NEW ZEALAND ACOUSTICS

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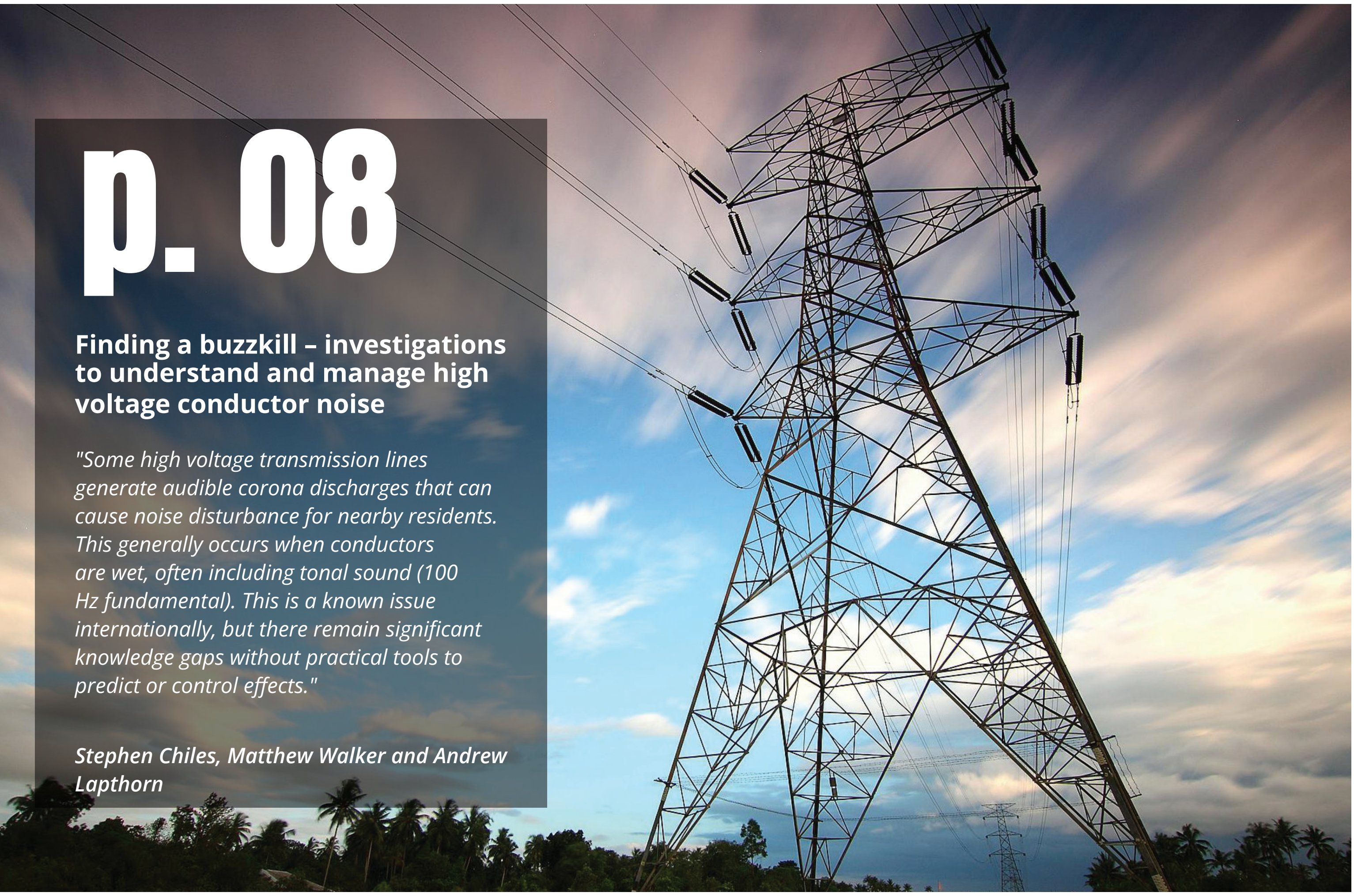

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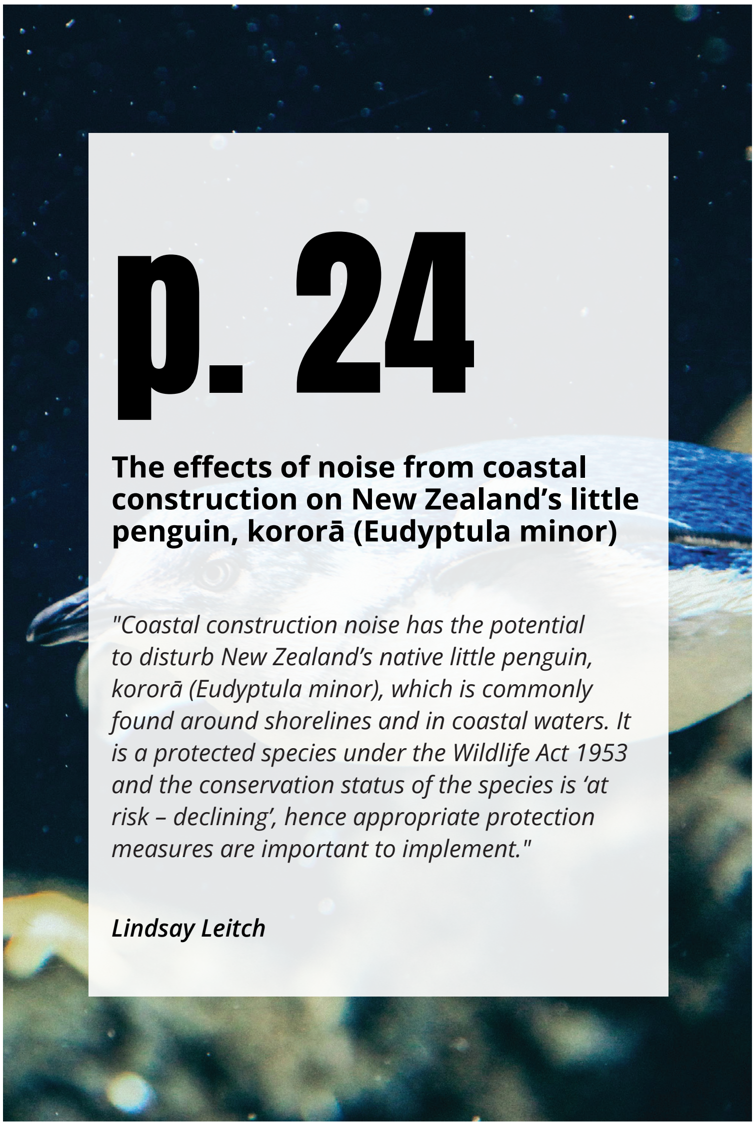
Stephen Chiles, Matthew Walker and Andrew Lapthorn



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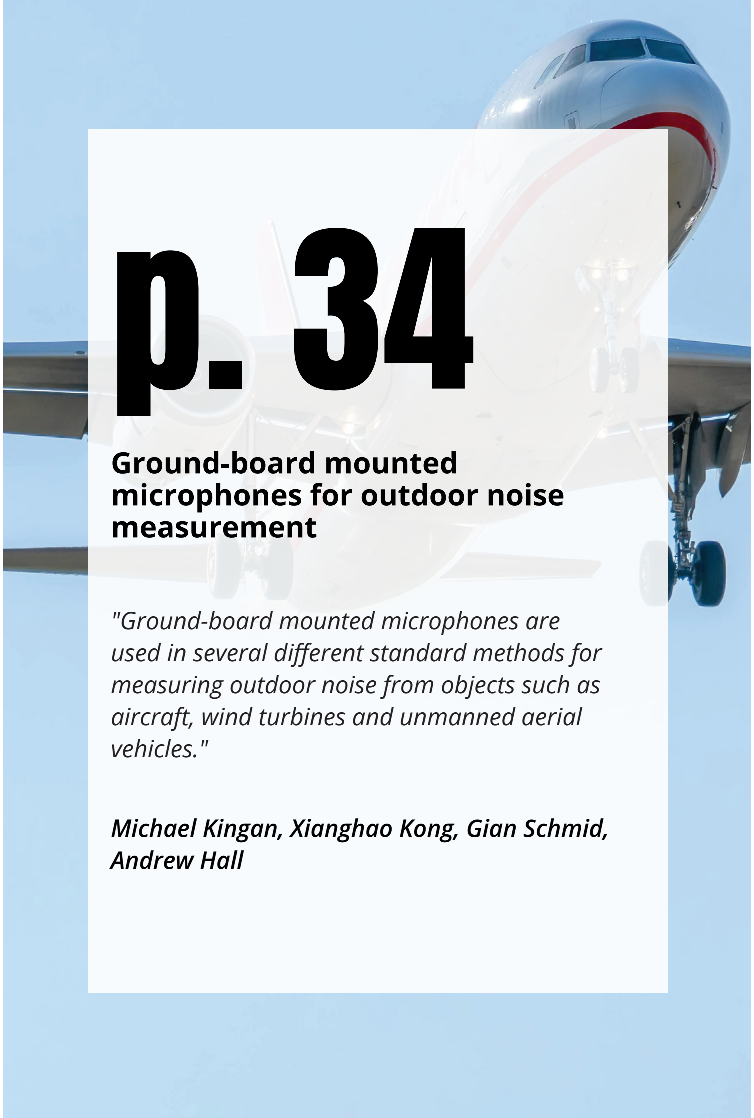
Lindsay Leitch



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Tracy Hilliker

President of the Acoustical Society of New Zealand Inc.

Dear Members,

By the time this Journal reaches your desk or coffee table, I am sure we will all be welcoming the change in season, and hopefully weather patterns too. The neutral El Niño conditions with low pressure systems over NZ have continued to lead to significant rainfall and devastating flooding. Unfortunately the warmer than average winter plays havoc with the frequency of such events and has an impact from our ski fields to our oceans, and all land in between. I trust all our members and families have managed to stay safe and dry. Here's to longer, lighter and drier days ahead.

Spring is a time of new beginnings, and our Society workings is no different. Our new website will be rolled out, and we will soon be offering credit card payments for membership fees to make the process more efficient for everyone. The proposed amendments for our ASNZ Rules (becoming our *Constitution* in accordance with the Incorporated Societies Act 2022) will also soon take effect. Along with these changes, the Council is proposing two new membership grades: Student Member and Executive Member. The latter is positioned above Member, and below Fellow. It will have greater requirements for professional experience, membership duration and contribution to ASNZ activities, along with higher fees and CPD requirements. With our growing membership and ongoing Society development, this intermediatory grade provides recognition for our long-standing Members, not diluting the prestige of our Fellowship award. Our **Annual General Meeting** date has been set for **Friday the 5th of September 2025** late morning. This year we are hosting the AGM fully online, and we will soon send out a meeting invite for your calendars. As always, your attendance is important as we need a quorum of members present on the day (or by proxy vote), so I thank you all in advance for your time and participation.

It is with great sadness that we received the news of the passing of our Fellow, Ross McBeth from heart complications in April. Ross was a stalwart of the ASNZ, and I am sure many of you remember him as the Brüel and Kjaer equipment distributor in NZ for many years; he was a fantastic salesman with conviviality and always generous with his time. Ross was made a Fellow back in 2012, acknowledging his contribution to our Society and the acoustic profession for over 30 years. You'll find his obituary warmly penned by Keith Ballagh a few pages in. Our condolences are with his wife Maureen and his children Andrew and Ameilia, and step-children Jonathan, Louise and Christian, during this difficult time.

Whilst our AGM approaches, the last quarter has seen similar activity with our affiliated international parties. The recent International Commission for Acoustics (ICA) Congress in New Orleans saw the election of Jorge P. Arenas (SOCHA, Chile) as the new President. We send our congratulations to our friends from the Pacific, Akio Ando (ASJ, Japan) who was voted in as Vice-President, and Danielle Moreau (AAS, Australia) as a board member. We also recently had our membership renewed with the World Hearing Forum. The AAAC released in April a Guideline for interpreting and applying NZS 6803:1999 *Construction Noise.* This is an important reference document for the NZ industry, and I encourage you to read it. Many thanks to all our members who contributed earlier this year, and our Council member, Tim Beresford, who coordinated the review, finalisation and document release. A bit closer to home, I was invited to talk at the Hearing NZ AGM held in Christchurch in late May. It was great to share information about our Society, who we are and what we do, with a quick overview of room acoustics and how good design enhances comfort and speech intelligibility. I know that this is a community that will benefit from our contribution to SoundPrint as well. We have many shared goals with such groups, and it is important to keep raising awareness, working together and connecting with those both in Aotearoa and beyond.

As we progress through the second half of the year, it shouldn't be too long before the anticipated updates to our dispute resolution pathway and processes are in place. This has the aim of improving our complaints process to make it fairer to our members, others involved, and to protect the Society. We have taken on board membership feedback, and the process itself will be more transparent, with an online form to be filled in. This will ensure the receipt of consistent information for any submission, enabling us to resolve valid disputes in a fair, efficient and effective manner. Nonetheless, our fundamental Rules of Conduct remain, and I'd like to give a gentle reminder to one in effect *"no member shall review the work of another member without taking reasonable steps to ensure that such member is informed".* Please remember to exercise courtesy and professionalism if you find yourself in this situation, or on the receiving end, and follow the Golden Rule, "Do unto others as you would have them do unto you".

I look forward to connecting with many of you in early September at our AGM, if not before.

Warmest regards,

Tracy Hilliker

President of the Acoustical Society of New Zealand Inc.

Lindsay Hannah and Wyatt Page

Principal Editors

Nau mai haere mai

Welcome to what might be described as the winter edition of New Zealand Acoustics for 2025 (Volume 38, Issue #2). For the Nelson Tasman area, two adverse weather events on top of each other have been devastating this winter. Our thoughts are with them as the slowly move into the recovery phase.

In this issue, we have a wider range of short papers for you to dip into, as well the regular features. You will get to find out what causes, and how to manage, noise from high voltage transmission lines. There is a series of case studies of noise and vibration monitoring in construction projects. You will find out how noise from coastal construction is affecting our little penguin, kororā. How Waka Kotahi can now produce asphalt surfaces that are reliably 4 dB quieter than standard porous asphalt, and finally, the properties and behaviour of ground-board mounted microphones.

Ngā mihi nui

Lindsay Hannah & Wyatt Page
Principal Editors

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president@acoustics.org.nz
www.acoustics.org.nz

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treasurer@acoustics.org.nz

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Editorial Board

Editor-in-Chief
Lindsay Hannah
Wyatt Page
journal@acoustics.org.nz

Advertising Manager
Paul Hazard
advertising@acoustics.org.nz

Design & Production
Holly Saunders-Wright
production@acoustics.org.nz

Submission All Articles
News, Products, Enquiries
journal@acoustics.org.nz

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New Legislation for Incorporated Societies in NZ

The Acoustical Society of New Zealand (ASNZ) is an incorporated society, operating as a not-for-profit legal entity. It was established in 1981 to formalise the structure of a group which had the common purpose to promote the science and practice of acoustics, and currently operates in accordance with the Incorporated Societies Act 1908. This gives the ASNZ its own legal identity, separate to that of any members, providing limited liability. In other words, our members are not personally liable for the society's debts and obligations. While members may change over time, the society's identity does not.

WHY THE CHANGE?

In October 2023, the Incorporated Societies Act 2022 (the 2022 Act) came into force. It has brought significant changes to the rules governing incorporated societies, including requirements for membership, governance, financial reporting and dispute resolution. The 2022 Act modernises the laws and the way societies need to operate. An incorporated society's legal documentation is published on the Incorporated Societies Register and made freely available to anyone searching the register.

If the ASNZ is to continue operating as an incorporated society, we must re-register under the new 2022 Act before April 2026. To do this, we need to make changes to our Rules, which will be called our *Constitution*, and adopt some new processes. For this to happen, the proposed changes need to be agreed in a vote by our members at our next Annual General Meeting (AGM) in early September 2025, to be held via video conference. We must have a quorum at the AGM, which is 25% of our total membership. We currently have 214 members, so we need at least 54 people to attend.

WHAT HAPPENS IF WE DON'T MAKE CHANGES?

If the ASNZ doesn't re-register under the 2022 Act before April 2026, it will cease to exist. This means our group would no longer be an incorporated society nor have a separate legal identity. In essence, we would lose control of the society's assets, including cash reserves, and an independent Registrar can direct how they are distributed. All members could be held personally liable for debts or obligations, and our society name would no longer be protected, so it could be used by any other group. It is therefore *critically* important for our membership to come to a resolution on our new Constitution.

CHANGES THAT WILL FORM OUR CONSTITUTION

For the most part, the draft *Constitution* is the same as our existing and current ASNZ Rules. It continues to set out our purpose, what we do and how we operate. However, along with making the necessary updates for compliance with the 2022 Act, the Council has taken the opportunity to review and propose further amendments. This way, we can ensure that the Constitution is fit for purpose, continuing to provide certainty and consistency in the way the ASNZ is run today, and in the future. These changes include:

- Updates to our procedures for managing complaints and disciplinary measures, including prescribed conditions to be met, and to include dispute resolution as required by the 2022 Act.
- Changes to our membership grade structure:
    - Removal of grades which are inactive or redundant; being Sustaining Member and Sponsor.
    - Introduction of a new Student member grade. Currently, students apply to be an Affiliate, but with a reduced subscription fee. The new grade will allow us to administer students, modify their subscriptions and provide benefits separate from Affiliates.
    - Introduction of a new Executive Member grade (EMASNZ). This grade will have greater requirements for professional experience, membership duration, contribution to ASNZ activities, and require higher annual subscriptions and CPD requirements. This new grade offers higher recognition for our long-standing Members, who continue to be active participants in the ASNZ and wider industry, but it does not have the same prestige as a Society Fellowship.

CHANGES TO OUR RULES OF CONDUCT

Our existing Rules of Conduct will remain unchanged, but we are proposing to add a few requirements. These will strengthen expectations, promote a positive and ethical environment, and support growth and development of our members, the Society, and wider acoustic community.

CHANGES TO OUR DISPUTES RESOLUTION AND DISCIPLINARY MEASURES

The ASNZ continues to take any concerns, disputes and complaints against the Society or our members seriously. Our Disputes Resolution and Disciplinary Measures process is focused on resolution, appropriate accountability, education and industry development.

Changes to the procedures for managing and resolving complaints are outlined in the updated *Rules of Conduct, Disputes Resolution and Disciplinary Measures* documents. This, in conjunction with the Constitution, now defines what a 'dispute' is, clearly outlines a threshold that a dispute complainant must meet, and what information needs to be provided prior to any alleged complaint being considered. It also provides more detail and transparency of the overall process, including expectations regarding confidentiality and communication. However, we retain the right to refuse a dispute if we consider any complainant to be using aggression, intimidation or violent behaviour.

To obtain adequate and consistent information about a dispute, we have developed a Complaint Form which will be available on our new website to guide complainants to write clear, concise and factual information for consideration.

WHAT WILL HAPPEN NEXT?

The Council will circulate an email copy of the draft *Constitution* and *Rules of Conduct, Disputes Resolution and Disciplinary Measures* documents that will be tabled at our upcoming AGM. Official notice of the upcoming AGM and other associated documents will also be issued to all members.

In the meantime, put a placeholder in your calendar for the online **AGM on Friday the 5th of September 2025**, keep an eye on your inbox, and encourage your colleagues to attend. Remember, we need 25% for a quorum, otherwise, we cannot vote on these essential changes.

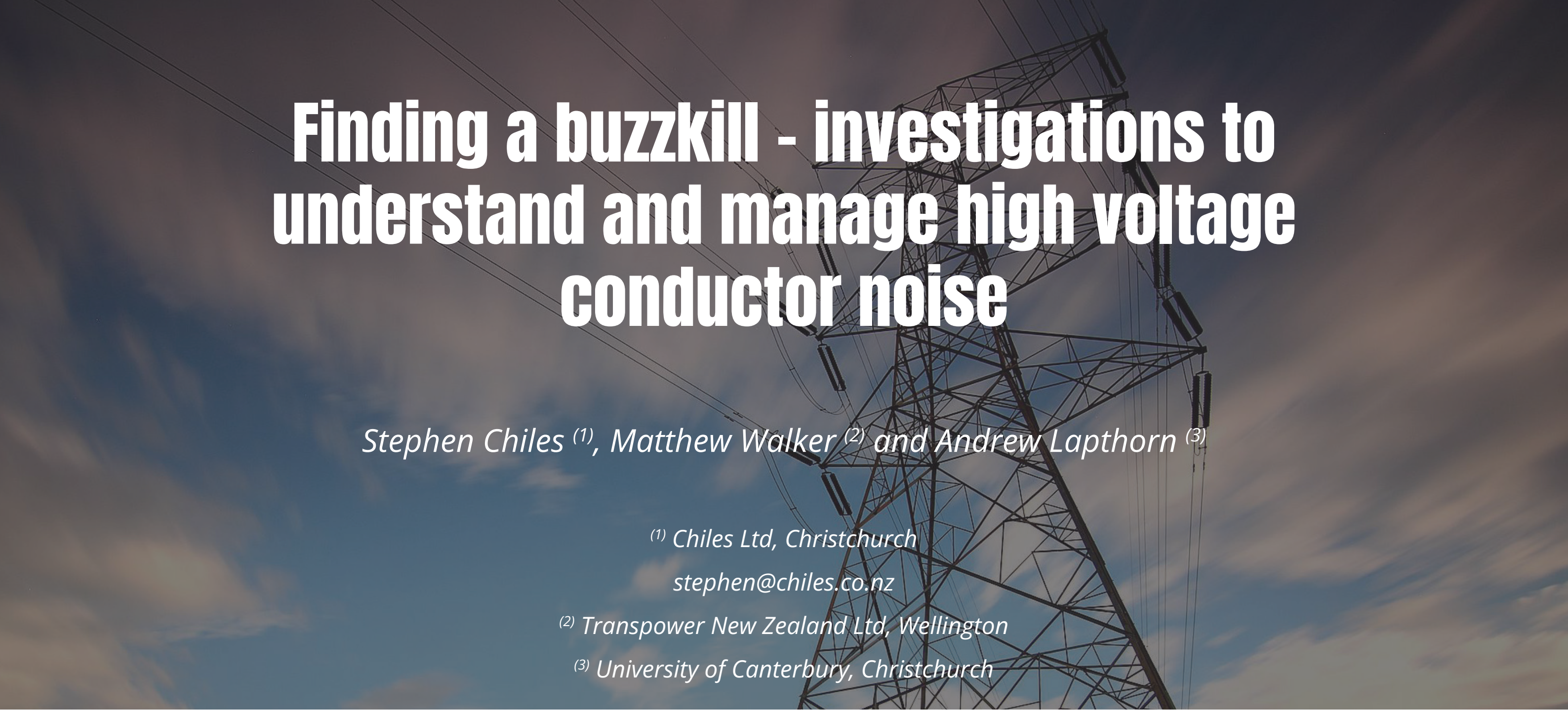
If you have any queries or questions, we are more than happy to discuss any aspect further. Please do not hesitate to get in touch by emailing president@acoustics.org.nz.

Tracy Hilliker, ASNZ President

In loving memory of
Andrew Ross McBeath
04 September 1944 to 14 April 2025

Andrew Ross McBeath

It is with sadness that we noted the recent death of Ross McBeath. Ross was a constant presence on the New Zealand acoustic scene for 32 years. Ross joined David Reid Electronics in 1981 and took over sales of Bruel and Kjaer equipment. In those days Bruel and Kjaer was pretty much the only supplier of acoustic measurement equipment and he travelled up and down the country selling and supporting their gear. While Ross didn't start with a deep background in acoustics he never pretended to know more than he did and was able to call on the Danes to answer the more technical matters. He was a pleasure to deal with and his happy good nature meant it was always a delight to have him call. I think there are cupboards of B&K gear up and down the country that are a testament to the great job he did. I was often amazed at the equipment he had managed to sell to City Councils. After the death of Donald Reid Ross formed AVIA Ltd in 2003 to take over the agency for Bruel and Kjaer, and he continued to represent them until he retired in 2013. An indication of his character was that when he retired he offered us his near new 2260 sound level for a bottle of good Cabernet Sauvignon as a thank you for the association over the 32 years we had known him. On a personal note it was an unexpected pleasure a few years ago to come across him at the Point Chev bowling club where our firm was having its Christmas function and he was one of the club members helping out, smiling and enjoying company as always.



Finding a buzzkill - investigations to understand and manage high voltage conductor noise

Stephen Chiles (1), Matthew Walker (2) and Andrew Lapthorn (3)

(1) Chiles Ltd, Christchurch
stephen@chiles.co.nz
(2) Transpower New Zealand Ltd, Wellington
(3) University of Canterbury, Christchurch

Abstract

Some high voltage transmission lines generate audible corona discharges that can cause noise disturbance for nearby residents. This generally occurs when conductors are wet, often including tonal sound (100 Hz fundamental). This is a known issue internationally, but there remain significant knowledge gaps without practical tools to predict or control effects. Transpower is replacing conductors reaching their end-of-life. When this work started in 2015, noise complaints arose from replacement conductor that had been predicted to be marginally quieter. In response, Transpower has undertaken extensive investigations into the causes, and methods to assess and reduce noise from new conductors. Testing in a high voltage laboratory, demonstrated how conductor geometry (shape and size) and surface finish both affect audible corona discharge. Hydrophilic surfaces that spread water generate less noise than hydrophobic surfaces that cause water to bead. New conductors with shiny metal, oil residue and grease applied to manage corrosion, are generally hydrophobic, whereas weathered and oxidised, aged conductor surfaces are generally hydrophilic. Treatments developed to dull new metal finish and reduce potential oil/grease on the surface were tested in the laboratory. Conductors with trapezoidal rather than round strands were also found to be quieter. Laboratory and theoretical findings on noise effects do not yet fully correlate with extensive long-term field monitoring and the effects experienced by people under re-conductored lines. Significant effort is ongoing examining variability in measured noise, in terms of acoustic and meteorological instrumentation issues, and physical conductor changes. Factors related to noise perception and community engagement have also been explored.

Introduction

Transmission lines

Transpower is the owner of the National Grid, which includes more than 11,000 km of high voltage transmission lines. The lines generally comprise one or two circuits, with each circuit having separate conductors for each of the three electrical phases, plus an earth wire in some places. Commonly, conductors are 'simplex' with a single conductor for each phase or 'duplex' with two bundled conductors for each phase.

Each conductor is made from concentric layers, typically with steel strands in the core for strength, and aluminium strands on the outer layers for conductivity (see Figure 1).

Figure 1: A conductor (Zebra) made up from layers of round strands

There is a wide range of conductor types, with variations including materials and sizes. For ease of reference, each conductor type has a code word, usually being an animal name (e.g. Goat, Zebra, Curlew). Conductor selection for a section of line is determined/optimised primarily based on a range of essential mechanical and electrical functional requirements.

Audible corona noise

Corona discharge from conductors occurs when the surface electric stress exceeds the dielectric strength of the surrounding air. A parameter called surface voltage gradient is a predictor of the onset of corona discharge. Lines are designed to operate below a surface voltage gradient threshold to avoid corona discharge, but perturbations on the conductor surface (e.g. insects, water droplets) can enhance electric stress such that corona can occur. As such corona discharge is typically perceived in wet conductor conditions. Corona discharge can generate sound, normally perceived as a broadband 'crackle' but more unusually as a tonal 'hum' with a fundamental frequency of 100 Hz (twice the power system frequency).

The susceptibility of a conductor to corona discharge depends on factors including the conductor type, conductor condition, line voltage, conductor configuration / spacing and height above the ground. Based on such parameters and a rainfall rate, predictions of audible corona noise can be made using international models. The development of such models has largely been based on aged in-service conductors rather than conductors, and mainly relates to the broadband rather than tonal noise.

Noise complaints

Routine maintenance of the grid includes periodic replacement of conductors ('re-conductoring') when they approach end-of-life, typically after several decades service. After an extended period without major reconductoring nationally, Transpower commenced work on the Bunnythorpe to Haywards (BPE-HAY) A and B 220 kV lines in 2015. A slightly larger diameter replacement conductor was selected (new 'Zebra' replacing old 'Goat'), which theoretically should result in lower surface electric stress and less corona discharge. However, several residents complained to Transpower about noise disturbance when initial sections of the lines were re-conductored with Zebra. The disturbance appeared to relate primarily to the tonal component of the audible corona noise occurring in wet conditions. The effect on people was seemingly a loss of amenity during these periods caused by the conductor noise being audibly present amongst other ambient noise, where it previously hadn't been noticed.

Transpower set out to thoroughly investigate the complaints, but soon found it had opened a Pandora's box. While issues with conductor noise have occurred internationally, these have generally been at much higher voltages, and few other utilities run 220 kV networks with single phase conductors on those lines. Initial work found there were no reliable methods for design, assessment or mitigation, with substantial knowledge gaps across most areas. Since that time, Transpower has undertaken extensive work to explore the knowledge gaps to help it responsibly manage ongoing maintenance of the grid. This paper summarises key findings from those ongoing investigations. Exploration of different facets has overlapped, such that the following is not a chronological sequence.

Laboratory Testing

Thirteen rounds of testing were undertaken by the University of Canterbury in its high voltage laboratory (with staff travelling to undertake the final round at the University of Manchester, UK). Each round lasted around a fortnight to test in the order of ten to twenty conductor samples, including some duplicates and repeats. Reference conductors were retested in each round as controls.

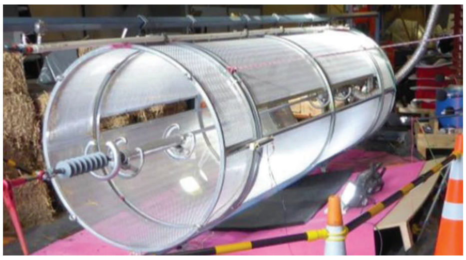


Figure 2: University of Canterbury corona cage

To test each four-metre-long conductor sample they were held horizontally in the centre of a suspended cylindrical corona cage (see Figure 2). Tension on each sample was applied to be in a range representative of a transmission line catenary for an in-service conductor. This maintains conductor/strand geometry and avoids water migrating along or to the bottom surface in an unrealistic manner.

Voltages were applied to the conductor to replicate surface voltage gradients on the BPE-HAY lines. For transmission lines, the surface voltage gradient for a conductor depends on the distances to other nearby conductors for other phases, circuits and lines and to the ground and earthwires. Using a corona cage in the laboratory relatively close to an individual conductor increases the surface voltage gradient compared to field conditions. Therefore, to replicate the surface voltage gradient on a 220 kV line, a lower voltage needs to be applied in the laboratory. In this instance the voltages in the laboratory were around 75 kV, depending on each conductor's diameter.

With voltage applied, sound emissions were measured to one side of the corona cage in dry conditions and then for simulated rainfall of 21 mm/h ('light rain') and 60 mm/h ('heavy rain') applied from nozzles above the conductor. The rainfall rates were controlled by adjusting the water pressure to the nozzles, with the required pressure settings having been determined by in situ rain gauge measurements. The laboratory rainfall characteristics, such as droplet size, have not been analysed, but this is a potential avenue for further investigation.

In addition to measurements during rainfall, sound was measured at intervals over fifteen minutes after each simulated rainfall stopped, as the conductors dried. During each condition, the conductor noise was a steady sound and was primarily measured using time-average levels ($L_{eq(30s)}$). Differences between conductors were evident from A-weighted levels, but measurements included third-octave bands. In later testing rounds, the 106/212 Hz tonal audibility was also determined from narrow band analysis.

Over the rounds of testing, various refinements were made to the method, including suppression of acoustic reflections in the laboratory, use of multiple microphone positions, and slight offset of the test electrical frequency to 53 Hz to exclude the possibility of any 100 Hz mains related ambient noise affecting measurements of tonal sound then occurring at 106 Hz. Measurements were at night to minimise ambient noise, given the acoustically sub-optimal space affected by road and aircraft noise as well as localised activity.

While conductor noise should have reasonably uniform directivity in a transverse plane, there is significant spatial variation of sound in the high voltage laboratory given the wavelength of the fundamental tone at 100/106 Hz and the uncontrolled acoustic environment. As well as introducing acoustic absorption, results were averaged across multiple microphone positions to reduce the influence of spatial variations.

The laboratory testing immediately visually and acoustically demonstrated differences between the aged Goat conductor removed from the BPE-HAY line and the replacement new Zebra conductor (see Figure 3).

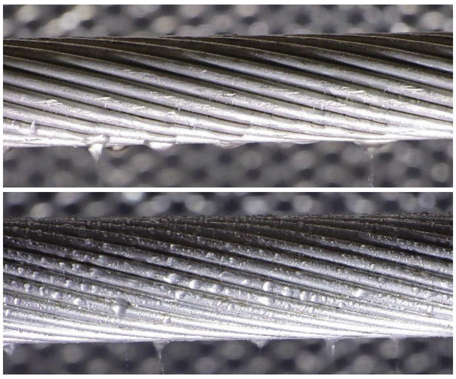


Figure 3: Aged Goat (top) and new Zebra (bottom) conductors with heavy rain, resulting in numerous prominent droplets retained on the new conductor

The new Zebra conductor generated several decibels higher

A-weighted broad-band levels and significantly higher levels in the 100 Hz third octave band, by over 10 dB in some tests/conditions such as when drying after light rain. The test method allows for relative comparisons of sound levels, but in earlier rounds of testing the repeatability was poor.

The aged Goat conductor appears to have developed a hydrophilic surface over time through weathering and oxidation (as commonly observed for all conductors). Rain incident on the conductor quickly disperses into the gaps between strands, and then forms relatively few large flat droplets on the underside of the conductor.

The new Zebra conductor has a more hydrophobic surface. This is due to both the shiny metal finish, and also drawing oil used in manufacturing, and migration of grease applied within the conductor to protect it from corrosion. In this instance, additional grease had been specified to combat corrosion in the coastal environment. The result of the hydrophobic surface is that rainfall beads in numerous smaller water droplets around the surface, that can remain for some time after rain stops. These small prominent droplets appear to be the cause of the increased noise.

The laboratory testing explored two main potential methods to reduce noise from new conductors:

- Treat the selected new conductor to achieve a hydrophilic surface, and
- Identify an alternative conductor type that inherently has a hydrophilic surface when new.

Treated Zebra conductor

An iterative series of tests were undertaken to treat new Zebra conductor at the Auckland manufacturing plant, including:

- Reducing grease application.
- Cleaning to remove excess drawing oil and grease, initially by hand and later by machine cleaning.
- Grit blasting at different blasting pressures and utilising different blast materials to dull the shiny surface.
- Replacing mineral oil as the die oil with emulsified fat, which is more readily cleaned from the surface.

The laboratory testing did not show consistent acoustic differences between some of these changes, but new Zebra samples with grit blasting and machine cleaned strands gave similar acoustic results to the aged Goat conductor, visually appearing to have achieved a hydrophilic surface (see Figure 4). A remaining difference was that the new treated Zebra conductor still takes longer to dry after rain than the aged Goat.

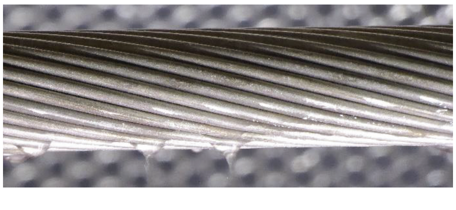


Figure 4: Blasted and cleaned new Zebra conductor with heavy rain

Trapezoidal strands

Conductors are available internationally with trapezoidal rather than round strands. The trapezoidal strands result in a flatter exterior conductor surface (see Figure 5). Theoretically the corners of the strands result in localised increased electrical stress and therefore higher risk of audible corona noise.

Figure 5: New Dublin conductor with heavy rain

For the current work, a sample of conductor with trapezoidal strands was obtained for laboratory testing ('Dublin'). This conductor was measured to have similar broadband and tonal sound to the aged Goat, representing a significant improvement compared to the new Zebra. The Dublin conductor dried quicker after rainfall stopped than most other conductors tested.

In addition to having trapezoidal strands, the Dublin conductor has a proprietary (undisclosed) surface treatment resulting in a matt finish, finer grained than the grit blasted Zebra. The testing did not conclusively separate the effect of the trapezoidal strand shape from the effect of this surface treatment. Results indicated that the proprietary surface treatment may reduce sound emissions for both round and trapezoidal strands, but the trapezoidal strand shape reduces the drying time after rain.

The Dublin conductor was a readily available sample, but had a composite core, which is not typically used in New Zealand. Subsequently, steel core conductors were tested with the same surface treatment and trapezoidal strands. The change in core material did not significantly alter measured sound levels, compared to variations between duplicate samples of the same conductor types.

Field Testing

In parallel with laboratory testing Transpower installed numerous semi-permanent noise and weather monitoring stations underneath various sections of the BPE-HAY lines, and subsequently other lines. As improved conductor options were identified through the laboratory testing, these were used for sections of the BPE-HAY reconductoring. Where possible, monitoring stations were installed with sufficient time prior to re-conductoring to also record noise from the aged Goat.

Field and laboratory monitoring results were regularly reviewed by a steering committee, determining which conductors warranted testing and where field monitoring should be continued. Initially, it was expected that conductors might age and noise would reduce over a period of months, but it transpired that the process occurs over a longer timeframe and the monitoring of many sites was extended, with some now having run for over five years.

The monitoring stations had a microphone in the order of four metres above local ground level, generally towards the belly of the conductor catenary, under the central of the three conductors.

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The height to the conductor varies between sites, and also varies at each site with conductor load/temperature. A fixed distance correction was applied to each site to normalise results.

The monitoring stations were configured to record consecutive 15-minute samples, consistent with general environmental noise assessment. Time-averaged thirdoctave band and A-weighted Levels were recorded for each sample, along with statistical levels including the LA90. As discussed below, refinement of the measurement sample time and parameters would be likely to assist in further investigations.

Data processing

Wet conductor noise can have a level in the order of 45 dB L_{Aeq} under the conductor. This is lower than the daytime ambient noise at many sites. A number of filtering steps were used to attempt to identify 15-minute samples where measured levels might be attributed to conductor noise:

- Time overnight between 2200h and 0700h.
- Wind speed less than 2m/s.
- L_{Aeq} – L_{A90} < 2 dB (to exclude 15 minute periods with fluctuating or sporadic sounds)

The L_{A90} value was taken as the L_{Aeq} of the conductor noise, in effect making an adjustment for the contribution of ambient noise. The 100 Hz and 200 Hz tonality was determined from level differences in the third-octave band L_{eq} spectra.

Samples which had rain recorded (by the tipping bucket gauge) in that period and the following sample were classified as 'wet or drying', and others were classified as 'dry'.

This processing was initially undertaken manually in spreadsheets, but was subsequently automated with an online dashboard able to display broadband and tonal levels for selected sites, dates and conductor types. The filtering process remains a relatively blunt tool and further work is ongoing seeking to refine the process potentially using machine learning tools to better identify periods of conductor noise.

Monitoring results

As alluded to above, field monitoring did not show quick reduction in the broadband and tonal noise from new conductors at most sites, as might have been expected from initial weathering. Instead, levels for most sites were found to fluctuate significantly and erratically between weeks and months, with longer term trends mainly emerging over several years (see Figure 6).

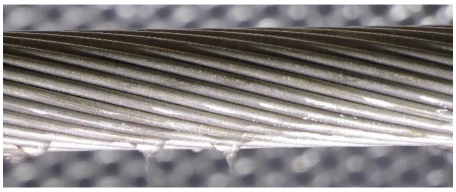

Figure 6: Time history of wet conductor noise at a site over eight years

A challenging issue was that findings in the laboratory testing were often not corroborated by field measurements. Extensive work has been undertaken to find the reasons for differences between laboratory and field results, primarily through the further investigations into field measurements described later. At this stage the causes of differences have not been confirmed, but the likely factors are discussed below.

A conductor with trapezoidal strands and matt surface finish ('Curlew') did still appear to provide a benefit in the field monitoring. The benefits varied between sites and the tonal component was more prominent in field tests than found in the laboratory.

Further investigations

Given the challenge interpreting field monitoring results and unexplained differences from laboratory tests, significant effort has been made to explore the factors causing variations. This has included investigations of source, pathway and receiver factors.

For the source (conductor), key issues considered have been variation in meteorological conditions and the conductor surface condition, such as whether it is affected by temporal variation in atmospheric deposits.

To investigate the conductor surface condition a drone photographic survey of six conductors (two circuits) was undertaken six times over a year for a section of line around a noise monitoring station. The methodology was susceptible to variations in light and position each time, so could not show surface condition changes at discrete points. Regardless, there were no widespread changes observed that would be expected to influence noise. This matter remains under consideration with potential for particles not being visible to drone photographs and possibly only being present for shorter durations.

The noise and weather monitoring stations record data in 15-minute periods. From examination of tonal sound time histories, it was found that the tipping bucket gauge was not identifying periods that appeared to be 'wet' based on the surrounding data. Alternative rain gauges were trialled and consequently a larger collector was fitted to the tipping bucket. Tests with an acoustic rain gauge could not be reconciled with the other devices. The resolution of the rain gauge remains a limitation of the system, with results seemingly influenced by when a bucket tip occurs following the onset of rain.

With respect to the pathway between the conductor and microphone, a potential issue is the constructive/destructive interference of coherent sound from each of the (typically) three conductors and the reflections of that sound from the ground. Theoretical modelling assuming specular ground reflections showed that 100 Hz levels could vary substantially (e.g. 10 to 15 dB) within relatively short distances. The '5 ears' trial was undertaken with five microphones over a 2.5 metre long transverse line to investigate this issue (see Figure 7).

From this trial it was found that the conductor noise broadband L_{Aeq} results were not unduly sensitive to the microphone positioning. The 100 Hz levels did vary significantly and erratically between microphone positions, although with a range typically in the order of 1 to 3 dB between microphone positions compared to in the order of 10 to 15 dB predicted by theory with reflective flat ground. The lesser 100 Hz variations in field measurements may arise from irregular ground reflections and fluctuations in 100 Hz sound spatial variations being averaged over 15-minute samples. Use of shorter sample periods is currently limited by the temporal resolution of rainfall data.

Figure 7: '5 ears' investigation monitoring station

The trial also examined changes to the conductor height. While the conductors regularly change height by over a metre, the range is limited at night without solar insolation and with reduced line loads, such that this was not found to be a material factor.

At the receiver (microphone), analysis of unfiltered monitoring results shows differences in ambient noise levels between sites. This is expected with sites located in different environments with varying proximity to roads, vegetation and other ambient noise sources. The filtering steps described above had been used to try and limit the influence of such factors by setting conservative thresholds for inclusion of data. However, comparison with data during line outages indicates that results at some sites are still being affected by ambient noise, particularly with quieter conductors such as the aged Goat.

Subjective Response

Noise disturbance from conductors appears to occur infrequently, at night in the rain. Under these conditions it might be thought that most people would be inside with windows closed such that they would not be overly sensitive to this occasional noise. It is assumed that the tonal nature of the wet conductor noise is the main issue that has caused disturbance. Adverse reactions may in part relate to the noise and the occurrence of tonality coming as an unexpected change following re-conductoring.

The University of Canterbury undertook laboratory subjective listening tests to explore human response to conductor noise, using Tranquility Ratings. Recordings from six Transpower field monitoring sites were used. A challenge with the work was selection of representative audio recordings of each conductor given the significant variation in emissions.

From listening tests, most wet and drying conductors were found to have low Tranquility Ratings, with only drying conductors at a site with new Curlew (trapezoidal, strand matt finish) rated slightly better. There was no significant correlation found between conductor sound level and perceived tranquility, which may represent a limitation of the methodology. The method could identify that aged conductor was perceived as better than new conductors, but did not differentiate between new conductor options. Further work would be required to better understand the features of conductor noise causing disturbance.

Prior to initial re-conductoring of the BPE-HAY lines, based on results of predictive models, Transpower told residents that noise should be reduced with Zebra due to its larger diameter compared to existing Goat. The initial complaints may have been in part triggered by the opposite occurring, with the new conductor being unexpectedly louder and significantly more tonal.

As work on the BPE-HAY lines approached the urban area of Waikanae, Transpower actively engaged with the community, sharing findings from investigations into conductor noise. In this location residents were told there would be an increase in noise and tonal noise. It was explained how Curlew was being used as the best practicable option to minimise that increase and a link was provided to a public website with ongoing noise logging results at two sites in the town. There were no noise complaints in Waikanae following re-conductoring, and a survey of 40 residents a year later revealed no adverse comments with most not noticing conductor noise and many making positive comments about Transpower's transparent and detailed communications.

There may be acoustic factors such as increased ambient noise in an urban area influencing responses, but it appears that subjective responses may at least in part be modified by accurate prior communication of the forthcoming change.

Conclusions

High voltage 220 kV lines can generate audible corona discharge in wet conditions. The level and tonality of the noise has been found to increase if the conductors have hydrophobic surfaces. New conductors with untreated shiny metal finishes and oil/grease residue tend to have hydrophobic surfaces, whereas aged conductors tend to have hydrophilic surfaces. Some new conductor options have more of a hydrophilic surface.

Conductor noise varies significantly between weeks and months, such that the characteristics cannot be robustly quantified by short-term field measurements. Human response to conductor noise following re-conductoring appears to be influenced by non-acoustic factors such as engagement and communications.

Significant knowledge gaps remain, with work ongoing to improve assessment and mitigation of conductor noise.

Acknowledgments

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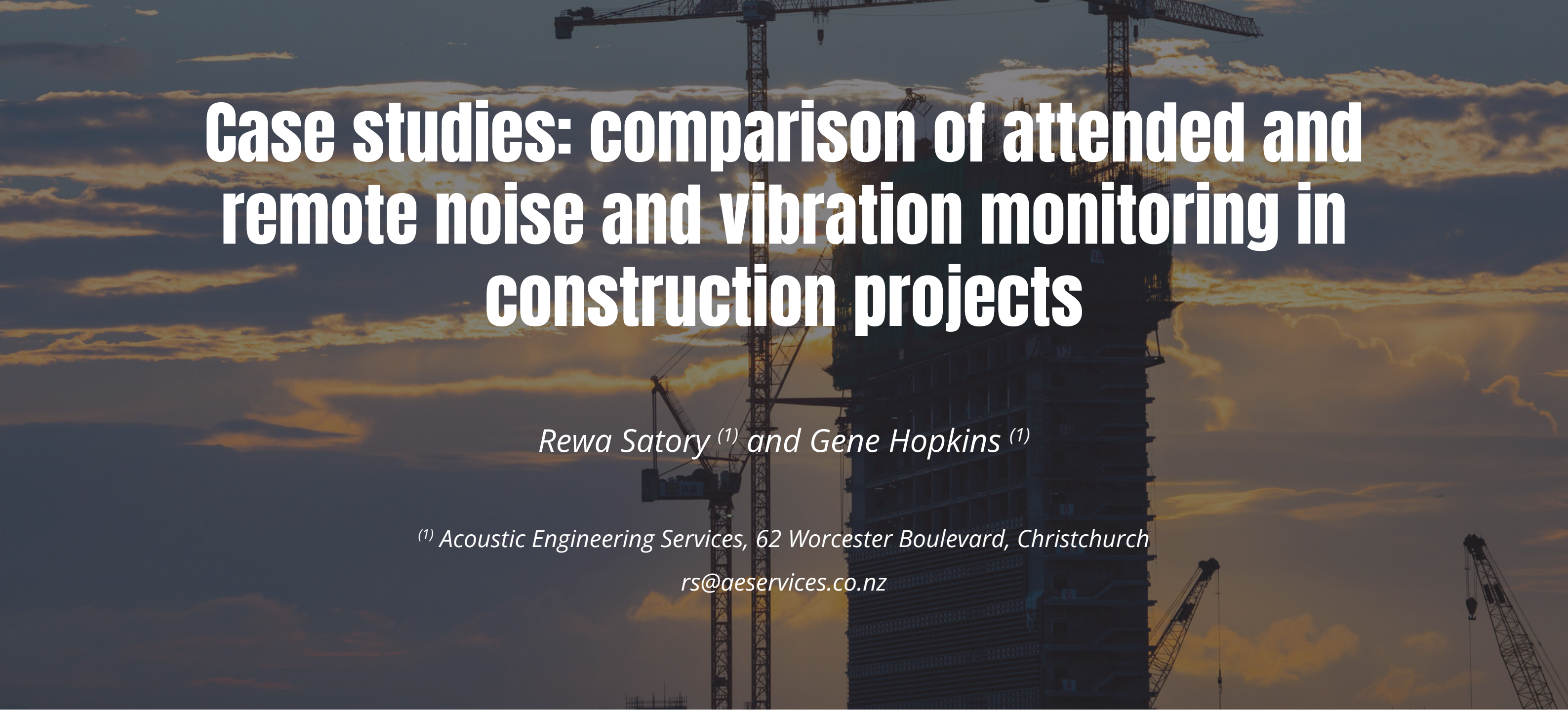

Case studies: comparison of attended and remote noise and vibration monitoring in construction projects

Rewa Satory $^{(1)}$ and Gene Hopkins $^{(1)}$

$^{(1)}$ Acoustic Engineering Services, 62 Worcester Boulevard, Christchurch

rs@aeservices.co.nz

Abstract

Construction noise and vibration monitoring is becoming more prevalent in New Zealand and the variety of available monitoring methods is increasing. There has been a growing trend over recent years to carry out construction noise and vibration monitoring remotely, removing the need to have trained personnel on standby permanently to conduct ad hoc measurements as required. As the capability to develop small form factor, affordable, and accurate measurement devices increases, it is likely that this will become more prevalent, and only be accelerated by the continued growth and popularity of the Internet of Things (IoT). This paper compares some of the ways construction noise and vibration monitoring is typically conducted in New Zealand. Following this we will discuss some of the advantages and challenges presented by use of both remote and attended noise and vibration monitoring and reflect on the possible implications of increased uptake of remote monitoring in the future.

Introduction

Construction noise and vibration monitoring is conducted to assist with appropriate management of construction noise and vibration emissions and is a useful aid for all stakeholders (including contractors, project managers, and territorial authorities) in mitigating adverse effects on nearby receivers.

Where noise and vibration levels from construction activities are expected to be high due to the location and nature of the activity, proximity to neighbours, or where construction activity is present for extended periods of time, in New Zealand a Resource Consent is often required. In these situations, noise and vibration monitoring can be required as a Condition of Consent, or as part of a Construction Noise and Vibration Management Plan (CNVMP). Where the monitoring is required as a Condition of Consent, additional specific requirements of the monitoring may be included, such as the use of qualified personnel and timing. A Condition requiring monitoring is typically implemented to provide assurance that activity is being conducted in accordance with the relevant Consent.

As there are a range of available monitoring alternatives which could be implemented, we have considered some different monitoring types and what benefits each provides.

What do the regulations say?

Consents in New Zealand typically refer to the local authority limits to obtain a reference point for acceptable construction noise and vibration limits. These rules often refer to NZS 6803:1999 *Acoustics – Construction Noise* [1]. Even where the local authority guidance does not refer specifically to NZS 6803, specific Conditions of Consent may refer to that Standard. NZS 6803 is now 25 years old and does not provide specific monitoring procedures.

NZS 6803 provides a framework and mitigation strategies to ensure that any adverse effects are minimised where compliance with the guideline limits is not practicable. Therefore, monitoring in the context of NZS 6803 may be used to compare noise levels with absolute numerical limits or to help ascertain whether the best practicable mitigation option has been considered and adopted.

NZS 6803 states that where not explicitly outlined in the Standard, measurement methods shall comply with the provisions of NZS 6801:1999 *Acoustics – Measurement of Environmental Sound.* This Standard has since been superseded by NZS 6801:2008 [2], which requires for measurements to be undertaken with a least Class 2 sound level meter but preferably a Class 1 meter determined in accordance with the relevant International Electrotechnical Commission (IEC) specifications.

NZS 6803 references British Standard BS 5228: Part 1:1997 – *Noise and vibration control on construction and open sites* [3], and we note that this Standard has since been updated in 2009 [4]. Unlike NZS 6803, BS 5228- 1:2009 does provide some advice relating to noise monitoring. The Standard provides guideline tolerances for the reliability of different sampling methods and suggests caution around using data from unattended equipment.

There is currently no officially accepted New Zealand construction vibration standard, resulting in variable vibration limits and assessment locations across different regions. Limits are generally set to avoid cosmetic damage to property and monitoring is undertaken in conjunction with property surveys. The most commonly referenced Standard for cosmetic damage is DIN 4150- 3:2016 *Vibration in buildings – Part 3: Effects on structures* [5]. Regulation and conditions around the specifics of vibration monitoring are typically more varied than those for noise monitoring.

Measurement types, locations and times

Construction projects often involve a large variety of activities. Some are continuous throughout the day and in a fixed location (for example supplementary power). Other activities are only present sporadically or periodically and can operate in various locations across a site (for example driven piling techniques may have relatively short periods of high noise interspersed with large periods of lower noise generation). This noncontinuous nature can be both in terms of the time where the activity occurs (i.e. for active piling there may be relatively long periods where active piling is not present while ground preparation occurs, and the rig is relocated) and the actual time that noise is produced within the activity period (i.e. for active piling high noise generation is only present for a short period with each hammer drop). For activities of this nature the measurement timing and duration could radically affect the measured level.

There can therefore be challenges with both short-term attended measurements and long-term unattended measurements.

Traditionally most monitoring has been conducted via attended methods, with unattended monitoring only becoming more widespread over recent decades.

While unattended monitoring is able to be carried out over a longer period of time than attended monitoring (which is limited to the snapshot in time when the person is actually carrying out the measurements), unattended monitoring that requires on-site data download has the major inconvenience of trained personnel needing to regularly access the equipment to extract data and conduct processing to get any useful information about noise and vibration levels.

For the remainder of this paper, we will consider unattended remote access monitoring that incorporates uploading data to an online portal and provide comparison to the more traditional attended monitoring approach.

Remote access monitoring equipment

The equipment that is selected for remote access construction noise and vibration monitoring will be dependent on several factors, including the preferences of the person carrying out and processing the measurements, the scale of the site, cost, safety and access concerns, the required frequency of the measurements, the nature of the receiving environment, and the noise and vibration limits that emissions are being assessed against.

From a review of the currently available remote monitoring equipment, we consider that the devices broadly fall into three categories; feature rich discrete devices, reduced functionality discrete devices, and system integrated devices. Examples of each of these are shown in figures 1 – 3 below.

Feature rich discrete devices incorporate most of the typical functionality that would be expected from a professional quality sound level meter or vibration monitoring meter, including options to measure results in different frequency ranges/ weightings, different measurement periods, track multiple statistics and descriptors, provide alarms when trigger levels are exceeded, and record frequency spectrum data. Systems such as the Svantek 258 Pro [6], Cirrus Research CK:685B [7], NTi Audio NoiseScout [8], and Pulsar Nova WK3 [9] are based around a general use Class 1 compliant meter being installed in a weatherproof box with a battery or external power supply and internet connection via modem, wireless internet connection, or mobile data. Other systems such as Class 1 Sonitus EM2030 [10], Class 2 Munisense INSIGHTNOW [11], and SYSCOM Rock vibration monitor [12] are designed specifically for remote monitoring use and require off site analysis, or a computer to be connected, to easily determine levels.

Figure 1: Example feature rich discrete device (Sonitus EM2030)

Reduced functionality discrete devices offer a lower level of information and configuration and are often constructed using micro-electromechanical systems (MEMS) devices. Typically, these are limited to providing only broadband statistics and a small selection of descriptors. Lower cost MEMS devices such as the Convergence NRSTW MK4 Class 1 sound level meter [13] allow the user to select between frequency weightings and fast or slow time weighting, with statistics limited to the minimum, maximum, and average noise level over the pre-determined measurement period, but are not able to record the frequency spectrum. Other options such as the Class 1 LiveNoise LNT-SE Noise Monitor [14] and Monitex Area Noise Monitor [15] which comes in both Class 1 and Class 2 configurations also allow the user to record percentile noise level descriptors.

Figure 2: Example reduced functionality discrete device (Convergence Instruments NSRTW MK4)

System integrated devices are often part of a wider system incorporating other construction monitoring functions relevant to the project, including air and water quality, weather, and dust. Some products such as the Class 2 SiteHive Hexanode [16], Class 1 SoftdB Watch Monitoring Station [17], and Class 1 Sonitus DM30N Sitesens [18] house multiple sensors within one device, while other providers like the Class 2 Adroit [19] and unclassified IOTSens [20] supply individual low cost sensors for each function that are then coordinated in a single cloud based monitoring portal.

Figure 3: Example system integrated device (Sonitus DM0N Sitesens)

Across all three categories of devices, we observed a general trend in data being automatically uploaded to an online portal at regular intervals where it can be viewed, and reports can be generated. However, some devices such as the Convergence units [13] had more limited functionality where the device connects to a remote server that is controlled by the user, and data has to be manually downloaded.

Approximately half of the devices included functionality to record audio alongside the measured noise or vibration data, with a mixture of continuous and trigger-based audio capture.

We observed some variance in whether ethernet, WiFi, or mobile data connections were used for data transmissions, with only a few devices offering multiple connection options.

Some devices offer additional features such as directional audio and integrated camera on the SiteHive Hexanode [16], or on-site mesh networking over LoRa and Zigbee with the Munisense INSIGHTNOW [11].

Challenges and benefits of remote access monitoring

Remote access construction noise and vibration monitoring has several benefits over traditional attended monitoring approaches, including the following:

- Time saving
- Real time access to data
- Threshold triggers
- Integration with other environmental monitoring
- Analysis of long-term trends

There can be a significant savings with regards to the amount of time personnel trained in conducting measurements in line with NZS 6803:1999 and DIN 4150- 3:2016 are required to be on-site. This also reduces a potential health and safety risk.

The ability to instantly access data through an online interface can be useful for confirming whether certain activities are complying with the applicable noise and vibration limits, as data can be referenced against the known time of a particular activity operating in a defined area. This also allows for noise levels to be communicated in a simplified graphical format that can be easily understood by external parties that may not have a detailed knowledge of acoustics.

All of the remote monitoring devices we reviewed included a feature for generating real time alarms if the device measured noise or vibration levels exceeding a predetermined threshold, whether via email, text message, or a notification within a proprietary application. This enables the contractor to react quickly in scenarios where noise or vibration levels are elevated, and take steps to identify and mitigate the source as required.

The ability to integrate construction noise and vibration monitoring with monitoring of other on-site environmental factors can provide a cost and time saving to the contractor, as they have the ability to utilize a combined service which tracks the relevant emissions site wide, rather than having to employ several different consultants to undertake regular measurements.

As the devices are generally located in a fixed position onsite, remote access monitoring enables repeatable measurements and long-term trend analysis. The ability to readily compare data across several months of operation and identify periods where noise and vibration levels are typically elevated or reduced can enable the site manager to better inform neighbouring parties of what to expect at different phases of the construction, and assist in better managing the associated effects. This enables a more proactive community liaison approach than traditional monitoring allows, and in Australia some large scale infrastructure projects (such as the Suburban Rail Loop in Melbourne [21]) are conducting trials of community response to providing the public with direct access to live noise and dust readings from the installed SiteHive devices.

However, despite the numerous benefits provided by remote access monitoring, there are still some constraints that need to be understood by the client, acoustic engineers associated with the project, contractors and project managers, and Council officers.

With remote access monitoring there is an inherent lack of understanding of the overall noise or vibration environment that would otherwise be perceived by the operator during attended measurements, making it difficult to identify the actual sources of emissions at any given time. To make any meaningful assertions about which activity or plant item is significantly contributing to noise and vibration emissions the onus is then on the site manager to have a detailed account of what activity is occurring on each part of the site at any given time, which is often not practical to expect.

Some devices and systems incorporate directional measurements, audio recordings or cameras to try and assist with the identification, but they are currently limited in capability and require time consuming evaluation.

Additionally, as the devices are generally installed in a fixed location, there is a risk that changes in construction activity may result in the measurements not being correctly representative of worst-case noise or vibration emissions at sensitive receivers. This makes their accuracy and usefulness reliant on the selected location being representative of the nearby receivers, and not being near any objects or activities that may obscure measurements, such as busy roads, trees, industrial or commercial noise sources, and the like. Care needs to be taken when reviewing monitored noise levels that are potentially contaminated by these external sources as may occur in scenarios such as that shown in red in figure 4 below, where a remote access monitoring device was installed on the upper level of a building that was separated from the construction site by a road with an Annual Average Daily Traffic count of greater than 15,000 vehicles.

Figure 4: Example of remote access device installation near busy road

A common requirement in Construction Noise and Vibration Management Plans is that when new critical pieces of plant are beginning to operate on-site, noise and vibration measurements will be conducted to determine if additional mitigation measures are required to reduce emissions. With remote access monitoring, this can be very difficult to accomplish, as the device locations are generally selected to be representative of the overall noise and vibration levels at a receiver rather than being placed in a location where it is possible to get uncorrupted measurements of individual items of plant.

From our experience, often the primary person responsible for viewing and interpreting the data from remote access monitoring equipment is a representative of the project manager or contractor, or other external party such a Council compliance officer. There may be temptation to provide the raw monitoring data to all parties, however this can introduce challenges where a specific party does not have sufficient understanding of the existing environment or construction activity, not to mention acoustic theory, to correctly interpret the data. There is a risk that open access to data can create additional challenges, such as incorrectly confirming compliance or exceedance of any limits.

Another consideration that was identified during our review of the available remote access devices is that of calibration. While several of the devices have the ability to be easily field calibrated without significant disruption to measurements, a trained person is still required to be on-site regularly to perform calibration. This raises potential issues with regards to access, as often the devices will be installed in locations that cannot be easily or safely reached from the ground and may be located on privately owned neighbouring sites.

Case study of device limitations

We have previously conducted predictions of noise and vibration emissions for a project, where the earthworks contractor then took on the responsibility for monitoring construction noise and vibration emissions during excavation and foundation works. The contractor chose to install several reduced functionality integrated devices at key receivers nearby to monitor noise, vibration, and air quality.

However, while the contractor had sufficient understanding of acoustic principles to install the devices at suitable locations relative to critical receivers, the selected locations were separated from the area of construction activity by busy roads which were expected to generate noise levels similar to the predicted construction noise emissions. Additionally, one of the devices had a large evergreen tree in front of it, and in any moderate wind this would generate a significant amount of noise from rustling leaves and branches.

Further complicating matters, the selected devices had hardware and software limitations which resulted in the devices only recording measurement data for one second every minute, then uploading the average noise level and peak vibration level for one second per minute across several samples at irregular intervals. This was primary due to a lack of sufficient onboard memory, and bandwidth restrictions across the integrated device network.

The implications of this combination of factors were beyond the knowledge and experience of the contractor, and as their review of the monitoring data indicated compliance with the relevant noise and vibration limits, no further investigation was carried out.

On this project a key noise and vibration source was hammer driven piling, and so there was a high likelihood that the times the device was recording would not align with the high noise impacts of the piling activity. To provide an illustration of the issue with the initial device settings, figure 5 below shows a comparison between 15 minutes of data measured during a period of drop hammer piling activity (blue data points) and indicative example data that might reasonably be expected for the same type of activity (red data points).

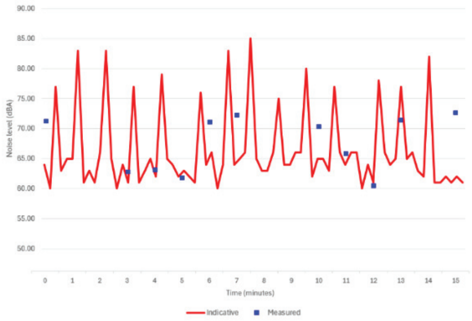

Figure 5: Comparison of device measurments with indicative example data

The devices were only providing discrete data points that were corresponding to the instantaneous noise for the one second period each minute the device was active, and a 15-minute average noise level was then calculated from 15 samples of dB $L_{Aeq\,(1\,second)}$. It is incorrect to calculate a 15-minute L_{Aeq} in this manner and furthermore it is not it is not possible to calculate a meaningful noise level for the activity from 1-second measurement intervals.

The monitoring data may have been useful to inform noise and vibration predictions for subsequent phases of the project. However, due to the above factors, proved to be unusable. When these issues were identified, the contractor and monitoring system began work to improve the situation, and enact software changes that enabled the devices to conduct continuous measurements and upload a selection of relevant data every minute within the bandwidth restrictions. A comparison of the device settings before and after these changes were made is provided in table 1 below.

Table 1. Comparison of remote noise monitoring settings

Setting	Initial device configuration	Updated device configuration
Recording uptime	1 second every minute	Continuous
Available noise descriptors	L_{AFmax}, L_{AFmin}, $L_{Aeq\ (1\ second)}$, $L_{Aeq\ (15\ minute)}$ The 15-minute average noise level is calculated in the online portal from 15 $L_{Aeq\ (1\ second)}$ samples.*	L_{AFmax}, L_{AFmin}, L_{ASmax}, L_{ASmin}, $L_{Aeq\ (1\ minute)}$, $L_{Aeq\ (N\ minutes)}$ The assessment period for all descriptors is user configurable with the derived average noise level calculated in the online portal from N number of $L_{Aeq\ (1\ minute)}$ samples, where $1 \leq N \leq 15$.
Data upload frequency	10 – 15 minutes	2 minutes

*Description of actual method used to determine $L_{Aeq\ (15-\ minute)}$ noise level, noting that as above this method is erroneous

While still not a perfect approach, as limitations of the hardware required some measurement downtime and without being able to remove the influence of other environmental noise and vibration sources, this data was then able to be post processed within the cloud portal to generate the required statistics for comparison to the noise and vibration limits with a moderate level of confidence.

Conclusions

In the coming years it is expected that remote access monitoring for construction noise and vibration will become more prevalent as devices become more cost effective to manufacture and deploy, and contractors, site managers and local Councils become more familiar with how the devices can be utilized.

The limitations associated with remote access monitoring currently present a number of challenges that can reduce the effectiveness and accuracy of measurements if not correctly understood early in the planning process, and will still require attended measurements to be carried out at different stages.

Based on the example presented in this paper, it appears that the adoption of remote access devices does not remove the importance of an acoustic engineer being involved in the monitoring process, as the complexities of understanding how to deploy the devices appropriately and interpret the data correctly require a level of knowledge that cannot be reasonably expected from contractors and site managers.

Acknowledgments

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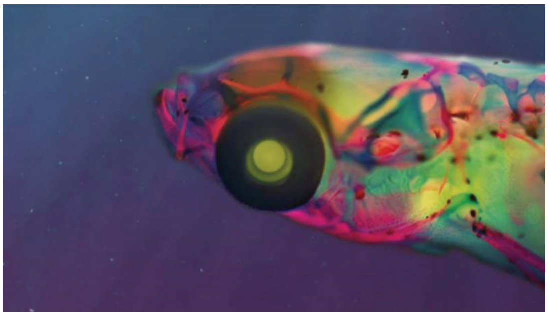

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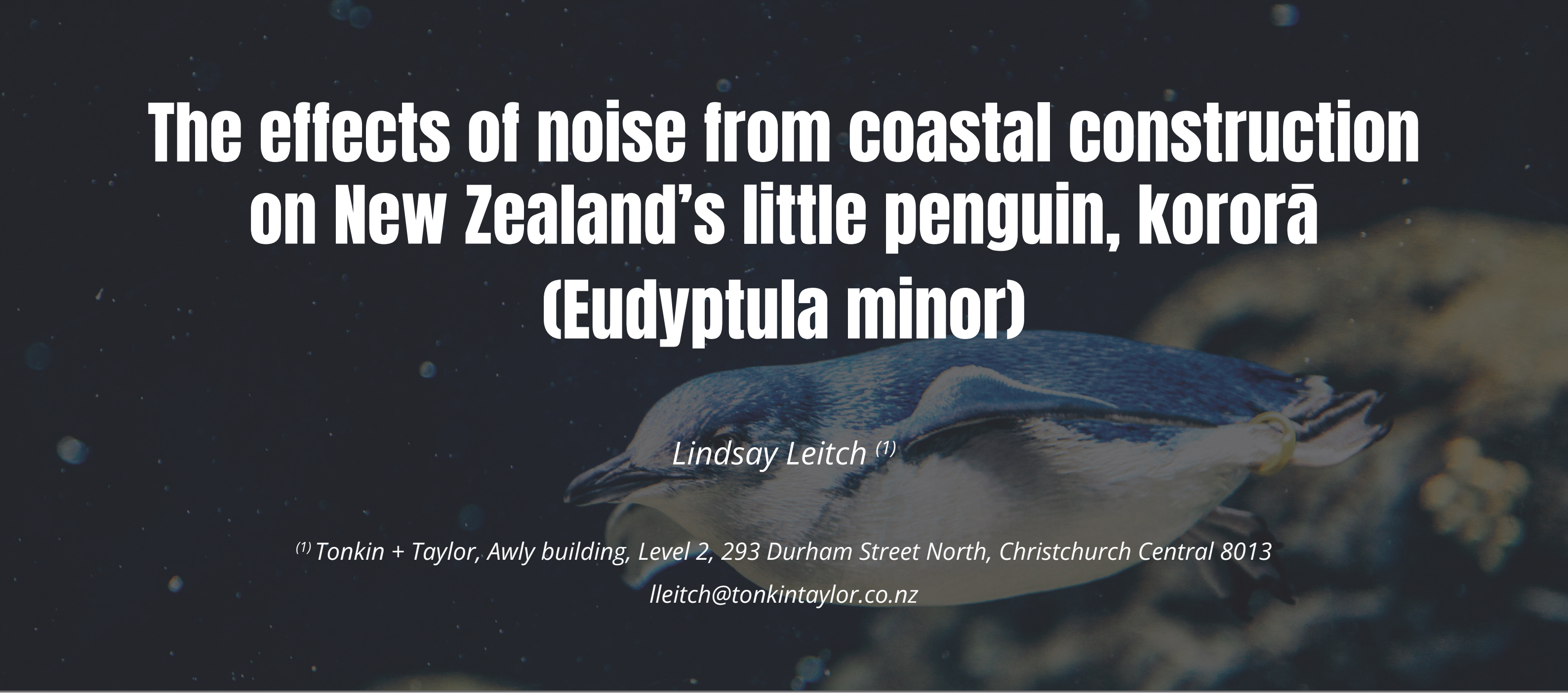

The effects of noise from coastal construction on New Zealand's little penguin, kororā (Eudyptula minor)

Lindsay Leitch (1)

(1) *Tonkin + Taylor, Awly building, Level 2, 293 Durham Street North, Christchurch Central 8013*

lleitch@tonkintaylor.co.nz

Abstract

Coastal construction noise has the potential to disturb New Zealand's native little penguin, kororā (Eudyptula minor), which is commonly found around shorelines and in coastal waters. It is a protected species under the Wildlife Act 1953 and the conservation status of the species is 'at risk – declining', hence appropriate protection measures are important to implement.

This paper identifies current knowledge around the noise sensitivity of kororā and the effects of noise on penguins, as well as identifying specific noise levels at which certain behavioural effects have been observed. It looks at two large-scale construction projects around New Zealand and the consent conditions in place to manage and mitigate the effects of construction noise on kororā. As there is a lack of research in this area, this paper raises questions and areas for further research.

For airborne noise, using A-weighting for kororā was found to be justified, and human construction noise limits have been adopted for the protection of kororā (70 dB LAeq(15min)). The observed behavioural effects of airborne noise on other penguin species include reduced vocalisations and increased activity such as walking away from the noise source. The effects of high levels of existing background noise on kororā sensitivity to additional construction noise are not known, although research in other avian species indicates there may be a negative correlation between level of background noise and sensitivity to additional noise events. There has been no research on the frequency range of underwater noise sensitivity thresholds, although an underwater startle response has been observed in gentoo penguins at 120 dB re 1μPa.

Consent conditions on three large coastal construction projects are provided for context: Kennedy Point marina on Waiheke Island, and iReX in Wellington harbour. The conditions include kororā surveys and on-going monitoring, exclusion zones (which may allow people and equipment to pass through while avoiding unnecessary noise), noise limits and restrictions on piling. These represent current best practice for managing kororā exposure to construction noise.

Introduction

Kororā, or little penguins (Eudyptula minor) are native to New Zealand and are found around much of the coastline, as well as round south-eastern and south-western Australia. When large scale coastal construction projects are proposed, there is the potential for adverse impacts on kororā from factors including noise. Effects on kororā may be managed via setting consent conditions and / or a kororā management plan.

This paper reviews existing studies on the hearing range and acoustic sensitivity of penguins and the behavioural response of kororā to noise. A summary is presented of consent conditions which aim to protect kororā from construction noise, as well as the construction projects where these have been implemented. These projects include construction of the Kennedy Point marina on Waiheke Island and the proposed ferry terminal at Kaiwharawhara.

Kororā background

Kororā are the smallest of all penguin species, at only around 30 cm height, and are also known as little blue penguin, blue penguin, fairy penguin and white flippered penguin. The largest colonies in New Zealand are found on Motunau Island in Canterbury, Pōhatu Bay on Banks Peninsula and the Oamaru Blue Penguin colony [1]. It is estimated there are around 12,750 individuals around New Zealand [2] and their conservation status is at risk – declining.

Kororā spend much of their time at sea, typically remaining within 25 km of the shore during breeding season but may head further out at other times [1]. They mainly return to land to breed and to moult, although they can be found on land at any point during the year. There are fewest kororā ashore in the period between the end of moulting and the start of breeding, typically between March and June [1], though they may still return to shore at night.

The breeding season is typically around July to December, although this will vary between colonies and around the country.

Incubation of around 37 days is shared by both parents before chicks hatch out [1]. The pair will continue taking turns foraging for fish until the chicks are two weeks old. After this, both parents will forage during the day and return at night to feed the chick until it fledges at around 55 days (7-8 weeks) [1]

Kororā moult "catastrophically" each year, i.e. all feathers are replaced. During this time kororā are not waterproof and are unlikely to survive if they are disturbed from their nest.

The breeding and moulting seasons are the times of greatest sensitivity for kororā, and therefore the times of most concern when considering potential disturbance. When an individual kororā is breeding or moulting it may have a stronger stress response to disturbance, which can lead to reduced breeding success.

Kororā nests can vary considerably, from an excavated burrow, to little more than an indentation in vegetation. They are frequently found in rocky revetments, and can make use of manmade materials, such as piles of construction materials, under houses, or purpose-built nesting boxes. Nests or burrows can be found up to 1.5 km from the shore and up to 300 metres above sea level [3].

Threats to kororā include predators such as dogs and human interference.

Noise sensitivity

Hearing range

There is a limited amount known about the hearing range of kororā and other penguin species. Wever et al. [4] established the audiogram of three African penguins *(Spheniscus demersus*), for in-air hearing as between 600- 4000 Hz. The specific hearing range of kororā has not been studied; however Nakagawa et al. [5] established that the frequency range of kororā vocalisations (which in most species correlates with hearing sensitivity) is 1000-5500 Hz, i.e. similar to the hearing range established for African penguins. This is broadly similar to the human hearing range and A-weighting has been adopted for kororā hearing on land on this basis. This is likely to be conservative as birds typically have lower hearing sensitivity than humans [6].

The author is not aware of any study establishing the hearing range of any species of penguin underwater, although Sørensen et al [7] hypothesises that it may be similar to the frequency range of hearing in air. Sørensen also notes that the underwater hearing threshold of cormorants (70-75 dB re 1µPa, [8]) may be comparable for penguins; if this is the case then penguins may be particularly sensitive to underwater noise based on the study's behavioural observations [7]. Establishing underwater noise sensitivity is potentially an area for further research.

Effects of noise on penguins

In contrast to kororā, effects of noise exposure on marine mammals are well established [9]. These range from masking and behavioural effects at lower levels of noise, to a temporary or permanent threshold shift in hearing (i.e. a reduction in hearing response), and in the worst case, injury or mortality [9]. A similar range of effects may occur in kororā, however the studies to date focus on behavioural and physiological effects as these are likely to indicate stress and may affect the fitness of individual birds and breeding success. Manser [10] notes that stress may be hidden and not evident in visible behaviour to avoid attracting predators.

Hughes et al. [11] observed the behavioural response of king penguins (*Aptenodytes patagonicus*) in a colony on South Georgia during helicopter overflights. The study found that the behaviour of individual birds changed significantly to be more active during the overflights, but that pre-overflight behaviour resumed within 15 minutes. The behavioural response reduced during the study, i.e. the birds habituated to the noise to some extent. The behavioural changes observed included reduced vocalisations during the overflights within the colony, some non-incubating adults and juveniles started walking away from the approaching helicopter (no incubating penguins were observed to start walking or abandon their eggs).

The helicopter overflights increased the measured noise level to a short-duration maximum level of 80 dB LAeq(1s) (this level was the mean of the 10 highest LAeq(1s) values for the lowest overflight at 230 metres).

Hughes et al [11] suggests that long-term impacts may include colony occupation rates year-to-year, mortality rates, and natural variability in breeding success. It should be noted that this study looked at king penguins which remain above ground, in contrast to kororā which typically nest in burrows below ground; therefore this study may not be representative of kororā behaviour.

Fanning et al [12] observed the behaviour of captive Fiordland penguins (*Eudyptes pachyrhynchus*) in Melbourne zoo on days when concerts were held within the zoo. The study notes that the birds increased their use of a nest and the pool, and spent less time preening and interacting with the habitat on concert days. This aligns with the higher level of activity noted by Hughes [11]. A sound level meter was deployed during the study but unfortunately measurements were affected by water noise from the zoo enclosure and the study was unable to present any behavioural effects related to measured noise levels.

Costello [13] studied whether little penguins in South Australia either returned to their nests late in the evening or did not return at all (i.e. lower penguin numbers overall) when there were concerts nearby. Returning late may have an impact on breeding success and individual birds' fitness. However, the study found there was no correlation between the occurrence of the concerts and penguins returning late or not returning at all.

Iasello [14] recorded the heartbeat of kororā while playing recordings of construction noise and rainfall noise to kororā for 5 minutes each, with gaps of 45 minutes between each playback to allow the heartbeat to return to normal. The speaker was set to produce approximately 70 dB at 1 metre, located approximately 50 cm from each nest, and a variety of construction noise was played in each recording. The study found that kororā significantly increased their vigilance and took longer to stop exhibiting such vigilance when exposed to construction noises compared to rainfall noises. However, they showed no difference in heartbeat response to the playback. The study concluded that "results suggest that exposure to an anthropogenic noise can cause individuals to become more alert but do not perceive the stimulus as a substantial threat." While useful to reference, this study only used five minutes of recorded construction noise and the response of kororā may not be representative of the response to longer-term construction noise.

For underwater response to noise, a startle response was observed in gentoo penguins (*Pygoscelis papua*) at a received noise level of 120 dB re 1µPa with a frequency of between 200 Hz and 6000 Hz, to coincide with the known frequencies of their response in air which Sørensen et al considered likely to be representative of hearing frequencies in water [7]. The startle response was defined as >90° change of swim direction and change of speed, and this was observed in over 60 % of playbacks at this sound level.

As a conservative approach, 120 dB (linear) re 1µPa has been adopted as a behavioural threshold on some projects the author is aware of. This low threshold results in a large area of potential behavioural impacts (in the order of several kilometres) when considering a noise source such as piling. Further research on the sensitivity of kororā to underwater noise would help to establish a suitable level of mitigation to minimise adverse underwater noise effects on kororā.

Noise levels

Since the hearing range of kororā is likely to be similar to that of humans, and in the absence of other conclusive evidence, the noise level from temporary construction works that is deemed reasonable for humans has been used for protection of kororā. The level specified for daytime construction works in NZS 6803 [15] is 75 dB LAeq for works with a duration of between two and 20 weeks ("typical duration") reducing to 70 dB LAeq for works with a duration of longer than 20 weeks ("long duration"). The noise limits specified in NZS 6803 include time-varying limits which reflect the greater sensitivity of people during evening, early morning and night-time. There is also a maximum level (LAmax) specified in addition to the LAeq level, i.e. both average level and maximum level are required to be met. Only the single LAeq limit for daytime construction noise has been utilised for the protection of kororā. Without an LAmax limit, this leaves open the possibility of exposure to shortterm high levels of noise while still complying with the 15-minute average noise limit, i.e. construction equipment producing a short-duration average level in excess of 80 dB LAeq(1s) (as found to cause some level of behavioural reaction [11]) could still comply with a 15- minute average noise limit of 70 dB LAeq(15min).

Ambient noise

Another potential factor in the sensitivity of kororā to construction noise is the existing level of ambient noise. Kororā are known to nest in locations with high levels of ambient noise, for example around Wellington harbour adjacent to State Highway 1 and the busy railway line. Other colonies are found in remote locations, such as the Pōhatu colony on Banks Peninsula, where it is expected that ambient noise levels are dominated by natural sounds.

The effects on kororā from different levels of background noise have not been studied, although habituation to noise has been observed [11]. The effects of existing high levels of background noise when introducing additional anthropogenic noise sources, such as construction noise, are similarly unknown.

It may be the case that kororā which have habituated to high levels of ambient noise will have a lower stress response to additional construction noise, while kororā that are used to a quiet natural environment may have a greater stress response to the same level of introduced anthropogenic noise. A greater understanding of this would help to inform appropriate construction noise limits in the vicinity of kororā nests. There may be an upper limit in the tolerance of kororā in absolute noise levels – this is also unknown.

Urban noisy miner birds (*Manorina melanocephala*) were found to have higher tolerance of a loud, startling sound than rural birds of the same species [16]. Although background noise levels are not specified in this study, it can be inferred that urban birds would have become habituated to higher levels of anthropogenic noise and disturbance than the rural birds. This supports the theory that kororā which have habituated to existing high ambient noise levels are likely to have lower sensitivity to introduced construction noise.

Kororā vocalisations have been found to increase with higher levels of ambient noise from anthropogenic noise (nearby concerts) and natural noise (vegetation noise from increased wind speed) [13]. However, the same study found that there was a negative correlation between number of people present and penguin vocalisations. Vocalisations have also been found to decrease during helicopter overflights [11]. It is possible that penguin vocalisations may decrease when a noise source is perceived to be a threat but increase in response to higher levels of non-threatening ambient noise, which may include anthropogenic noise (such as concerts). If this were found to be the case through further research, observing vocalisations might give an indication of whether kororā felt threatened and / or stressed by an introduced noise source.

Noise conditions

An overview of consent conditions that have been utilised on recent coastal construction projects provides an indication of current practice and the practical considerations with managing adverse impacts on kororā. Kororā management plans (KMP) can be implemented on projects. These plans address all consent conditions relating to kororā and set out management and mitigation measures that are project specific.

Surveys

A common consent condition in locations where kororā are known or suspected to be is the requirement for surveys and monitoring. This can be pre-construction surveys (e.g. for Kennedy Point marina) to establish the level of kororā activity and to inform the construction methodology and level of kororā management required. Monitoring throughout the construction period can also be required (Kennedy Point marina).

In addition to specified regular surveys (such as weekly or fortnightly), it is possible on any given day that a penguin may have swum in overnight. It is understood to be best practice to undertake penguin detection surveys on the morning of construction works. A kororā detection dog can be used for these surveys.

Exclusion zones

Another common condition related to noise is a simple exclusion zone, i.e. an area around an occupied kororā nest within which construction works are not permitted. This is straightforward to implement and enforce (subject to kororā surveys to establish occupancy); however it can cause problems on a construction site with restricted access to parts of the site. In some circumstances, although no works are allowed within the exclusion zone, a practical solution is to allow people and equipment to move past the active nest or moulting penguin to access work sites while avoiding unnecessary noise [17].

The disadvantage of this type of condition is that it is not flexible, for example quieter works could meet noise limits within the set distance, and noisier works may exceed a noise limit at greater distances. It may be beneficial to combine an exclusion zone for ease of implementation with a noise limit, although potential disturbance from simple proximity of equipment may need to be considered as well as noise level.

Noise limits

Consent conditions can specify noise limits either as a time-averaged LAeq value (e.g. over 15 minutes) or as a short-term maximum level (e.g. LAeq(1s)). A setback distance for equipment is relatively easy to calculate based on known equipment noise levels or from monitoring.

Underwater

Conditions regarding underwater noise are harder to specify since there is no information regarding the hearing range of penguins underwater and there are practical difficulties in mitigating piling noise, which is usually the main source of underwater noise in a coastal construction project. Mitigation from bubble curtains has been implemented on some projects to reduce underwater noise [18].

Piling restrictions

A common condition for piling works in proximity to penguin nests is to restrict piling so that it does not start until at least 30 minutes after sunrise and stops prior to at least 30 minutes before sunset. This therefore avoids the typical times when penguins are likely to be swimming to or from their nests.

Other restrictions on piling typically used to protect marine mammals include stopping piling (or not starting) when a marine mammal is spotted within a certain distance of the piling. This type of condition typically requires observation of the surrounding area by a DOC trained marine mammal observer (MMO) for the duration of piling. This type of condition has not been used as a condition for penguins (to the author's knowledge), which may be because penguins are much harder to spot in the water, or because they are more commonly in the water at dawn and dusk.

Example projects

Two large-scale coastal construction projects are provided as examples of these types of conditions in practice.

Kennedy Point marina, Waiheke Island

Consent was granted for the Kennedy Point marina on Waiheke Island in May 2017, with a subsequent lengthy legal battle centred on opponents' concerns around kororā protection. Construction ultimately commenced in March 2021 and the marina opened in November 2023 [19]. The marina required a substantial amount of piling for berths and pile moorings in relatively close proximity to known kororā habitat.

The consent conditions (as set out in Appendix 1 of [20]) required inspection of the area to detect kororā burrows and nests, clear visual marking of these burrows and nests and monitoring to detect any impacts of construction works on kororā, with a requirement to adapt the construction programme as necessary to avoid these impacts.

Construction hours were limited to between 7.30 am and 6 pm from Monday to Saturday. Piling was restricted to between 8 am and 5 pm Monday to Friday, with an additional restriction during the breeding season (defined as 1 July to 1 December) that all water-based activities should occur no earlier than 1 hour after nautical dawn and no later than 1 hour before nautical dusk. The conditions also required that "the construction work within the penguin breeding season will be reduced to the greatest extent practicable." There appears to be no reference to the moulting season.

Marina construction activities including piling were required within the 50 metre setback during the breeding season. A noise limit of 80 dB LAeq(1s) was used to minimise the impact of piling noise on kororā [21] (based on [11]). Noise levels were monitored to confirm that this limit was not exceeded.

During the monitoring of piling noise, measurements were made within the chamber of a burrow and at the entrance to quantify the sound reduction achieved by a burrow. A difference of 8

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dB was measured, and the paper concludes that assuming a minimum sound reduction of 5 dB from a burrow is likely to be reasonable [21].

iReX Kaiwharawhara

Consent was granted for the Kaiwharawhara InterIslander ferry terminal in January 2023 via the Covid-19 Recovery (Fast-Track Consenting) Act 2020 and conditions specified [17]. The project was cancelled in December 2023 due to escalating costs and funding shortfalls [22]. However, the conditions relating to kororā are still relevant.

The non-breeding / non-moulting season is defined in the conditions as 1 March to 15 June when there is a lower chance (although not zero chance) of kororā being present. It is noted that the iReX conditions reference the moulting season as well as the breeding season, unlike the conditions for Kennedy Point marina. The conditions require kororā detection within the 24 hours prior to construction activity to confirm the presence or absence of active nests or moulting penguin. No rock removal or piling activities are permitted within 10 metres of an active nest or moulting penguin, although people and equipment are permitted to move past within that distance.

A noise limit of 70 dB LAeq(15min) applies "as measured outside of the entrance of an active penguin nest or moulting penguin roost." This is in line with the long duration limits in NZS 6803.

The iReX conditions also required the consent holder to provide an annual stipend of $20,000 for a minimum of three years to a project related to investigating the potential effects of airborne and/or underwater noise disturbance on kororā in Wellington or elsewhere in New Zealand. This reflects the general need for a greater level of knowledge in this area.

Under the marine mammal suite of conditions for iReX, mitigation measures for piling noise are listed as:

- Minimising pile driving to reduce noise levels;
- Restricting in-water impact or vibration pile driving to daylight hours;
- Using 'soft starts' for piling, and the consideration of utilising alternative driving methods
- Implementation of noise dampening measures such as pile sleeves and bubble curtains or alternative methods that achieve similar, or better, levels of dampening;
- Using a non-metallic 'dolly' or 'cushion cap' between the impact piling hammer and the driving helmet.

These will potentially benefit kororā within the water as well as marine mammals, in particular the condition restricting in-water impact or vibration pile driving to between half an hour after sunrise and half an hour before sunset (i.e. daylight hours only).

Due to the cancellation of the project, the practicalities of implementing these conditions are unknown.

Summary

A-weighting has been adopted for kororā based on an audiogram study of African penguins and the vocalisation range of kororā. The range of hearing underwater has not been studied for any penguin species and therefore a linear hearing response is assumed. This is expected to be conservative.

Stress in birds in general can affect the fitness of individuals and their breeding success, and can manifest as either behavioural or physiological responses (such as increased heartbeat). However, the sole study of heartbeat of kororā found that it did not increase when a short duration recording of construction noises were played.

A limited number of studies have identified noise levels at which behavioural responses are seen. Observed behavioural responses to noise include more active behaviour such as vigilance, walking away from the noise source or spending more time in the pool. A behavioural response at 80 dB LAeq(1s) was observed in king penguins, although subsequently human construction noise limits (70 LAeq(15min)) have been adopted for the protection of kororā due to the similarities in hearing range.

Underwater, a startle response has been observed in gentoo penguins at 120 dB re 1μPa.

Kororā vocalisations have been found to increase when ambient noise levels are higher due to both concerts and wind-induced vegetation noise, but decrease when there are greater numbers of people present or during helicopter overflights. It is possible that the change in level of vocalisation is related to whether kororā perceive the increased background noise to be threatening or not.

Kororā are known to nest in locations with high noise levels, such as next to busy roads. The effects of high levels of background noise when introducing construction noise are not known. Studying the stress response of kororā to noise and how it varies with existing background noise levels would be beneficial when setting appropriate construction noise limits, i.e. a noise limit relative to the background noise level might be appropriate.

Typical consent conditions include kororā surveys and ongoing monitoring, exclusion zones (which may allow people and equipment to pass through while avoiding unnecessary noise), noise limits and restrictions on piling. These restrictions typically include not starting until at least 30 minutes after sunrise and finishing prior to at least 30 minutes before sunset to avoid times when kororā are more likely to be swimming to or from nests. Specific consent conditions are set out for the Kennedy Point marina and iReX projects.

Conclusions

There are many gaps in current knowledge of kororā hearing and response to noise. As large-scale construction projects are frequently located in areas known to have kororā nesting nearby, a greater understanding of the noise sensitivity of kororā, the effects that construction noise may have on individual kororā or on populations and what noise limits are appropriate to minimise adverse effects would be beneficial.

Further work

Areas where the potential for further work has been identified over the course of researching this paper are described below.

Hearing range

Current assumptions around kororā noise sensitivity are based on studies of other species including African penguins (in-air), and gentoo penguins (underwater). A specific understanding of the audiogram of kororā both inair and underwater would be beneficial to establish, as well as the threshold of hearing.

Effects of noise on penguins

When monitoring and observing kororā for possible adverse effects in a construction setting, it is vital to know what behaviours and indicators to look out for.

Hughes et al. [11] identified that responses may be longterm as well as short-term, and that longer-term studies are needed to assess the long-term impacts. The paper also considered it useful to examine the physiological response (e.g. heart rate), particularly in incubating birds, to understand the stress level response, tolerance of noise and / or disturbance.

Iasello et al [14] noted that identifying at which point an individual initially becomes stressed by an introduced stimulus, before it experiences long-term fitness costs, is vital to inform effective mitigation strategies.

Recommendations for further work from Costello et al [13] include investigating how individuals respond to specific human activity, and how factors such as age or experience with humans may influence the response. This can be extrapolated to investigating individuals' response to construction noise.

Although some behavioural responses to noise have been studied, the overall stress response to noise does not appear to be well understood and longer-term studies are needed to establish the effects of noise on individuals, the differences between breeding birds and moulting birds, and the long-term fitness impacts.

Noise levels

It is imperative to know what noise level is likely to cause adverse effects when setting construction noise limits.

Questions raised during the research and writing of this paper include:

- Is a short-term "startle response" noise limit appropriate, e.g. LAeq(1s) or LAmax in addition to a longer-term average level such as LAeq(15min)?
- What is the longer-term sensitivity of kororā, will they habituate to a constant construction noise source or will elevated noise levels over the longerterm cause increased stress or other adverse effects?
- Does the type of noise source make a difference? For example, a constant noise source such as engine noise as compared to an intermittent or impulsive noise source such as impact piling?
- Is kororā response to noise related to how threatening a noise source is perceived to be? What factors might affect the perceived threat level?
- Does sensitivity vary between day and night? Might lower noise limits at night be appropriate, as per NZS 6803 for humans?
- What effect does the existing background noise level have on the sensitivity of kororā to introduced construction noise?
- Does it make a difference if background noise is natural (such as wave or vegetation noise) or anthropogenic (such as traffic noise)?

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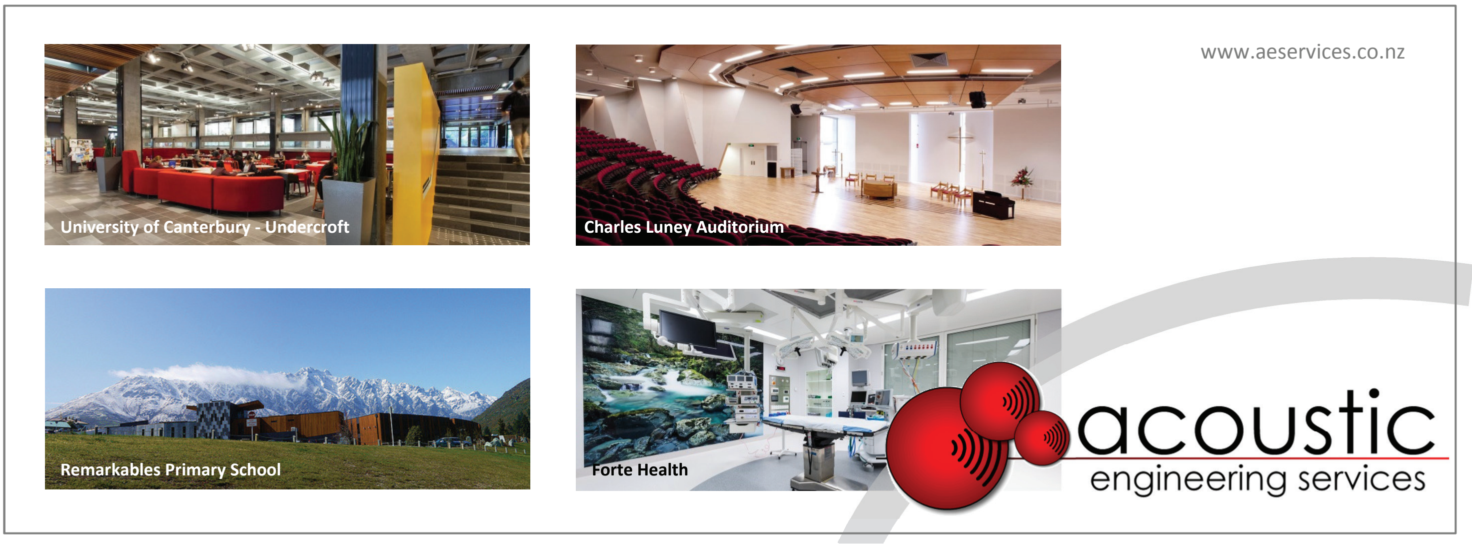
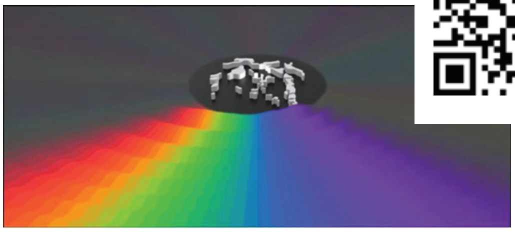


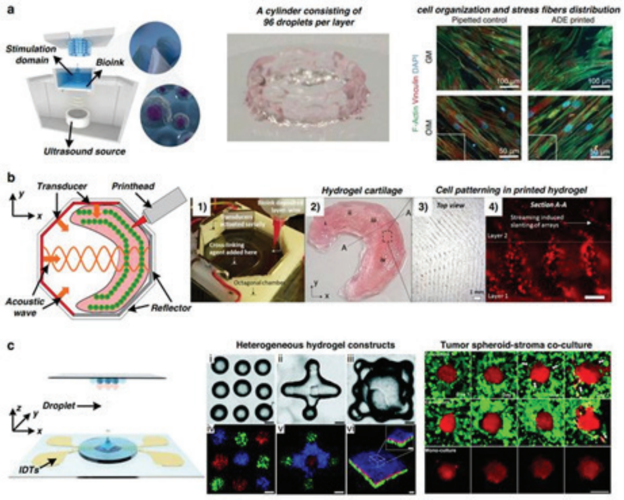
ACOUSTICS IN THE NEWS AND MEDIA

How Silk Can Create Quiet Spaces [9]



3D-printed device splits white noise into an acoustic rainbow without electricity [10]

From sound to structure: how acoustic technologies are shaping the future of tissue engineering [11]



When architecture listens [12]

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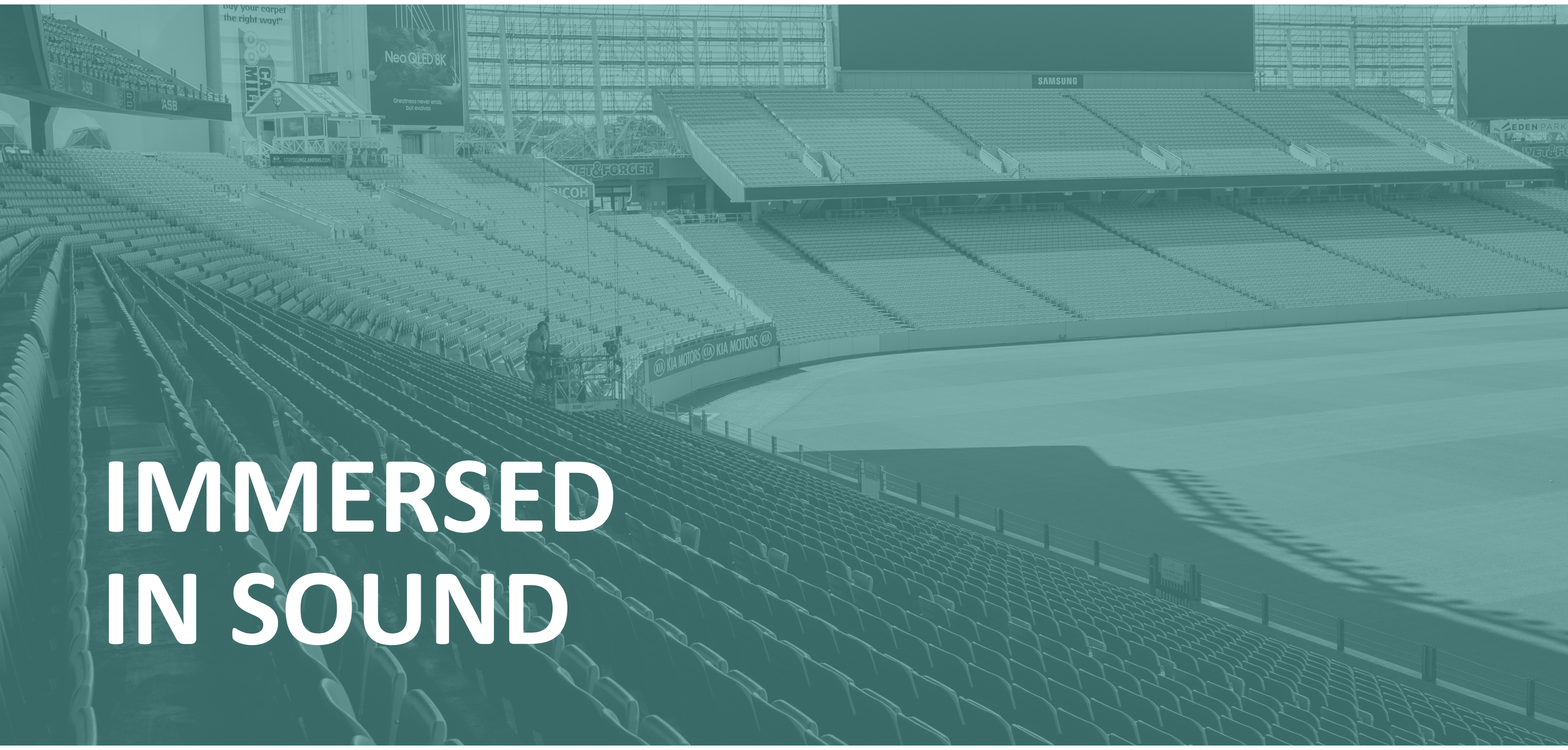
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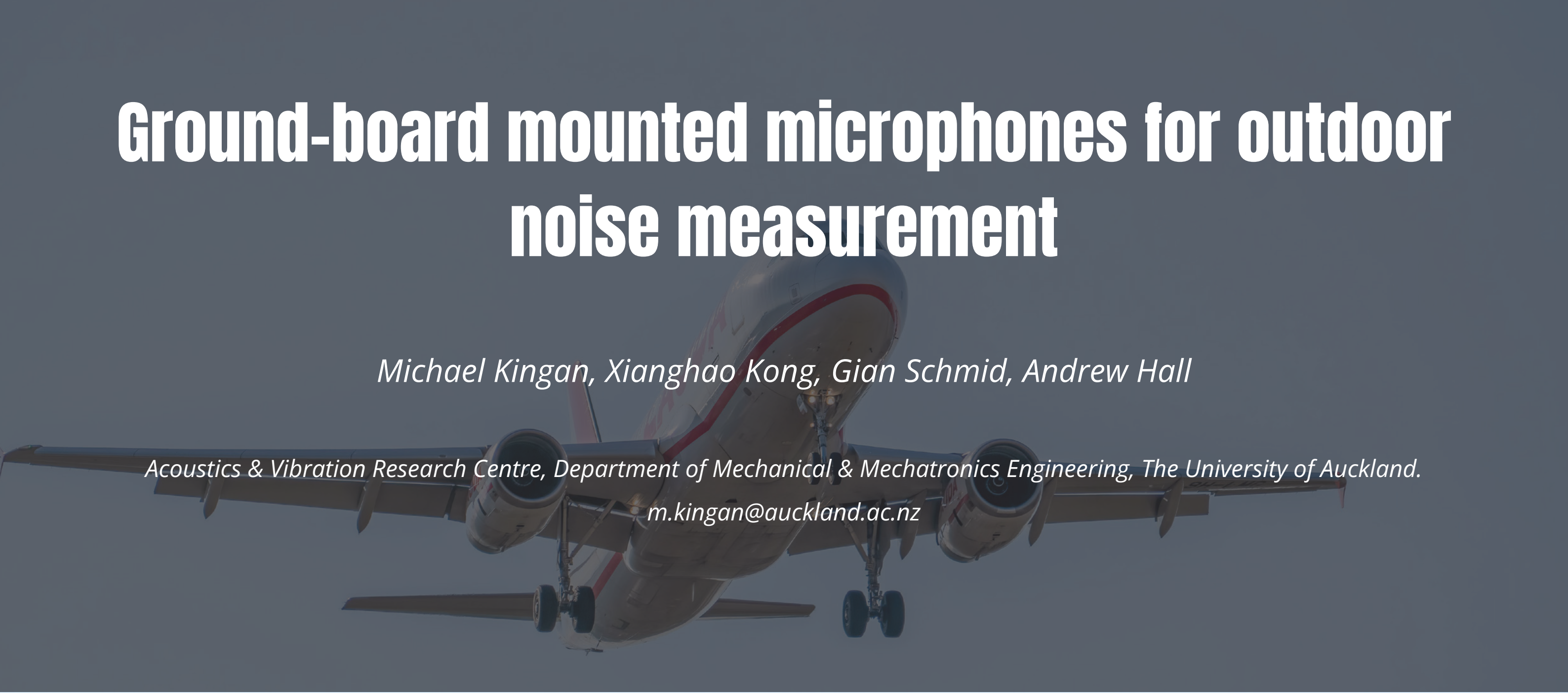

Ground-board mounted microphones for outdoor noise measurement

Michael Kingan, Xianghao Kong, Gian Schmid, Andrew Hall

Acoustics & Vibration Research Centre, Department of Mechanical & Mechatronics Engineering, The University of Auckland.

m.kingan@auckland.ac.nz

Abstract

Ground-board mounted microphones are used in several different standard methods for measuring outdoor noise from objects such as aircraft, wind turbines and unmanned aerial vehicles. Outdoor noise measurements made by ground-board mounted microphones are affected to some degree by diffraction of the incident sound field by the edges of the board due to the shape of the board, the angle of incidence and frequency of the sound and the finite impedance of the surrounding ground. This can result in the sound pressure level varying over the top surface of the board and deviating from the 6 dB increase (relative to the incident sound field) expected if the board was very thin and the surrounding ground was also acoustically rigid. This paper summarises the work which has been done to date on this topic by our research group and briefly summarises the work which is planned for the near future.

Introduction

Outdoor noise measurements made by a microphone mounted above the ground are usually affected to some degree by ground reflections. The significance of this effect depends on the angle of incidence and frequency of the sound, and also the physical characteristics of the ground (e.g. its impedance and profile).

In order to quantify the noise from sources such as wind turbines and aircraft, it is desirable to eliminate the dependence of the measured noise level on the physical characteristics of the ground so that measurements made in different locations, with different ground types, are comparable. For this purpose, several different standardised methods for measuring outdoor noise utilise ground-board mounted microphones where a microphone is mounted into or on an acoustically rigid thin board lying on the ground. For example, ICAO Annex 16 [1] specifies that aircraft noise measurements should be made using an inverted 12.7 mm diameter microphone mounted 7 mm above a metal, circular ground-board with a diameter of 400 mm and a thickness of at least 2.5 mm. A guideline for the measurement of noise from unmanned aerial vehicles (UAVs) published by the European Union Aviation Safety Agency [2] specifies that outdoor noise measurements should be made using a similar method. Also, a draft ISO standard [3] has recently been developed for measuring the noise from UAVs which also requires that outdoor measurements are made using ground-board mounted microphones similar to those described in [1]. However, this draft standard also suggests that flushmounted microphones can be used and that these may be more accurate at high frequencies (further discussion of this can be found in [4]). Ground-board mounted microphones are also used to measure the noise produced by wind turbines according to IEC 61400-11 [5].

A microphone flush mounted in an infinite rigid plane will measure a pressure which is twice that of the incident acoustic field. It is thus expected that a microphone mounted on or in a thin, rigid ground-board which is placed on an acoustically hard flat ground will measure a sound pressure level which is approximately 6 dB greater than the free-field sound pressure level. Correcting such measurements to an equivalent free-field level is thus straightforward. However, in many cases there may be a significant difference between the impedance of the ground and the rigid ground-board, or the ground-board could be relatively thick. Both of these effects cause diffraction of sound at the edges of the ground-board which results in the sound pressure level varying over the upper surface of the board and deviating from the 6 dB increase expected for a rigid flat plane. In such cases, correcting the measurement made by the ground-board mounted microphone to a free-field equivalent requires a more sophisticated approach.

Numerical prediction

Kingan et al [6], developed a boundary element method for simulating the sound pressure on and above a rigid ground board placed on an impedance plane. The method makes use of the Green's function for the Helmholtz equation above an infinite plane with constant complex impedance [7]. Predictions of the excess attenuation (EA) minus 6 dB on the upper surface of a circular ground board mounted on a ground plane with an impedance corresponding to that of artificial grass are plotted below for sound at 5000 Hz and an angle of incidence of 30°. It is observed that the noise level varies significantly over the surface of the ground board (this is particularly true at high frequencies and for smaller angles of incidence).

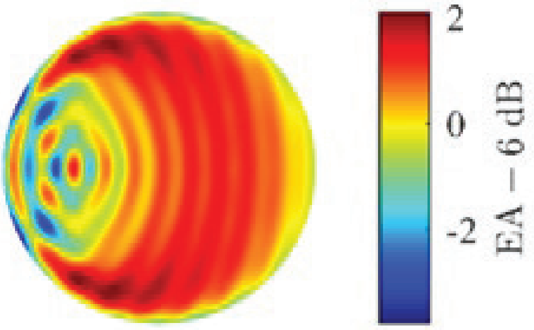

Figure 1: Simulated variation in EA – 6 dB on the upper surface of a 400 mm diameter ground-board on an artificial grass-covered ground at 5000 Hz for sound incident at 30° to the horizontal

Experimental investigation

Go et al. [8] conducted an experimental and numerical investigation to assess the variation in the sound pressure level over the top surface of a 400 mm diameter circular ground-board from sound incident at several different angles. The experiments utilised a probe microphone flush-mounted into a thin metal ground board placed on both an artificial-grass covered ground surface in a hemianechoic chamber and a grass-covered field outdoors (see figures 2-4). The effect of different microphone mountings was also investigated. These included the sideset mounting used for wind turbine noise measurements and the flush and inverted mounting methods commonly used for aircraft and UAV noise measurements (see figure 3).

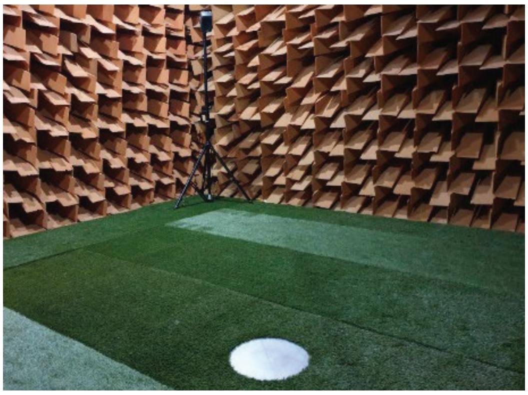

Figure 2: Ground-board mounted on the floor of the hemianechoic chamber with artificial grass-covered floor and speaker mounted to produce sound at an incidence angle of 30°

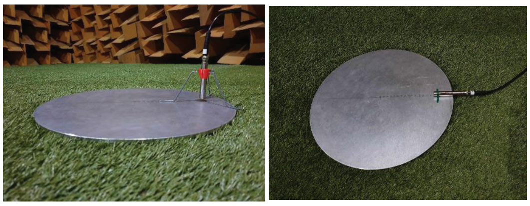

Figure 3: Photographs showing the inverted microphone and side-set microphone mounting methods

Figure 4: Photograph showing the outdoor testing setup

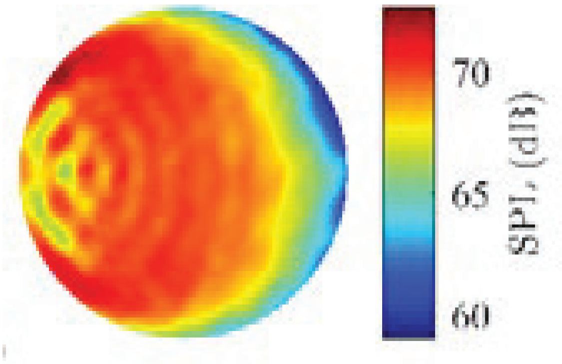

Figure 5: Experimental variation in sound pressure level on the upper surface of a 400 mm diameter ground-board on an artificial grass-covered ground at 5000 Hz for sound incident at 30° to the horizontal

The probe microphone was used to make detailed measurements over the entire upper surface of the ground board. For this purpose, 20 small holes were drilled in the board along a radial line. Multiple measurements were made at each radial location by rotating the ground board. An example measurement is shown in figure 5.

The ground impedance was measured prior to each set of experiments using the Nordtest method [9]. This impedance was then used in the numerical predictions. There was generally very good agreement between the predictions and the measurements made in the hemianechoic chamber and moderately good agreement between the predictions and measurements made outdoors.

Future work

Further work needs to be undertaken to experimentally measure how different ground board designs affect the measured noise level. Ideally, the variation in the measurement due to ground impedance and incidence angle at different frequencies would be minimised. This can be done using a large ground board with an irregular surface which minimises the interference of the waves scattered from the edge of the ground board at the microphone location (see for example, [10]). We plan to conduct such experiments in the near future. These will be made using an experimental rig in which a speaker is traversed through a range of incidence angles and detailed measurements are made of the variation in sound pressure level with frequency and angle of incidence. These measurements will be made in the hemi-anechoic chamber and also outdoors on a variety of different surfaces. A variety of different ground board geometries will be assessed.

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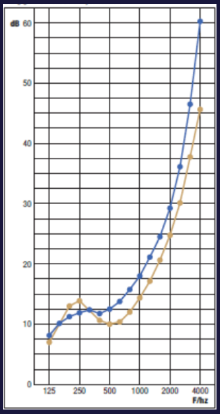

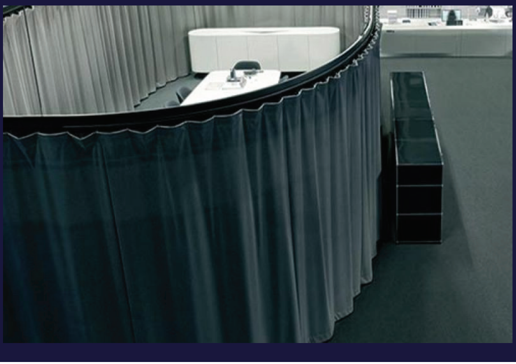

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SOUNDS OF THE SUNSET COAST

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12 - 14 November 2025

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4 - 5 December 2025

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2026 ONWARDS

55th International Congress and Exposition on Noise Control Engineering (INTER-NOISE 2026)

9 - 12 August 2026

Adelaide, Australia

26th International Congress on Acoustics (ICA 2028)

11 - 14 Sept 2028

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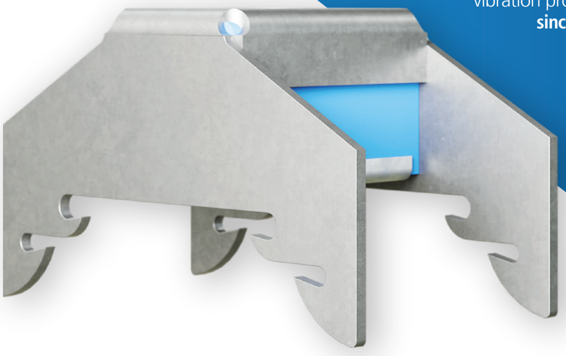

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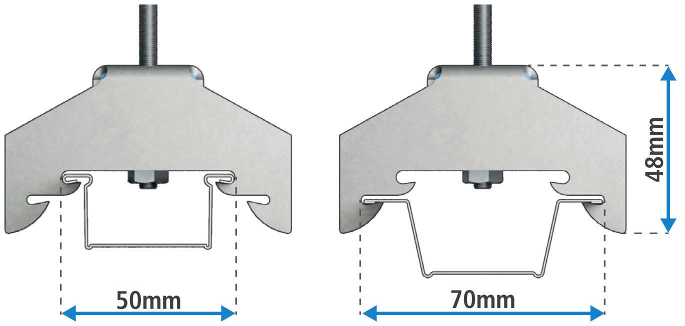

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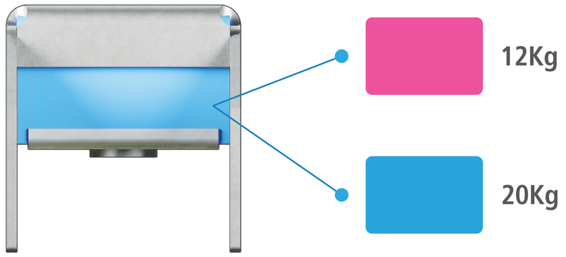

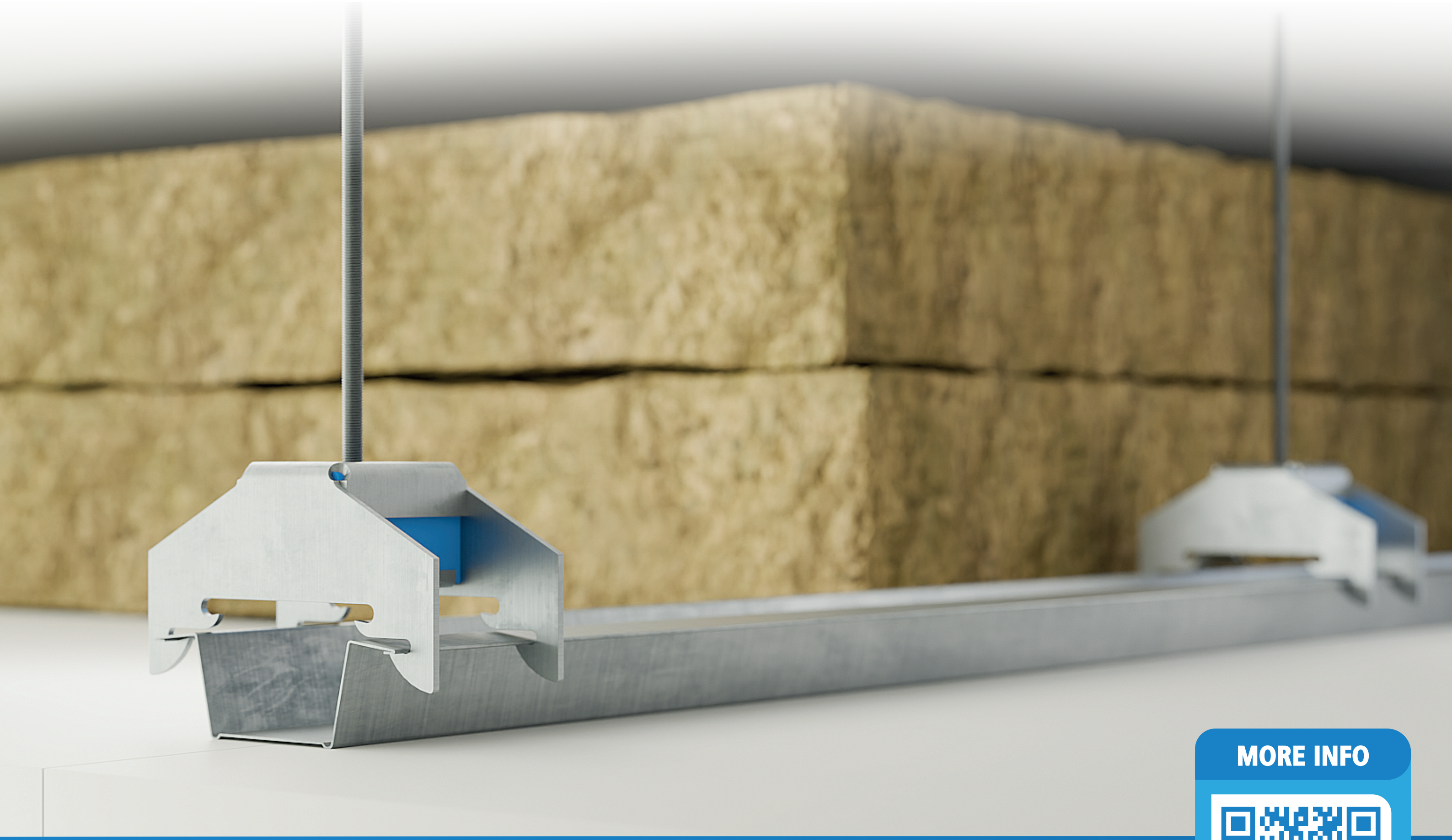

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