is critical to understand. High-level and long-duration vibrations can potentially both fatigue and cause resonance effects, which are of far less importance in short-lived, infrequently repeated blasting vibrations that last a few seconds. It is important to understand that 'modern blasting', including construction noise blasting, is generally small-scale controlled blasting that lasts a few seconds in duration and is assessed and conducted by suitably qualified and experienced engineers such as an explosives expert who would primarily be responsible for physical blasting on site.

9 Construction Vibration

Vibration is a common by–product of construction work. The effects of vibration may relate to potential damage to buildings (structural or cosmetic damage) and human response such as annoyance, effect on health, and loss of amenity value. There is no known relationship between response and vibration levels when comparing new vibration levels from construction works and existing ambient vibration. Ambient vibration is rarely significant or even perceptible, hence it is rarely necessary to consider the change in level from the existing ambient to what may occur during construction works.

The main sources of ground vibration at construction sites are normally related to pile driving activity, dynamic compaction, blasting, or the operation of heavy construction equipment or plant. The motion caused by the vibration can be described in terms of displacement, velocity and acceleration, in each direction, all of which are frequency dependant. The resultant value is the vector sum of the quantity over the three axes of motion (commonly termed x, y, and z). **Figure 10** illustrates an example of vibration measurement with the resultant's peak particle velocity PPV (mm/s) and associated vertical, transverse, longitudinal axis.

Figure 10. Vibration measurement resultants PPV (mm/s) and associated vertical, transverse, longitudinal axis [(4)]



If the vibration in one direction is significantly higher than in the other two directions, the highest component of the PPV and the resultant PPV, are very similar in value. However, if one direction is not dominant, then the resultant PPV is larger than each of the components.

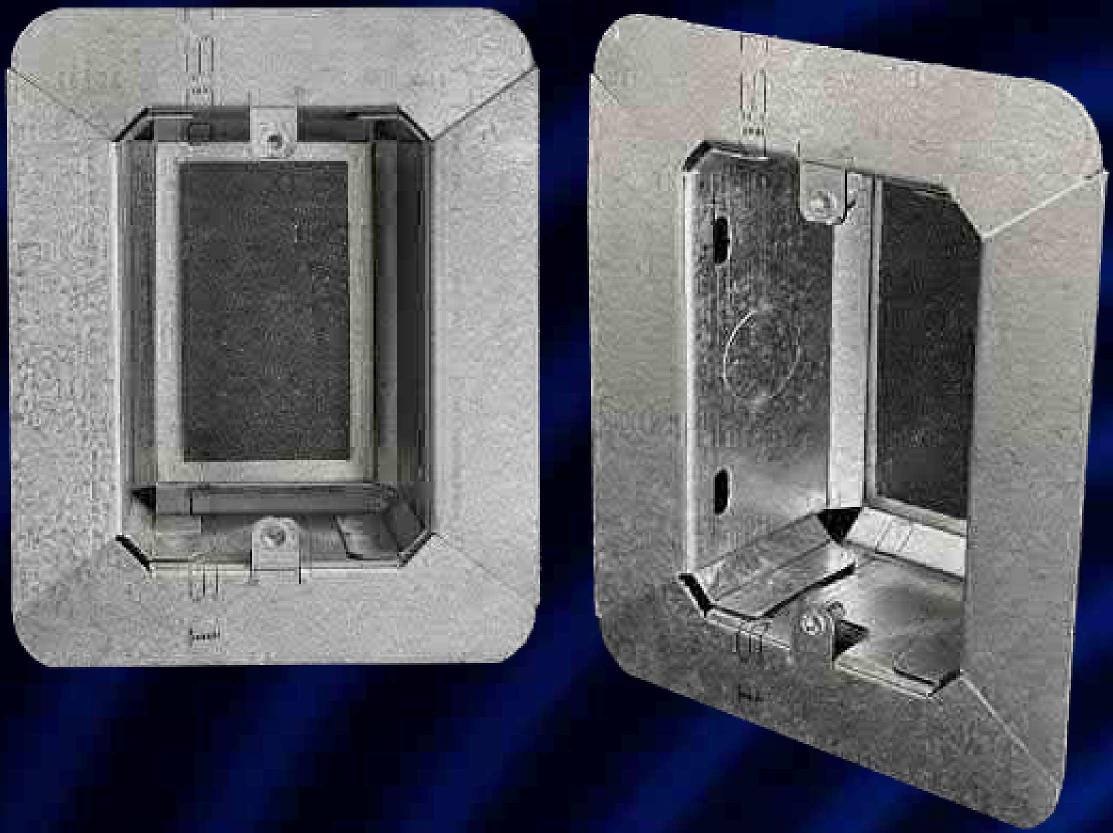
Vibration propagation from construction activities is the transfer of energy to the ground from the machinery, plant or construction process, which results in elastic and inelastic deformation of the surrounding materials. Part of this energy travels in the form of elastic waves and results in ground and structural vibration. The duration and amplitude of vibration generated by construction activities varies based on the nature and scale of the event. The vibration from blasting has a high amplitude and short duration while vibration from may be grading is low in amplitude but longer in duration. **Figure 11** illustrates a photo set of site grading and construction works adjacent to historic structures.

Figure 11. (Left) Site grading adjacent Sullivan Arch which lies adjacent to the Modern Wing addition at the Art Institute of Chicago. (Right) Construction works adjacent the Saint Louis Art Museum, Saint Louis, Missouri, construction underway for expansion, 2010 [(5)]

Construction equipment continuous vibration includes excavation equipment, static compaction equipment, tracked vehicles, vibratory pile drivers and vibratory compaction equipment. Construction equipment with single impact (transient) or low repeat rate includes impact pile drivers, drop mass balls, and pile drivers.

In general, the longer the duration of vibration activities on a site, the more likely it is that vibration from the site will prove to be an issue. The primary vibration concerns are the potential for damage to buildings, underground services, and often just as importantly, the human response to vibration. Humans can detect and be annoyed by vibration levels that are well below those likely to cause any risk of damage to a building or its contents. The risk of human discomfort is generally lower for short-duration vibrations. The risk of cosmetic building damage is also lower for short-duration vibrations compared to continuous vibrations of the same magnitude. This is because short-duration vibrations would be less likely to fully 'excite' resonant vibration responses in the buildings structure. The Resource Management Act 1991 defines 'noise as including vibration'. NZS 6803:1999 specifically states that the standard does not cover vibration.

[5] *Source Vibration Limits for Historic Buildings and Art Collections. Arne P. Johnson and W. Robert Hannen, Apt Bulletin Journal of Preservation Technology, 46:2-3 2015*



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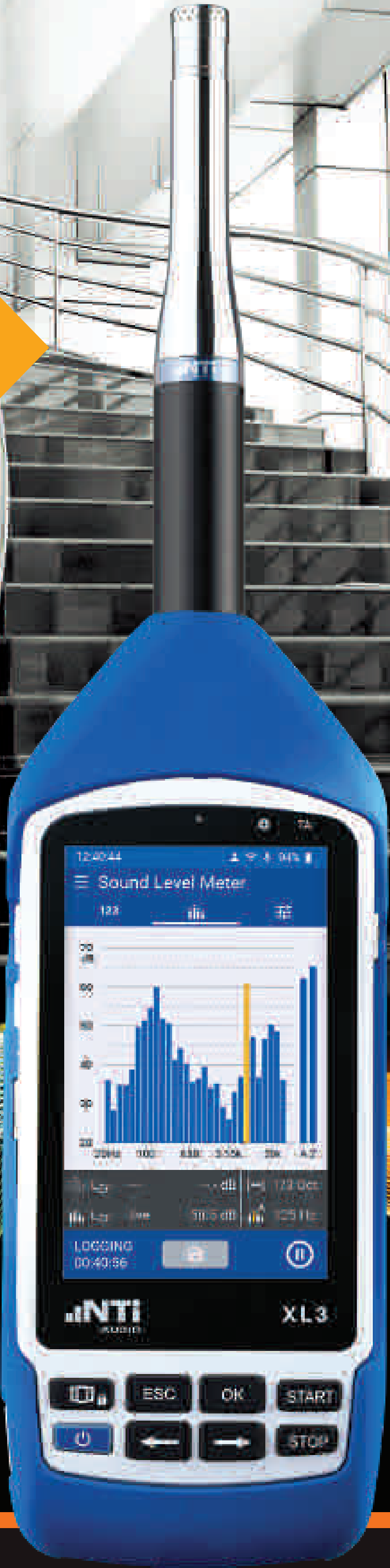

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10 NZS 6803:1999 Acoustics - Construction Noise

The New Zealand standard NZS 6803:1999 Acoustics – Construction Noise, is widely adopted nationwide and is known as one of the three 'base' standards for the measurement and assessment of environmental noise in New Zealand along with NZS 6801:2008 *Acoustics – Measurement of Environmental Sound and NZS 6802:2008 Acoustics – Environmental Noise.* These standards are used for the day-to-day measurement and assessment of environmental noise. The scope section of NZS 6802:2008 states *"This Standard (6802) does not apply to the assessment of sound where the source is within the scope of, and subject to, the application of other New Zealand acoustical Standards."* NZS 6802:2008 should therefore not, therefore, be applied to sound from construction noise. NZS 6803 provides methods for the assessment, prediction, and management of construction noise and should however be read and used in conjunction with NZS 6801:2008 and NZS 6802:2008.

NZS 6803:1999 was prepared by the 'Acoustics Construction Noise Committee' (EV/10/9) for the Standards Council established under the Standards Act 1988 as a 'New Zealand' only project. NZS 6803 was released over 20 years ago as a valuable tool to practitioners and Councils providing guidance for the measurement, assessment, and prediction of construction noise as well as current noise management methods. The standard replaced NZS 6803:1984P *The measurement and assessment of noise from construction, maintenance and demolition work*. NZS 6803:1984P was a provisional standard, hence the 'p' in the title.

10.1 Terminology and key Noise Descriptors

Many different single-number measurement quantities or 'noise descriptors' (or noise indices, or noise indicators) have been developed and provide a way to measure a property of noise, in a standardised way. Broadly speaking noise descriptors are either used to quantify the continuous part of the exposure or the transitory part of the exposure The use of several noise descriptors enables the assessment of the noise in relation to the human response and/or impact on health and amenity. NZS 6803 measures and assesses construction noise using two noise descriptors, $L_{Aeq(t)}$ and L_{AFmax} both of which are in general use and recommended internationally for the description of environmental noise (including construction noise).

$L_{Aeq(t)}$ is the time average sound pressure level, the equivalent continuous A-weighted sound pressure level, in decibels (dB), over the time interval t;

$L_{AFmax,t}$ is the maximum sound pressure level, using A-weighting over the measurement period t. It is commonly measured using the L_{AFmax} descriptor (the maximum sound pressure level using A-(frequency) weighting and F-time weighting) but it can also be measured using the maximum of $L_{Aeq,t}$ using a short integration time of 100-125 ms.

To avoid ambiguity, recent New Zealand standards use a standard notation or format, called '*value-unit-descriptor*', which should explicitly include the time duration. For example, 75 dB $L_{Aeq(15\ min)}$, is read as 75 dB (deciBels), A-frequency weighted equivalent level, over a 15-minute period. The correct use of this standard notation helps ensure that the persons using it are clear on which noise descriptor is being reported. More complex indicators introduce weighting factors to take account of human response or sensitivity to noise at different times of the 24-hour day, however, it is not common for construction noise assessment to adopt such measures.

It is well accepted that in order to avoid sleep disturbance at night, guidelines for community noise (including construction) should be expressed in terms of equivalent sound pressure levels, $L_{Aeq(t)}$ as well as L_{AFmax} (for single event night time sleep protection). This is because it is not sufficient to characterize the noise in terms of just the energy average (L_{Aeq}) as transient noise events that can cause waking, would not show up. The addition of L_{AFmax} ensures that such events are captured, providing protection against sleep disturbance.

10.2 Assessment and Limit

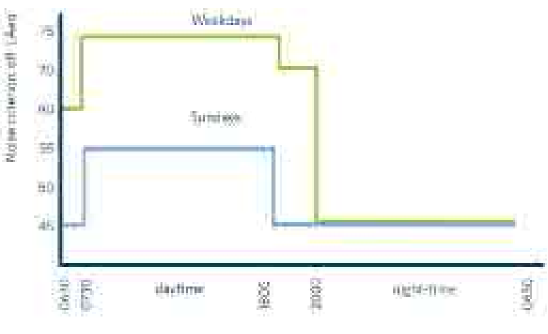
Noise from construction projects *generally* cannot at all times comply with the day-to-day permitted operational noise limits set out within District Plans or those recommended in NZS 6802. Although this may mean that the noise produced is undesirable by some parties, it does not mean that the noise is unreasonable when all the relevant factors such as the limited duration, time of operation, and mitigation measures, are taken into account.

NZS 6803 is intended to cover construction work of limited duration. Projects such as the demolition of a structure, alterations or additions to buildings, road reconstruction, or re-alignment work, are covered. These examples all represent temporary noise sources and so they are assessed differently than noise from ongoing activities. For example, quarrying, landfill, or the ongoing construction of pre-fabricated buildings or building components, are unlikely to be of limited duration and so would be assessed using NZS 6802. Having said that, the methods for the measurement, assessment, prediction, and management of construction noise under NZS 6803, should be read and used in conjunction with NZS 6801:2008 and NZS 6802:2008.

NZS 6803 states it should be used for the setting of noise limits to *"reduce the likelihood of annoyance, nuisance and adverse health effects to people in the vicinity of construction work."* The standard sets limits based on duration-of-work, time-of-day, and if the activity occurs on a weekday or holiday. The standard provides two key tables; the first (Table 1) is for noise-sensitive 'residential and rural areas' and the second (Table 2) is for 'industrial or commercial areas'. Three categories are described for work duration, 'short', 'typical' and 'long', which relate to the duration of the proposed works. 'Short' term is up to 14 days, 'typical' is 14 days to 20 weeks, and 'long' term is greater than 20 weeks.

Figure 12 illustrates the long-term construction noise limits for L_{Aeq} (adapted from NZS 6803) for residential sites (note L_{AFmax} is not shown)

Figure 12. Long-term construction noise limits adapted from NZS 6803:1999 [(4)]



Section C7.2.1 of NZS 6803 provides the commentary that noise from construction is limited and thus the community would normally tolerate higher noise levels compared to that for permanent activities provided that the noise is no louder than necessary, thus the limits set in Table 2 and Table 3 of the standard reflect this by allowing higher levels for shorter duration works. The applicable limits in NZS 6803 for short term (weekdays) projects are:

- Morning (6.30am to 7.30am): 65 dB $L_{Aeq(15\,min)}$ and 75 dB L_{AFmax}
- Daytime (7.30am to 6.00pm): 80 dB $L_{Aeq(15\,min)}$ and 95 dB L_{AFmax}
- Evening (6.00pm to 8.00pm): 75 dB $L_{Aeq(15\,min)}$ and 90 dB L_{AFmax}
- Night-time (8.00pm to 6.30am): 45 dB $L_{Aeq(15\,min)}$ and 75 dB L_{AFmax}

NZS 6803 sets strict limits for weekends and public holidays, for example, the limits for short-term works on a Sunday are:

- Daytime (7.30am to 6.00pm): 55 dB $L_{Aeq(15\,min)}$ and 85 dB L_{AFmax}

The night-time limits set out in NZS 6803 are between 8.00pm and 6.30am the next day, and they are set low at 45 dB $L_{Aeq(15\,min)}$ and 75 dB L_{AFmax}. As a point of reference, this is the same recommended upper limit guideline value recommended in NZS 6802:2008 for general activities using a 15-minute sampling time. The only minor change is that NZS 6802 defines night as 10.00 pm to 7.00 am.

10.3 Some examples of limitations of NZS 6803:1999

The limits set in NZS 6803 do not take account of any noise-sensitive locations, the standard only assesses: 1) residential and rural areas; or 2) commercial or industrial areas. There is no mention of vulnerable groups or noise-sensitive activity types. Such locations include hospitals, retirement villages, marae, places of worship, educational facilities, and cultural or heritage locations. These locations and their associated activities typically require a higher level of screening and protection from noise. Other construction standards, for example, the 'EPA Interim Construction Noise Guideline', sets out guideline levels for noise at sensitive land uses and clearly states assessment should only apply when a building that is actually occupied.

Section 7.4 'Compliance with noise limits' of NZS 6803 states that other than emergency works, *"every effort should be made by the contractor to comply with the applicable noise limits"*. However, the standard is often adopted in District Plans or Resource Consents as 'strict limits' as opposed to targeted limits (noise control targets). As discussed further below, many standards are moving away from strict limits towards a two-tier method which is to adopt targeted limits while ensuring the best practice is adopted to manage noise. In New Zealand, if the noise limits in NZS 6803 are technically required to be complied with via a rule in a District Plan or Resource Consent condition, and they are not complied with, this can cause technical and compliance issues along with reputational issues for the developer. Moving towards 'targeted limits' would ensure that regardless of strict compliance, the best practical option (BPO) (to mitigate noise) under section 16 of the Resource Management Act 1991, is achieved.

NZS 6803 further states that when the limits in Table 2 and Table 3 of the standard are met these are the *"desirable upper limits for construction noise received by the community for the reasonable protection of health and amenity"*. Importantly, the standard goes on to state that *"desirable limits vary according to the type of land use, time of day and anticipated duration for the construction works. The best practical options should always be adopted to ensure that the emission of noise for the site is minimised."* The limits set in NZS 6803 are for the *"reasonable protection of health and amenity"* (Section 7.1.1), while the specific night time limits (L_{AFmax}) are intended to "*protect the average person from disturbance to the onset of sleeping and awaking during the night*".

One key matter with the use of the three duration categories ('short', 'typical', and 'long') is that the 'long' category is open-ended. There is no maximum duration stated, only that it is greater than 20 weeks (5 months). In some cases, such as large-scale developments for buildings or major infrastructure projects involving roading, rail, or water, construction components last for years on end as opposed to a few months. There are various examples of projects lasting for several years or even a decade. Such developments in the same location or site for several years often occur adjacent to a host of noise-sensitive receivers or sites, such as dwellings, apartments, and education or healthcare facilities.

As noted above, NZS 6803 clearly provides the justification that noise from construction is limited and thus the community would *"normally tolerate higher noise levels"* provided that the noise is no louder than necessary and that setting such noise limits *"reduce the likelihood of annoyance, nuisance and adverse health effects to people in the vicinity of construction work",* noting, of course, the upper limits vary based on various factors, including the duration for the construction works. Anecdotal evidence would suggest that in some cases, some projects, albeit long or short duration, are not always tolerated by the community (even if BPO measures are adopted).

Major projects of nature and scale that are long in duration are clearly required. But the question arises around the suitability of the current limits in NZS 6803 to provide the necessary protection of health and amenity for projects that operate for much more than 20 weeks in one location, adjacent to noise-sensitive sites. Should there be a fourth category for major infrastructure projects such as 'extended duration', greater than 40 weeks or an another threshold? Does the standard require review for large or complex projects which have both local or national significance and which may include roading or other matters such as power or water?

Interestingly, unlike other standards (in particular the base standard, NZS 6801) the permitted noise limits in NZS 6803 require noise assessment at 1 metre from any exposed wall of a building used for a noise-sensitive activity and not at the site boundary or notional boundary of the applicable assessment location. The construction standard is also unique in that the measured levels when compared against applicable limits in the standard are not adjusted for special audible characteristics (SACs, which affect the perceived loudness of the sound) or any other factors, such as façade effects, as is required in NZS 6802. These assessment differences, appear to be in place to simplify the assessment. However, if measurements are taken 1 m from a façade, then due to sound reflection, the measured value will typically be 2 dB higher than away from the surface.

NZS6803 says that *"Sound from construction work is usually highly variable. Therefore care must be taken to ensure that the measurements are representative of the sounds under investigation."*. It then goes on to say that the *"measurement sample times should not exceed one hour, and 15 minutes will often be adequate".* The somewhat looseness of measurement duration can cause conflict, as it relies on the professional judgment of the assessor. Usually, when a justification for a different duration is provided, the is no issue. It should be noted that a duration of 15 minutes is consistent with the guidance in NZS 6801 and the guideline noise descriptor measurement limits in NZS 6802.

Other minor matters arise with NZS 6803 due to its age. The annexes B, C, and D of the standard are 'informational', that is, they are not formally part of the standard, but are there as useful information that used to be relied upon. All of these annexes are reproduced from the British standard BS 5228-1 from back in 1997, making this information over 25 years old and in some cases, well out of date. The current version of BS 5228 is dated 2009, which itself is now well over 10 years old.

Another area not covered by NZS 6803 is night time noise exemptions for public works. There is no guidance around the standardisation of any exemption, as well as timing and costs. For example, if a contractor requires resource consent to do night works, this process can take weeks to months to complete and has significant costs associated with it. There are many common examples of night time work, such as the set-up of a crane, road works, water or gas works, through to basic road works in a bus lane or traffic lights, that generally cannot be closed during typical working hours without having a major impact on the wider population. Such works are critical to modern society and ensure the day-to-day efficient running of any modern city. However, in many cases, noise from this construction work is not considered at all or is poorly mitigated or managed. In most cases, larger territorial authorities or Tier 1 Councils will have protocols to address such matters, however, the smaller councils may not have the resources or expertise to address such matters.

There are examples that exist that allow exceedances of construction limits, for example in the operational Auckland Unitary Plan (AUP), Rule E25.6.29 provides specific construction noise rules for works on a road. Rule E25.6.29 enables exceedance of the noise limits in E25.6.27 and E.25.6.28 under certain circumstances, including when they are of limited duration and have a certified noise management plan. There are also examples of Councils, such as Wellington City Council, that have specific protocols and measures in place that allow critical night time work to take place when required. The WCC procedures require BPO measures to be adopted, community consultation via letter drops clearing explaining why the work must be done at night, along with other matters.

11 New Zealand Planning Standards

In 2017, the Ministry for the Environment (MfE) began introducing 'national planning standards' as part of amendments to the RMA. The purpose of the national planning standards is to improve consistency in plan and policy statement structure, format, and content. Their development is enabled by the addition of sections 58B to 58J to the RMA. The guidance document for National Planning Standard 15, 'Noise and Vibration Metrics[14], states that the standard should be read alongside recommendations on submissions included in report 2J Noise and Vibration Metrics Standard for further context. It states that *"The standard provides direction on the New Zealand Acoustical Standards (NZAS) (to which it means the NZS 68xx series for acoustics) and other relevant noise and vibration standards to be used in plan rules. It does not provide direction on content.".* The standard does not mention construction noise but does mention the management of damage to structures from construction vibration by the use of *'ISO 4866:2010 Vibration of Fixed Structures',* which establishes principles for carrying out vibration measurement and processing data with regard to evaluating vibration effects on structures. ISO 4866:2010 is not a well-adopted standard due to a number of matters in New Zealand and it is unclear why this standard has been adopted when other more suitable standards like DIN-4150-3 exist.

12 Vibration Standards - Structural effects, amenity, and perception

Standards New Zealand does not have a current vibration standard relating to vibration or human exposure. The last standard adopted in New Zealand was *ISO 2631-2:1989 'Evaluation of human exposure to whole-body vibration – Part 2: Continuous and shock-induced vibration in buildings (1 to 80 Hz)*. It was adopted as NZS/ISO 2631.2:1989 until it was withdrawn and not replaced, in 2005. The current version of ISO 2631-2 is dated 2003 and was last reviewed by ISO in 2018 and is their current version.

Although the adoption of vibration limits and standards as rules in District Plans or consent conditions has increased over the years, many territorial authorities, such as District Councils, still may not set limits for vibration or they may only adopt limits for the protection of structures and not comfort or annoyance from vibration. Yet, noise in the RMA is defined as including vibration. The overarching requirement in section 16, is to adopt the best practicable option (BPO) to ensure that the emission *of noise and vibration* does not exceed a reasonable level, and this applies to every construction site.

The effects of vibration from construction are well known and include potential damage to nearby structures, loss of amenity, and health effects. A host of international standards exist which assess vibration effects on human comfort, perception, and buildings. There are also vibration standards solely for specific sources, such as traffic noise. Antidotally, complaints of vibration from construction sites are less compared to complaints regarding airborne noise. Complaints for vibration are often location specific, for example, the occupants of one building may complain while the occupants of the building next door do not. Other examples exist when the occupants on one floor of a building (top levels) complain while the occupants on other floors (lower levels) do not. During construction activities, the level of tolerance, particularly from residents and commercial office buildings, relates to a wide range of factors, such as concern over potential building damage and human response. Antidotally, if vibration complaints are received in many cases the person complaining will first and foremost have concerns around damage to their property and building, and secondarily about amenity (the fact that the vibrations can be felt even at low levels) and then in limited cases health effects.

[6] *Source https://environment.govt.nz/assets/Publications/Files/guidance-for-noise-and-vibration-metrics-standard.pdf*

12.1 DIN 4150-3:2016 Vibration in Buildings - Part 3: Effects on Structures

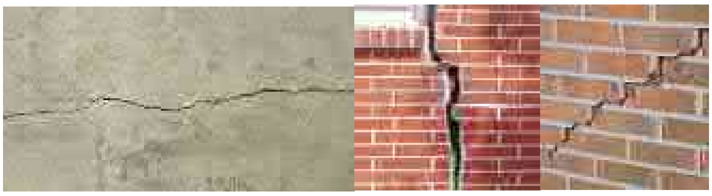
The German standard, *DIN 4150-3:2016 'Vibration in buildings – Part 3: Effects on Structures*, includes guidelines for ground-borne vibration for residential buildings together with criteria for both commercial/industrial buildings, and high sensitivity structures. The use of DIN 4150-3 is widespread in New Zealand, and it has a history of successful implementation in projects involving construction activities. Many District Plans or resource consent conditions have adopted its use, especially for larger projects. The standard has been adopted for major infrastructure projects throughout New Zealand, including the Waterview Connection (road and tunnel in Auckland), MacKay's to Peka Peka expressway (Wellington), Victoria Park tunnel (road and tunnel in Auckland), and the Marsden Point Rail Link, to name a few. It also appears that DIN 4150-3 has an extra degree of conservatism built in. Although this is not transparent or explained explicitly in the standard, comments to this end are often made antidotally by experts in the field of vibration. To illustrate this conservatism, BS 5228-2:2009 allows values up to three times those in DIN 4150-3 for buildings of the same type.

Experts in vibration have noted the adoption of a data-driven approach to the implementation of DIN 4150-3 is considered pragmatic, and promotes comprehensive monitoring and assessment of vibration activities during construction works. The key criterion in the standard relates to the avoidance of structural building damage. The standard recognises the difference between the structure of residential, historic buildings, and commercial buildings (with commercial buildings being able to withstand higher vibration levels). The criteria are expressed in peak particle velocity (PPV) and are intended to avoid superficial damage to buildings. The use of the PPV metric in vibration is generally viewed as the most basic and direct parameter for a vibration event to connect with the stress increments in the ground or a built structure.

There are generally two classifications for damage to structures, cosmetic or structural. Section 3.2 terms and definitions of DIN 4150-3 define 'damage' as *"any permanent consequence of an action that reduces the serviceability of a structure or one of its components"*. Structural damage refers to any type of change that could compromise the stability and integrity of the structure. A suitably qualified and experienced engineer would determine what is structural damage after completing a review. Structural damage can often be 'hidden or disguised' by overlying cosmetic damage and can involve damage to mechanical systems, for example, air conditioning, as well as to the structure itself. Structural damage is very serious and could result in structures being evacuated.

Cosmetic damage is generally everything else outside of structural damage, which affects the appearance of the building. It could be the cracking of plaster, screw pops on plasterboard walls, or exterior damage to the finish or cladding of the building, such as the cracking of concrete paths. Cosmetic damage may also be referred to as 'minor damage' or 'superficial damage'. **Figure 13** illustrates two samples of cosmetic damage and structural damage from vibration.

Figure 13. Examples of cosmetic vibrational construction damage (left) and (right) and structural vibrational damage [3]



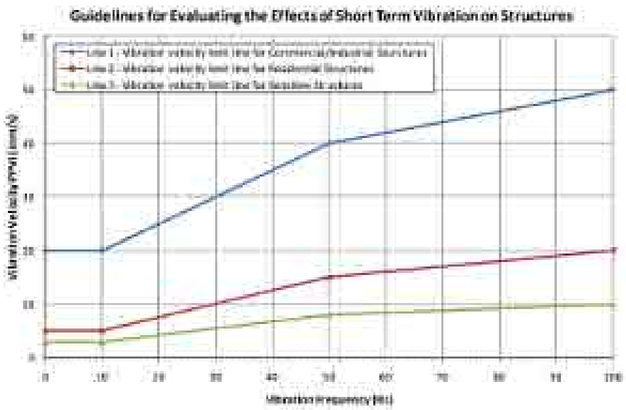
Damage from vibration may also appear by other means, such as settling of foundations or thermal cycling (i.e. temperature changes) and normal aging. Hairline cracks in a building after construction are not necessarily indicative of construction vibration causation. Although vibration can be felt, this also does not mean it causes damage. If care is taken by the contractor, such as the use of the correct equipment, sufficient buffers, and compliance with relevant vibration standards, potential vibration damage can be mitigated. A further measure is if planned construction occurs in your area persons can document on video or via photo the pre-construction condition of their site and structures.

The guideline values in DIN 4150-3 are different, depending on the vibration source, and are separated on the basis of short-term and long-term vibration. The definitions for 'short-term' and 'long-term' vibration in this standard are not directly related to duration, but to their effect. DIN 4150-3 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."*. In general, the short-term vibration definition would be applied to activities that consist of a single shock, followed by a period of rest. For example, rock blasting, mass weight/drop hammer pile-driving (non-vibratory), or dynamic consolidation. Long-term vibration is defined as *"all other types of vibration not covered by the definition of short-term vibration"*.

DIN 4150-3: applies a three-level classification system for buildings, according to their susceptibility to vibration damage. These definitions for short-term (transient) vibration on structures are as follows and are illustrated in **Figure 14**:

- Category 1: Buildings used for commercial purposes, industrial buildings and buildings of similar design (Line 1);
- Category 2: Dwellings and residential buildings of similar design and/or occupancy (Line 2);
- Category 3: Structures that because of their particular sensitivity to vibration, cannot be classified under Line 1 and 2, and are of great intrinsic value (e.g. buildings listed buildings under preservation order (Line 3)).

Figure 14. DIN 4150-3:2016 vibration limits for short-term (transient) vibration on structures[6]



The key criteria for short-term and long-term vibration activities as a function of building types are shown in **Table 2**.

Table 2. DIN 4150-3:2016 short and long-term vibration criteria as a function of building types (commercial, residential and sensitive).

Type of Structure	Short-term vibration				Long-term vibration
	Foundation - All directions at a frequency of			Top/Highest Floor Horizontal direction	Top/Highest Floor Horizontal direction
	1-10 Hz (mm/s)	10-50 Hz (mm/s)	50-100 Hz (mm/s)	All frequencies PPV (mm/s)	All frequencies PPV (mm/s)
Line 1 - Commercial and Industrial	20	20-40	40-50	40	10
Line 2 – Residential dwellings or buildings	5	5-15	15-20	15	5
Line 3 – Sensitive Historic (heritage)	3	3-8	8-10	8	2.5

In addition to short-term and long-term vibration activities as a function of building types, DIN 4150-3 also sets standards for services. For example, the minimum guideline value given in DIN 4150-3 for evaluating the effects of long-term vibration on buried pipework is 25 mm/s PPV (measured on the pipe). The following table indicates the damage to buried pipes for short-term vibration. The vibration goals for electrical cables and telecommunication services such as fibre optic cables range from between 50mm/s and 100mm/s.

Table 3. Vibration limits (ppv) for various pipe materials.

Peak Wall Vibration Velocity (PPV)	Pipe Material
100 mm/s	Steel (including welded pipes)
80 mm/s	Clay, concrete, reinforced concrete, prestressed concrete, metal with or without flange (other than steel)
50 mm/s	Masonry, plastic

The standard ISO 4866:2010 (Mechanical Vibration and Shock — Vibration of Fixed Structures — Guidelines for the Measurement of Vibrations and Evaluation of their Effects on Structures) also establishes principles for carrying out vibration measurement and processing data with regard to evaluating vibration effects on structures. This standard is not well adopted in New Zealand.

12.2 BS 5228-2:2009 Code of Practice for noise and vibration control on construction and open sites – Part 2: Vibration

The British standard, BS 5228-2:2009 + A1:2014 (with amendment 1, 2014) *'Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration'* (BS 5228-2:2009), provides recommendations for vibration control for construction and open sites, with industry-specific guidance. It also addresses the *"disturbing effect of vibration"* from construction vibration and acknowledges that even very low levels can be perceptible by people and can cause anxiety, annoyance, and disturbance of sleep, work, and leisure activities.

The standard is comprehensive and includes detailed prediction, measurement, assessment, and control of vibration from construction works. As with DIN 4150-3, this standard uses PPV to assess vibration from construction, and for its assessment criteria for the human response to construction vibration effects. The criteria with respect to building damage, are like that in DIN 4150-3. **Figure 15** shows criteria (as component ppv mm/s) for short-term vibration on house structures, drawn from BS 5228-2:2009.

Figure 15. BS 5228-2 criteria (as component ppv mm/s) for short-term (transient) vibration on house structures [4]

Annex B of BS 5228-2:2009 provides guidance on human response to vibration. The perceptibility of continuous vibration as a function of the degree of perception is summarised in **Table 4**.

Table 4: BS 5228-2:2009 vibration level and degree of human perception for continuous vibration

Vibration Level (PPV)	Effect
0.14 mm/s	Just perceptible in sensitive environments
0.3 mm/s	Just perceptible in residential environments
1 mm/s	Will cause complaints but I tolerated if prior warning/notification
10 mm/s	Intolerable – even for brief periods

The vibration perception values in BS 5228-2:2009 relate to effects on residences, however, such limits could also be reasonably applied to offices, with 1 mm/s being acceptable provided notification has been given.

12.3 Additional vibration standards for construction acitvity

The British Standard BS 6472-1:2008 *'Guide to Evaluation of Human Exposure to Vibration in Buildings – Part 1: Vibration Sources other than Blasting'* does not appear to be widely used in New Zealand. The standard assesses operational vibration effects via a dose-response metric known as the Vibration Dose Value (VDV). VDV is a measure of vibration exposure that is believed to give a better correlation with human response than RMS based methods when the vibration includes short bursts of high amplitudes, such as from impulses and shocks. VDV is calculated from the frequency-weighted vibration acceleration curves for vertical and horizontal acceleration respectively, raised to the fourth power and integrated over the day or night time period. There is also VDVe which is the estimated vibration dose value, as it is possible to estimate vibration dose using the alternative method of VDVe. However, measurement is the preferred method, as the vibration may vary and in some cases be intermittent. **Table 5** offers guidance on the quantitative threshold guidance for human perception of continuous vibration level as a function of frequency between 8 Hz to 80 Hz (PPV).

Table 5. Quantitative threshold guidance for human perception of continuous vibration level for 8 Hz to 80 Hz.

Vibration Level (PPV mm/s)	Degree of Human Perception (8 Hz to 80 Hz range)
0.10 mm/s	Not felt
0.15 mm/s	Perception threshold
0.35 mm/s	Barely noticeable
1 mm/s	Noticeable
2.2 mm/s	Easily notable
6 mm/s	Strongly noticeable
14 mm/s	Very strongly noticeable

Like noise, there is no definitive vibration level, people's tolerance and perception vary greatly across the population. With respect to vibration effects on sleep disturbance at night, there is no significant body of research specifically investigating this matter (see https://www.extrica.com/article/19059/pdf VDV for more information). In practice, vibration in buildings that disturbs sleep is often perceived as structure-borne regenerated noise, that is, noise generated by rattling objects or through visual cues such as movement of wall hangings, rather than through tactile perception only. **Table 6** offers quantitative guidance in respect of the threshold for the effects of vibration on buildings over the frequency range typical of vibration in buildings from construction activities (approximately 8 Hz to possibly 100 Hz). A secondary matter is that vibrations can cause structure-borne noise which can be an additional irritant to occupants of buildings. Loose fittings are prone to rattle and movement.

Table 6. Quantitative guidance for threshold effects of vibration on buildings.

Approx Vibration Threshold Level (PPV mm/s)	Potential Effect (8 Hz to 80 Hz range)
0.5 mm/s	Visible movement of susceptible building contents such as hanging pictures, blinds
Less than 0.9 mm/s	Windows rattling in some buildings (if combined with sound pressure waves)
0.9 mm/s	Audible rattling of loose objects such as plates or crockery
> 1 mm/s	Day-to-day activities such as footfalls, doors closing

13 Other international construction standards

There are literally dozens of construction standards and guidelines for noise and vibration internationally. Many countries have their own methods for the assessment of construction and vibration noise and in many cases where there are states within a country, such as Australia or the United States, there are further standards and guidelines adopted. Each country also has its own unique legislation and Acts for noise and vibration. The following provides a brief review of construction noise based on British Standards. A further review of construction noise is also provided in Singapore. The review shows for the below standards and other countries that at present there is a mixture of requirements that range from having to meet strict limits, to controlling noise via best practice. Other examples exist, such as those adopted in New Zealand where set limits must be met, as well as adoption of best practice to manage noise and vibration.

13.1 BS 5228-1:2009 Code of practice for noise and vibration control on construction and open sites

The British Standard BS 5228:2009 *Code of practice for noise and vibration control on construction and open sites* (BS 5228), provides guidance on the methods that can be used to predict and measure noise and vibration from construction activities and how to assess the impact on those exposed to it. Annex F of Part 1 (BS 5228-1:2009 + A1:2014, with amendment 1, 2014) sets out the methods for estimating noise from construction sites which take into account distance, ground effects, reflections from surfaces, and screening by objects. Annex E of Part 2 (BS 5228-2:2009 A1:2014, with amendment 1, 2014) provides a wide range of empirical formulae for predicting ground-borne vibration for specific construction activities.

NZS 6803:1999 makes specific reference to the historic version of BS 5228-1:1997, however, due to the age of NZS 6803:1999, no further update has been made with respect to the latest version of the standard. The main change from 1997 to the current version (2009 + A1:2014) are:

- Part 1 covers noise; and
- Part 2 covers vibration

BS 5228-1:2009 refers to the need for the protection against noise and vibration of persons living and working in the vicinity of, and those working on, construction and open sites. The standard recommends procedures for noise and vibration control in respect of construction operations and aims to assist architects, contractors and site operatives, designers, developers, engineers, local authority environmental health officers and planners.

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Section 8.4 of BS 5228-1:2009 states with respect noise control targets,

"All reasonably practicable means should be employed to ensure the protection of local communities and of people on construction sites, from detrimental effects of the noise generated by construction operations. The means employed should be determined by local circumstances and can include the methods described in 8.2 (Control at source) and 8.3 (Controlling the spread of noise)".

Significance of construction noise levels

Annex E (informative) of BS 5228-1:2009 provides alternative and/or additional methods to determine the significance of construction noise levels is to consider the change in the ambient noise level with the construction noise. There are two main methods, both with similar approaches, of which examples are the 1) 'ABC method' detailed in Annex E.3.2 and 2) the '2 – 5 dB(A) change method' where noise levels in Annex E.3.3.

The two methods are summarised in the next two sections.

ABC method

The 'ABC method' sets threshold values to determine if there will be a significant effect at dwellings for three different categories (A, B, and C). The table below from BS 5228-1:2009 shows an example of the threshold of significant effect at dwellings when the total noise level, rounded to the nearest decibel, exceeds the listed values. The threshold values are different for each ABC category and different time periods. The ambient noise level is determined for the appropriate period and then rounded to the nearest 5 dB. This is then compared to the total noise level, including construction noise. If the total noise level exceeds the appropriate category value (A, B or C), then a significant effect is deemed to occur.

The ambient noise is the *"total sound in a given situation at a given time, usually composed of sound from many sources near and far"*. The standard also defines 'site noise' being *"the component of the ambient noise in the neighbourhood of a site that originates from the site"*.

(See table 7 below)

The values in Category A, B, and C are the threshold values to be used when ambient noise levels (when rounded to the nearest 5 dB) are less than, equal to, or higher than the values in Category A column, respectively. The calculation method of takes account of the duration of an activity per hour, the 'on-time'; and the attenuation of sound due to the effects of distance, ground attenuation, and barrier effects. An example of the application of this method to a school location is shown in **Table 8**.

(See table 8 below)

2-5 dB change method

The *'2 – 5 dB change method'* applies where noise levels generated by site activities are deemed to be significant if:

- The total noise (pre-construction ambient plus site noise) exceeds the pre-construction ambient **noise by 5 dB** or more, subject to lower cut-off values of:
  - 65 dB L_{Aeq} Daytime;
  - 55 dB L_{Aeq} Evening; and
  - 45 dB L_{Aeq} Night-time

Sound insulation and temporary rehousing

BS 5228-1:2009 refers to sound insulation, reasonable costs, or temporary rehousing options, where in spite of the mitigation measures applied, and any Section 61 consents under the Control of Pollution Act 1974, noise levels at receiver sites exceed noise trigger levels for the periods as defined in Table E.2 of BS 5228-1:2009.

Moving noise sources

On many open sites, the noise sources are located in the same location or within the defines of a specific area or site boundary. In some cases, construction sources also move, and as such, BS 5228-1:2009 provides two methods for assessing the noise of moving sources (mobile plant), and alternative methods for assessment are required. The first method is discussed in Annex F (informative) *Estimating noise from sites*. Section F.2.5 *Method for mobile plant using a regular well-defined route (e.g., haul roads)'*, applies to trucks plants on a haul road, and the second method in section F.2.4 *Method for mobile plant in a defined area,* applies to slow-moving vehicles in a constrained area such as a work site.

Table 7. Example of the threshold of significant effect at dwellings when the total noise level

Assessment Category Threshold Value Period	Threshold Value dB $L_{Aeq(T)}$ (A1)		
	Category A A)	Category B B)	Category C C)
Night-time (23:00hrs to 7:00 hrs)	45	50	55
Evenings and weekends	55	60	65
Daytime (07:00hrs and 19:00hrs) D)	65	70	75
Saturday (07:00hrs and 19:00hrs) D)	65	70	75

A1 Note 1: significant effect has been deemed to occur if the total L_{Aeq} noise level, including construction, exceeds the threshold level for the Category appropriate to the ambient noise level.

Note 2: If the ambient noise level exceeds the threshold values given in the table (i.e. the ambient noise level is higher than the above values), then a significant effect is deemed to occur if the total L_{Aeq} noise level for the period increases by more than 3 dB due to construction activity. (A1)

Note 3: Applied to residential receptors only.

A) Category A: threshold values to use when ambient noise levels (when rounded to the nearest 5 dB) are less than these values.

B) Category B: threshold values to use when ambient noise levels (when rounded to the nearest 5 dB) are the same as category A values.

C) Category C: threshold values to use when ambient noise levels (when rounded to the nearest 5 dB) are higher than category A values.

D) 19.00–23.00 weekdays, 13.00–23.00 Saturdays and 07.00–23.00 Sundays.

Table 8. Example application of the ABC method

Noise Survey Pos.	Location	Distance (m)	Phase	Activity	Construction Noise Level dB $L_{Aeq(1hr)}$	Measured Baseline Noise dB $L_{Aeq(16hr)}$	Combined Noise Level dB L_{Aeq}	Threshold	Significant
1	School	50m	1	Demo	76 dB	58 dB	76 dB	65 dB	Yes

13.2 AS 2436-2010 Guide to noise and vibration control on construction, demolition and maintenance sites

Similarly, to New Zealand, the statutory requirements for the control of construction noise in Australia are the responsibility of each State Government or local Council, and as such, each state and local government has different requirements. There is a long list of Acts, local by-laws, standards, policies, guidelines, or other documents, that are adopted across each Australian state. These documents provide noise criteria and guidelines that are used when managing construction noise projects.

AS 2436:2010 *Guide to noise and vibration control on construction, demolition and maintenance sites*, is the Australian National Standard for the construction, maintenance, or demolition of a building or structure. The standard was prepared by Committee EV-010, Acoustic Community Noise. It was approved on behalf of the Council of Standards Australia on 22 April 2010. This Standard was published on 18 May 2010 and provides guidance for the preparation of noise and vibration management plan, work method statements, and environmental impact studies. The standard notes:

"Some construction and demolition activities are by their very nature noisy. The authorities responsible for setting noise level criteria for essential works will take note of the constraints imposed by such activities, especially when they are of short duration."

The Environmental Protection Authority (EPA) of New South Wales (NSW) produced an 'Interim Construction Noise Guideline (ICNG 2009) in 2009. It recommended standard hours for construction work. These hours are, however, not mandatory as there are situations where construction work may need to be undertaken outside of these hours, for example:

1. The delivery of oversized plant or structures that require special arrangements to transport along public roads;
2. Emergency work;
3. Maintenance and repair of public infrastructure where disruption to essential services is not an option;
4. Public infrastructure works that shorten the length of the project and are supported by the affected community; and
5. Works where an applicant demonstrates and justifies a need to operate outside the recommended standard hours (the guidelines state in the last two categories, clear justification for reasons other than convenience, should be provided).

The ICNG 2009 standard defines construction hours as:

- Monday to Friday 7.00am to 6.00pm;
- Saturday 8.00am to 1.00pm;
- No work on Sundays or public holidays.

The ICNG 2009 includes the rating background level (RBL) descriptor, which is used when determining the management level. The RBL is the overall single-figure background noise level measured in each relevant assessment period (during or outside the recommended standard hours). The term RBL is described in detail in the NSW Industrial Noise Policy [(7)]. The noise affected level represents the point above which there may be some community reaction to noise. For residential properties, the 'noise-affected' level occurs when construction noise exceeds ambient levels by more than:

- 10 dB $L_{Aeq(15min)}$ for work during standard construction; and
- 5 dB $L_{Aeq(15min)}$ for work outside standard construction hours.

The *'highly noise-affected'* level represents the point above which there may be a strong community reaction to noise. For residential properties, the highly noise-affected level occurs when construction noise exceeds 75 dB $L_{Aeq(15min)}$ at nearby residences. The highly noise-affected level only applies during standard construction hours. The ICNG 2009 sets out guideline levels for additional noise at sensitive land uses (other than residences) using quantitative assessment, such locations include schools, hospitals, and places of worship. For example, a hospital has an internal level set at 45 dB $L_{Aeq(15min)}$. The levels only apply when the structure or building is actually occupied and there is a mixture of levels set for outside or inside, depending upon the activity.

The ICNG 2009 also set levels for commercial and industrial premises. For example, 75 dB $L_{Aeq(15min)}$ is used for industrial premises, or 70 dB $L_{Aeq(15min)}$ for offices and retail outlets. Reference is also made to AS 2107 *Acoustics – Recommended design sound levels and reverberation times for building interiors*, to assist in determining relevant noise levels as this standard provides detailed guidance on a host of noise-sensitive types. The overall purpose of AS/NZS 2107:2016 is to provide guidance on recommended design sound levels and reverberation times for building interiors, including measurement for compliance assessment purposes, with the standard recommending design criteria conditions within building interiors to ensure *"healthy, comfortable and productive environments for the occupants and end users.".*

In 2020 the NSW EPA released a public consultation document, *Draft Construction Noise Guideline*. Consultation on the draft guidelines closed on 30 April 2021 and the feedback is currently under review. The feedback will be used to produce a final guideline to replace the ICNG 2009.

13.3 Singapore National Environmental Agency -Construction noise standards

Singapore is a nation that is just over 700 km^2 with a population of over 5 million. The population size is similar to New Zealand but sits on a land area about the size of Lake Taupo. There are approximately 18 people in New Zealand per square kilometre on average whereas in Singapore it is 8000. Singapore has high levels of intensification and continues to develop its residential, commercial, and transport infrastructure. With people living in such close proximity, noise issues from construction and other related work are inevitable. The Singapore National Environmental Agency (NEA) regulates noise levels from construction sites and industrial operations, based on a set of permissible noise limits. The NEA sets some of the most stringent construction noise levels, with limits as low as 50 dB being set for day and night at places such as hospitals or aged care facilities, and 75 dB for residential locations. In addition to establishing permissible noise limits, NEA has also implemented rules which prohibit work on Sundays and public holidays for construction sites located within 150m of residential premises and noise-sensitive premises. There is no work is allowed from 10.00 pm on Saturdays or eves of public holidays to 7.00am on the following Mondays or days after public holidays. **Table 9** illustrates NEA noise levels from construction sites.

[7] *EPA 2000 (See https://www.epa.nsw.gov.au/your-environment/noise/industrial-noise/noise-policy-for-industry-(2017))*

Table 9. NEA noise levels from construction sites [8]

Type of Building	Monday to Saturday			Sunday and Public Holidays		
	7am – 7pm	7pm – 10pm	10pm – 7am	7am – 7pm	7pm – 10pm	10pm - 7am
a) Hospitals, schools, institution or higher learning, home of aged sick etc	60 dB $L_{Aeq(12\ hr)}$ 75 dB $L_{Aeq(5\ min)}$	50 dB $L_{Aeq(12\ hr)}$ 75 dB $L_{Aeq(5\ min)}$		60 dB $L_{Aeq(12\ hr)}$ 75 dB $L_{Aeq(5\ min)}$	50 dB $L_{Aeq(12\ hr)}$ 55 dB $L_{Aeq(5\ min)}$	
b) Residential buildings located less than 150m from the construction site	75 dB $L_{Aeq(12\ hr)}$ 90 dB $L_{Aeq(5\ min)}$	65 dB $L_{Aeq(1\ hr)}$ 70 dB $L_{Aeq(5\ min)}$	55 dB $L_{Aeq(1\ hr)}$ 55 dB $L_{Aeq(5\ min)}$	75 dB $L_{Aeq(12\ hr)}$ 75 dB $L_{Aeq(5\ min)}$	55 dB $L_{Aeq(5\ min)}$	
All buildings other than those in (a) and (b)	75 dB $L_{Aeq(12\ hr)}$ 90 dB $L_{Aeq(5\ min)}$		65 dB $L_{Aeq(12\ hr)}$ 70 dB $L_{Aeq(5\ min)}$	75 dB $L_{Aeq(12\ hr)}$ 90 dB $L_{Aeq(5\ min)}$	65 dB $L_{Aeq(12\ hr)}$ 70 dB $L_{Aeq(5\ min)}$	

Singapore adopts a host of significant noise mitigation measures, both physically and managerially, and adopts stringent limits. Regardless of this, a reasonable number of complaints about construction noise are still received. Minister (Mr) Lim Biow Chuan on 6 July 2021 in a written response to a formal (parliamentary) question with respect to construction noise complaints near residential locations reported:

"The number of complaints on construction noise near residential areas was stable at around 800 per month on average from 2018 to February 2020, and rose to 1,160 in March 2020 when people started working from home. From April to July 2020, fewer than 400 complaints were received per month due to the Circuit Breaker and before full resumption of construction work. From August 2020 to May 2021, when construction activities fully resumed but with many people still working from home, the number of complaints increased to about 1,100 per month. Investigations established that around 11% of complaints in 2021 were attributed to cases where construction sites had breached the regulatory limits." [9]

[8] *Source https://www.nea.gov.sg/our-services/pollution-control/noise-pollution/construction-noise-control*
[9] *Source https://www.mse.gov.sg/resource-room/category/2021-07-06-written-reply-to-pq-on-construction-noise)*

14 Construction noise effects and the Resource Management Act

14.1 Noise and the RMA

New Zealand's primary environmental legislation the Resource Management Act 1991 (RMA), provides a framework for managing the effects of activities on the environment. The RMA replaced many acts, regulations, and orders of the time. A total of 59 Acts and amended Acts were repealed, such as the Noise Control Act 1982 and the Town and Country Planning Act 1953. To achieve its goals, the RMA provides the process for planning and mechanisms for controlling potential or actual effects on the environment, including noise and vibration. The RMA aims to *"promote the sustainable management of natural and physical resources"* through sustainable management which involves balancing the use of resources with the need to protect the environment and to provide for the needs of future generations. Under the RMA, managing the effects of noise and vibration is a function of territorial authorities such as District Councils.

Excessive Noise – Excessive Noise Direction, and Construction Noise Abatement

Section 326 of the RMA defines excessive noise as any noise that can "unreasonably interfere with the peace, comfort, and convenience of any person (other than a person in or at the place from which the noise is being emitted) peace, comfort and convenience of any person". This does not include noise from aircraft, trains, or vehicles on roads, and must be heard from a place other than where the noise is made. The excessive noise provisions may be used to manage construction noise from a site, but this depends upon each local Council's policy. For example, the excessive noise provisions may be used if night time construction work was unlawfully undertaken. If the Council were to receive a complaint about the work, they would investigate and if the construction noise was deemed excessive, an Excessive Noise Direction (END) notice would be served to abate the noise <u>immediately</u>. Section 327 of the RMA sets out the "issue and effect" of an END, while s.328 sets out "compliance with an excessive noise direction". Sections 322-325B cover abatement notices. Section 322 covers the "scope of abatement notices". Unlike excessive noise directions, Councils may issue an abatement notice in response to ongoing noise matters for construction sites or construction noise.

Unreasonable Noise – Best Practical Option and Abatement

Section 16 of the RMA, Duty to avoid unreasonable noise, requires "every occupier of and every person carrying out an activity in, on, or under a water body or the coastal marine area, 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 further states that "every person has a duty to avoid, remedy, or mitigate any adverse effect on the environment arising from an activity carried on by or on behalf of the person". The duties of s.16 and s.17 are required, whether or not the activity is carried on in accordance with a rule, a resource consent, or a designation. Meaning in lay terms, even if the activity complies with the rule, the best practicable option (BPO) must be adopted to manage, for example, noise and vibration.

<u>Definition of Best Practicable Option</u>

The BPO in the RMA is defined as:

in relation to a discharge of a contaminant or an emission of noise, means the best method for preventing or minimising the adverse effects on the environment having regard, among other things, to—

(a) the nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects; and

(b) the financial implications, and the effects on the environment, of that option when compared with other options; and

(c) the current state of technical knowledge and the likelihood that the option can be successfully applied

There is the duty under the RMA to ensure the BPO is adopted whether or not an activity is in accordance with a rule. Even when an activity complies with a rule, there is a requirement to ensure the BPO is followed. Because noise and vibration can cause serious disturbance, stress, and inconvenience to anyone exposed to it, and in certain circumstances, noise and vibration can be a hazard to health, it is absolutely critical that any project has suitable noise control measures in place in line with the duties of the RMA.

Emergency Construction Works

Section 330 of the RMA, *Emergency works and power to take preventive or remedial action,* allows under emergency situations, councils and some other authorities to do (or require someone else to do) any work needed to prevent, remove the cause of, or fix any adverse effect arising from an activity – including adverse effects that are likely to happen. During such emergencies, council officers might go onto a site and direct someone to do something to help the situation, or they may even take over machinery themselves to fix or improve the problem. Emergency situations include sudden events causing or likely to cause loss of life, injury, or serious damage to property. They also include situations when something must be done immediately to stop adverse effects on the environment, such as the discharge of a contaminant, when the person responsible is unable or unwilling to fix it immediately.

When a council or other authority needs to use these emergency powers, it can act without first obtaining resource consent (if it would normally be required). Section 330B Emergency works under Civil Defence Emergency Management Act 2002" states:

> *"If any activity is undertaken by any person exercising emergency powers during a state of emergency declared, or transition period notified, under the Civil Defence Emergency Management Act 2002, the provisions of Sections 9, 12, 13, 14, and 15 do not apply to any activity undertaken by or on behalf of that person to remove the cause of, or mitigate any actual or adverse effect of, the emergency."*

Resource management reforms

The Natural and Built Environments Act (NBA) is the name of one of the three proposed primary legislation to replace the RMA. It is intended that the NBA will be used in tandem with the Spatial Planning Act (SPA). The NBA will provide a greater focus on positive outcomes for both natural and built environments, rather than only controlling effects. It will ensure that the use, development, and protection of resources only occur within prescribed environmental limits. Other key changes include stronger national direction, one single combined plan per region, and a more efficient resource consent process. At the time of drafting this paper, the Resource Management Act 1991 still had full legal effect, and only the Natural and Built Environments Bill and the Spatial Planning Bill have been released.

14.2 District Plans construction noise standards - Activity Type

The New Zealand acoustic standards, NZS 68XX, are often used or referred to in district plans, resource consent conditions, and designation conditions. Standardising noise metrics makes it much easier for councils to update noise measurement methods over time. A standard is not, of itself, mandatory and has legal power unless it is specifically referenced as a rule or condition under a district plan. A standard must be incorporated by reference in an Act or delegated legislation, to be mandatory. Once referenced, it becomes part of the technical regulation framework.

Most district plans make direct reference NZS 6803:1999, in part or whole, or refer to the standard in resource consent or building consent conditions. An example of a noise rule that would typically appear in a district plan, is drafted as follows:

<u>Noise S.1 Construction Activities</u>

The noise from any construction, maintenance, earthworks and demolition activities must be measured, assessed, managed and controlled in accordance with the requirements of NZS 6803:1999 Acoustics Construction Noise.

In other plans, there may be a slight difference between noise criteria in the Plan and that of NZS 6803:1999. For example, the District Plan rule may be stricter during certain periods or have specific exceptions.

Vibration rules for construction noise in district plans are not as common as airborne noise rules for NZS 6803:1999. However, when a Plan does include vibration rules for construction, they may adopt DIN 4150-3. Here is an example draft:

<u>Noise S.1 Construction Vibration</u>

The vibration from any construction, maintenance, earthworks and demolition activities must be measured, assessed, managed and controlled in accordance with the requirements of DIN 4150-3:2016 Structural vibration – Part 3: Effects of vibration on structures.

The rules within a District Plan determine the class (status) of any particular activity and whether resource consent is required for that activity to be carried out. Each of the rules in the plan must specify whether a particular activity is *Permitted; Controlled; Restricted Discretionary; Discretionary; Non-complying;* or *Prohibited*. Generally, construction is a permitted activity, when compliance with the rules as drafted, is achieved, which in most cases means complying with the noise limits set out in NZS 6803:1999. If an activity does not comply with the permitted activity standards in a District Plan, for example, the construction noise rules, the activity would fall into another category, such as restricted discretionary or non-compliant, depending upon the case. The assessment criteria that authorise a Council, may consider the relevant assessment criteria for restricted discretionary activities. From the list below, for noise and vibration, this could include:

- BPO s.16 and whether activities can be managed so that they do not generate unreasonable noise and vibration levels on adjacent land use, particularly activities sensitive to noise; and
- The time and period to which the noise or vibration would be generated for example hours of operation; time of day, week etc; and
- The extent the noise or vibration generated would exceed the existing background noise and vibration levels in that environment and the reasonableness of the cumulative levels; and
- The extent to which the effects on amenity generated by vibration from construction activity; and
- Any other reasonable information.

It is not uncommon that at the time of preparing an assessment of effects during a 'Resource Consent Application', the application has no detailed construction programme or methodology available. Such detail may not indeed be available, especially for large or complicated projects, until a lead contractor has been appointed and they have fully devised their methods of working and have decided on what equipment and plant, and the construction schedule, they will use. The reason a full methodology is generally not ready relates to final designs and specifications not being completed until post Resource Consent stages.

14.3 Construction noise effects on animals, fauna and flora

There are currently no requirements in New Zealand for consideration of noise, albeit construction or other types of noise and its effects on animals, such as livestock, or more generally, fauna and flora. Based on anecdotal evidence, seldom have construction noise or vibration effects been considered for animals or fauna and flora. The author's first-hand experience with loud sudden noise exposure (for example fireworks), can result in 'panic and escape-type behaviours' for certain animals, such as horses. The severity of response to disturbance will typically vary with the noise level, type of noise, distance from the source, species, age, vegetation cover, and time of the year, among other things. Many animals may adapt to their environment and the noise. A well-known example (**Figure 16**) is the cows in an adjacent field termed "space cows", watching the SpaceX Raptor Engine testing, and not being startled, and they continue to look away and craze without any concerns.

Figure 16. Bovine ("space cows") in field adjacent SpaceX Raptor Engines testing [10]

The takeaway is noise impacts (including from construction activities) have the potential to startle or upset animals such as domestic livestock and pets. Noise impacts and disturbance from unexpected and/or excessive noise and vibration (including from construction activities) may result in displacement and potential disruption to nesting/roosting/foraging behaviour. However, with suitable assessment and mitigation measures in place, the risk of impact associated with noise and vibration on animals, fauna, and flora, may be addressed.

[10] *Source YouTube https://www.youtube.com/watch?v=4PB9FGbB0-w*

14.4 Level of noise and vibration effects

The effects of noise are varied and complicated. These effects not only include interference with speech communication, disturbance of work or leisure activities, disturbance of sleep, and annoyance, but also effects on mental well-being and physical health.

Section 3 of the RMA defines an 'effect' as including:

(a) any positive or adverse effect; and

(b) any temporary or permanent effect; and

(c) any past, present, or future effect; and

(d) any cumulative effect which arises over time or in combination with other effects—regardless of the scale, intensity, duration, or frequency of the effect, and also includes—

(e) any potential effect of high probability; and

(f) any potential effect of low probability which has a high potential impact.

The effects of construction noise on people may vary significantly, some individuals may be more or less sensitive to construction noise than others. Table 10 offers guidance on various measures that may be used to assess effects based on the use of the RMA terminology.

Table 10. Noise effects

Noise Effects	Scale
Nil	No effects at all
Less than Minor	Noise effects that are discernible day-to-day effects and barely noticeable They are insignificant to adversely affect other people/environment
No more than Minor	Effects that are noticeable day-to-day effect, but they are too small to adversely affect other people/environment.
Minor effects	Effects that are noticeable but will not cause significant adverse impacts on person/environment
More than Minor effects	Effects that are noticeable that may cause adverse impact but can potentially be avoided, remedied or mitigated
Significant adverse effects	Adverse effects that are noticeable and will have adverse impacts on people/environment, but the effects could potentially be avoided, remedied or mitigated
Unacceptable adverse effects	Widespread extensive adverse effects that cannot be avoided, remedied or mitigated

Section 6 of Schedule 4 of the RMA, 'Information required in assessment of environmental effects', states that in an assessment of the activity's effects, *"...if it is likely that the activity will result in any significant adverse effect on the environment, a description of any possible alternative locations or methods for undertaking the activity..."* must be undertaken.

Although audibility is not an assessment criterion, the following offers some guidance in respect of the audibility of a noise source with respect to background levels:

- **Inaudible/ Not Audible** - the noise source cannot be heard at the receiver location. This may be due to the sound level at source being low and thus has reduced to be inaudible at the receiver or the noise source may be masked from extraneous (background noise sources) not associated with the source. If a noise source is 'inaudible' its noise level would generally be 10 dB or more below extraneous sound;
- **Barely or Just Audible** - the noise source can be 'barely' heard at the receiver location; audibility is very low. This may be due to the sound level at source being low and thus has reduced to be inaudible at the receiver or the noise source may be masked from extraneous (background noise sources) not associated with the source. If a noise source is 'barely audible' its noise level would generally be 5-7 dB below extraneous sound.
- **Audible** - the noise source can be heard at the receiver location. If a noise source is 'audible' its noise level would generally be above extraneous sound.
- **Dominant** - the noise source can clearly be heard at the receiver location. If a noise source is dominant, it would be clearly 'audible', and would be dominate/significant above extraneous sound. If a noise source is 'dominate', its noise level would generally be 10 dB or more above extraneous sound.

15 Construction noise management

There is a wide range of mitigation and management methods available to manage construction noise and vibration impacts. These methods range from managerial methods, such as limiting the operating days, hours, and the timing of the works, through to the temporary or permanent barriers, enclosures, buffers, or the selection of 'quieter' plant and equipment. The following is a high-level overview of some available measures.

The hierarchical approach to construction noise management is the **Source–Path–Receiver** model. **Figure 17** shows the model, with intervention effectiveness decreasing from the top to the bottom. The model starts at the 'Source' (where changes are generally the most effective) and begins by considering elimination and reduction of source noise. For example, by making changes to processes, components, machines, or layout (arrangement) so that they make less noise. This can include a host of measures such as substitution, replacing noisy machinery with quieter alternatives, and by adopting a company policy of buying quieter machines. Engineering control of the noise 'Path' is the second method of control and would typically include the use of acoustic screens and/or barriers enclosing and isolating noisy processes, or isolation vibration for certain fixed plant. Intervention in the path is also known as 'isolation', it involves the partial 'blocking' of the noise path and so reduces the noise before it reaches the receiver. The final area of intervention, when the first two have been reviewed and found to be inadequate, is at the receiver. This typically involves the application of sound insulation of buildings occupied by the receivers. What is commonly called administrative controls, typically involves limiting the exposure time, and is a management method that can be applied at the source and/or receiver location.

Figure 17. Source - Path - Receiver method [3]

15.1 Physical Control Measures

A key approach to minimise noise and vibration from construction works is to adopt physical measures in line with s.16 duties of the RMA. Some examples include:

- **Buffer Distance** - Most people understand through common sense without understanding the science or engineering, the greater you are away from a source, albeit light, noise plant or vibration, the lower the levels and the less likely the person is likely to be annoyed or affected by it. The buffer

[3] *L, Hannah. Page, W 2023*

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distance from the source of vibration or noise, is probably the single most factor, after the energy of the source itself, that drives the final levels.

- **Noise barriers and enclosures** – Provide effective mitigation when they break the acoustic line-of-sight and are close to either the source (preferable) or the receiver.

  As a rule, when a noise barrier breaks the direct line-of-sight between the source and the receiver, the noise is reduced by 5 to 15 dB. Increasing the height of the barrier increases the performance, but with diminishing returns with increasing height. There is a theoretical attenuation limit of 24 dB for a barrier, but a realistic practical limit is 15 dB. The actual reduction level a barrier can provide is complex and relies on a host of factors such as the barrier geometry, the source and receiver geometry and whether they are any reflecting surfaces.
- **Siting of plant and equipment** – Locating and keeping plant as far as possible from noise-sensitive sites is always a good idea.
- **Building condition surveys** – Conducting building condition surveys of receiver locations prior to the commencement of construction operations is a good idea. A detailed pre-construction survey can identify at-risk buildings, services, and structures, and should be carried out by a suitably qualified engineer.
- **Vibration barriers and isolators** – These can be used to attenuate ground-borne vibration.

15.2 Managerial and best practice work methodology

A (cost) effective method to manage the effects of construction noise and vibration is to deploy good on-site management and ensure there is effective communication between stakeholders including contractors, sub-contractors, managers, staff, and the affected receivers (the nearby community).

A key measure to minimise construction noise and vibration, is to follow best practice work methods. These have evolved over time and include:

- Restricting the absolute level that can be produced by setting limits in Construction Standards, Resource Consents, District Plans.
- Training for all staff as part of the site induction programme and ongoing training throughout the programme;
- Scheduling and phasing of work, in particular, noisy or vibration intensive activities, to occur during less sensitive periods of the day and at less sensitive times;
- Use of low-noise plant and equipment that is the quietest and most suitable for the project;
- Ensuring all noise plant and equipment is well maintained and operating within specifications;
- Ensuring consultation and community engagement with affected parties;
- Preparation of Construction Noise and Vibration Management Plans (CNVMP);
- Preparation of site-specific Construction Vibration Noise Management Plans (SSCVMP). A CNVMP or SSCVMP may form part of a wider set of plans such as a Master Environmental Management Plan (EMP);
- Preparation of schedules if the limits cannot be met all the time that include BPO assessment methods;
- Temporary resident relocation - Where all practicable noise and vibration management and mitigation measures have been considered but compliance with the criteria is still not achievable, and the effect is significant and ongoing, then temporarily relocating the affected receivers may need to be considered.

The above recommendations are high-level summary only, and accordingly, the practicability of implementing each measure, should be assessed on a case-by-case basis by a suitably qualified and experienced specialist in noise and vibration. Not every measure can be practically utilised, each measure should be assessed in line with s.16 duties of the RMA for BPO to mitigate noise and vibration.

Vibration management measures are more limited compared to construction noise. However, measures typically include the use of alternative methods, such as for piling, or the use of smaller capacity equipment, such as rollers, or the use of static rollers as opposed to vibrator rollers/compactors (where practical). A vibratory roller is deemed 'more effective' than a static roller in terms of compaction. It may produce more vibration, but generally takes less time to complete the work. The management of the operation of the roller should also be considered, as they typically have various frequency and power settings, for example, Low-Frequency and Low-Power through to High-Frequency and High-Power and values in-between.

Other mitigation measures may include a reduction of energy per blow if doing drop piling. Or the removal of obstructions that may constitute a hindrance to progress and exacerbate the transmission of vibration, for example, old basement floors, and old foundations. Other measures include the provision of cut-off trenches for vibration control. Such trenches can be regarded as analogous to a noise screen, in that it interrupts the direct transmission path of vibrations between source and receiver. There are however serious limitations to the efficacy of trenches, for maximum effect the trench should be as close to the source (preferable) or receiver as possible. In the author's experience, the use of a trench can (if not implemented by an expert), "increase" vibration or make the situation worse, thus careful implantation is critical.

15.3 Community engagement and relations

The community's attitudes to a project and its effects with respect to noise and vibration can be influenced by their attitudes to the contractor and the project itself. Noise and vibration from a site will tend to be more readily accepted by local residents, if they consider that the contractor is adopting best practice and is taking all possible measures to avoid unnecessary noise or vibration effects. The attitude to the contractor can also be improved through good community liaison and information distribution and the provision of a helpline to respond to queries or complaints. The acceptability of the project itself can also be a factor in determining community reaction. Community engagement and relations are therefore given special mention as it is one of the most critical noise and vibration control measures. Having a good working relationship with the community and the people living and working in the vicinity of the construction site can significantly reduce complaints and improve acceptability. The early establishment of these relationships and their ongoing maintenance during the project, helps to educate the community about what a project involves. It enables them to be informed ahead of time that there is going to be a construction activity that may be noisy, enabling them to be prepared. It also provides a point of contact for a development that can help allay people's concerns knowing that there are open channels of communications to addressed concerns.

Community engagement may not always be essential, such as in a small residential build, but even in this case, it is always a good idea to inform nearby neighbours. For large developments or ongoing projects, community engagement is critical. Community engagement and relations are also critical for special cases, such as one-off short-term/duration operations involving blasting as both the noise and vibration effect often give rise to concern or even alarm to persons unaccustomed to it. Forewarned is forearmed.

15.4 Managerial and best practice work methodology

The hierarchy of noise or vibration mitigation allows an analysis to be conducted to review the most effective and appropriate mitigation options to be considered and implemented. Reviews in New Zealand are generally conducted in line with s16 duties of the RMA, which takes into account not only how effective the mitigation measures will be, but also considers these in terms of cost and how well the measures reduce the noise (or vibration) and their effect on the environment.

Each project or operator may have a different hierarchical assessment based on the specific job and the nature and scale of the activity. The following sets out a summary of some basic questions and sequence for hierarchical assessment. Each question should be considered in sequence before moving onto the next one, but all questions should be considered.

1. Have equipment and methodologies been chosen that reduce the overall noise from the activity?
2. Can quieter alternative equipment or methodologies be practicably implemented?
3. Can buffer distances be practicably implemented to reduce noise and/or vibration?
4. Can temporary noise or vibration barriers or screens be erected within the site that provides effective shielding of the equipment/activity/plant?
5. Can the works be sequenced to avoid sensitive times for neighbouring residents/businesses? For example, can works be scheduled for school holidays of they are near a school?
6. Have potentially affected persons been contacted and implications discussed/feedback taken into consideration in the planning of this activity?
7. When appropriate, have residents been offered temporary relocation to suitable alternative accommodation, and have they accepted the offer?
8. If there is any night time work, or work outside typical hours, is it imperative that this work needs to be carried out at that time or can it be re-scheduled to be conducted during typical daytime hours. Night time work should only be conducted when necessary and not out of pure convenience.
9. Is a specific management plan required?

15.5 Exclusions and Notifications including night-time work

Many authorities such as District Councils will restrict construction activities to normal working hours, which are treated in most cases as 7.30 am to 6.00 pm Monday to Saturday. These restrictions are in place to manage potential adverse impacts on health or amenity and as such do not allow activities to take place over weekends, Sundays, or public holidays. These non-construction periods provide critical respite, particularly for the most affected people. In some circumstances and in some cases, construction may need to take place outside of typical hours or consented hours. Such examples may include the delivery of oversized plant structures at night or on a public holiday, where heavy vehicles are restricted to the operating hours on the road, or for emergency work, such as repairing a water main or gas leak. Other examples include working on state highways or major roads where the road cannot be closed during the daytime due to high traffic volumes.

In some cases, District Plan rules may exempt urgent repair or work undertaken in the CBD outside typical hours if the BPO is adopted. In such cases, pragmatic regulators would have exemption processes or notification processes to follow, such as notifying the community. The critical part of the exemption is community consultation and awareness and advising the community and residents exactly why the work must be done outside the normal permitted hours. In all cases, even if an authority provides approval to conduct work outside typical permitted hours, the operator still must legally adopt s16 duties to mitigate noise and vibration. The exemption to carry out the work outside the permitted hours is not an exemption to produce excessive or unreasonable noise.

15.6 Monitoring noise and vibration

Monitoring of noise and vibration often forms part of the overall management strategy used on large projects. This will typically include the use of unattended monitors that send alert messages to project staff if noise or vibration levels exceed pre-determined thresholds. In most cases, the Construction Noise and Vibration Management Plan (CNVMP) will set out the procedures to follow when an exceedance occurs. Continuous monitoring allows the persons undertaking the work to ensure that much of the construction work can proceed without delay. It also allows work to be stopped or supervised if there is a risk of criteria being exceeded. In New Zealand monitoring and sampling of construction noise are commonplace, however, monitoring of ground-borne and structure-borne noise is not as common. It usually happens when it has been identified as a potential issue for a project.

16 Construction noise - Community reaction and annoyance

16.1 Community Reaction

The World Health Organization (WHO) defines health as *"state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"*. Construction noise can affect both health and amenity, if not suitably managed. The effects of construction noise on the community and individuals vary greatly, as a function of time and noise source. The effects of construction noise are complicated and can include interference with speech communication, disturbance of work or leisure activities, through to disturbance of sleep, annoyance, and possible effects on mental and physical health if the construction is of long duration. The guidance values or limits in standards are set for populations and may not satisfy or assess the effects on individuals, particularly those who are more sensitive to noise (or vibration). Consideration of this group of people is important in ensuring the acceptability of the project to the community.

It is well established that people's attitudes to noise, including construction noise or vibration, can be influenced by their attitudes toward the source or activity, and even the person in control (the contractor for example). There are many factors associated with the community reaction to construction noise and vibration. These include (but are not way limited to):

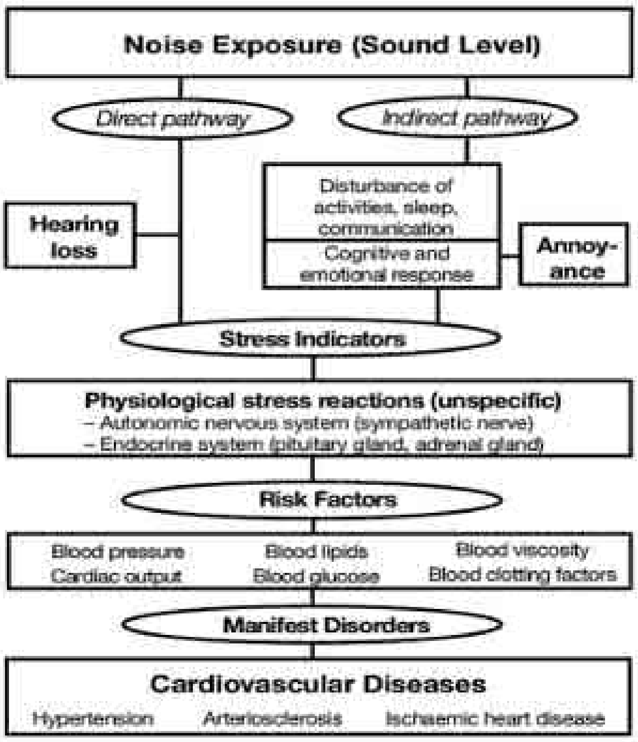
- Noise level;
- Noise characteristics;
- Site location;

- Receiver location;
- Existing ambient (background) noise levels;
- Duration of work;
- Hours of work;
- Execution of noise management methods;
- Community consultation, attitude to the site operator towards management of noise;
- Attitude of the noise receiver towards the site operator and level of disturbance to work; and
- Leisure or specific tasks such as trying to watch TV or simply sleep.

Figure 18 is a simplified noise exposure reaction diagram. The direct pathway is generally considered to be noise that results in hearing loss. This is unlikely to be the case for environmental noise from construction activities. Most of the adverse effects occur down the indirect pathway, beginning with the disturbance of activities and noise annoyance. Collectively, both pathways result in 'stress', which increases the risk factors for particular conditions.

Noise from construction projects *generally* cannot comply with the day-to-day permitted operational noise limits set out within District Plans or those recommended in standards such as NZS 6802:2008. This standard recommends criteria or noise limits for the protection of health and amenity. These guideline limits are upper noise limits for residential situations and use both $L_{Aeq,(t)}$ and L_{AFmax} noise descriptors to provide 'reasonable' protection of health and amenity. The 2008 (and current) version of the standard introduced an evening time frame with limits between the day and night limits (evening limits) if local authorities wished to incorporate them into their rules. The recommended residential upper limits are: Daytime of 55 dB $L_{Aeq(15\ min)}$ and night-time of 45 dB $L_{Aeq(15\ min)}$ and 75 dB L_{AFmax} to help protect sleep from disturbance due to noise.

Figure 18. Noise exposure reaction chart[11]



The limits recommended in NZS 6802:2008 are consistent with the guideline values for community noise in specific environments published by the World Health Organization in 1999. This guideline states that during the daytime, few people are seriously annoyed by activities with levels below 55 dB $L_{Aeq(16h)}$.

The night-time limit recommended should not exceed 45 dB $L_{Aeq(8h)}$ outside dwellings so that people can sleep with windows open for ventilation and achieve the desirable indoor 30 to 35 dB $L_{Aeq(8h)}$ level as a design level to protect against sleep disturbance. The WHO recommends various guidelines for specific environments. In the case of bedrooms, the critical effect is sleep disturbance, where guideline indoor limits are 30 dB $L_{Aeq\ (8\ hr)}$ for continuous noise and 45 dB L_{AFmax} for single sound events. The WHO does however acknowledge that lower levels may be annoying depending on the nature of the sound source. Since the publication of the 1999 WHO community noise guidelines, there have been several significant WHO publications on the effects of environmental noise. Collectively, this has seen the limits at which adverse health effect occurs, lowered, as more evidence has been collected and analysed for different noise sources and environments.

16.2 Community Annoyance

Noise annoyance (NA) to different environmental noise sources has been studied for many years. NA may be defined as a feeling of *'displeasure, nuisance, disturbance or irritation caused by a specific sound'*. Well-known NA studies involve specific noise sources, such as road, rail, aircraft, industry, and others, such as wind turbines. Construction noise has been studied, but to a limited degree compared to transport noise. Annoyance is an emotional state connected to feelings of discomfort, anger, depression, and helplessness. It can be measured in a standardised way using ISO/TS 15666:2021 *Acoustics — Assessment of noise annoyance by means of socio-acoustic surveys and social surveys.* The standard

[11] *Source Babisch W (2002). The noise/stress concept, risk assessment and research needs. Noise & Health, 4 (16):1–11.*

survey questions focus on how the noise affects someone, to what extent, and how often. The standard also includes question response scales and key aspects of conducting the survey and reporting the findings. Commonly, a five-point rating scale is used, with the points defined as: 1. not annoyed; 2. slightly annoyed; 3. moderately annoyed; 4. very annoyed; and 5. extremely annoyed.

It is well established that construction noise and vibration can irritate people, for example by intruding on their daily activities and interferes with health, amenity, peace, and enjoyment. Construction noise annoyance is a commonly reported adverse health effect of noise. Annoyance is one of the key factors that lead to formal complaints being received by Councils with respect to construction noise. In compliance terms, noise annoyance is a primary indication that noise is a problem for the person, and by itself, noise annoyance means that the quality of life is adversely affected in some way.

There are considerable differences in an individual reaction to the same noise, and this is particularly true for NA. To try to quantify NA, Schultz[12] developed a relationship between the percentage of people choosing the top two descriptors (very annoyed and extremely annoyed), which are combined to produce the term 'highly annoyed'. Schultz used a mixture of several different social surveys that employed different response scales and defined 'highly annoyed' respondents as those respondents whose self-described annoyance fell within the upper 28% of the response scale (roughly under 1/3 of the population). Schultz's definition of 'percent highly annoyed' (%HA) became the criterion for developing a dose-response relationship for different types of noise sources. The perception and reaction to sound are complex, acoustic factors alone typically only account for 50% (or less) of the contribution to NA as measured by %HA.

In the most recent WHO guidelines for noise, the Environmental Noise Guidelines for the European Region (ENGER 2018), '*annoyance*' refers to long-term noise annoyance. The main reason the scientific community adopted the use of long-term annoyance as a primary indicator of the community response to noise, is because it attempts to account for the ongoing negative aspects of effects from noise, which are often cumulative when viewed over a period of a year or more.

Socio-acoustic surveys are the key tool used to measure noise annoyance in communities. The resulting responses can be combined with noise descriptors to produce a noise-dose response curve for a particular situation or noise source. Once established, the dose-response curve may be used as a predictor of the 'average' response of the exposed population. The curves cannot predict the response of a single individual, as they may have a greater or lesser than average sensitivity to the noise source.

With respect to construction noise, there are few studies that assess the effects related to noise annoyance, and most have limited sample sizes. Studies that have investigated annoyance related to construction noise include Ng, 2000, Golmohammadi et al., 2013, Darus et al., 2015, Lee et al., 2015, Liu et al., 2017, van Kamp et al., 2020. One study by Camirand estimated that the prevalence of individuals highly annoyed by construction noise is around 4.6% (Camirand et al., 2016). Another study by Liu concluded that there was a significant correlation between ratings of annoyance due to construction noise and the recorded level of noise (Liu et al., 2017). Specifically, the study noted that the degree of annoyance depended upon the noise levels recorded at specific times of the day. In a recent study, van Kamp concluded that only two studies have shown an association between annoyance scores and noise levels from construction work, and that little is known about the factors that may predict annoyance from construction noise (van Kamp et al., 2020).

17 Analysis and opinion

This paper has been prepared first and foremost as a teaching resource, this has been achieved by providing a host of high-level matters pertaining to construction noise and vibration including highlighting trends of population growth, giving examples of data around complaints, and commenting on the ongoing developmental needs of the population around housing and the supporting infrastructure of our towns and cities.

The review has provided basic theory around construction noise and vibration, as well as mitigation and management measures. A summary of national and international standards as well as applicable legislation and planning tools have been discussed. Key areas of New Zealand legislation such as section 16 of the RMA have been highlighted with respect to best practices in managing noise. Several noteworthy construction standards have been highlighted, including NZS 6803:1999, DIN 4150-3:2016, and BS 5228-2009 (parts 1 and 2). The potential adverse effects of construction on health, amenity value, and community reaction, have also been discussed.

The importance of acoustic standards has been presented, indicating that such standards are essential, not only to ensure standardization across government, private, and public sectors, but also to provide tools for the measurement, assessment, and management of construction noise.

The review indicates that the theory behind noise and vibration from construction on land is well understood. But because construction activities can be highly variable, this can present significant challenges with respect to assessment. Underwater construction noise and vibration effects on the health and well-being of marine life is recognised as a rapidly developing area for consideration.

There is no silver bullet to managing construction noise and vibration. There will always be tensions among the various stakeholders, in particular, the persons undertaking the development and the surrounding community and neighbours. Construction by its very nature is noisy at times, finding the right balance with respect to continued growth while ensuring noise (and vibration) effects on communities are suitably managed, is an ongoing challenge. As our cities become more and more densely populated, and there are changes in the way we live, such as hybrid work environments, community expectations around acceptability will also change. Community engagement and communication is a critically important management tool to be used a day-to-day basis to manage the adverse effects of construction activities. In addition to providing a high level overview of construction noise and vibration, this paper also sets out to discuss the current use and application the New Zealand standard NZS 6803:1999. The following observations and opinions are provided with respect to this standard.

[12] *Source https://nwtteis.com/portals/nwtteis/files/references/Schultz_1978_Noise_Annoyance.pdf*

[13] *Golmohammadi R, Mohammadi H, Bayat H, Habibi Mohraz M, Soltanian AR. "Noise Annoyance Due To Construction Worksites". J Res Health Sci. 2013;13(2):201-207.*

[14] *N. Darus et al. "Construction Noise Annoyance Among the Public Residents". Journal of Teknologi. 2015*

[15] *Lee et al. "Effects of Acoustic Characteristics of Combined Construction Noise on Annoyance" Building Environmental Journal. 2015*

[16] *Yong Liu et al. "Community Response to Construction Noise in Three Central Cities of Zhejiang Province, China". Journal of Environmental Pollution. 2017, Volume 230.*

[17] *Irene van Kamp. "Evidence Relating to Environmental Noise Exposure and Annoyance, Sleep Disturbance, Cardio-Vascular and Metabolic Health Outcomes in the Context of IGCB (N): A Scoping Review of New Evidence". Int J Environ Res Public Health. 2020.*

[18] *H. Camirand et al. "L'enquête québécoise sur la santé de la population 2014-2015: pour en savoir plus sur la santé des Québécois: résultats de la deuxième edition Institut de la statistique du Québec". 2016.*

17.1 Does NZS 6803 remain fit for purpose?

In the opinion of the authors, NZS 6803:1999 remains fit for purpose, in part, however as highlighted in this paper due to the age of the standard, and specific concerns discussed, the authors are of the view a review is now needed. As noted below, further analysis would be required with respect to not only technical matters but also the cost-benefit before any changes were made to the standard.

As noted, a host of matters have been highlighted with respect to possible matters to address, these include (but are not limited to):

1. Technical matters around measurement and assessment;
2. Technical requirements for projects greater than 5 months, currently deemed long-term;
3. Technical requirements for key public works such as exemptions and noise notifications;
4. Updates to include current legislation requirements (eg. s.16 of the RMA and the replacement legislation);
5. Updates for management and mitigation methods in line with current best practise;
6. Updates on key areas such as equipment sound power data provided in Appendix C;
7. Updates on process around community engagement and relations, noting this is a critical area now, and for the future.

In addition to the above, the following question-and-answer commentary is provided.

Are the current noise limits in NZS 6803 acceptable?

The design limits in NZS 6803:1999 are a key part of the standard. In the author's opinion, the limits are acceptable when treated as recommended upper maximum limits. The standard permits relatively liberal daytime limits, however, it is restrictive during evenings, night time, Sundays, and Public Holidays, which allows community respite from the adverse effects. NZS 6803:1999 sets what is known as 'strict limits' as opposed to 'targeted limits'. Moving towards 'targeted limits' while ensuring that best practice to mitigate the adverse effects of noise and vibration, could be a pragmatic way forward. The use of targeted limits with the requirement of adopted best practice is standard in other countries. For example, a critical difference between NZS 6803:1999 and BS 5228-1:2009 is that the former sets strict limits, while the latter sets targeted limits. Noise control targets are reasonably practicable, if it means controlling noise from constructions sites ensures the protection of local communities and of people, so long as all reasonable and practical sets to mitigate noise and vibration effects are also adopted (as currently required by section 16 duties under the RMA).

Are the current assessment areas in NZS 6803 acceptable?

The design limits set in NZS 6803:1999 are currently set for: 1) residential zones and dwellings in rural areas, and 2) commercial or industrial areas. There is no mention of vulnerable groups or noise-sensitive activity types, such as hospitals or culturally sensitive areas such as cemeteries (urupā). These locations may require higher levels of protection, depending upon the circumstances. It is generally accepted that standards set acceptable levels of noise which are essentially derived from observations and studies on the effects of noise on the 'average' population. Vulnerable groups of people or sensitive locations are not given consideration when they probably should be. However, imposing a more restrictive standard in order that the most vulnerable groups are protected would likely result in additional costs and/or time delays for construction work. In addition, NZS 6802:2008 warns against setting low noise limits which cannot be properly measured and assessed within the context of existing ambient sound levels (see NZS 6802:2008 Clause 8.6.3). It is understood that in the New Zealand Environment Court, 'noise nuisance' is generally judged from the viewpoint of the average person's sensitivity to noise. For the above reasons, any changes to the assessment areas (albeit groups, areas, or activity types) would require further analysis including cost versus benefit. It should also be noted this does not mean site-specific noise limits could not or should not be set in a resource consent situation, due to the nature of the sound, such as extra quiet ambient noise climate, or high ambient noise climate. Generally, such matters to do with vulnerable groups or noise-sensitive activity types should be treated on a case-by-case basis.

17.2 Options for changing the Standard

If changes were to be made to NZS 6803:1999, what methods could be adopted to facilitate any updates, and what options should be considered? Before we look at the options, it is worth understanding the current process by which Standards New Zealand (SNZ) updates a standard. International standards such as from ISO, and even standards across the Tasman in Australia, are reviewed every five years to see if they are fit-for-purpose. A standard may be reconfirmed for another 3-5 years, or a process initiated to revise the standard within the next 3-5 years. This ensures that standards remain fit-for-purpose, and incorporate the latest knowledge, best practices, and evolving stakeholder expectations and experiences. This is not the current process at SNZ, they only manage the development and publication of standards and standards-related solutions, as well as selling New Zealand, joint Australian/New Zealand, and international standards via their web store. SNZ has no in-house expertise to assess if a standard is still fit-for-purpose and appears to have no budget to do so. This is reflected in their current catalogue, where for New Zealand Standards (NZSxxxx), a significant number are older than 5 years and there are many that a much older, like NZS 6803. A standard is only updated if there is a 'commissioning sponsor' and this sponsor must provide a budget. The process begins by completing a 'Project Commissioning Brief' template, which is used by a potential commissioner to provide some of the initial information, and then SNZ assesses the viability of the project.

Recent communication with SNZ querying the process and cost to commission an update to a standard produced the following response:

"The cost for commissioning a standards development project can vary greatly based on a range of different factors that can impact on the complexity of a project. Some of these factors include:

- *Type of project (i.e. revision, amendment, revision or amendment through adoption, etc) – each of these different types of projects will have different scope and require different level of work and timeframes for the project to be successfully completed*
- *Size of committee and number of committee meetings to be facilitated. This varies greatly depending on the type of project as well as interested/relevant stakeholders needed to form balanced committee representation*
- *Level of contentiousness of the document, which can give us an indication of the volume of public comments that we can expect to be submitted and dealt with*
- *Size of the publication (i.e. number of pages, charts, graphs, pictures, design rework needed, etc.) – all of these have a big impact on the publication part of the cost to revise a standard."*

A follow-up query to ask about a ball-park cost to update NZS 6803:1999, at the time of publication, had not been answered.

What are some of the options to update NZS 6803:1999?

Option 1 – Prepare guidance note to the standard

The most economical, practical, and likely easiest method to facilitate change to the existing standard would be via issuing a formal 'Guidance Note' which sets out commentary and guidance around the use of the standard and address any matters, particularly those relating to its age. Such an approach would likely only be useful if the changes were straightforward and not technically cumbersome. If such measures were to be adopted, for example, by the Acoustical Society of New Zealand and its members, the guidance note would not be legally binding or have any actual legal effect, unless the guidance note was referenced in a District Plan rule or condition (which is unlikely). If a guidance note were to be adopted, it would be critical that stakeholders are consulted in the very early stages around the purpose and again at the draft stage. For a guidance note to work, 'buy-in' from all stakeholders is a must, which is unlikely to occur in all cases.

Option 2 - Revise the standard via the SNZ Process

This option could be the legal equivalent to the Option 1 guidance note, meaning any technical changes to the standard go through the formal process with the outcome being an updated standard that addresses the required matters. A key stage in the process is of course agreeing on the matters to address. Once updated, the standard could be formally adopted via updates to the "National Planning Standards" or the proposed mechanism under the RMA reform legislation, so to make it legally binding.

Option 3 - Adopt an existing (non-NZ) Standard

Standards New Zealand website indicates that when looking to develop an existing standard, they may also consider adopting a standard from another international body or adopt parts of that standard. For example, the recent adoption IEC 61672:2013 Electroacoustic - Sound Level Meters (all three parts) as AS/NZS IEC 61672:2019 Electroacoustic – Sound Level Meters. Based on the research from this paper, the British Standard BS 5228:2009 would be a good place to start. NZS 6803:1999 was initially based on the 1997 version of Part 2 of BS 5228. The current version of both parts (Part 1: Noise, Part 2: Vibration) was amended in 2014 and deemed 'current' by the standards body. BS 5228 is a comprehensive standard providing detail on prediction, measurement, assessment, and control of noise and vibration from construction works.

A variation on this option that is likely to be attractive from a commissioning cost perspective, is the adoption of the Australian standard, AS 2436-2010 *Guide to noise and vibration control on construction, demolition and maintenance sites,* which was reconfirmed in 2016. Adopting it as a joint standard, such as *AS/NZS 2436-20XX* would help share the burden, and leverage-off Standards Australia's much more formal, and budgeted, review and maintenance processes.

The key argument for the adoption of an existing standard (or adopting part of an existing standard) is that it can be easier and more straightforward, as it has already gone through a formal process and has been adopted elsewhere. The main argument against this approach is that depending upon the standard chosen to adopt, it may not be fit for purpose in all New Zealand environments.

Option 4 – Prepare a new construction noise standard (NZS 6803:202X)

Due to the age of NZS 6803: 1999 the option to develop a new standard from scratch could be considered. Developing a new standard would allow the entire standard to be drafted anew, while widely reviewing existing standards and literature. This option would be the author's preferred one if commissioning cost was not a significant consideration, as it gives the most flexibility to draft a new standard, fit for the New Zealand environment, incorporating the latest knowledge, best practices, and evolving stakeholder expectations.

17.3 Challenges of developing a new standard or revising the existing standard

The three key matters needed for developing or changing the standard are, a funder, a committee of professionals with the necessary expertise, and stakeholder buy-in. There is appropriate expertise in New Zealand, including consultants, academics, and officers in city councils. Stakeholder buy-in can be achieved by undertaking genuine consultation with stakeholder groups. A key sticking point may well be finding a commissioning funder. Anyone within New Zealand can complete a Project Commissioning Brief to initiate SNZ to explore the viability of the project. But for it to proceed, they must have the necessary funds. In principle, a commissioning funder does not receive preferential treatment or consideration in relation to the technical content and outcome of the standards development process. Once a proposal is approved by SNZ, a committee is established. It is critical that the committee be balanced and represent the wider stakeholders and includes both experts and end users, not just consultants. The stakeholders include (but are not limited to) consultants, local and central government (Council, MfE, NZTA for example), academia, public and environmental health, planning, and end users such as contractors, building industry, and related associations.

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19 Reference list - Noise and vibration standards

NZS 6803 1999	Acoustics Construction Noise
NZS 6803 1984P	The measurement and assessment of noise from construction, maintenance and demolition work
NZS 6801:2008	Acoustics – Measurement of Environmental Sound
NZS 6802:2008	Acoustics – Environmental Noise
NZS 2107:2016	Acoustics – Recommended design sound levels and reverberation times for building interiors
AS 2187 2-2006	Explosives - Storage and Use
AS 2436 2010	Guide to Noise and Vibration Control on Construction, Demolition and Maintenance Sites
DIN 45669-1 1995	Mechanical vibration and shock measurement – Part 1 - Measuring equipment
DIN 4150-2 1999	Structural vibration – Part 2: Human exposure to vibration in buildings
DIN 4150-3 2016	Structural vibration – Part 3: Effects of vibration on structures
BS 5228-1 2009	Code of practice for noise and vibration control on construction and open sites. Part 1 - Noise
BS 5228-2 2009	Code of practice for noise and vibration control on construction and open sites. Part 1 – Vibration

20 Glossary of basic terms

"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 (frequency)-weighting'.

Airblast overpressure: 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.

Blasting: With respect to construction activity, this is generally the breaking-up of rock or other hard material by the use of explosives.

Decibel (dB): A unit of measurement on a logarithmic scale that describes the magnitude of sound pressure with respect to a reference value (normally taken as 20μPa).

Ground borne noise: The noise inside a building caused by vibration of the building structure due to vibration through the ground from an external vibration source associated with construction works.

Ground borne vibration: The vibration inside or outside a building due to vibration through the ground from an external vibration source.

$L_{Aeq(15min)}$ is the A-weighted time-average sound level over a 15-minute period, measured in units of decibels (dB) (or dBA in old standards).

L_{AFmax} is the maximum A-weighted, F time-weighted, sound pressure level measured in units of decibels (dB).

L_{Zpeak} is the peak Z-weighted noise level, measured in units of decibels (dB).

Moving Construction Noise Source: A construction noise source that moves and 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 or mobile road work plant.

Noise: May be considered as sound that serves little or no purpose for the exposed persons and is commonly described as 'unwanted sound' in the case of construction. Airborne noise is inside or outside a building caused by sound propagated through the air.

PPV: Peak Particle Velocity (mm/s) is the greatest instantaneous particle velocity over a given time. If measurements are made in 3-axis then the resultant PPV (peak particle velocity) is the vector sum (or resultant or component PPV) i.e. the square root of the summed squares of the maximum velocities, regardless of when in the time history those occur. PPV is a standard metric for assessing construction vibration levels.

Sound: Pressure levels are an objective measure of changes in pressure levels that may be heard by humans. Unwanted construction sound can be considered as construction noise.

Sound Pressure is the local pressure deviation from the ambient (average or equilibrium) atmospheric pressure caused by a sound wave. The sound pressure level is the sound pressure measured in decibels.

Sound Power is the measure of the energy of a sound source per time unit. Sound power is only attributed to the sound source. The sound power level in decibels is ten times the log of the ratio of the sound power (W) to the reference sound power (W_o) usually taken as 1 picowatt.

Vibration: The periodic motion about a normal position. Vibration with respect to construction vibration generally refers to the movement in the ground ('ground borne vibration') or in a structure. Vibration is commonly expressed in terms of acceleration, velocity, displacement and frequency which are related.

21 Qualifications of Review

This paper review is intended as an educational guide only. The reader and end users should understand that the information within this review does not attempt to cover all areas and applications of the broad topics and therefore there will be omissions. While all care has been taken in the preparation of this work and the information which is included is believed to be correct at the time of preparation, users of this paper must apply discretion and rely on their own judgements regarding the use of the information. Users of the work must also review the original source material and standards themselves. Where relevant the user should obtain independent professional advice from a suitably qualified and experienced person, acoustician or acoustic specialist. Any views or comments expressed in this paper do not necessarily reflect the position of the authors employers or that of the Acoustical Society of New Zealand (ASNZ).

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ARTICLE

Construction noise reform - refocussing on management out-comes over noise limits

Craig Fitzgerald and James Whitlock

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Abstract

Construction noise assessments in Auckland have become a high cost, low value exercise. Nearly all urban construction projects exceed the construction noise limits for short periods, triggering a restricted discretionary activity status. Requiring a Construction Noise Management Plan (CNMP) to manage exceedances is a routine condition of consent to minimise noise levels and ensure residual effects are reasonable. In this age of RMA reform, we have an opportunity to refocus on construction noise effects and refine the best practice manage-ment measures that reduce community disruption and improve process certainty. We urge local government to reframe construction noise 'limits' as 'trigger levels' in a CNMP certification process. This approach aligns with recent revisions to British and Australian construction noise standards, and the Auckland Unitary Plan rules for 'construction noise and vibration levels for work within the road'.

1 Introduction

The New Zealand Construction Noise Standard (NZS 6803:1999) uses phrases like 'desirable upper limit', 'should not generally exceed' and 'every effort should be made by the contractor to comply'[1]. These phrases all convey a degree of flexibility, but when its recommended limits are translated into a regulatory framework like a district plan, this flexibility can disappear.

We are proposing a reform of construction noise policy. This is likely to be controversial, so here is a succinct list of what we would like to change:

- Use noise trigger levels, not noise limits, to inform construction noise effects assessments
- Convince councils that a management framework can be robust and dependable
- Convince councils that best practice can be defined and enforced
- Generate momentum for updating NZ Standard NZS 6803:1999

In this paper, we have focused on noise, but the same issues are relevant to vibration.

2 The current construction noise assessment process needs to change

2.1 Construction noise is inherently variable

A construction site could have 10 different excavators (of varying size, age and condition) being used by 10 different operators (of varying skill and temperament) in 10 different locations doing 10 different tasks (of vary-ing intensity and duration, using different attachments).

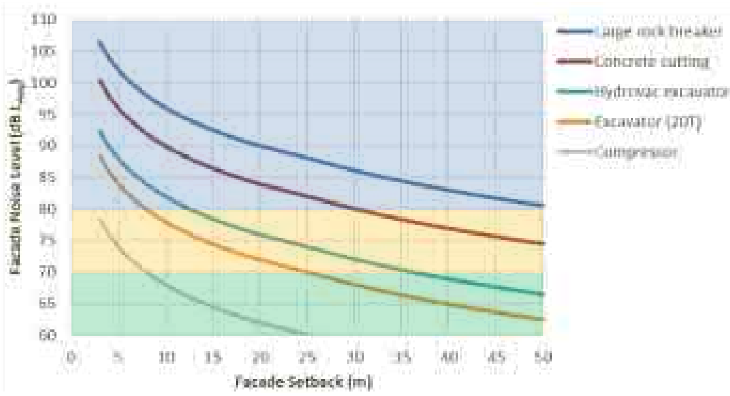
Acoustic Consultants have the tools to predict construction noise levels with high modelling precision, but the resulting accuracy is low due to the factors we have listed above.

2.2 Most urban construction activities exceed the construction noise limits

As consultants, we predict noise levels from a 'typical worst-case' scenario to understand the potential effects envelope, which is key to the planning process.

Figure 1 below shows the noise level – distance relationships for a range of typical construction activities. The construction noise limit for long-term projects is 70 dB L_{Aeq} in NZS6803:1999. The graph shows that nearly all activities can exceed this threshold when close to a neighbouring building. Even when applying a 10dB factor for mitigation from effective screening, a medium-sized 20 tonne excavator is predicted to exceed 70 dB LAeq when operating 8m from a neighbouring building, which is inevitable at some stage during most urban projects.

Figure 1: Typical construction noise levels of machinery (without mitigation)



Any predicted exceedance (regardless of duration, frequency and timing) triggers the need for a resource con-sent. In many cases, this amounts to regulatory 'red tape', less planning certainty, protracted timeframes and unnecessary cost. For notified projects, public hearings tend to focus on the predicted noise levels, rather than whether effects will be reasonable.

Consultants are often pushed to provide more certainty that compliance will be achieved. Our proposal aims to move the focus from 'level certainty' to 'process certainty'.

[1] *NZS 6803:1999, Sections 7.1.1, 7.1.2 and 7.4 respectively*

2.3 Stakeholder engagement and management is more important than noise level

In construction, predicting a noise level allows consultants to assess the likelihood of disturbing the neighbours (stakeholders). Construction noise limits are supposed to provide a clear line: compliance = good, exceedance = bad. But the real test is whether or not the neighbour is affected, and they will be affected at a noise level that bears little or no resemblance to the limit.

There are various factors that feed into whether a person is disturbed by a noise source, and the noise level is only one of them. They might be particularly sensitive because they work nights, or have a 6 month old baby, or they may be planning a 6 week trip and won't be home at all.

Telling someone that they can't complain about 70 dB of construction noise because it complies with the limit is unhelpful and misses the point. It makes them feel like they're being kept at arm's length, without any say in the process. A considerate member of the communications team who listens to concerns, and makes good on commitments to mitigate using the Best Practicable Option (BPO) has been said to be worth at least 10 dB!

Consistent messaging about construction management is also critical. Building trust with stakeholders is par-amount, and it can be undone in a second if what they observe on the site is not what they were told during the initial process.

It is important to note that flexibility does not mean that the contractor can act with impunity. There should still be strict requirements, and consequences for non-compliance, but the requirements shouldn't be based on construction noise levels alone – they should be based on the BPO.

2.4 A CNMP is the bridge between predicted exceedances and reasonable effects

We have established that exceeding the NZS 6803 limits is inevitable in built up areas, and that receivers bene-fit from BPO mitigation, engagement and goodwill with the contractor. A CNMP ties this all together – by identi-fying potential exceedances, setting the blueprint for how the construction should unfold, and drawing clear lines of communication and reporting.

A draft CNMP is routinely submitted to Council as part of a resource consent application, so it is already a common feature in the consenting process. Its content sometimes causes debate between experts and con-senting officers, but it is clear that a well-crafted CNMP gives all parties certainty of process and reassurances that potential effects will be suitably managed.

3 The UK and Australian standards have evolved, the NZ standard has not

3.1 New Zealand Standard NZS 6803:1999

The title of this Standard is "Acoustics - Construction Noise". It is one of the oldest NZ standards in the 680X Series. It is largely based on the 1997 version of British Standard BS 5228:1997 which has since been revised (refer Section 3.2). It is long overdue for an update.

In general, its content is still relevant and fit for purpose. But, when implemented in District Plans, the rules of-ten refer to the recommended noise limits only, and ignore everything else.

We consider that NZS 6803 intended the noise limits to be a trigger for mitigation and management. We note that it states: "A noise management plan will often be appropriate to achieve the aims of the Standard. The re-quirements for a noise management plan are outlined in Annex E." [2]

Annex E is often overlooked, and in our opinion, provides the 'bridge' we discussed in Section 2.4. It recom-mends a CNMP framework and a method for implementation, and can be used by Council for certification and determining if residual effects are reasonable. Annex E consists of three parts:

- Annex E1 clarifies that the intent of a CNMP
- Annex E2 recommends a list of CNMP contents, which include predicted noise levels, mitigation measures, training of staff, monitoring and community engagement
- Annex E3 provides guidance on the implementation of the CNMP

3.2 British Standard BS 5228-1:2009

The title of this Standard is "Code of practice for noise and vibration control on construction and open sites". Note the phrase 'code of practice' emphasises the focus on noise management. It is already used by consultants to supplement NZS 6803:1999 when recommending BPO.

It uses 'noise control targets' as management triggers and doesn't mention of 'noise limits'. Predicted noise levels are simply a tool to inform an appropriate management response.

3.3 Australian Standard AS 2436:2010

The title of this Standard is "Guide to noise and vibration control on construction, demolition and maintenance sites". The key term here is 'guide to... control' which, like 'code of practice', indicates it is a blueprint for how construction sites should be managed.

[2] *NZS 6803:1999, Sections 8.1.2*

It was prepared by the Australian members of the Joint Standards Australia / Standards New Zealand Committee EV-010. The ASNZ representative at the time was a building acoustician who opted not to be involved in its development, but Standards NZ has the option of adopting it. It aligns with, and reproduces large parts of, BS 5228:2009 (it also has no noise limits). Implementation varies by State. The Northern Territory implementation is very simple, so makes an excellent example for this paper. In short, it requires:

- Work in normal hours
- Undertake the works in accordance with AS 2436
- Provide 48 hours' notice to neighbours prior to disruption

OR

- Undertake works in accordance with a CNMP registered with the Council (includes a list of minimum components and where to register it for certification)

4 A case study: Auckland Unitary Plan (AUP)

4.1 The Unitary Plan's construction noise rules conflict with its objectives and policies

The Auckland Unitary Plan (Auckland Council, 2016) sets out an objective for construction noise in Rule E25.2 (4). It states the following (we have added bold font for emphasis):

*"Construction activities that cannot meet noise and vibration standards are **enabled while controlling du-ration, frequency and timing** to manage adverse effects".*

This acknowledges that there are often periods or activities where the construction noise standards cannot be met. The objective is to enable them provided they are no louder than necessary.

AUP policies E25.3 (2) states "Minimise, **where practicable**, noise and vibration at its source or on the site from which it is generated to mitigate adverse effects on adjacent sites". E25.3 (10) states:

"Avoid, remedy or mitigate the adverse effects of noise and vibration from construction, maintenance and demolition activities while having regard to:

a) the sensitivity of the receiving environment; and

b) the proposed duration and hours of operation of the activity; and

c) the **practicability of complying** with permitted noise and vibration standards."

Again, this acknowledges that compliance may not be practicable.

In direct contrast, the construction noise rules in AUP rules E25.6.27 and E.25.6.28 state that "noise from con-struction activities **must not exceed** the levels" set out in the relevant tables. This wording provides no flexibil-ity, and any exceedances give the activity a restricted discretionary status.

4.2 The rules for construction in the road reserve are more pragmatic

AUP rule E25.6.29 provides specific construction noise rules for works in a road. It enables exceedance of the noise limits in E25.6.27 and E.25.6.28 under certain circumstances, including when they are of limited duration and have a certified CNMP.

We propose that this approach would work for all construction noise assessments, and the CNMP certification process would allow the flexibility we are looking for.

4.3 The assessment criteria for restricted discretionary activities are pragmatic too

If a project exceeds the limits, and is classified as restricted discretionary, Council has to assess the consent application according AUP rule E25.8. It sets out assessment criteria for the consenting officer, which read very much like a management plan.

"The Council will consider the relevant assessment criteria for restricted discretionary activities from the list below:

(1) for noise and vibration:

a) "whether activities can be managed so that they ***do not generate unreasonable noise and vibration levels*** *on adjacent land uses particularly activities sensitive to noise;*

b) the extent to which the noise or vibration generated by the activity:

- *i. will occur at times when disturbance to sleep can be avoided or minimised; and*
- *ii. will be compatible with activities occurring or allowed to occur in the surrounding area; and*
- *iii. will be limited in duration, or frequency or by hours of operation; and*
- *iv. will exceed the existing background noise and vibration levels in that environment and the reasonableness of the cumulative levels; and*
- *v. can be carried out during daylight hours, such as road works and works on public footpaths"*

c) [this rule relates to vibration only]

d) Whether the measures to minimise the noise or vibration generated by the activity represent the ***best practicable option****."*

In summary, like NZS 6803:1999, the Auckland Unitary Plan has enough pragmatism and flexibility to result in good consenting outcomes. But, the wording of its noise rules is too rigid, and this undermines the consenting process.

5 The Auckland Unitary Plan's certification process should be explained

By expanding the CNMP certification process to all construction noise assessments (instead of just works in the road reserve), the focus of acoustic consultant and Council would shift from the planning phase to the con-struction phase. This will simplify the planning process, improve value and reduce costs. A comparison of the existing situation and proposed improvements are summarsied in Table 1.

(see Table 1 on next page)

Figure 2 shows the existing planning process for construction noise and the proposed simplifications.

Introducing more flexibility around how predicted noise levels are expressed, and how the consenting process relies on them, will:

- Reduce the fixation on noise level compliance
- Focus the attention of council staff on BPO enforcement
- Enable a more straightforward and reliable planning process
- Promote a more holistic view of the proposed construction activities
- Allow adaptation when activities on site necessarily change or evolve
- Move acoustic experts' main involvement from the planning phase to the construction phase, where it is more valuable

(see Figure 2 on next page)

6 Conclusions

Construction noise assessments in Auckland have become a high cost, low value exercise. Exceedances of construction noise limits is very common – especially in urban areas – and applying noise limits rigidly adds cost and frustration to the consenting process.

CNMPs are common, but their real value isn't being realised because of the rigid application of noise limits. In this age of RMA reform, we have an opportunity to reframe our construction noise assessment and focus more on BPO measures that reduce community disruption and improve process certainty.

We urge local governments throughout NZ to reframe their construction noise 'limits' and apply them as 'trigger levels' along with a CNMP certification process. This approach aligns with recent revisions to British and Australian construction noise standards, and the Auckland Unitary Plan rules for construction noise in the road reserve.

References

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AS 2436:2010, *Guide to noise and vibration control on construction, demolition and maintenance sites*, Standards Australia, ISBN 978 0 7337 95817

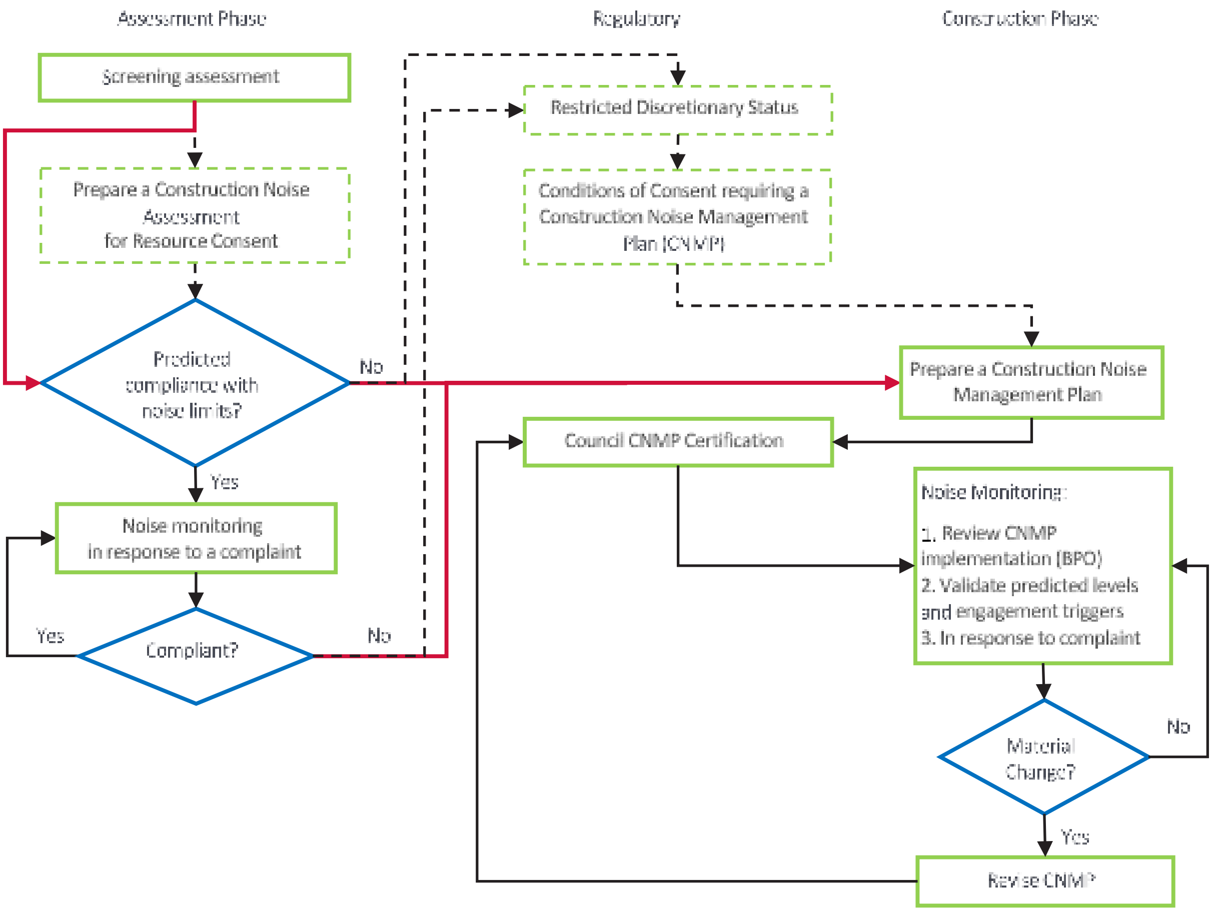
BS 5228: 2009, *Code of practice for noise and vibration control on construction and open sites,* British Standards Institute, ISBN 978 0 580 56049

NZS 6803: 1999, *Acoustics - Construction Noise*, Standards New Zealand, Wellington

Table 1: Construction noise – proposed improvements to the planning and construction phase

Phase	Existing situation	Proposed improvements
Planning	High Cost: - Consenting is the primary focus of acoustic consultants and Council - Predicted exceedance of noise limits triggers restricted discretionary status - Generic draft CNMP prepared to demonstrate BPO	Low cost: - Exceedances should automatically trigger a CNMP for certification - CNMP framework can be standardised
Construction	Low Value: - Contractor has little input to the CNMP provided during consenting so takes a re-active approach to noise complaints - Low enforcement rates from Council with focus on noise limits rather than BPO	High Value: - A better place for acoustic consultants and Council to focus their energy - Acoustic consultant should support contractor to improve training and use monitoring to provide management feedback - Council should focus on BPO monitoring and enforcing good management

Figure 2: Typical construction noise planning process (proposed deletions dashed and changes in red)



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